2009

Natal Habitat Use by Dragonflies Along Landscape Gradients in Rhode Island

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NATAL HABITAT USE BY DRAGONFLIES ALONG LANDSCAPE GRADIENTS IN RHODE ISLAND

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

ENVIRONMENTAL SCIENCE

UNIVERSITY OF RHODE ISLAND

2009

DOCTOR OF PHILOSOPHY DISSERTATION

OF

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DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
2009

ABSTRACT

Urban environments often support depauperate insect faunas, although they can serve as suitable habitats for some taxa. The potential value of urban wetlands as habitat for regional dragonfly populations has not been well studied. Landscape patterns of natal habitat use by lentic dragonflies were studied at small wetlands in Rhode Island, U.S.A. during three field seasons (2004, 2005, 2006). Dragonfly exuviae were collected along defined perimeter paths on six (2004) or five (2005, 2006) site visits per season (May – October). The exuviae were identified in the laboratory, and the number collected per species/hour was tallied for each field season. Three landscape gradients (urbanization, distance from coast, and wetland size) were measured and assessed for each wetland, and the dragonfly and landscape data were analyzed in three different ways.

First, natal habitat use by dragonflies was assessed on an urban to rural land-use gradient at a set of 21 wetlands, during two emergence seasons (2004, 2005). The wetlands were characterized for urbanization level by using the first factor from a principal components analysis combining chloride concentration in the wetland and percent forest in the surrounding buffer zone. Species diversity measurements and its components (species richness and evenness) were analyzed and compared along the urbanization gradient, as were distributions of individual species. Dragonfly diversity, species richness, and evenness did not change along the urbanization gradient, so urban wetlands served as natal habitat for numerous dragonfly species. However, several individual species had strong relationships to the gradient and most were more commonly found at urban sites, and at sites with fish. In contrast, rare species occurrences were predominantly on the rural end of the gradient. These results suggest that urban wetlands can play important roles as dragonfly habitat and in dragonfly conservation efforts, but that conservation of natural, rural wetlands is also important for some dragonfly species.

Dragonfly species richness was assessed in relation to four environmental variables: chloride concentration, surrounding forest cover, wetland size and wetland distance from the maritime coast. The effect of fish presence on dragonfly diversity patterns was also evaluated. Dragonfly landscape distribution patterns based on data collected in 2004 and 2005 was compared with patterns from newly-selected sites in 2006. Species richness increased with wetland area, but no strong patterns emerged with chloride concentration, forest cover, or distance from the coast. However, some individual species showed strong trends along each of these gradients. Fish presence/absence had strong effects on some species, but did not result in different diversity patterns along the gradients in this study.

Species that showed greater abundance at sites with high chloride concentration and little forest cover (urban sites) tended to be commonly collected species, while rarely collected species were more common at rural sites. Species that showed trends along the coastal-inland gradient tended to be more common inland. Some species were more common in wetlands with fish and some at sites without fish, but most showed no clear difference in abundance based on fish presence. Because individual lentic

dragonfly species vary in their use of sites along these gradients, diverse wetlands at various points along these landscape gradients, including both urban and natural sites, have conservation value for the dragonfly fauna of southern New England.

Knowledge of the persistence of exuviae on various substrates is necessary to accurately interpret exuvial surveys, so in 2006 I recorded exuvial persistence at defined areas in several of the study wetlands. Exuviae were field-identified, labeled with small daubs of nail polish, and observed every three weeks from June through September. Overall, exuvial persistence displayed exponential decline, disappearing rapidly during the first few weeks, and more slowly thereafter. The initial rate of decline was similar for most species, but differed in some taxa. There was no significant difference in exuvial retention on emergent vegetation vs. rock substrate.

In conclusion, small urban wetlands can serve as natal habitat for numerous dragonfly species, so they can play a role in conservation of odonates. Small wetlands in rural areas should also be protected because they provide additional value by supporting different, and often rare, species.

ACKNOWLEDGEMENTS

First and foremost, I thank my fabulous committee, Howard Ginsberg, Peter August and Patrick Logan. Howie, my doctoral advisor, has been wonderful—and patient!—and is a dear friend and mentor.

My husband, David Lubertazzi, and my parents, Virginia and Vincent Aliberti, have been behind me from the beginning.

The URI CELS Coastal Fellowship program was generous with me for all three field seasons, and gave me two excellent "coastal fellows", Ryan Abney and Megan Priede. It is such a great intramural internship program for undergrads, and I truly hope it continues. Several other undergraduates also helped me out in the field from time to time: Megan Dyer, Marissa Picca, Nikki Nedeau.

Dr. Art Gold, Kelly Addy, Linda Green, and the entire URI Watershed Watch lab supported me in my water quality analyses, and were patient with my questions and concerns.

Many people helped me to find appropriate field sites, and some even "lent" me theirs…especially Rick Enser, Dr. Frank Golet, Jon Mitchell, Dennis Skidds, Ginger Brown, Nina Briggs, Roland Duhaime, ASRI and Emily Brunkhurst. I also thank the property owners/managers who allowed me to use their wetlands and property for my study (see Appendix 1 for names).

There are many others who have helped me in this process, in one way or another, over the years—especially Dr. Peter Paton, Dr. Roger LeBrun, Dr. Lisa Harlow, Dr. Jim Heltshe, Jen West, Dr. Axel Bachmann, Dra. Elisa Angrisano, Dr. Mark McPeek, Dr. Betsy Colburn and Dr. Mark Chandler. Also, Dr. Golet, thank you for the best—and hardest—course I have ever had (and REALLY needed!), *Wetland Ecology*.

Karen Gaines, now a dear friend, was the first person to really justify my vague ideas about using dragonfly exuviae for serious ecological research (was it in LaCrosse or Pittsburgh?!?)...even though the system she studies is so different from mine! Good luck, Karen!!!

The idea that came to fruition in my doctoral research began almost 10 years ago, while I was working at MassAudubon's now defunct Aquatic Ecology Lab. Joan Milam and I often talked about all kinds of things in the lab, usually related to the aquatic creatures we were identifying there. When I told her that I had found this most unusual creature (exuviae of *Tramea* sp.) for the first time, ever, on emergent vegetation at a filthy city park pond, she told me that I should 'go after' the questions this brought up for me—namely, what is going on with dragonflies in these trashed, urban, ponds? Joan, thank you for your insight, and the impression your advice had on me—it let me believe that my ideas *were* justified.

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Introduction

The past three centuries of historical land-use in the northeastern United States have resulted in dramatically-altered landscape patterns (Foster 1992). Agriculture, industrial development and urban sprawl have altered wetland patterns and processes. However, small wetlands, such as vernal pools, retention ponds, coastal plain ponds and ornamental park ponds, still serve as reproductive habitat for many species of aquatic insects that prefer lentic habitat for adult feeding, mating and oviposition. Diverse invertebrate species utilize lentic wetlands in natural areas, but little is known about the invertebrate faunas of urban or suburban wetlands.

Small wetlands are often common in the urban landscape, and they are likely to differ in many abiotic characteristics from wetlands in less urban areas (Ehrenfeld 2000). Three hypotheses about invertebrate diversity in urban habitats have been proposed. One holds that urban, or disturbed, wetlands are merely ecological sinks (Pulliam 1988), with low diversity and only widespread, generalist species present. A second hypothesis suggests that diversity is greatest in areas with moderate levels of disturbance (the 'Intermediate Disturbance Hypothesis' of Connell 1978), which would suggest that diversity should be greatest at wetlands in the suburban or urban-edge portions of the urbanization gradient. A third possibility is that diversity does not change along the urbanization gradient. Over the past decade, some investigators have studied *terrestrial* invertebrates along urban gradients, with varying results. Blair and Launer (1997) found butterfly diversity to be highest at intermediate sites along the gradient, while Magura et al. (2004) found carabid beetle diversity to be lowest at intermediate sites. Winfree et al. (2007) found highest bee diversity in areas with fragmented forest, while Gibbs and Stanton (2001) found silphid beetle diversity to be higher in more intact forest areas. Overall, however, most studies have found terrestrial invertebrate diversity to be lower in the more human-modified areas of the gradient (e.g., spiders [Shochat et al. 2004], bees [McIntyre and Hostetler 2001], ants [Thompson and McLachlan 2007]). Aside from study of urban mosquito habitats (e.g., Fischer et al. 2000), most urban studies of aquatic invertebrates have concentrated on lotic systems (e.g., Paul and Meyer 2001, Kaushal et al. 2005). Furthermore, studies of adult odonates (e.g., Creveling 2003, Brown [In preparation]) that are found in urban environments may include species that have flown there from other wetlands, and might not utilize the study wetlands as natal habitat (Buskirk and Sherman 1984, Pulliam 1988). Hence, it remains unclear whether urban lentic wetlands function as part of a faunistic gradient with clear conservation value.

In this study I sample exuviae—the last nymphal exoskeleton, which is shed upon emergence from the aquatic habitat—to assess dragonfly natal habitat use along landscape gradients. Standardized collection of dragonfly exuviae can be a direct and low-impact method for monitoring the emerging dragonfly communities at small wetlands, because exuviae indicate that the individuals sampled developed in the wetland of interest, and successfully emerged (Morin 1984a, Corbet 1993, Foote and

Rice Hornung 2005). Furthermore, exuvial surveys have low impact on the local population because live individuals are not removed or disturbed. [More information on the methodology, use and value of dragonfly exuviae for wetland surveys can be found in ***Chapter 3***.]

The goal of this project is to describe the emerging dragonfly communities at small wetlands along the urban to rural landscape gradient in Rhode Island, USA. To accomplish this goal, I surveyed the dragonfly exuviae of twenty-one wetlands over two field seasons. Specifically, I ask these questions: 1—do small wetlands surrounded by urbanized landscapes provide successful natal habitat to fewer species of dragonflies than wetlands in more natural areas?; and 2—how does the presence of fish influence these patterns? Within this framework, I compare diversity measurements (e.g., species richness, diversity indices and evenness) for their applicability to analyses along urban gradients.

Materials and Methods

Site selection

Twenty-one small Rhode Island wetlands were surveyed for dragonfly exuviae over two field seasons (May – October), 2004 and 2005 (for specific dates, see Appendix I). They were selected for size (usually less than 1 ha), accessibility, long hydroperiod (mostly permanent), and to represent a variety of positions along the urbanization gradient, including both natural and human-modified lentic habitats. Figure 1.1 shows wetland locations and a map of human population density in Rhode Island. For specifics of each wetland, see Appendix I.

Field sampling protocol

I conducted timed searches for dragonfly exuviae on 6 visits/site in 2004, and 5 visits/site in 2005. Search routes around the wetland were selected to include all potential habitat types, and I searched the same route on each visit (see Appendix I for routes). Exuviae were identified to species in the laboratory, using taxonomic keys (Walker 1958, Walker and Corbet 1975, Soltesz 1996, Bright and O'Brien 1999, Needham et al. 2000) and validated specimens, and counted. For each species, the number collected per hour was summed for all sampling dates of each season, by site, for a season-wide score (see Conrad et al. 1999). Fish presence-absence was determined by extensive dip-net sampling throughout the sampling seasons at each wetland.

I measured pH and chloride concentration both years at each wetland (see Appendix II). pH was measured with an Accumet model AR20 research pH and conductivity meter (Fisher Scientific, Pittsburgh, Pennsylvania) within 24 hours of water collection. In fall 2004, water samples were measured for chloride concentration by titration with the Argentometric Method (APHA-AWWA-WEF 1998). Water samples from the 2005 field season were analyzed for chloride in the URI Watershed Watch Analytical Laboratory using an Astoria-Pacific International model 303a segmented continuous flow autoanalyzer (Astoria-Pacific International, Clackamus, Oregon), using method

SM 4500-Cl- E in *Standard Methods for the Examination of Water and Wastewater* (Clesceri et al. 1998).

Measurement of landscape variables

All study wetlands were located and digitized from the *RIGIS03/04 Digital Orthophotos of Rhode Island 2003-2004*, using ArcMap software (Environmental Systems Research Institute, Redlands, CA). The resulting shapefiles were used for wetland buffer analysis. I constructed 100 m buffers around each of the study wetlands, also using ArcMap software. The buffer polygons were used to clip the 1995 RI state land-use datalayer (RIGIS 2005), which had been recoded to 6 land-use categories by merging Anderson land-use classes (Anderson et al. 1976; see Appendix IV, and Marchand and Litvaitis 2004, Price et al. 2004): high-medium density residential, low-medium density residential, commercial/industrial, open/other, forest and wetland (Table 1.1, Appendix IV). The study wetland area was erased, leaving a donut-shaped buffer polygon. Since analysis of surrounding land-use might elucidate patterns of successful dragonfly foraging, localization and colonization of the wetlands (Conrad et al. 1999), I calculated the percent area in each buffer polygon that consisted of each land-use category (Marchand and Litvaitis 2004).

Data analysis

The relative abundances of the dragonfly species (total number of individuals collected at all sites) were compared between years with a G-Test by using the PopTools version 3.0.3. extension for Excel (Microsoft® Office Excel 2003 © 1985-

2003 Microsoft Corporation; Hood, G. M. [2008]; available on the internet: URL http://www.cse.csiro.au/poptools). Only species present both years were used in this analysis. The species' distributions were compared between years by conducting a G-Test on the number of sites the species was collected each year (only species collected at at least 5 sites, at least one of the years, were used for this analysis). A dominance-diversity curve was constructed for each year, and the curves were compared between years with a G-Test of abundance.

CANOCO software (ter Braak and Smilauer 1997-1999) was used for canonical correspondence analysis (CCA) of species (seasonal score = number of exuviae collected per hour per season for each species, at each site) and environmental data (pH, chloride concentration and the 6 land-use values) for each year (Figure 1.2). A strong environmental pattern emerged that was related to 'urbanization', characterized by the percent forest and chloride concentration vectors (Figure 1.2). Therefore, an urbanization variable was formulated using the PCA Factor 1 from a principal components analysis (STATISTICA 6.0, StatSoft, Inc., Tulsa, OK 1984 — 2002) of percent forest cover and chloride concentration at each site, for each year. Chloride concentration can be a useful, indirect measure of watershed urbanization in the northeastern U.S. (A. Gold, pers. comm.; Kaushal et al. 2005, Watershed Watch 2006) because most towns treat roads with salt during winter ice conditions. The amount of forest surrounding a wetland is an inverse measure of urbanization (Miller et al. 1997), as it indicates the lack of anthropogenic land-clearing and development (Booth et al. 2002). Level of urbanization was used as the independent variable for ANOVA and/or regression analyses with species richness as dependent variable. To assess the independent effects of the variables used to characterize 'urbanization', standard least squares analyses were calculated for species richness vs. percent forest and chloride concentration (and interaction) for both years. JMP (JMP® 7.0, 2007 SAS Institute, Inc.) and STATISTICA software were used for these analyses. Additionally, a Student's *t*-test was used to evaluate the urbanization variable at sites with vs. without fish (JMP).

Individual species found at > 2 sites/category (all sites, fishless and fish sites) were also evaluated for patterns along the urbanization variable each year. Their seasonal scores (log (x+1) transformed to eliminate trends in residuals) served as dependent variables in univariate regression analyses with urbanization as the independent variable (JMP).

Because clustering of sites on the landscape may result in spatial autocorrelation (Legendre 1993), I analyzed spatial autocorrelation at these sites by performing the Moran's I analysis (Fortin and Legendre 1989), based on species richness (GS+: GeoStatistics for the Environmental Sciences, Version 7; 1989-2006, Gamma Design Software, Plainwell, Michigan).

Comparison of diversity measurements

Shannon-Wiener Diversity Index (Shannon and Weaver 1949) was calculated for each site, each year, using Excel software (Microsoft® Office Excel 2003 © 1985-2003

Microsoft Corporation). To assess the utility and validity of this and other diversity-related measurements along an urbanization gradient, I also calculated Simpson's Diversity Index (Simpson 1949) and three measurements of evenness for 2005, and compared their patterns along the gradient, and its component variables, for that year.

In addition to species richness, species evenness (= equitability [Muhlenberg 1989, in Chwala and Waringer 1996]) contributes to the diversity measurement of natural communities. Evenness was assessed for the 2005 data by using three different measurements: 1 - the Berger-Parker dominance index (proportion of dominant species in total catch; Southwood and Henderson 2000); H'/log(species richness) (Southwood and Henderson 2000); and the slope of a log-log plot of the dominance-diversity curve at each site (the yearly abundance value for each species was log (x + 1) transformed, and plotted against its log-transformed rank, to linearize the slope/relationship). With this last measurement, evenness is inversely related to the magnitude of the negative slope. Each of these 6 measurements was then plotted along the urbanization variable for 2005, to compare and assess the patterns of diversity and evenness along the urbanization gradient and its component variables. Evenness was analyzed separately from species richness so that these two factors, which both contribute to the value of standard diversity indices, could be clearly interpreted.

Results

The numbers of exuviae collected per hour, for each species, at each site each year (= seasonal scores) are given in Appendix V. Environmental variables related to urbanization and dragonfly diversity measures for both years are given in Tables 1.2 and 1.3, respectively. pH and chloride values for the 21 wetlands surveyed were highly correlated between years ($r = 0.637$, $p < 0.002$ and $r = 0.948$, $p < 0.0001$ respectively). Chloride concentration differed between sites (F-ratio = 15.144, $p < 0.0001$, df = 20, 20) and years (F-ratio = 4.960, $p = 0.038$, df = 1, 20).

In 2004, Factor 1 in the PCA was used as the urbanization variable, and it explained 72.5% of total variability (eigenvalue = 1.45). In 2005 the urbanization variable explained 72.2% of the total variation (eigenvalue = 1.44). Although chloride differed between years, the urbanization values for the sites were highly correlated between years ($r = 0.982$, $p < 0.0001$). Both percent forest and chloride concentration had equally strong Factor I coordinates both years (see Appendix III). It is important to note that sites with negative values are more urban.

Greater than ten thousand exuviae were collected at all sites in 2004, and almost nine thousand were collected in 2005. Overall, species richness at individual sites ranged from 4 to 18 in 2004, and 2 to 20 in 2005. Species richness differed between sites (F-ratio = 8.961, $p < 0.0001$, df = 20, 20), but not years (F-ratio = 1.052, $p = 0.317$, df = 1, 20). Dominance-diversity patterns (Figure 1.3) differed between years ($G(adj) = 2393$, df = 33, $p < 0.0001$). Nevertheless, one species, *Pachydiplax longipennis*

(Burmeister), was by far the most abundant in both years, and the most common in 2005. Overall, the species' relative abundances differed (G(adj) = 6008.35, df = 32, $p < 0.0001$), but the species distributions among sites were the same both years (G(adj) = 10.32, df = 22, $p = 0.983$).

Urbanization and dragonfly diversity

Shannon-Wiener and species richness values for both years are given in Table 1.3, along with the Simpson's Diversity Index and the three evenness measurements for 2005. Species diversity (H') was not related to urbanization either year, with or without fish (2004: overall $R^2 = 0.052$, $p = 0.322$; fish $R^2 = 0.0002$, $p = 0.962$; no fish $R^2 = 0.154$, $p = 0.385$; 2005: overall $R^2 = 0.002$, $p = 0.853$; fish $R^2 = 0.010$, $p = 0.740$; no fish $R^2 = 0.114$, $p = 0.458$). Species richness was not significantly related to the degree of urbanization, or the component variables (percent forest and chloride concentration), in either year, even when fish and fishless sites were analyzed separately (Table 1.4, Fig. 1.4). Interestingly, species richness is correlated with all of the diversity and evenness measurements ($p < 0.10$) except for the log-log dominance diversity slopes ($p = 0.277$) and H'/log(species richness) ($p = 0.468$). None of the 2005 diversity, richness or evenness measures shows a relationship with the urbanization variable, or its component variables (Table 1.5). One site ("Industrial") was excluded for analyses with the log-log slopes and the H'/log(species richness), as only two species were recorded there in 2005.

Presence of fish

Dragonfly species richness tended to differ in sites with compared to sites without fish in 2004 ($t = 2.03$, $p = 0.067$), with apparently greater species richness in wetlands with fish, but not in 2005 ($t = 0.37$, $p = 0.716$). Additionally, the urbanization variable was significantly different at sites with vs. without fish populations both years (2004: $t = -3.12$, $p = 0.007$; 2005: $t = -3.31$, $p = 0.004$); in effect, the sites with fish were more urban than the sites without fish.

Spatial autocorrelation

The Moran's I statistic on species richness gives no regular pattern of autocorrelation among the sites. All of the Moran's I correlations are low and do not show significant relationships. In fact, the *a priori* expected pattern (close sites being autocorrelated) is not evident, as close points do not have high positive I values. All values from these tests can be found in Appendix VI.

Urbanization and species distributions

In contrast to overall diversity, abundances of some common (i.e., found at > 2 sites/category/year) species were always correlated with the degree of urbanization at $p = 0.05$ level (Table 1.6); e.g., *Libellula luctuosa* Burmeister and *Tramea* spp. At sites with fish, *Pachydiplax longipennis* and *Epitheca cynosura* (Say) were also more abundant at urbanized sites ($p < 0.10$). *Gomphus exilis* Selys was more common ($p < 0.10$) at less-urbanized sites with fish in 2004 only, and *Sympetrum janae* Carle was generally more abundant at less-urban sites overall. Rare species (those found only at

1 or 2 sites) were found predominantly at sites on the less-urban side of the gradient (Figure 1.5).

Discussions and Conclusions

Dragonfly species richness and diversity did not change along the urbanization gradient in this study. Most of the individual abundant species with strong, distinct patterns on the gradient, however, favored the urban, and not the rural end (Table 1.6). This result contrasts with those of several studies that found the proportion of specialized invertebrate species to be lower in urban areas than natural, intact areas (Gibbs and Stanton 2001, McIntyre and Hostetler 2001, Koh and Sodhi 2004, Clark et al. 2007, Thompson and McLachlan 2007). My finding that less common species were generally found at more rural sites is compatible with this pattern. However, the lack of a relationship between species diversity and urbanization suggests that urban sites have high value as dragonfly habitat.

Like the present study, McIntyre et al. (2001) found a continuous taxon richness along an urbanization gradient, and similar to this study, the communities consisted of very different species assemblages along the gradient. However, that study looked at a very broad group of invertebrates—all ground arthropods—so it is difficult to compare to narrower taxon-based patterns. Other studies of (terrestrial) invertebrate diversity support the intermediate disturbance hypothesis (Connell 1978), which predicts that species richness is highest in the intermediate (in this case, the 'suburban') areas along the gradient (e.g., Blair and Launer 1997). In contrast, I found no region along the urbanization axis with distinctly higher species richness (Table 1.4, Figure 1.5), even when sites with or without fish were considered separately.

Studies of other invertebrate taxa along urbanization gradients have found that one native species accounts for a half of the individuals collected along the gradient. Examples include bees (McIntyre and Hostetler 2001), stream dragonflies (Hawking and New 2003), and carabids (Magura et al. 2004). Similarly, Samways and Steytler (1996) found low (adult) dragonfly diversity but highest abundance at a city site comprised of just a few, super-abundant species. Over half of the odonate exuviae D'Amico et al. (2004) collected at non-restored wetlands with poor abiotic conditions were of one, 'opportunist' species of damselfly, while the predominant species at reference wetlands was a different species, and much less abundant. Perhaps the presence of a super-abundant species indicates poor environmental conditions. In fact, a steep dominance-diversity curve, with one or two overall exceptionally abundant species (either native or exotic) is a common feature in regional invertebrate surveys of urban areas (e.g. McIntyre and Hostetler 2001, McFrederick and LeBuhn 2006, Clark et al. 2007). However, in this study, the steep, negative slopes on the log-log plots of dominance-diversity curves, which denote low diversity and low evenness, did not predominate in any zone of the urbanization gradient.

On the other hand, the intermediate disturbance hypothesis may apply for some types of invertebrates, in some cases (e.g., Blair and Launer 1997). Although Niemala et al. (2000) specifically suggest the intermediate disturbance hypothesis for carabid beetles worldwide, their sampling protocol did not define how to quantify the 'disturbance regime' (i.e., the urban-rural gradient) for their study. In response, Magura et al. (2004) found lowest carabid diversity in the intermediate areas of the gradient, but their method of categorizing urbanness was not clear. In these and other cases, the concept of defining an urbanization gradient can be difficult, and it is doubtful that an overarching method can exist for all invertebrate (and other) fauna.

Measurement of urbanization

Researchers of landscape ecology have taken many positions on how to measure or characterize urbanization (Theobald 2004). While some have assumed it to be an "understood", qualitative state of the landscape (e.g. Blair 1999, Thompson and McLachlan 2007), others have based urbanization gradients on human population density (e.g. Rubbo and Kiesecker 2005), or impervious surface (e.g., Winfree et al. 2007). Several investigators have categorized land-use of the sites in question by measuring conditions chosen for their direct relevance to the organisms under study (McIntyre 2000)—e.g., vegetation type (larval host plants for butterflies; Blair and Launer 1997), amount of "developed" land (creating three-dimensional habitat factors used by some hawks, excluding others; Schmidt and Bock 2004); and road density (for reptiles, amphibians; Marchand and Litvaitis 2004, Rubbo and Kiesecker 2005). However, the method of 'urban' site categorization and/or quantification (McGarigal and Cushman 2005) remains inconsistent and poorly defined in most studies (Theobald 2004), even when it involves measurement of impervious surface (Booth and Jackson 1997) in wetland watersheds.

Booth et al. (2004) found that impervious surface (= paved areas which alter the local surficial hydrology, and can ultimately concentrate toxic substances) alone cannot effectively predict the biological condition of lotic systems in urbanizing regions. Kaushal et al. (2005) suggest that chloride concentration should be actively monitored in lotic systems that drain urbanizing areas, because of its potential toxicity to the biota. Critical threshold concentrations (e.g., 250 mg/l; Environment Canada 2001), which can damage the aquatic fauna, are becoming commonplace in the northeastern U.S. In France, Piscart et al. (2005) found that net-spinning caddisfly diversity followed the intermediate disturbance hypothesis, along a pollution-based stream salinity gradient. Small lentic wetlands, like in my study, are likely to sustain very high chloride concentrations because they have limited "flushing" outflow (Environment Canada 2001). Some wetlands in this study exceeded the 250 mg/l threshold (Table 1.2), but there was no clear effect on species richness of dragonflies (Table 1.4). Dragonflies are generally not considered to be strongly affected by water quality (e.g., pH [Bell 1971, Hudson and Berrill 1986]), but their vertebrate predators might be (Eriksson et al. 1980, Dermott 1985, Bendell and McNicol 1987, 1995, Johansson and Brodin 2003). Like pH, this water quality factor did not appear to affect lentic dragonfly populations at my sites. However, the effects of salinization on other elements of the wetland food web (e.g., amphibians, fish) should be evaluated in urbanizing areas.

Hahs and McDonnell (2006) suggested the use of multivariate ordination techniques (like PCA), to combine the important factors related to urbanization into a useful metric for evaluating taxon patterns; in particular, they stress the use of factors with high variability and low redundancy. My composite measure of urbanization included chloride concentration ("process") and forested buffer area ("pattern"), two 'dimensions' required for effective measurement of the framework of urbanization (Theobald 2004). My approach allowed for the quantification of urbanization using variables relevant to the biology of aquatic invertebrates. However, it is still uncertain what direct mechanisms related to urbanization account for the distribution patterns of individual species.

Many studies of invertebrates and urbanization are focused on plant-feeding or otherwise plant-dependent invertebrates, which respond directly to changes in herbaceous plant distributions (e.g., ornamentals, agriculture, increased impervious surface; e.g., Blair and Launer 1997, Denys and Holger 1998, McIntyre and Hostetler 2001, New and Sands 2002, Shapiro 2002, Collinge et al. 2003, Koh and Sodhi 2004). In fact, many insect species may be generalists with regard to food resources, but specialists in nesting habitat features, as are some birds. Perhaps species that are limited, either directly or indirectly, by natal habitats or nesting sites (such as dragonflies in our study, and taxa such as bees [McIntyre and Hostetler 2001, McFrederick and LeBuhn 2006, Matteson et al. 2008] and birds [Blair 2004] that are limited by nesting sites), might show different trends than species that respond more directly to the abundance of food, including larval food resources.

McKinney (2006) classified the biotic patterns found along urbanization gradients, stating that they tend to follow an avoidance, adaptation and exploitation paradigm. Avoiders are native species that are no longer found in urbanized areas, adapters take advantage of the resources left by humans, but maintain other aspects of their ecology (e.g. nesting sites) in patches of native habitat, and exploiters take advantage of many aspects of urbanization, for all of their ecological needs. From my data it appears that dragonfly emergence patterns are too complex to fit into this paradigm. Some species (e.g., the rare species, or 'avoiders', see Figure 1.4) may fit, but many don't fit easily into these categories. In the paradigm, for example, exploiters appear to favor low vegetation and low predator presence (McKinney 2002). In this study, urban wetlands were surrounded by less vegetation (low percent forest), but for dragonflies they are more likely to have predator populations, i.e., fish, in urban wetlands (Rubbo and Kiesecker 2005). The results of this study illustrate that, given habitat *availability* in urban areas (which is often not plausible for other biota, e.g. large forest fragments), the species that find and utilize it combine to form communities that differ in species composition from those in less-urbanized areas.

Factors that influence species communities in urbanized habitats often represent one extreme of certain landscape gradients, and the overall effects of urbanization have been interpreted as 'homogenization' of habitat types, even on a global scale (McKinney 2006). Rubbo and Kiesecker (2005) found both fish presence and wetland permanence to be associated with urbanization. Fish presence was higher at the urban end of the spectrum in this study, but, although often related, wetland hydroperiod was only qualitatively assessed. Locating sites with similar size and wetland classification (e.g., small, palustrine, open-water, semi-permanent to permanent)—in addition to accessibility— was difficult at both extremes of the urbanization gradient. Regardless of urbanization, others have found that hydroperiod *and* predator populations, which are often linked, play major roles in structuring odonate assemblages in natural wetlands (Stoks and McPeek 2003).

Many studies have shown that it is difficult for some odonate species to successfully complete their nymphal stage in waters with fish (e.g., Morin 1984b, Pierce et al. 1985, McPeek 1990a, 1998, Stoks and McPeek 2003), resulting in behavioral (Johnson and Crowley 1980, Pierce et al. 1985, Robinson and Wellborn 1987, Blois-Heulin et al. 1990, McPeek 1990b, 1995, McPeek et al. 1996, Stoks et al. 2003, Johansson et al. 2006), morphological (McPeek 1995, McPeek et al. 1996, McPeek 1997) and/or life-history (Morin 1984b, McPeek 1990a, Stoks and McPeek 2003) traits to avoid fish predation. Hence, I would expect to see some definitive patterns in species composition along the urban gradient when fish vs. fishless sites are compared. This is particularly evident for the individual common species with strong relationships to the gradient (Table 1.6). However, even with few 'urban' sites in this study that do not have fish populations (see Figure 1.4), the diversity does not change along the gradient when fish vs. fishless sites are analyzed separately (Table 1.4). Furthermore, it appears that some fish populations can tolerate high chloride levels in lentic wetlands, to some degree. Therefore, further study is needed to distinguish the effects of urbanization from the effects of fish presence.

Beyond factors known to affect dragonflies (like fish presence) some other factors related to urbanization (e.g., deforestation; Miller et al. 1997) might influence dragonfly species recruitment or development. For example, forested land can be considered an inverse measure of urbanization (Miller et al. 1997, Booth et al. 2002), but dense forest could also impede dragonfly colonization by obstructing the view of dispersing adult dragonflies. Ormerod et al. (1990) and Nilsson and Svensson (1995) found that a forested wetland buffer could visually or topographically impede recruitment or development of some aquatic invertebrate species, but favor the recruitment of others. The only abiotic/landscape feature that predicts occurrence of one European dragonfly species, for instance, is the type of forest (coniferous vs. deciduous) on the stream margins (Ormerod et al. 1990). This could result from adult females seeking out a specific *degree* of riparian shading before oviposition. The adult Shadow Darner (*Aeshna umbrosa* Walker), a common species in my study, is known to be active predominantly in shady wetland areas (Dunkle 2000, Nikula et al. 2003), where it oviposits in damp wood (Nikula et al. 2003). Foote and Rice Hornung (2005) found that odonate diversity increased with the height of littoral emergent vegetation in prairie wetlands, possibly for a similar reason. Other potential urbanization factors that might influence dragonflies include urban heat-island effects (Bornstein 1968, Collins et al. 2000) and parasite or disease frequency in urban areas (Johnson and Chase 2004, Skelly et al. 2006).

In contrast to the lack of relationship between emerging dragonfly diversity and the urbanization gradient, some individual species were more common in urban than in natural or rural wetlands (Table 1.6). The trend might be driven by certain species that selectively find and utilize non-forested habitats, which nowadays often result from human alteration of the landscape in urbanizing areas; in effect, they may be specialists, albeit common specialists in this dataset. On the other hand, the rare species in my dataset were found more often at less-urban wetlands (Figure 1.4). Other studies of invertebrate taxa have found nonnative species to flourish most in urban areas (e.g., Holway and Suarez 2006, Clark et al. 2007, Matteson et al. 2008). No dragonfly species found in southern New England is considered exotic. However, some are very likely to be generalists or opportunists; in my study, *P. longipennis* comprised about half of all the specimens collected in both years

Like birds, dragonflies utilize distinct habitats in a given landscape for reproduction (Moore 1991). Indeed, some native bird species are known to prefer, and flourish, in urban areas of the northeastern US. As avian landscape ecology has played a pivotal role in conservation decisions, natal habitat use by dragonflies might have an analogous role for small wetlands in the urbanizing northeast. My results suggest that urban, suburban, rural and 'pristine' wetlands can all play important roles in conservation of biodiversity on our landscape (Moore 1991, Clark and Samways 1997). Urban habitats in general (Simberloff 1997, Faeth et al. 2005), and specifically wetlands (Ehrenfeld 2000), should probably be viewed as novel types of habitat, and distinct from the more 'natural' habitats in more rural landscapes. The more 'urban' sites may be offering a distinct habitat type (i.e., open, no surrounding woods), regardless of fish populations, that is very attractive to some dragonfly species.

The lack of a relationship between diversity and urbanization indicates that urban wetlands provide natal habitat to many dragonfly species. Therefore, urban wetlands support a diverse dragonfly fauna, and not just a few, tolerant species. In fact, for some species, ponds in urban parks and restoration sites serve as dragonfly natal habitat more commonly than ponds in natural areas (Table 1.6). Currently, rare lentic odonate species in southern New England are often linked to rare habitats that can be heavily influenced by surrounding land-use (e.g. *Williamsonia lintneri* [Hagen in Selys]; Biber 2002, MNHESP 2003). Nevertheless, some rare dragonfly species utilize urban wetlands elsewhere (Johnson et al. 2001), further suggesting the potential conservation value of small urban ponds (McKinney 2006). My results suggest conserving wetlands all along the urbanization gradient, because some species do well specifically in urban wetlands, and others (including some relatively rare species) appear to only use wetlands in natural areas. With changes in urbanization patterns—and increasing rates of change—species' response to the management of existing wetlands (and their upland surroundings) requires more attention. With ecosystem health and species and habitat conservation in mind, we should further assess how (and why) dragonflies (and other aquatic invertebrates) respond to wetland landscape patterns—including the creation of new types of wetlands—on our continually changing landscape.

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Table 1.1. Land-use codes (Anderson/RIGIS) merged into six land-use categories. Note: RIGIS codes are not equal to Anderson codes for forest classes.

	High-Medium Density Residential	Low-Medium Density Residential	Commercial/ Industrial	Forest	Open	Other/ Wetland
Anderson Land-Use Codes Included	111 112 113	114 115	120 130 150	310 320 330 340 400	141-147 161-163 170, 210 220, 230 250, 500 710, 720 730, 740	600

Table 1.2. Fish presence, chloride concentration, %forest in 100m wetland buffer, and urbanization variables (Factor 1 of PCA: chloride and % forest) for both 2004 and 2005.

SITE	FISH? Y/N	Cl (mg/l) 2004	Cl (mg/l) 2005	%Forest (100m buffer)	Urbanization Variable 2004	Urbanization Variable 2005
AMTRAK	N	1	2	0.60	0.76	0.73
BLACKSTONE	Y	121	159	0.74	-0.22	-0.09
BRISTOLSK	Y	148	154	0.57	-0.91	-0.44
CAMPUS	Y	115	159	0.03	-1.71	-1.65
CAROLBIG	N	2	6	0.85	1.30	1.26
DEXTER	Y	29	42	0.28	-0.25	-0.26
EIGHTROD	Y	-2	4	0.42	0.42	0.33
GLOBE	Y	17	11	0.35	0.03	0.12
INDUSTRIAL	Y	23	33	0.50	0.31	0.30
KITTBIG	N	2	3	0.89	1.40	1.37
NBGROUND	N	30	4	0	-0.87	-0.59
PAINTBALL	Y	25	49	0.46	0.20	0.09
PHELPS	Y	125	288	0.24	-1.37	-2.13
RUMFORD	Y	231	334	0	-3.04	-2.99
SAILADUMP	N	0	8	0.80	1.23	1.14
SANDY	Y	41	53	0.77	0.70	0.74
SKLT	N	0	3	1.00	1.66	1.60
SLATERFRIEND	Y	1	18	0	-0.54	-0.69
SPECTACLE	Y	106	112	0.22	-1.19	-0.88
STRATHMORE	N	3	2	0.65	0.86	0.85
WAJONES	Y	4	6	0.83	1.23	1.21

Table 1.3. Dragonfly diversity measurements at all sites in 2004 and 2005. Note: Simpson's diversity index and all evenness measurements were only calculated for 2005.

	(H')		Spp. Richness		Simpson's	1-BP Index	H'/logSR	log-log slope
SITE	2004	2005	2004	2005	2005	2005	2005	2005
AMTRAK	1.11	1.54	10	12	3.41	0.54	-1.43	-2.01
BLACKSTONE	1.58	1.51	11	11	4.05	0.68	-1.45	-2.31
BRISTOLSK	1.61	2.23	15	17	7.64	0.79	-1.81	-1.65
CAMPUS	1.15	1.39	8	9	3.22	0.57	-1.45	-2.34
CAROLBIG	1.04	2.23	16	15	7.48	0.77	-1.89	-1.42
DEXTER	1.88	2.10	18	20	6.11	0.74	-1.62	-1.78
EIGHTROD	0.66	0.47	8	5	1.27	0.11	-0.67	-2.82
GLOBE	1.50	1.02	8	7	2.06	0.34	-1.21	-2.08
INDUSTRIAL	1.24	0.69	6	2	1.98	0.44	NA*	NA*
KITTBIG	1.23	1.37	10	17	2.36	0.38	-1.12	-2.03
NBGROUND	0.43	0.90	4	8	1.63	0.23	-1.00	-2.03
PAINTBALL	1.28	0.82	14	13	1.57	0.21	-0.74	-2.75
PHELPS	1.83	1.48	16	15	3.30	0.57	-1.26	-2.13
RUMFORD	1.19	0.73	12	15	1.40	0.16	-0.62	-2.43
SAILADUMP	0.51	1.38	6	9	2.75	0.44	-1.45	-2.07
SANDY	1.62	1.31	13	13	2.20	0.34	-1.18	-2.08
SKLT	0.80	0.92	4	9	1.64	0.23	-0.96	-1.96
SLATERFRIEND	1.38	1.70	13	12	3.26	0.48	-1.58	-1.37
SPECTACLE	1.63	1.71	10	10	4.49	0.67	-1.71	-1.83
STRATHMORE	1.53	1.50	8	7	3.53	0.57	-1.78	-1.42
WAJONES	1.56	1.15	18	15	1.94	0.30	-0.98	-1.81

*Values for this site were not used in analyses because only 2 species were recorded there in 2005.

Table 1.4. Univariate regression analyses of species richness with urbanization variable, chloride concentration, and forest cover in 2004 and 2005.

		Urbanization variable		Chloride concentration		Percent forest in buffer	
		Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
All sites	2004	-0.422	0.610	0.014	0.361	0.114	0.971
	2005	-0.478	0.576	0.013	0.194	1.034	0.746
Fishless	2004	1.723	0.453	-0.140	0.419	4.251	0.464
	2005	2.174	0.352	0.124	0.871	4.756	0.351
Fish	2004	0.304	0.764	0.002	0.916	2.767	0.492
	2005	-0.946	0.442	0.015	0.243	-0.001	1.000

Table 1.5. Relationships between dragonfly diversity and evenness measures and urbanization (2005 data). See text for details.

		Urbanization variable		Chloride concentration		Percent forest in buffer	
Measure	**# sites**	**Coefficient**	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
Diversity							
Shannon-Wiener (H')	21	-0.018	0.853	-0.001	0.689	-0.239	0.555
Simpson's	21	0.006	0.987	0.003	0.544	-0.953	0.533
Species richness	21	-0.478	0.576	0.019	0.110	3.526	0.306
Evenness							
1 - BP Index	21	-0.008	0.847	0.000	0.442	0.097	0.568
H'/logSR	20	-0.036	0.629	0.000	0.774	-0.066	0.835
log-log slope	20	0.082	0.279	-0.001	0.323	0.042	0.894

Table 1.6. Univariate analyses of selected common species (seasonal scores, log [x + 1] transformed) vs. urbanization variables. Only species that were present at > 2 sites per category per year, with significant relationship at least one year, were included. A) at all sites; B) at sites with or without fish. ND = not detected

A

Species	Year	# of Sites	Coefficient	P-value
Family Aeshnidae				
Anax junius	2004	16	0.071	0.603
	2005	15	0.220	0.065
Family Corduliidae				
Epitheca cynosura	2004	13	-0.249	0.061
	2005	13	-0.340	**0.014**
Family Libellulidae				
Erythemis simplicicollis	2004	14	-0.240	**0.048**
	2005	14	-0.159	0.242
Libellula luctuosa	2004	6	-0.169	**0.011**
	2005	3	-0.209	**0.013**
Sympetrum janae	2004	16	0.377	**<0.001**
	2005	18	0.166	0.104
Sympetrum vicinum/ semicinctum	2004	20	-0.018	0.903
	2005	17	-0.253	0.099
Tramea spp.	2004	8	-0.323	**0.009**
	2005	10	-0.206	**0.018**

B

		No Fish (7 sites)			Fish (14 sites)		
Species	Year	# of Sites	Coefficient	P-value	# of Sites	Coefficient	P-value
Family Gomphidae							
Gomphus exilis	2004		ND	NA	5	0.256	0.067
	2005		ND	NA	4	0.260	0.120
Family Corduliidae							
Epitheca cynosura	2004	3	0.131	0.737	10	-0.303	0.084
	2005	2		NA	11	-0.391	**0.032**
Family Libellulidae							
Libellula luctuosa	2004	1		NA	5	-0.234	**0.017**
	2005	0		NA	3	-0.266	**0.048**
Pachydiplax longipennis	2004	4	0.698	0.368	12	-0.437	0.069
	2005	7	0.181	0.681	12	-0.420	0.093
Sympetrum janae	2004	7	0.393	0.157	9	0.296	**0.045**
	2005	6	0.325	0.402	12	0.130	0.313
Tramea spp.	2004	2		NA	6	-0.464	**0.009**
	2005	4	-0.574	**0.023**	6	-0.265	**0.018**

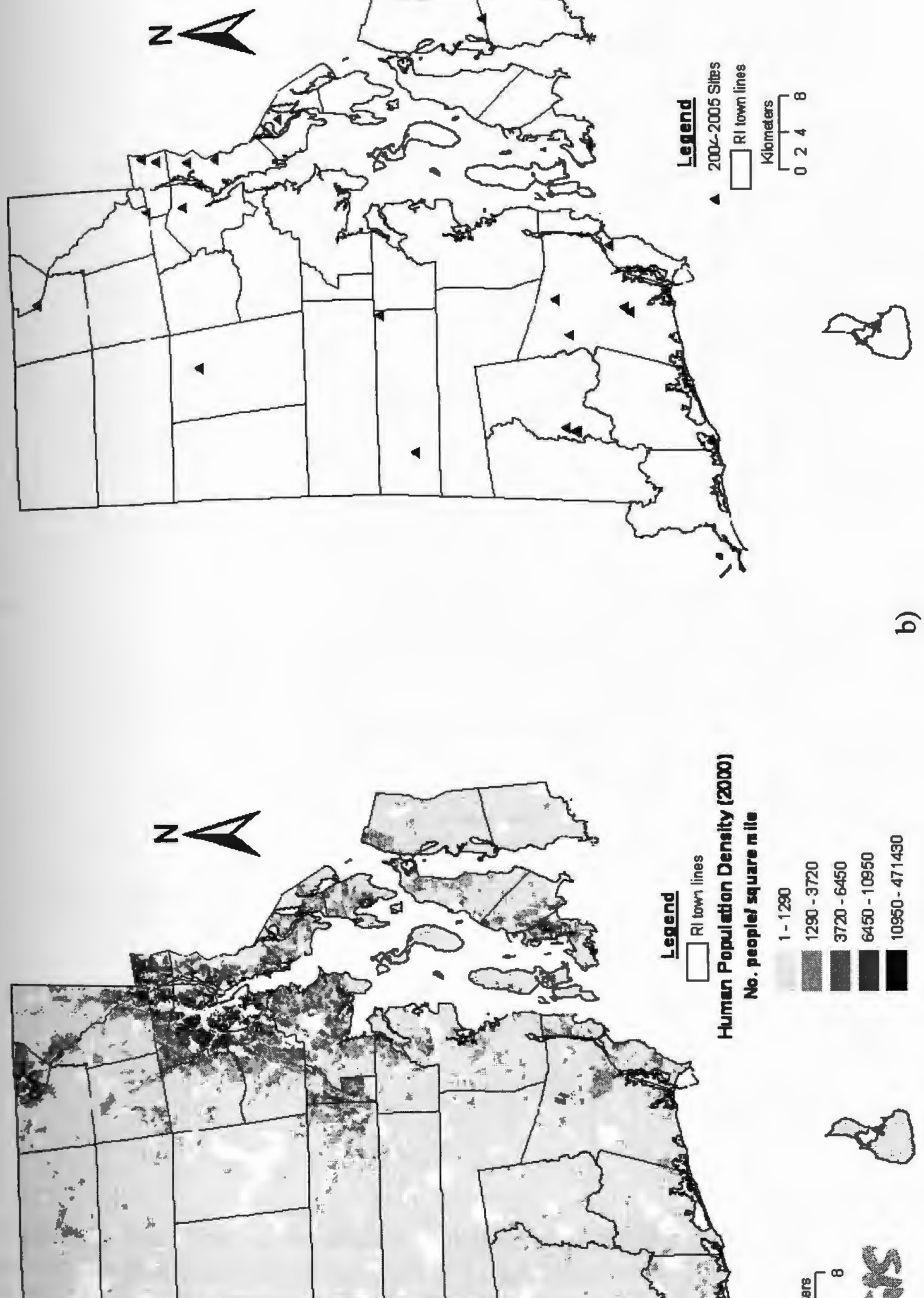


Figure 1.1. Maps of Rhode Island with a) human population density (by quantile) in Rhode Island (source: RIGIS 2002) and b) location of wetland sites.

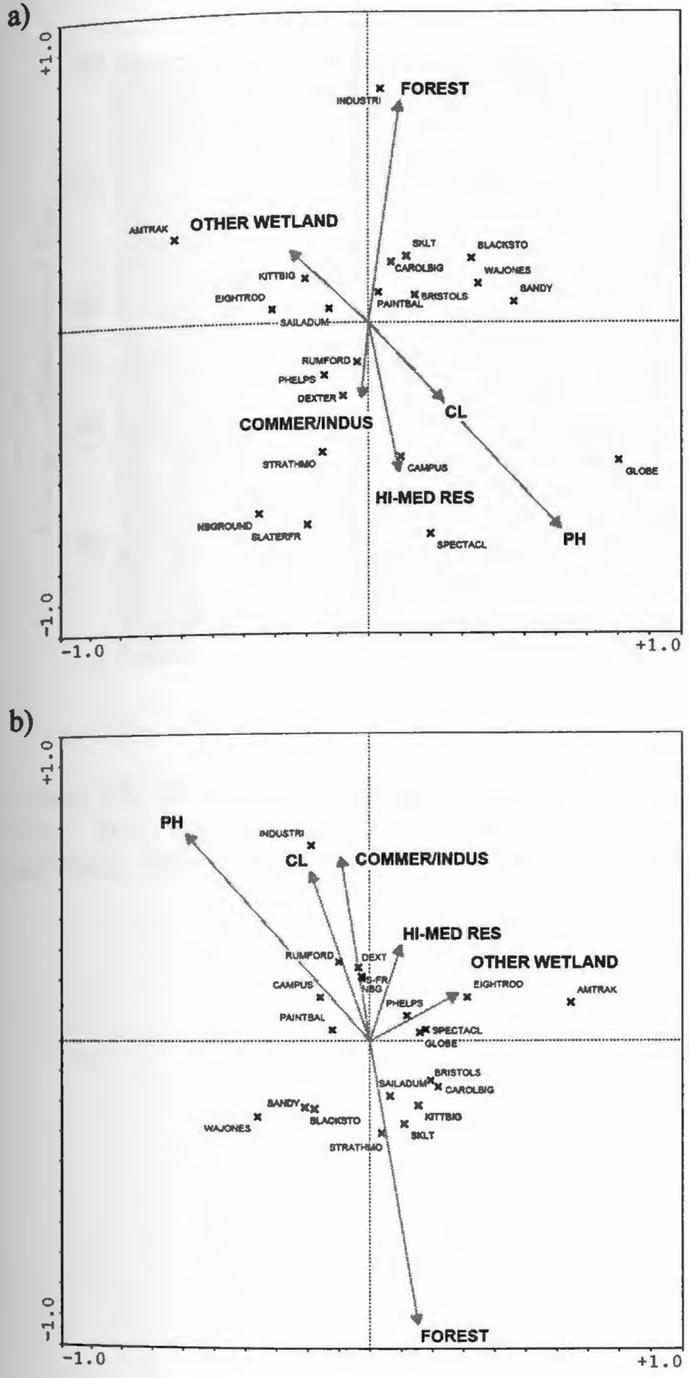


Figure 1.2. Canonical correspondence analysis plots of sites ("X"-marks; based on species composition) with environmental variable vectors in 2004 (a) and 2005 (b). FOREST = percent forest in 100m buffer; PH = water pH; CL = water chloride concentration; OTHER WETLAND = percent cover of (other) wetland in 100m buffer; COMMER/INDUS = percent cover of commercial/industrial land-use in 100m buffer; HI MED RES = percent cover of hi-medium density residential land-use in 100m buffer; for detailed information on land-use categories, see Appendix IV.

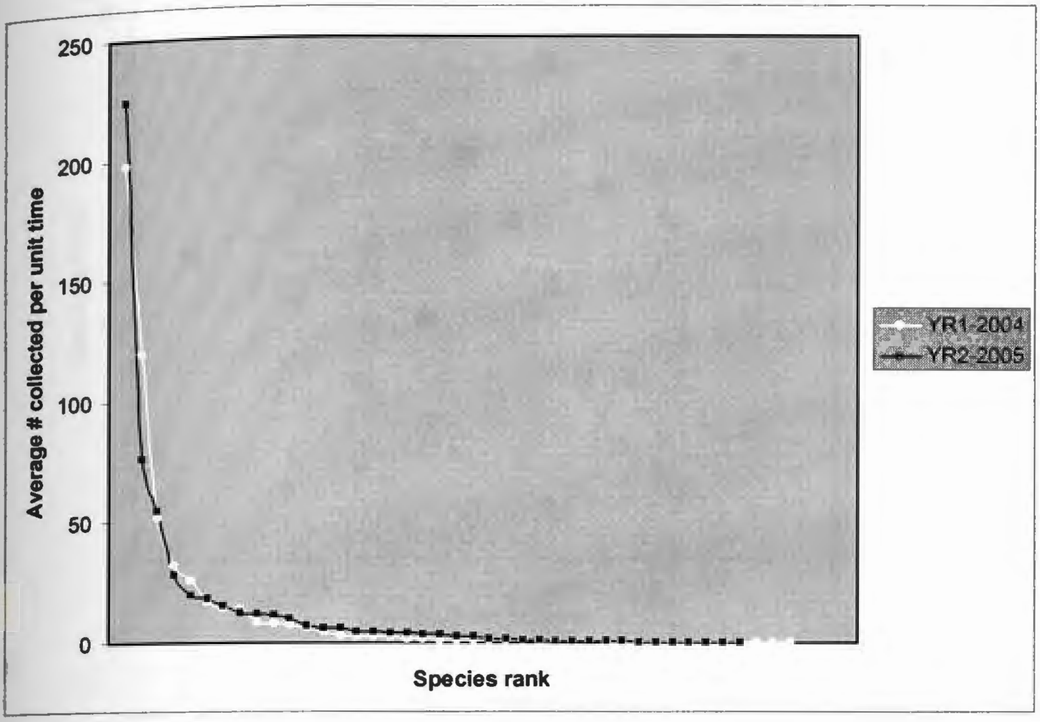


Figure 1.3. Dominance-diversity curves for average species abundance in 2004 and 2005. The y axis is the average number of individuals collected (per hour) at all sites, each year, for that year's species of a given rank (x axis).

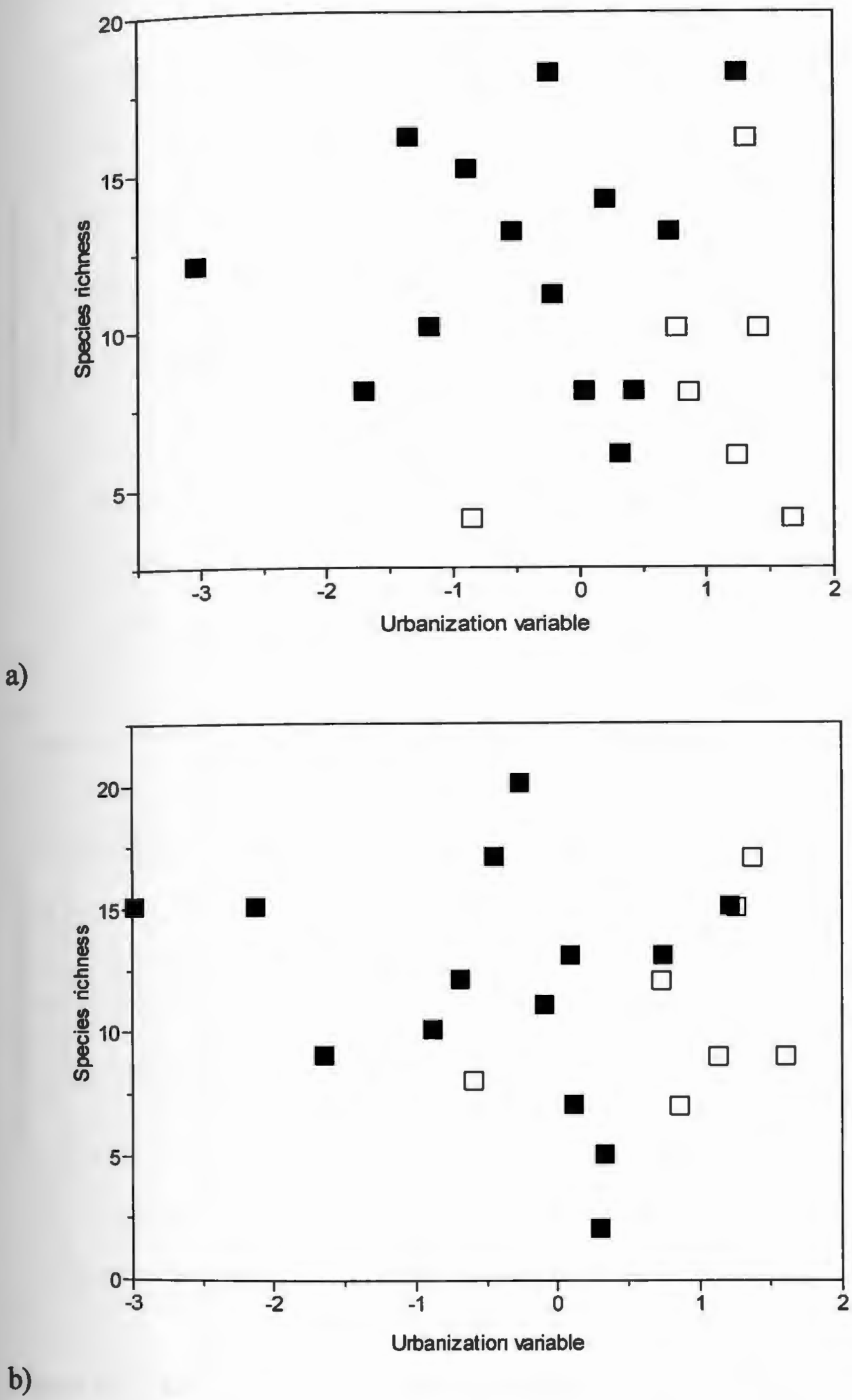
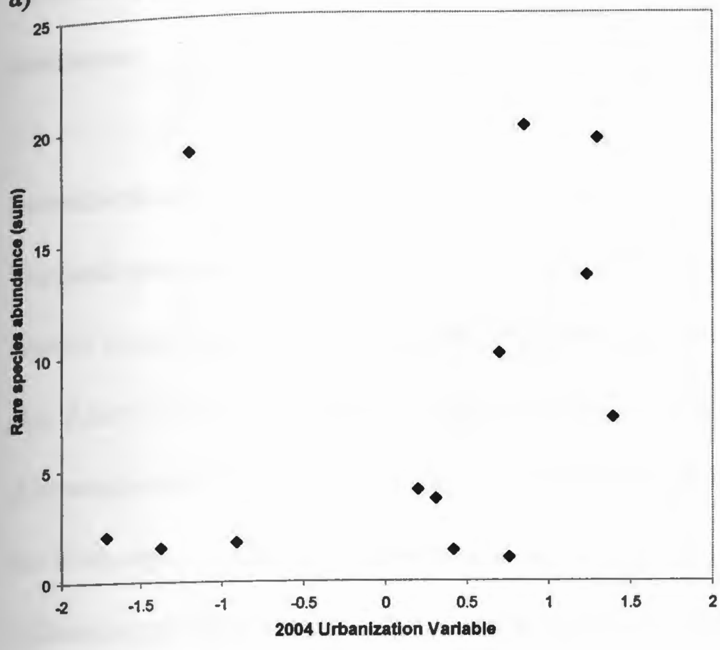


Figure 1.4. Species richness along urbanization variable for 2004 (a) and 2005 (b). Black squares are wetlands with fish populations, open squares are fishless wetlands. The negative side of the urbanization scale denotes the "more urban" side of the variable.

a)



b)

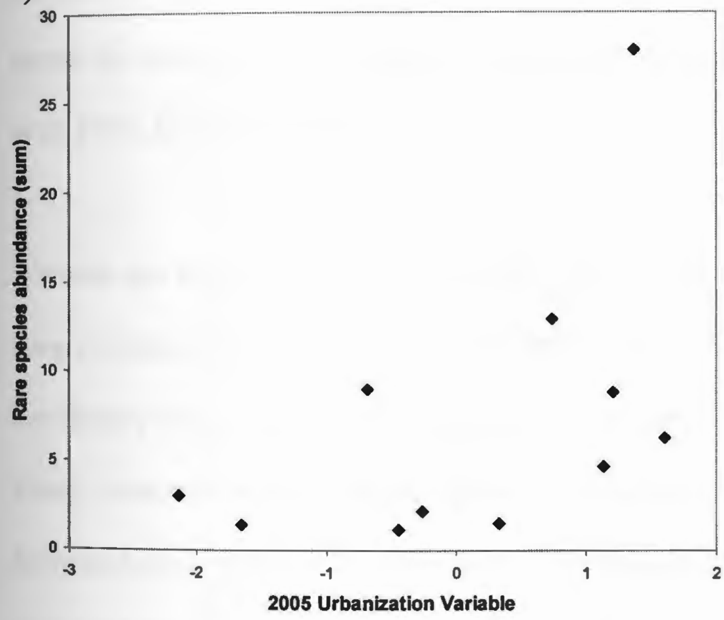


Figure 1.5. Abundance of rare species (those found at ≤ 2 sites) along urbanization gradient in 2004 (a) and 2005 (b). Abundance is the sum of the seasonal scores of all rare species at sites with rare species present.

Manuscript II: Environmental factors influencing dragonfly distributions on the landscape

Introduction

Wetlands possess numerous features that influence their suitability as natal habitat for aquatic invertebrates, like dragonflies. Factors that have been documented include size (Oertli et al. 2002), floral succession (Jeffries 1998), and surrounding land use (Ormerod et al. 1990), all of which can become modified with human development of the landscape. Additionally, wetland proximity to the maritime coast might influence dragonfly habitat choice for those species that migrate along the coastline. The effects of these factors on dragonfly faunas have not been well studied. Another factor, the effect of fish presence, has been better studied (e.g., Morin 1984b, Pierce et al. 1985, McPeek 1990a).

Wetland size has been shown to influence odonate diversity (e.g., Oertli et al. 2002). Larger wetlands might support more species, but there may also be species that specifically select larger (or smaller) sites for oviposition (Buskirk and Sherman 1984). Although some dragonfly species specifically use coastal salt marsh habitat for reproduction here in New England (e.g., *Erythrodiplax berenice* (Drury)), others have been found to form migrating swarms that appear to follow coastlines (e.g., Russell et al. 1998). However, it is unknown whether their natal habitat distribution on the landscape reflects this phenomenon.

Little is known about the effects of urbanization on the biogeography of dragonfly natal habitat use. Some aspects of land-use changes with urbanization may, in fact, affect which species can find, oviposit and successfully emerge from wetlands in disturbed or unnatural areas. One aspect, the structure of riparian and/or emergent vegetation, can be important for attracting, or repelling, some species (Ormerod et al. 1990, Jeffries 1998, Foote and Rice Hornung 2005). Additionally, water quality, quantity and variability can affect many aspects of dragonfly biology, often by indirectly affecting their major predators, fish.

Here I assess environmental factors relevant to dragonfly natal habitat use by measuring environmental and landscape factors and sampling dragonfly exuviae at small wetlands in Rhode Island, USA. I characterize and analyze several environmental features of the study wetlands, including water quality, surrounding forest cover, wetland distance from the coast, wetland area, and fish presence/absence to evaluate their relevance to regional dragonfly population patterns on the landscape. I develop a basic description of dragonfly distribution in small lentic wetlands using data from 18 wetlands sampled in 2004 and 2005, and test this description with data from 23 newly-selected wetlands sampled in 2006. The purpose of this effort is to provide specific information about features that influence dragonfly use of wetlands on the landscape for natal habitat, which may be used to make resource management decisions for dragonfly conservation, and direct future study of dragonfly habitat use.

Methods and Materials

Site selection

Sites were selected in spring of 2004 for accessibility, long or permanent hydroperiod, and to represent small wetlands in a variety of positions along the urbanization and coastal-inland gradients of Rhode Island. Wetlands were located by consulting state road maps, aerial photos (RIGIS orthophoto server: http://ortho.edc.uri.edu/), and wetland scientists, and by searching the non-island regions of the state. In spring 2006 the replicate set of sites was selected in the same way. The three largest ponds in the 2004/2005 samples were considerably larger than the others, and contained several species that were not found at any other sites (see Chapter 1; M. Aliberti Lubertazzi, unpublished data). To avoid complications from mixing pond size classes, I removed those three ponds from the initial set of sites, and selected sites in 2006 that were in the size range of the smaller 18 initial wetlands (< 1.5 ha). Figure 1.1 shows the locations of both sets on a map of Rhode Island. For the specific details of each wetland, see Appendix I.

Field sampling protocol

Site visits were conducted five (2005, 2006) or six (2004) times over the field season (May – October; for further details, see Chapter 1, Appendix I). I sampled exuviae using a timed search of a defined perimeter route at each wetland (for route maps, see Appendix I). Water quality was tested for chloride concentration and pH at the beginning and end of the field seasons (see Chapter 1); for 2006 the values were averaged (L. Green, pers. comm.; for entire value dataset, see Appendix II). Chloride measurements were calculated slightly differently in 2004, compared with 2005 and 2006 (see Chapter 1).

Measurement of landscape variables

The wetland buffer analysis, area and distance-from-coast variables were calculated with ArcMap software (Environmental Systems Research Institute, Redlands, CA; see Chapter 1). Each wetland's perimeter was hand-digitized on the orthophoto (*RIGIS03/04 Digital Orthophotos of Rhode Island 2003-2004*), and area was calculated for the resulting polygon. One hundred meter buffers were constructed around each wetland in ArcMap, and the state land-use data layer (RIGIS 2005) (with re-coded Anderson land-use categories—see Table 1.1, Appendix IV) was clipped with the buffer area. For each buffer the percent area of each category was then calculated. The distance between the closest point of the wetland polygon to the maritime coast of Rhode Island (RIGIS 1993) was also measured with ArcMap (wetland 'distance from coast').

Data analysis

Multivariate exploratory analyses were conducted using exuviae data (seasonal score = number collected per hour per season for each species), pH, chloride concentration, wetland area, the 6 land-use values and distance from the coast, for each year at the initial sites, and for the replicate (2006) sites. CANOCO software (ter Braak and Smilauer 1997-1999) was used for canonical correspondence analysis (CCA) of species and environmental data for each year. Spatial autocorrelation was also evaluated; for methodology, see Chapter 1.

I analyzed the effects of the strong environmental variables (chloride concentration, forest cover, wetland area and distance from the coast) on species richness with regression for each year (JMP software; JMP® 7.0, 2007 SAS Institute, Inc.). In addition to the overall analysis, sites with and without fish were analyzed separately each year. To assess whether the presence of fish affects the distribution of each environmental variable and dragonfly species richness, I conducted Student's *t*-tests for all 5 of these measurements using JMP. The effect of the presence of fish on abundances of some common species was also tested using a Student's *t*-test (JMP). Species abundances (or seasonal scores) were log (x + 1) transformed to eliminate trends in the residuals. Multiple regression analyses were performed for individual species' relationships with the environmental variables each year, for the 10 most common species over all years.

Additionally, a multiple regression analysis was conducted using data from all variables for three years (including the 3 large ponds) to increase power, and to assess overall trends. Chloride concentrations change from year to year because of changes in road salt application in response to snowfall, so a chloride x year interaction term was added to the model.

Results

Overall patterns

The raw environmental variable data are summarized for all sites in Table 2.1. The dragonfly species collected in this study are listed, from common to rare (based on average number of sites per year), in Table 2.2. Canonical correspondence analyses show the same overall pattern for 2004, 2005 and 2006 (Figure 2.2). Wetland area was a strong vector in all three plots (Figure 2.2). Other strong environmental patterns that emerge include percent forest and chloride concentration vectors, two factors related to the degree of urbanization, and distance from the coast. Although pH was also a strong environmental variable, and usually correlated with chloride concentration, it can be related to forest features, and is not as direct a measure of urbanization as is chloride. There were 11 sites with, and 7 without fish among 2004/2005 sites, compared to 14 sites with fish and 9 without fish in 2006. Regression analyses of species richness with chloride concentration, percent forest, area and distance from the coast, at all sites, and at sites with and without fish, are given in Table 2.3. In general, species richness increased with wetland area, but did not change significantly with regard to forest cover, chloride concentration or distance from coast. Significant distributional patterns for the 10 most common species along the 4 environmental variables is provided, for each year, in Table 2.4.

Fish presence/absence

Species richness did not differ between sites with and without fish for 2004 ($t = 1.787$, $p = 0.098$), 2005 ($t = 0.210$, $p = 0.836$) or 2006 ($t = 0.155$, $p = 0.879$).

Wetland area of initial and replicate sites did not differ for sites with or without fish, but distance from coast was significantly larger for sites without fish in the 2006 sites ($t = -3.014$, $p = 0.009$). Chloride concentration differed significantly between sites with and without fish in both 2004 and 2005 (2004: $t = 2.519$, $p = 0.029$; 2005: $t = 2.705$, $p = 0.022$), but not in 2006 ($t = 0.782$, $p = 0.445$). However, although percent forest did not differ significantly between groups for 2004/2005 ($t = -2.003$, $p = 0.069$), it did for groups in 2006 ($t = -2.227$, $p = 0.043$). Some species showed strong trends with regard to fish presence or absence (Table 2.5).

Spatial autocorrelation

The Moran's I statistic on species richness gives no regular pattern of autocorrelation among the sites for either set. All of the Moran's I correlations are low and do not show significant relationships. In fact, the *a priori* expected pattern (close sites being autocorrelated) is not evident, as close points do not have high positive I values. All values from these tests can be found in Appendix VI.

2004-2005 sites

Effects of forest cover and chloride concentration

Dragonfly species richness did not vary with regard to forest cover or chloride concentration (Table 2.3). However, the distributions of some common species did change along these gradients (Table 2.4), especially *Sympetrum janae* Carle (forest) and *Epitheca cynosura* (Say) (chloride).

Effects of wetland area

Species richness significantly increased with wetland area (Table 2.3). One common species was significantly more abundant at larger sites (*Sympetrum vicinum/semicinctum*), while its congener, *Sympetrum janae*, showed the opposite pattern (Table 2.4).

Effects of wetland distance from the coast

There was no significant relationship between species richness and wetland distance from the coast, but there was a slight positive trend at fish sites in 2006 (Table 2.3). Some species were significantly more abundant at sites further from the coast, but none were found to favor coastal sites (Table 2.4).

To summarize, species richness did not change with regard to forest cover or chloride concentration, or with distance from coast, but larger ponds tended to have more species than smaller ponds. Individual dragonfly species showed significant trends along each of these gradients, and many were consistent between years. Some species were more abundant in ponds with fish, while others were more abundant where fish are absent (for examples, see Table 2.5).

2006 sites

Effects of forest cover and chloride concentration

Species richness at the 2006 sites was not significantly related to forest cover or chloride concentration (Table 2.3). None of the common species showed a relationship with forest cover, although one was negatively correlated with chloride concentration at sites with fish, only in 2006 (Table 2.4).

Effects of wetland area

Species richness was not significantly related to wetland area at 2006 sites, overall (Table 2.3). However, for wetlands without fish there was a positive trend at these sites. Neither of the common species with relationships in 2004 and 2005 had a significant relationship with wetland area in 2006 (Table 2.4).

Effects of wetland distance from the coast

Species richness was not significantly related to wetland distance from the coast (Table 2.3), although the trend was positive for sites with fish. In 2006 one common species, *Pachydiplax longipennis* (Burmeister), showed a slight, but significant, positive relationship with wetland distance from coast (Table 2.4).

Fish presence/absence

Three of the common species showed similar trends with regard to fish presence in 2006 compared with the patterns in 2004 and/or 2005 (Table 2.5). In 2006 another species, *Epitheca cynosura*, also differed significantly in abundance between site categories.

Overall species richness patterns in 2006 followed those of 2004/2005 for wetland distance from coast, forest cover and chloride concentration, but not wetland area in all categories. Individual species patterns with regard to these variables differed among years, but three of the common species that showed strong patterns with regard to fish presence/absence in 2004/2005 also did in 2006 (Table 2.5).

An overall analysis using all three years' data showed similar trends to the yearly analyses (Table 2.6). Species richness was not related to forest cover or chloride concentration, but increased slightly with distance from the coast. Wetland area, however, significantly affected species richness only at sites without fish. Some individual species showed trends with each of these environmental variables (Table 2.7), and many were similar to the patterns detected in individual years.

Discussion

Overall, the dragonfly fauna showed similar trends with regard to forest cover, chloride concentration, wetland area and distance from coast over all years. Species richness did not vary with forest cover or chloride concentration in any year. Diversity increased with pond area in the 2004/2005 sites, but not significantly in the 2006 sites. Nevertheless, there was a positive trend at the 2006 sites that was marginally significant at sites without fish. Species diversity did not change significantly with distance from the coast in any individual year, although there was a significant but modest effect in the overall analysis. In contrast to these general faunistic trends, some individual species showed significant trends along each of these environmental axes.

Forest cover and chloride concentration. These variables are often correlated with the degree of urbanization (see Chapter 1) because forest cover declines with urban development, and chloride concentration increases from road salt. Dragonfly diversity was not correlated with the level of either variable in any of the years or overall (Tables 2.3 and 2.6). Indeed, some highly 'degraded', or heavily used (Chovanec and Raab 1997), urban wetlands supported prolific, diverse dragonfly communities. This result contrasts with some studies, which have found only a few superabundant species at heavily impacted sites (e.g., Samways and Steytler 1996). However, those studies focused on adults, and did not sample the entire dragonfly fauna that actually used the wetlands for development. My results suggest that small urban wetlands can potentially serve as important natal habitat for regional dragonfly populations.

Forested area surrounding wetlands is well known to be important for persistence of some taxa, such as amphibians (e.g., Guerry and Hunter 2002, Gibbons 2003, Rubbo and Kiesecker 2005, Gibbons et al. 2006, Skidds et al. 2007). Recently, Tsubaki and Tsuji (2005) intensively analyzed dragonfly data (presumably mostly adult records) along with broad-scale land-use data for the entire country of Japan, and found that for many species, presence was correlated with forest or urban-heterogeneous landcover. At least 50% of the odonate species included in that analysis appeared to depend on forest in the landscape. However, numerous species also showed affinities for urban-heterogeneous land-use. These 'urban' areas were probably the best surveyed areas, since most of the data were from volunteers and naturalists, who are most likely to live in more urbanized regions. Regardless, their findings agree, in large part, with the patterns in my results. Specifically, some species may favor forested areas for natal habitat (e.g., *Sympetrum janae*; Table 2.4), while others appear to favor wetlands in more urban areas, as indicated by high chloride levels in this study (e.g., *Epitheca cynosura*; Table 2.4).

Wetland area. Dragonfly diversity increased with pond area at the 2004/2005 sites, which is consistent with standard ecological theory (e.g., MacArthur and Wilson 1967), and some previously established urban terrestrial insect patterns (e.g., Faeth and Kane 1978). Wetlands with larger area had more emerging species. For the initial analyses reported in this chapter I removed three large outlier sites that were included in initial 2004/2005 samples (see Chapter 1), because several species were found at those larger wetlands and not elsewhere (M. Aliberti Lubertazzi, unpublished data). When the larger sites were included in the final overall model, however, three other common species had significant results for area, both positive (e.g., *Epitheca cynosura*; Table 2.7) and negative (*Pachydiplax longipennis*; Table 2.7). Therefore, along the small-large continuum there are species that have definite 'preferences' for wetland size. Oertli et al. (2002) also found two of these patterns (positive relationship between species richness and pond size, and some species found only at the larger ponds) for odonates in Switzerland. Pond area and adult species richness were also positively correlated at recently-built 'dragonfly ponds' in Japan (Kadoya et al. 2004), but Ackerman and Galloway (2003) found the highest dragonfly species richness (based on larvae and exuviae) at the smallest of the retention ponds they studied in Manitoba, Canada. Preference for smaller wetlands, as is apparent for *Sympetrum janae* in this study, has been suggested by Buskirk and Sherman (1984) for some species.

Lake area is related to fish presence (Tonn and Magnuson 1982), and some investigators suggest that wetland area could thereby influence habitat selection for dragonfly oviposition (Johnson and Crowley 1980a, Buskirk and Sherman 1984, Johansson and Brodin 2003), including for species with very specialized habitat preferences, like fish absence (Johnson and Crowley 1980a). In my datasets, however, wetland area did not differ between sites with and without fish.

Similar species-area patterns have been found for other freshwater invertebrates, especially coleopterans (e.g., Rundle et al. 2002). Nilsson and Svensson (1995) found increased species richness in larger wetlands among dytiscid beetles in boreal forest habitat. Generalist species were found everywhere, augmented by species with stronger minimum pool-size preferences along the gradient. However, when lakes (the large end of the size gradient) were included, the gradient's relationship to species richness disappeared (Nilsson and Soderberg 1996). Although Butler and deMaynadier (2007) did not find lake area to be a factor influencing adult damselfly communities, their lake area range was very large (2 - >11,000 ha). Overall, the question of wetland size should be critically evaluated when considering species patterns on the landscape. Ehrenfeld (2000) suggests using the largest, intact wetland(s) in an urban area for establishment of reference conditions for constructing a biomonitoring program at urban wetlands. However, I found distinct patterns of species distribution along the wetland size gradient, so selecting only large ponds would give a biased sample of the dragonfly fauna.

Wetland distance from maritime coast. Although the results for individual years show no relationship with species richness, and little coastal habitat 'preference' by species, the overall analyses showed weak patterns with distance from coast (Tables 2.3, 2.6). In contrast, there were strong patterns that favor the inland end of the gradient for a few common species (see Tables 2.4, 2.7).

I measured the distance of each wetland from the maritime coast because dragonfly migration has been observed on the east coast of North America, including directed flight patterns of thousands to millions of individuals, often in response to topographic lines (like coastlines) and weather factors (e. g., Russell et al. 1998, Moskowitz et al. 2001, Artiss 2004, Wikelski et al. 2006). In this study, all species with significant trends along the coastal-inland gradient were found at the inland end of the gradient. Detailed regional natural history guides (e.g. Nikula et al. 2003) sometimes mention inland vs. coastal patterns for adult insect distributions, but this pattern has received relatively little quantitative attention.

One of the common species with a strong relationship to distance from coast, *Sympetrum janae*, was more common at inland sites in some years, but this result did not also occur in the overall model. Another species, *Libellula incesta* Hagen, was significant only at sites without fish. More common inland, *L. incesta* was not found to be more common with fish, as has been previously documented (McCauley 2008), so this distinct pattern at fishless sites could be an anomaly. *Sympetrum janae* (the third most common species) has been reported to be more common at sites without fish (McCauley 2008), and this trend was apparent in my samples for at least two years (Table 2.5).

Anax junius (Drury) and *Tramea* spp., the two taxa with documented coastal migration (e.g., Moskowitz et al. 2001, Wikelski et al. 2006), were not found in this study to have significantly higher rates of emergence at sites closer to the coast. The "swarm migrations" described by Russell et al. (1998) appear to occur in late summer, follow topographic features like coastlines (either marine or lacustrine), temporally follow the occurrence of cold fronts, and are primarily composed of *A. junius*. Both Russell et al. (1998) and Wikelski et al. (2006) note that the majority of the odonate migration observations and data regard the southward, autumn migrations. However, the northward spring migration appears to be more diffuse and has not been well studied. Insect migration typically occurs soon after adult emergence (Southwood 1962, Johnson 1969); hence, the northward migration is likely more relevant to the distribution of exuviae (Trottier 1971), which would be the result of oviposition by mature northward migrants from the south. The results of the present study are more compatible with a diffuse rather than a concentrated coastal migration northward.

Presence of fish populations. The presence of fish populations can strongly influence dragonfly faunas (Johnson and Crowley 1980b, 1980a, Morin 1984a, Blois-Heulin et al. 1990, McPeek 1990b, 1995, Johansson and Brodin 2003, Stoks and McPeek 2003, Stoks et al. 2003, McCauley 2008). In my dataset some common aeshnid, corduliid and libellulid species appear to follow broad, previously established trends regarding fish presence/absence (see Table 2.5). I documented several species that were more abundant when fish were present, and a couple that were more abundant when fish were absent (Table 2.5); however, the other five common species were apparently not influenced by the presence of fish in my dataset.

Factors contributing to the observed patterns

It is important to first distinguish natal habitat from adult foraging habitat patterns. While this study focuses on the emergence patterns of dragonflies, most odonate landscape studies have focused solely on adult sightings (e.g., Samways and Steytler 1996, Gibbons et al. 2002, Creveling 2003, Butler and deMaynadier 2007). Adults might have emerged from the wetland where they were observed, but many species can fly considerable distances from emergence sites to different ponds for foraging (e.g., Trottier 1971, Samways 1989, McGeoch and Samways 1991). The species distributions at my study sites might be related to the suitability of various ponds for nymphal development, but adult oviposition cues clearly also influence which ponds will have which dragonfly species emerging from them (Buskirk and Sherman 1984). In the following paragraphs I discuss the relationship of cues that may influence attractiveness to adults, to the distribution of exuviae at my study sites. Of course, the choice of oviposition habitats are undoubtedly related to the potential for the offspring to survive and successfully emerge.

Emergent macrophytes. Lenz (1991) argued for the primary importance of the structural heterogeneity of vegetation at wetlands for attracting and maintaining a diverse assemblage of odonates. One study of damselflies in Maine, U.S.A. (Butler and deMaynadier 2007) found that abundance and richness of emergent aquatic plants affect which species occur there—presumably because of oviposition preference (damselflies oviposit endophytically). However, in my study only aeshnids are known to be endophytic ovipositors (Walker 1958). Most species in my dataset are libellulids and corduliids, which usually oviposit directly into water (Walker and Corbet 1975). Buskirk and Sherman (1984) suggest that oviposition into vegetated habitats (not specifically into the vegetation tissue) may be common, probably because of the spatial refuge from predation that emergent and submerged plants provide to aquatic invertebrates (Crowder and Cooper 1982, Gilinsky 1984). Some dragonfly species (especially Aeshnidae) might select oviposition sites based on the amount and/or structure of wetland vegetation present (Moore 1991, De Marco Jr. et al. 1999, Kadoya et al. 2004, Foote and Rice Hornung 2005). I did not analyze the vegetation patterns at my sites, but they all had at least some patches of herbaceous emergents. However, since this study is focused primarily on non-endophytic species, it is probably not a strong factor in the species patterns.

Surrounding land-use. Three-dimensional landscape features might play a role in dispersal and habitat encounters for visually-oriented insects. For example, Foote and Rice Hornung (2005) found that the three-dimensional structure of the (non-forest) riparian vegetation, not the species composition of the vegetation, was the strongest factor in the composition of adult odonate faunas in prairie potholes, within an agricultural landscape. They speculate that the visual factor of tall vegetation around a wetland could provide adult habitat cues, in addition to oviposition cues. Chwala and Waringer (1996) found that lack of both insolation (from tall riparian vegetation) and emergent macrophytes reduce odonate diversity at degraded wetlands in Austria. While the surrounding *forested* area might affect the ability of adult dragonflies to find wetlands, some may specifically search for those conditions. For example, the adult Shadow Darner (*Aeshna umbrosa* Walker), a moderately common species in my study, is known to be active predominantly in shady wetland areas (Dunkle 2000, Nikula et al. 2003), where oviposition is in damp wood (Nikula et al. 2003). Percent forest in wetland buffers was a strong factor in defining 'urbanness' in my study (see Chapter 1), and it is also evident that adults of some species probably 'choose' wetlands in a more 'open' matrix. For instance, the most 'urban' site ("Rumford")—with very high dragonfly diversity (and abundance; see Chapter 1)—had no forest in the surrounding buffer and very little emergent vegetation.

Some damselfly dispersal studies suggest that landscape topology and connectivity may 'funnel' individuals that otherwise do not have directed flight (e.g., Conrad et al. 2002) and might therefore affect levels of oviposition at individual sites. Similarly, Petersen et al. (2004) evaluated adult dispersal of mayflies, stoneflies and caddisflies away from their natal streams within ecosystems of different land-use, and found more stream corridor dispersal than lateral dispersal, regardless of surrounding land-use (e.g. forested, moorland, open). It is not clear whether this phenomenon influences dragonfly distribution.

Other factors. Investigators have speculated about several other factors that might influence oviposition choice for aquatic invertebrates in general, and dragonflies in particular. For example, adult odonates appear to respond to polarization patterns of light reflected from the water surface, but this may play only a minor role in oviposition site selection (Wildermuth 1998, Bernath et al. 2002). Bernath et al. (2002) found that some species only oviposited at sites with 'darker' water polarization, others only used sites with 'brighter' water, and others appeared to use both without a distinct preference. Kairomones (chemical signals of animal presence in aquatic environments) may also influence site selection, but this has not been studied for dragonflies.

Buskirk and Sherman (1984) concluded that dragonfly oviposition-site selection is based on visual cues of landscape and/or habitat features (e.g. wetland size) that could potentially be *indicators* of the factors that could affect the offspring, like predation, hydroperiod, etc. Johanssen and Brodin (2003) suggest that adult dragonflies visually assess wetland size as an indication of fish presence, possibly because size is related to hydroperiod and fish presence (Tonn and Magnuson 1982). Buskirk and Sherman

(1984) also argue that females of species that cannot tolerate dessication would specifically oviposit in large wetlands on the landscape to maximize the chances of avoiding it. I selected wetlands within a narrow size range but some species were nevertheless found more at the slightly larger wetlands (Tables 2.4, 2.7). Although the three larger sites surveyed in 2004/2005 were not included in these analyses, some species were found primarily at the larger sites those years (e.g., *Basiaeschna janata* (Say), *Dromogomphus spinosus* Selys), and were not found in the smaller, 2006 wetlands (M. Aliberti Lubertazzi, unpublished data). Therefore, some dragonfly species apparently select wetlands of a specific size range for oviposition.

Most field guides give some distributional information for lentic dragonfly species (e.g., Dunkle 2000, Nikula et al. 2003)—for example, coastal vs. inland, bog vs. lake—but these patterns are usually based entirely on adult observational data. My results indicate strong patterns of dragonfly emergence along several landscape gradients. Several species were common in urban environments, so urban habitats have conservation value for some species, and some rare species were most abundant at more natural, rural sites. Therefore, conservation of a variety of wetland types can be important to maintain diversity of aquatic species on the landscape (Cayrou and Cereghino 2005, Jeffries 2005a). Ultimately, it is important to understand the mechanisms that underlie the distributions of organisms along the landscape gradients, which would likely require experimental, in addition to observational, research (McIntyre 2000, Blair 2004).

It is hard to know what the distributions of odonate species were on the forested pre-colonial, or the colonial agricultural New England landscape. Did species that prefer wetlands in 'open' areas emigrate into the northeastern U.S. when potential habitat became abundant (e.g., like some songbirds [Wright 1921, Litvaitis 1993, Unknown 2002]), or did they take advantage of the increase in disturbed or successional habitat availability (Werner et al. 2007, Winfree et al. 2007) and go from rare to abundant? Very few, if any, of my study wetlands were small, naturally-occurring ponds; in fact, many are essentially stream impoundments that were probably the result of agriculture and/or municipal landscape design (see Appendix I). Interestingly, such a large change in landscape features, and consequent odonate species distributions, has been documented in another part of the world. Small, anthropogenically-created wetlands (farm dams) provide habitat for a relatively high diversity of pond dragonflies in an open, arid region of South Africa where such natural habitats are/were generally rare (Samways 1989). It would be very interesting to document the changes in dragonfly populations on the New England landscape over the past few centuries, but quantitative data from previous centuries are lacking.

By comparing the patterns at sample sites across years, it is evident that dragonfly diversity did not differ with regard to forest cover or chloride concentration in wetlands in Rhode Island, nor did it differ substantially along the coastal-inland gradient. This suggests that small urban wetlands can play a substantial role in maintaining regional dragonfly faunas; they are not population sinks, as is sometimes assumed. Indeed, Jeffries (2005a) and Cayrou and Cereghino (2005) stress the need of wetland heterogeneity on the landscape, which can refer to many factors (e.g., size, predator populations, hydroperiod, successional stage, etc.). Jeffries (2005a) additionally suggests that these important characteristics of ponds are similar to the requirements of butterflies along the landscape gradients (i.e., larval host plants) for some aquatic invertebrates. Since my samples were taken at a limited number of wetland sites, in one geographic area, over only three years, additional study of these patterns, and of the processes that generate them, are needed to understand the general applicability of these findings. I concur with many aquatic and invertebrate ecologists, who stress the need for more extensive, long-term wetland studies (Hawking and New 2003, Jeffries 2005b, Werner et al. 2007), along with intensive study of the habitat requirements of individual species.

My results argue strongly for the conservation value of diverse habitat types, including both urban and natural lentic wetlands of all sizes, for odonate conservation. For freshwater systems in general, analysis of natural populations should incorporate both larval and adult data, since the two life stages exhibit very different spatial and resource ecologies and requirements (Hawking and New 2003, Petersen et al. 2004). Because odonates require both wetland and terrestrial ecosystems for their complex life histories, over time they can serve as indicators of disruption, or change, to the wetland-upland transition and upland buffer zones (Foote and Rice Hornung 2005). Further study of the patterns—as well as the processes that generate them—will be extremely useful for conservation and land management programs in areas experiencing land-use change.

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Table 2.1. Environmental and species richness data for all sites in study.

Site	Fish?	Area (ha)	Land-use (proportion of area) in 100 m buffer: Commercial Industrial	Forest	HMDR[1]	LMDR[2]	Open	Other wetland	Distance from coast (m)	pH 2004	pH 2005	Chloride concentration (mg/l) 2004	Chloride concentration (mg/l) 2005	Species Richness 2004	Species Richness 2005
2004-2005															
AMTRAK	NO	0.1149	0	0.5970	0	0	0.0500	0.3529	7570	4.81	4.70	0.99	2.00	10	12
BLACKSTONE	YES	0.3246	0	0.7444	0.0114	0	0.2442	0	38	6.54	6.58	120.96	159.00	11	11
BRISTOLSK	YES	0.4580	0	0.5657	0.1500	0	0.0976	0.1867	662	6.79	6.53	148.45	154.00	15	17
CAMPUS	YES	0.3245	0	0.0326	0	0	0.9674	0	5992	7.32	7.33	115.00	159.00	8	9
CAROLBIG	NO	0.3669	0	0.8518	0	0	0.0491	0.0991	11157	5.95	5.09	2.50	6.00	16	15
DEXTER	YES	0.5585	0.2228	0.2754	0.3064	0	0.0349	0.1605	17253	7.23	7.80	29.49	41.50	18	20
EIGHTROD	YES	0.0747	0	0.4226	0	0	0.2630	0.3144	2538	5.83	5.84	-2.50	4.00	8	5
GLOBE	YES	0.2828	0	0.3459	0.0580	0	0.5469	0.0492	17056	8.65	5.93	17.49	10.50	8	7
INDUSTRIAL	YES	0.1269	0.3989	0.5046	0	0	0.0168	0.0798	2691	5.85	6.85	23.49	33.00	6	2
KITTBIG	NO	0.4224	0	0.8948	0	0	0.1052	0	1925	5.31	4.99	2.50	3.00	10	17
NBGROUND	NO	0.0504	0	0	0	0	1.0000	0	2427	6.56	6.58	30.49	4.00	4	8
PAINTBALL	YES	0.1115	0	0.4624	0	0	0.2444	0.2932	3422	6.45	7.17	25.49	49.00	14	13
PHELPS	YES	1.7844	0	0.2392	0	0	0.7313	0.0295	7935	6.37	6.59	125.46	288.25	16	15
RUMFORD	YES	0.3170	0.1102	0.0000	0.0987	0	0.7911	0	1433	6.98	7.91	231.43	334.00	12	15
SAILADUMP	NO	0.1042	0	0.8037	0	0.0761	0.1202	0	10417	5.65	5.38	-0.50	8.00	6	9
SANDY	YES	3.6552	0	0.7707	0	0.1676	0.0617	0	10336	6.92	6.37	41.49	53.00	13	13
SKLT	NO	0.0868	0	1.0000	0	0	0.0000	0	2417	5.83	5.01	-0.50	3.00	4	9
SLATERFRIEND	YES	0.1164	0	0.0049	0	0	0.9628	0.0323	2490	6.94	6.70	1.50	18.43	13	12
SPECTACLE	YES	1.6646	0.1893	0.2239	0.4858	0	0.1011	0.0000	2390	8.47	7.52	105.97	111.50	10	10
STRATHMORE	NO	0.0917	0	0.6530	0.2596	0	0	0.0873	584	6.68	6.67	3.50	1.50	8	7
WAJONES	YES	0.7530	0	0.8303	0	0	0.1017	0.0679	22730	6.61	6.82	4.50	6.00	18	15
2006															
BARRGAZEBO	YES	0.1568	0.1577	0	0.24653	0	0.5958	0	131	6.58		24.82		6	
BFARMPD	NO	0.0241	0	0.2743	0	0	0.6129	0.1128	13732	6.57		30.50		1	
BFRATPD	NO	0.1435	0	0.6873	0	0	0.1524	0.1602	13962	6.53		25.00		9	
CCRIWARWICK	YES	0.2428	0	0.4548	0.0180	0.3995	0.0985	0.0293	2937	6.61		13.43		13	
COWESETT	YES	1.0667	0	0.2719	0.29879	0	0.2741	0.1552	552	6.45		22.66		5	
EASTFARM	YES	0.2095	0.7872	0	0.13631	0	0.0482	0.0283	4046	9.18		33.77		10	
FALCONE	YES	0.0811	0.3821	0.1437	0	0	0.4742	0	1037	6.87		55.09		7	
FLATRIVRES	YES	0.0764	0	0.0756	0.77291	0	0.1515	0	14081	6.51		29.59		7	
GODDARDSP	YES	0.1390	0	0.7593	0	0	0.2407	0	191	6.23		31.39		8	
GWPUMP	NO	0.0390	0	0.5715	0.04248	0	0.3252	0.0608	31150	5.29		40.38		10	
HARRINGTON	NO	0.1949	0	0.4059	0	0	0.5497	0.0444	10766	5.85		3.63		3	
NANCYBUXTON	NO	0.0934	0	0.6864	0.24668	0	0.0669	0	24052	5.31		3.35		7	
NATURESWAY	YES	0.0714	0.3355	0.2267	0.41187	0	0.0186	0.0073	13402	6.47		29.31		9	
PEEPER	YES	0.4529	0	0.5993	0	0	0.0735	0.3272	10014	5.57		4.41		13	
PLAINPD	NO	1.3835	0	0.8578	0	0	0.1319	0.0103	11336	4.81		3.00		16	
SHIPPEEOP	YES	0.0531	0	0.2946	0.63553	0	0	0.0699	7522	6.16		7.02		6	
SIMMSMILL	YES	0.3236	0	0.5090	0	0	0.1548	0.3362	2142	6.43		30.37		7	
SNAKEDEN	YES	0.0524	0	0.5515	0	0	0.1596	0.2888	11043	6.22		3.50		10	
SOM	NO	0.0619	0	0.9432	0	0	0.0568	0	15615	6.31		10.31		8	
TEPEEPD	NO	0.0541	0	0.9911	0	0	0	0.0089	29412	4.61		7.43		13	
WASHCOCC	NO	0.1104	0.0733	0	0	0	0.7509	0.1758	9037	6.06		28.10		9	
WEYMRIDGE	YES	0.2232	0	0.4995	0.2492	0	0.0653	0.1860	13141	5.98		14.67		6	
WRIGHTFARM	YES	0.0942	0	0.0766	0	0	0.9234	0	24469	6.47		3.51		15	

[1] High-medium density residential

[2] Low-medium density residential

Table 2.2. All species documented at all sites in 2004, 2005 and 2006; species list organized by average number of sites where each was collected over the three years.

Family	Species	2004	2005	2006
Libellulidae	*Sympetrum vicinum/semicinctum*	20	17	20
Libellulidae	*Pachydiplax longipennis*	16	19	19
Libellulidae	*Sympetrum janae*	16	18	13
Aeshnidae	*Anax junius*	16	15	11
Corduliidae	*Epitheca cynosura*	13	13	15
Libellulidae	*Erythemis simplicicollis*	14	14	12
Libellulidae	*Libellula incesta*	6	12	16
Libellulidae	*Leucorrhinia intacta*	12	11	8
Libellulidae	*Perithemis tenera*	6	7	9
Libellulidae	*Tramea* spp.	8	10	4
Aeshnidae	*Aeshna umbrosa*	6	7	8
Libellulidae	*Celithemis elisa*	8	8	4
Libellulidae	*Plathemis lydia*	6	5	6
Aeshnidae	*Aeshna clepsydra*	6	9	1
Libellulidae	*Libellula pulchella*	6	7	3
Libellulidae	*Libellula cynosura*	7	6	1
Aeshnidae	*Aeshna tuberculifera*	3	6	4
Libellulidae	*Libellula semifasciata*	2	9	2
Gomphidae	*Gomphus exilis*	5	4	3
Libellulidae	*Libellula luctuosa*	6	3	3
Gomphidae	*Arigomphus villosipes*	4	5	2
Libellulidae	*Celithemis eponina*	4	7	0
Corduliidae	*Epitheca princeps*	5	5	1
Corduliidae	*Dorocordulia lepida*	0	3	4
Libellulidae	*Ladona julia*	0	1	6
Libellulidae	*Libellula vibrans/axilena*	2	2	3
Aeshnidae	*Aeshna canadensis*	2	2	2
Corduliidae	*Epitheca semiaquea*	1	3	2
Aeshnidae	*Nasiaeschna pentacantha*	0	2	3
Aeshnidae	*Aeshna constricta*	2	1	1
Aeshnidae	*Aeshna verticalis*	1	2	1
Aeshnidae	*Basiaeshna janata*	2	2	0
Gomphidae	*Dromogomphus spinosus*	2	2	0
Aeshnidae	*Aeshna mutata*	2	1	0
Aeshnidae	*Anax longipes*	1	1	1
Corduliidae	*Cordulia shurtleffi*	0	0	3
Libellulidae	*Libellula auripennis*	2	1	0
Libellulidae	*Pantala hymenaea*	3	0	0
Macromiidae	*Macromia illinoisensis*	0	1	1
Cordulegastridae	*Cordulegaster diastatops*	1	0	0
Macromiidae	*Didymops transversa*	1	0	0
Aeshnidae	*Epiaeschna heros*	1	0	0
Gomphidae	*Lanthus vernalis*	1	0	0
Libellulidae	*Leucorrhinia frigida*	1	0	0
Libellulidae	*Leucorrhinia hudsonica*	0	0	1
Libellulidae	*Leucorrhinia proxima*	0	0	1
Libellulidae	*Pantala flavescens*	1	0	0
Corduliidae	*Somatochlora williamsoni*	0	0	1

Table 2.3. Standard least squares multiple regression of species richness vs. wetland area, distance from coast, percent forest in 100m buffer and chloride concentration. Underlined values are significant at $p < 0.05$.

Variable	Year	All sites Coefficient	All sites P-value	No fish Coefficient	No fish P-value	Fish Coefficient	Fish P-value
Area	2004	16.727	≤ 0.001	21.182	0.049	13.612	0.017
	2005	16.485	0.001	23.504	0.002	16.689	0.028
	2006	3.024	0.203	6.290	0.090	-2.304	0.497
Distance from coast	2004	< 0.001	0.068	< 0.001	0.235	< 0.001	0.198
	2005	< 0.001	0.289	< 0.001	0.535	< 0.001	0.446
	2006	< 0.001	0.187	< 0.001	0.506	< 0.001	0.071
Forest	2004	0.405	0.905	4.251	0.464	3.282	0.504
	2005	1.204	0.737	4.756	0.351	-0.377	0.954
	2006	3.378	0.189	7.708	0.125	1.051	0.778
Chloride conc.	2004	0.011	0.526	-0.140	0.419	< -0.001	0.989
	2005	0.013	0.309	0.124	0.871	0.016	0.373
	2006	-0.082	0.132	-0.067	0.595	-0.096	0.097

Table 2.4. Significant relationships of abundance with environmental variables among the 10 most common dragonfly species. Seasonal scores (log(x+1) transformed) were used as dependent variables in standard least squares multiple regressions.

			All sites		No fish		Fish	
Variable	Species	Year	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Area	*Sympetrum vicinum/ semicinctum*	2004	3.677	**0.028**				
		2005	3.226	**0.052**				
		2006	0.890	0.106				
	Sympetrum janae	2004	-2.027	**0.040**				
		2005	-2.557	**0.014**				
		2006	-0.672	0.180				
Dist	*Pachydiplax longipennis*	2004	< -0.0001	0.930				
		2005	< -0.0001	0.272				
		2006	< 0.0001	**0.043**				
	Sympetrum janae	2004	< 0.0001	0.205				
		2005	< 0.0001	**0.017**				
		2006	< 0.0001	0.523				
	Epitheca cynosura	2004	< -0.0001	**0.008**				
		2005	< 0.0001	**0.022**				
		2006	< -0.0001	0.118				
	Libellula incesta	2004			< 0.0001	0.327		
		2005			< 0.0001	**0.022**		
		2006			< 0.0001	0.169		
Forest	*Sympetrum janae*	2004	1.537	**0.002**			1.858	**0.047**
		2005	1.001	**0.027**			1.272	0.151
		2006	0.740	0.188			0.201	0.690
Chloride	*Epitheca cynosura*	2004	0.011	**0.004**				
		2005	0.007	**0.007**				
		2006	-0.011	0.331				
	Leucorrhinia intacta	2004					-0.007	0.167
		2005					-0.001	0.651
		2006					-0.022	**0.044**
	Tramea spp.	2004	0.007	**0.033**			0.006	0.225
		2005	0.002	0.349			0.005	**0.008**
		2006	0.002	0.862			-0.003	0.877

Table 2.5. Species that differed significantly in abundance (= seasonal scores, log (x + 1) transformed) between sites with vs. without fish populations.

	2004		2005		2006	
Species	**t**	**P-value**	**t**	**P-value**	**t**	**P-value**
Anax junius	-0.343	0.739	-3.810	**0.002**	-2.015	0.067
Epitheca cynosura	0.888	0.391	1.129	0.277	3.352	**0.003**
Erythemis simplicicollis	2.356	**0.033**	1.007	0.329	0.848	0.406
Perithemis tenera	2.791	**0.019**	2.625	**0.025**	3.743	**0.003**
Sympetrum janae	-2.165	**0.047**	-0.930	0.371	-2.700	**0.023**

Table 2.6. Overall regression analysis for species richness vs. wetland area, percent forest in 100m buffer, distance from coast and chloride concentration all 3 years. Model includes 21 sites in 2004 and 2005, and 23 sites in 2006. Note: there were no significant chloride x year interactions.

	All sites F = 3.330, p = 0.007		**No fish** F = 3.337, p = 0.025		**Fish** F = 3.206, p = 0.013	
Variable	**Coefficient**	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
Intercept	6.695	**< 0.001**	3.359	0.240	7.174	**< 0.001**
Area	1.213	0.094	8.473	**0.006**	0.359	0.637
Forest	2.327	0.174	2.963	0.353	2.000	0.406
Distance	< 0.001	**0.018**	< 0.001	0.205	< 0.001	**0.003**
Chloride	0.021	0.140	-0.038	0.794	0.018	0.253

Table 2.7. Overall regression analysis of the abundance (= seasonal scores, log(x+1) transformed) of the 10 most common species vs. wetland area, percent forest in 100m buffer, distance from coast and chloride concentration all 3 years. Asterisk denotes species with significant chloride x year interactions ($p \leq 0.05$).

		All sites		No fish		Fish	
Variable	**Species**	**Coefficient**	**P-value**	**Coefficient**	**P-value**	**Coefficient**	**P-value**
Area	*Pachydiplax longipennis*	-0.474	0.004			-0.424	0.004
	Sympetrum janae	-2.225	0.034	-1.356	0.010		
	Epitheca cynosura	0.286	0.014			0.318	0.011
	Erythemis simplicicollis			0.912	0.016		
Distance	*Pachydiplax longipennis*	< -0.001	0.005			< -0.001	< 0.001
	Libellula incesta			< 0.001	0.007		
Forest	*Sympetrum janae*	0.864	< 0.001				
	Anax junius	0.754	0.009				
Chloride	*Epitheca cynosura*					0.006	0.021*
	Erythemis simplicicollis	0.006	0.015				
	Tramea spp.	0.007	< 0.001*	-1.145	0.012	4.013	< 0.001*

*significant chloride x year interaction

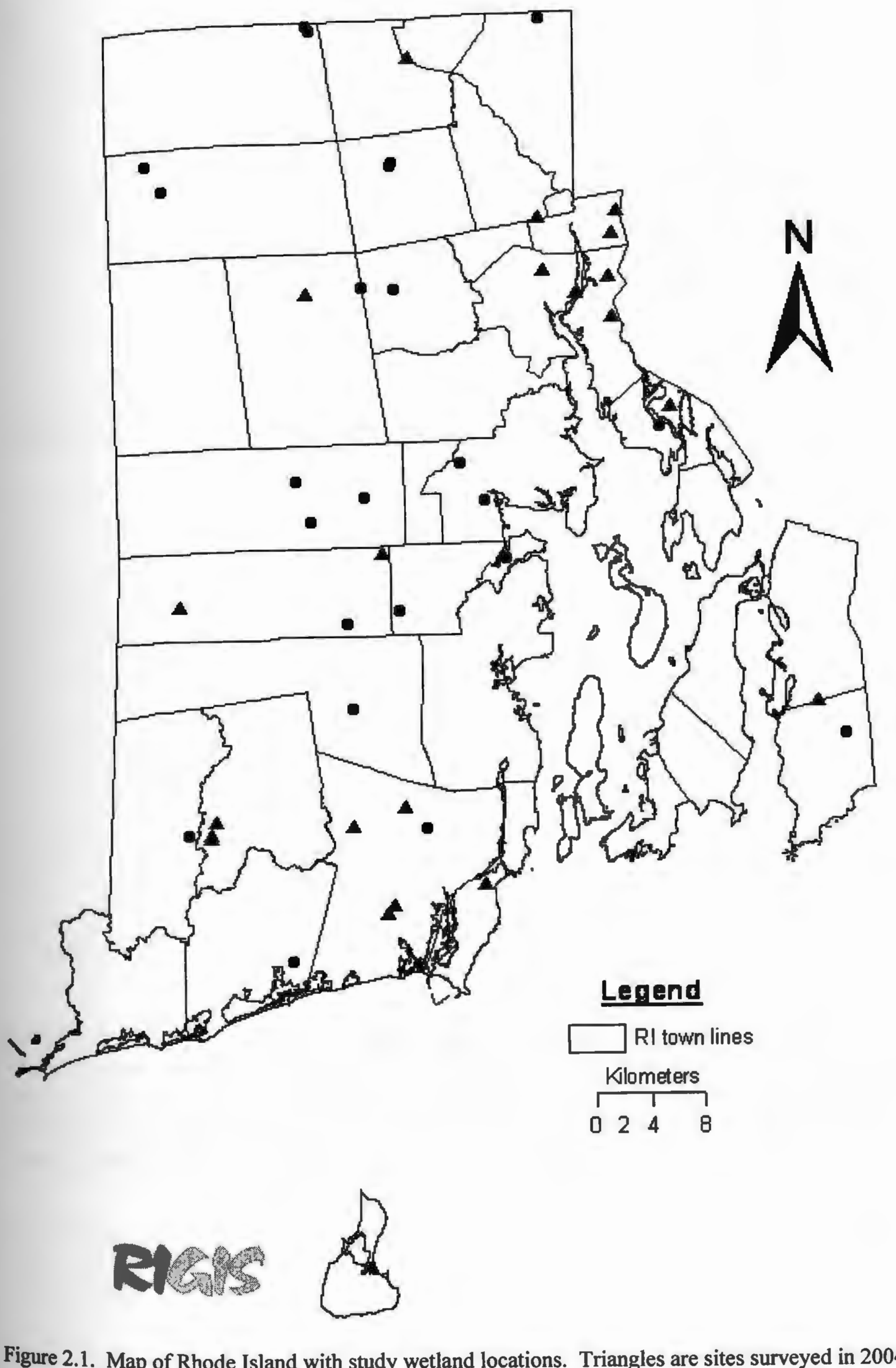

Figure 2.1. Map of Rhode Island with study wetland locations. Triangles are sites surveyed in 2004 and 2005 and circles are sites surveyed in 2006.

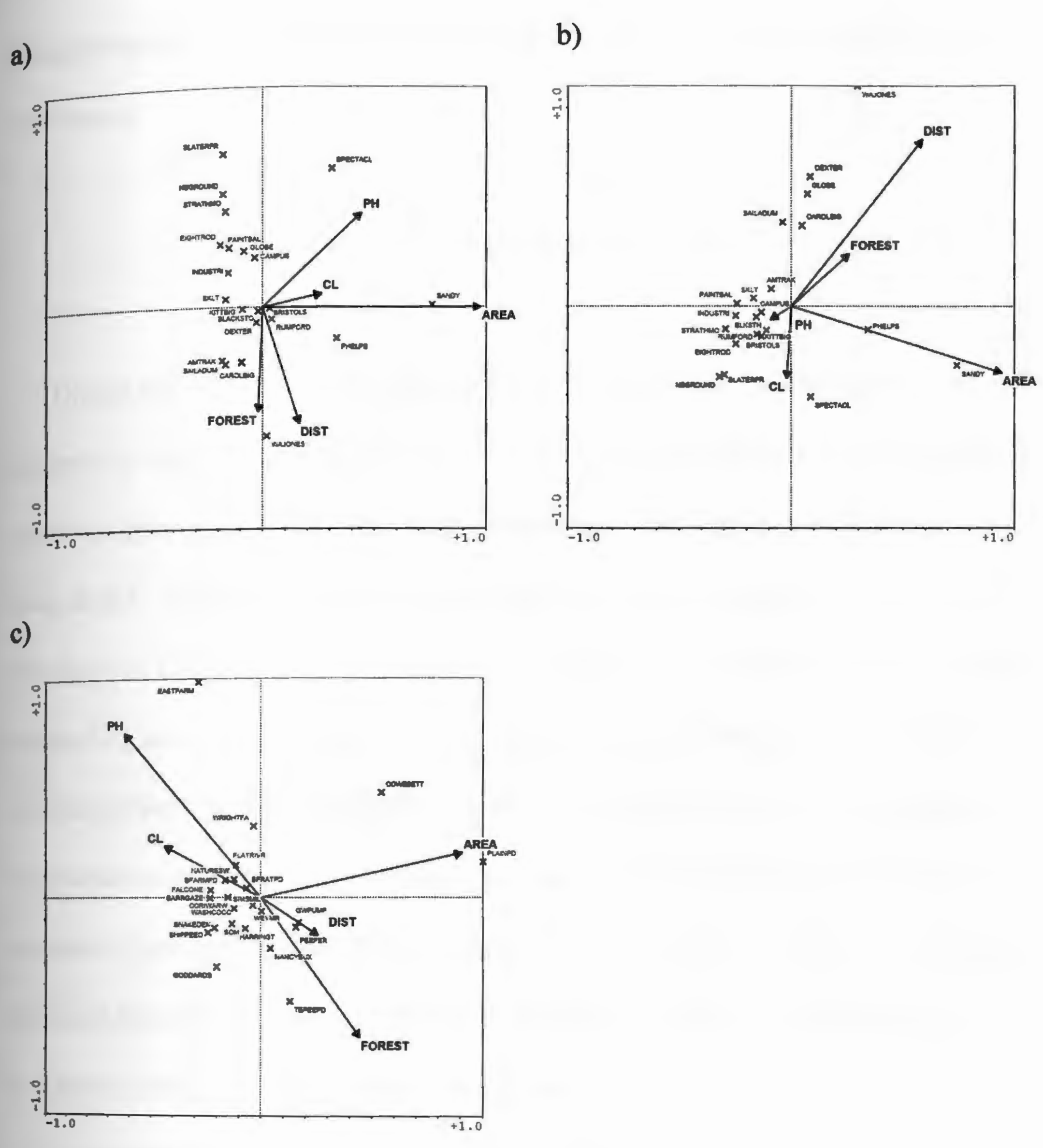

Figure 2.2. Canonical correspondence analysis plots of sites ("X"-marks; based on species composition) with environmental variable vectors in (a) 2004, (b) 2005 and (c) 2006. FOREST = percent forest in 100m buffer; PH = water pH; CL = water chloride concentration; DIST = wetland distance from the coast; AREA = wetland area; for detailed information on land-use categories, see Appendix IV.

Manuscript III: Persistence of Dragonfly Exuviae on Vegetation and Rock Substrates

Introduction

Dragonflies (Odonata: Anisoptera) are hemimetabolous insects that spend the majority of their lives as aquatic nymphs. Upon transformation to adulthood the last-instar nymphs emerge from the water and ecdysis occurs when a suitable substrate has been found. The shed nymphal exoskeleton—or exuviae (singular and plural, Needham et al. 2000)—is left behind. Dragonflies have traditionally been studied by conducting adult or nymphal (= 'larval', Needham et al. 2000) surveys. However, exuvial surveys hold the potential for substantial, direct analyses of the dragonfly communities because exuviae indicate that the individuals sampled developed in the wetland of interest (Corbet 1993). Furthermore, exuvial surveys have low impact on the local population because live individuals are not removed or disturbed, and volunteers can be easily trained to collect them.

Pupal midge exuviae (Diptera: Chironomidae) have been used for stream water quality assessment (e. g., Ruse 1995), and the consistent collection of pupal exuviae of midges (Diptera: Chironomidae and Ceratopogonidae) and mosquitoes (Diptera: Culicidae) has been used for measuring productivity of small, temporary pools with differing predation factors (Stav et al. 2000). Dragonfly exuviae have been used to study seasonal emergence patterns of individual species (Corbet 1999, Kormondy and Gower 1965). However, there have been relatively few surveys of dragonfly exuviae as potential faunistic monitoring tools at diverse emergence sites. Pollard and Berrill (1992) conducted intensive exuvial surveys to assess lake water quality status, Johansson and Brodin (2003) collected exuviae to document dragonfly community structure, Foster and Soluk (2004) used exuviae to monitor an endangered dragonfly species, and Gaines (in preparation) used exuviae to census the dragonfly populations of rare, fragile desert pothole ecosystems. Exuvial surveys of dragonflies have also been used to evaluate wetland restoration (D'Amico et al. 2004) and habitat quality of recently constructed wetlands (Chovanec and Raab 1997) in Europe. To accurately interpret these and similar studies, it is necessary to know how long the exuviae persist on rock and vegetation substrates. Knowledge of exuvial persistence will help to determine optimal sampling frequency, and can be used to calibrate population estimates based on exuvial surveys.

In this chapter I assess exuvial persistence for several dragonfly taxa on rock and vegetation substrates. I then discuss the effects of exuvial persistence on the interpretation and limitations of exuviae-based studies of odonate biology.

Methods

Five Rhode Island wetlands were chosen in June 2006 for the exuviae retention study, based on the presence of discreet potential emergence sites. Three sites contained anthropogenic rock-like structures (e.g., stone walls, concrete supports) that emerged directly from the water (CCRIWarwick, Phelps Pond, Slater-Gazebo Pond). Two sites with abundant emergent vegetation were also selected (Strathmore, BristolSk) (Table 3.1). Four of the five sites were initially visited between June 15-27, then July 5-25, July 28-August 15, August 18-September 7; all but one site (CCRIWarwick) were visited a fifth time between 1-13 September. The first visit to the fifth site (Slater-Gazebo) occurred when sufficient water was present (August 21), and there was one follow-up visit on 13 September. Areas with emergent structures were selected on the initial visit (e.g., cement planks, stands of cattails, etc.). These sample substrates were thoroughly examined for dragonfly exuviae, which were then visually identified to species- or genus-level and marked with daubs of bright-colored nail polish. I used photographs and detailed diagrams of the sample substrates to record location and species-group of each individual. Exuviae that were present at subsequent visits received additional daubs of nail polish, with each visit represented by a unique color.

All exuviae data were compiled after the last visit of the season. The number of color-coded individuals of each species-group was quantified by visit. Loss of exuviae from substrates was characterized by fitting curves to the proportion of exuviae remaining through time using Excel. I measured time in terms of the number of time periods since the exuviae were first marked. The initial visit was counted as number 1, with each time period (between visits) being about three weeks. This sampling period was utilized because this study was part of a larger project (see Chapter 1) in which dragonfly populations were sampled at numerous sites with roughly three weeks between visits to each site.

Data were analyzed using BIOMstat, version 3.3 (Rohlf and Slice 1999). Differences in declines of exuviae of different species through time were analyzed using R x C tests (row by column G-tests) of independence (Sokal and Rohlf 1985) and differences in persistence on rock vs. vegetation substrates were tested by 3-way ANOVA using log-linear models (presence x substrate x time period).

Results

Species-groups consisted of the following: CEEL = primarily *Celithemis elisa* (Hagen, 1861) (calico pennant; Libellulidae), SYVISE = *Sympetrum vicinum/semicinctum* (meadowhawks; Libellulidae), TRAMEA = *Tramea* sp. (gliders; Libellulidae), and EPI-LIBEL = *Epitheca-Libellula* (Corduliidae: Libellulidae). Exuviae of the genera *Epitheca* (baskettails; Corduliidae) and *Libellula* (skimmers; Libellulidae) are often of similar size, and are not easily separable in the field, especially when remaining attached to the substrate. The exuviae of *Anax junius* (Drury 1770; common green darner; Aeshnidae), the only species that was marked at the Strathmore site, are not analyzed separately here; however, they were included in the presence vs. substrate vs. time analysis (Figure 3.2). The interval between site visits was roughly 3 weeks (overall average, 21 ± 3.2 days SD).

Exuviae were initially lost rapidly from the sample substrates, with declines leveling out after the first few weeks (Figure 3.1). The declines for CEEL, EPI-LIBEL and SYVISE exuviae gave close fits to an exponential decline model (Table 3.2). I had only two sample times for TRAMEA (initial sample and a second sample three weeks later) but I fit the data to an exponential decline model for consistency with the other taxa (Fig. 3.1).

The initial rate of decline (proportional decline after one period) differed among species groups (R x C test, G = 28.015, df = 3, P = 0.0000036), with CEEL, SYVISE, and TRAMEA (G = 4.710) and SYVISE and EPI-LIBEL (G = 6.003) forming non-significant subsets. Thus, short-term retention of EPI-LIBEL exuviae differed from that of CEEL and TRAMEA.

There was no significant 3-way interaction between exuvial presence x substrate x time period (3-way ANOVA using log-linear models, G = 2.194, df = 3, P = 0.533) and in each time period, exuvial presence was independent of substrate type (G = 2.263, df = 4, P = 0.6875). Therefore, persistence of exuviae did not differ on rock vs. vegetation substrates (Fig. 3.2).

Discussion

Loss of exuviae was rapid over the first three weeks for all species, but differed among species groups, with least decline in EPI-LIBEL. EPI-LIBEL species tend to be larger in size than CEEL and SYVISE, but smaller than TRAMEA. Therefore, I detected no consistent relationship between body size and persistence. Persistence of exuviae did not differ significantly on vegetation vs. rock emergence substrates. My results suggest that there are no consistent effects of dragonfly body size or substrate type on exuvial persistence, but more comprehensive sampling with larger sample sizes and additional taxa might reveal subtle differences that I did not detect. I did not specifically study position of the substrate, but that aspect might be important because wind action can be stronger on more exposed than on sheltered areas. For example, at two of the study sites with rock substrates, I noted that exuviae tended to persist longer in areas protected from the wind.

Johansson and Brodin (2003) collected exuviae 2-3 times per week during the entire emergence season, with sufficient data to conduct a variety of analyses with environmental variables. Benke and Benke (1975) performed daily collections of exuviae to provide a close measurement of the total number and diversity of successfully-emerging dragonflies along a stretch of shoreline. Wissinger (1988) also utilized daily collections of exuviae in his survey of the dragonfly fauna in an Indiana farm pond over several years. In addition to virtually year-round surveys of nymphs, he collected exuviae daily for one field season, and every 3 days the next year. An attrition experiment indicated a 15% discrepancy in emergence quantification between 3-day and 1-day intervals when sampling exuviae. My results are consistent with Wissinger's because they also indicate rapid declines through time. Interestingly, Wissinger's species emergence phenologies from one wetland are very similar to those compiled from 3-week exuvial surveys at multiple wetlands in Rhode Island (Aliberti Lubertazzi unpublished).

The relatively rapid loss of exuviae in this study suggests that non-daily exuvial surveys typically record only a partial sample of the individuals of a species-group emerging from a given wetland. Furthermore, exuvial samples might be biased toward certain species groups, because certain taxa differed from others in the rapidity of loss from the substrate. For most taxa in my study, more than half of the exuviae were lost in three weeks. Therefore, species with brief and synchronous seasonal emergences could be underrepresented (if emergence occurred soon after a sample) or overrepresented (if emergence occurred just before a sample) in samples taken three weeks apart. D'Amico et al. (2004) sampled exuviae and adults at 10 sites every two weeks, and found similarities, but also some differences, between the exuvial and adult surveys. Collection of both types of data allowed a more comprehensive interpretation of odonate population status at treated and reference study ponds, even with samples taken only every two weeks. Nevertheless, my results suggest that samples should be taken as frequently as possible to reduce unknown biases in detection of individual species.

One of the advantages of surveys conducted with exuviae is that species can be detected whose other life stages are difficult to collect in the field. For example, Benke and Benke (1975) found that one of the most abundant dragonfly species emerging from their study pond (Libellulidae: *Perithemis tenera* (Say, 1839), eastern amberwing) was not common in extensive nymphal surveys of the pond. Indeed, Kormondy and Gower (1965) used permanently positioned wire screen cages to survey emerging odonates at perimeter versus central locations of a small pond, and found that some species emerged in distinct locations. Thus, some common species might not be detected in wetlands if their aquatic life stage inhabits hard-to-sample areas, like profundal zones. The adults of some river species are rarely seen near emergence areas, and collection of their exuviae has provided useful documentation of their presence, abundance and habitat use (Orr 2006). Ruse (1995) reported a similar phenomenon in comparative samples of chironomid larvae and pupal exuviae in chalk-gravel streams, where the exuvial surveys documented species whose larvae inhabit macrophyte stands that are minimally included in larval surveys. Benke and Benke

(1975) found a >90% pre-emergence mortality rate for most species in intensive surveys of a pond's nymphal dragonfly population from hatching through late-instar stages. Hence, exuvial surveys can be the best measure of a pond's adult productivity. I should point out, however, that exuviae of some species can be located in cryptic sites, or in sites distant from the water, and can thus be difficult to detect.

Surveys of rare taxa have documented successful reproduction of an individual species at a site by collecting exuviae. For example, the federally-endangered Hine's emerald dragonfly (Corduliidae: *Somatochlora hineana* Williamson 1931), whose nymphal life stage lasts several years before adult emergence, can be sampled with low-impact population surveys by collecting exuviae (Foster and Soluk 2004). Thus, surveys targeting either habitat (i.e., wetlands) or species status (e.g., establishment, conservation, restoration, etc.) can potentially benefit from exuviae-based sampling.

Acknowledgments

Special thanks to M. Freeman and S. Droege for constructive comments on early drafts of the manuscript. Karen Gaines provided excellent advice and inspiration, with regard to the merits of focusing on exuviae.

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Table 3.1. Sample sites for 2006 dragonfly exuviae retention study. See text for explanation of taxon categories.

Site Name (Town)	**Survey Substrate**	**Dates**	**Taxa**
Rock Substrates			
CCRIWarwick	Stone wall	27 June, 25 July,	EPI-LIBEL
(Warwick)		15 August, 7 Sept	SYVISE
Phelps Pond	3-sided cement	20 June, 10 & 28 July,	CEEL,
EPI-LIBEL			
(West Greenwich)	structure	18 August, 1 Sept	SYVISE
Slater-Gazebo Pd	Cement decorative	21 August, 13 Sept	TRAMEA
(Pawtucket)	stone wall		
Vegetation Substrates			
Strathmore	*Typha, Sagittaria*	15 June, 5 & 29 July,	*Anax junius*
only			
(Narragansett)		18 August, 12 Sept	
BristolSk	*Juncus, Phragmites,*	23 June, 10 & 31 July,	CEEL,
EPI-LIBEL			
(Barrington)	*Typha*	21 August, 13 Sept	

Table 3.2. Statistical models for loss of exuviae from substrate. See text for explanation of taxon categories.

$$\text{Proportion remaining} = (\text{coefficient})e^{(\text{exponent})(\#\ \text{periods})}$$

Taxon	**Coefficient**	**Exponent**	**R^2**
CEEL	1.337	-0.5263	0.951
EPI-LIBEL	1.2265	-0.2642	0.885
SYVISE	1.2345	-0.4803	0.758
TRAMEA	4.5455	-1.5141	

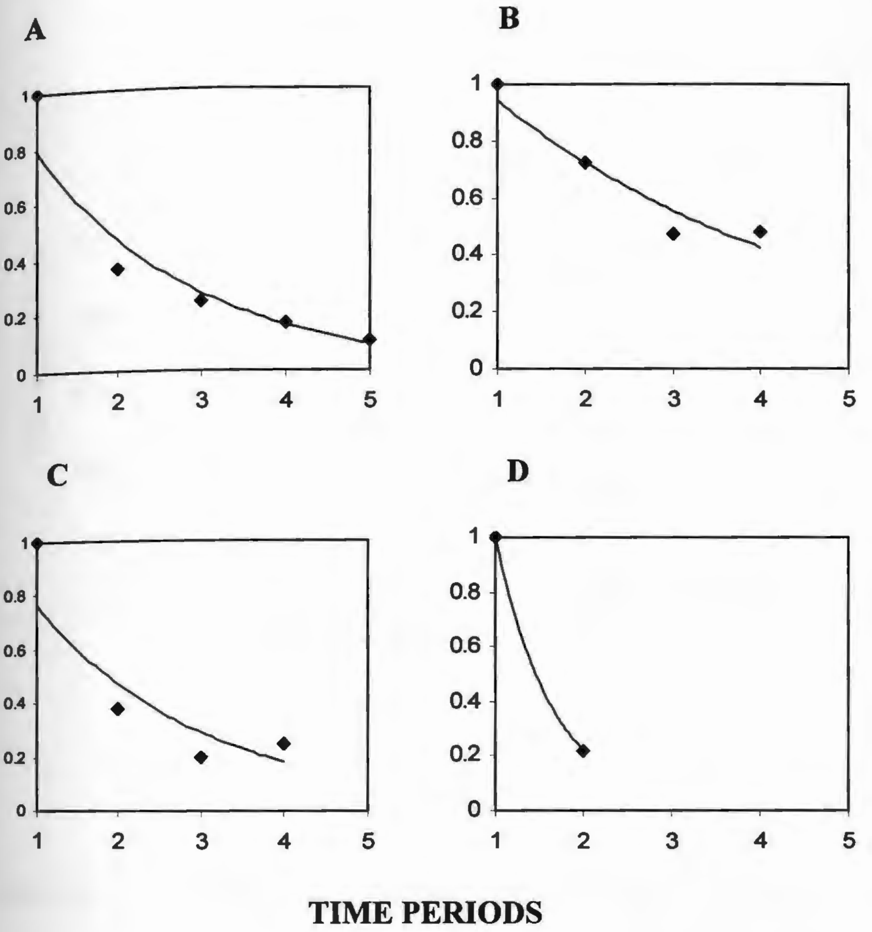


Figure 3.1. Proportion of exuviae remaining at each follow-up site visit; A) CEEL; B) EPI-LIBEL; C) SYVISE; D) TRAMEA. Time period = 3 weeks.

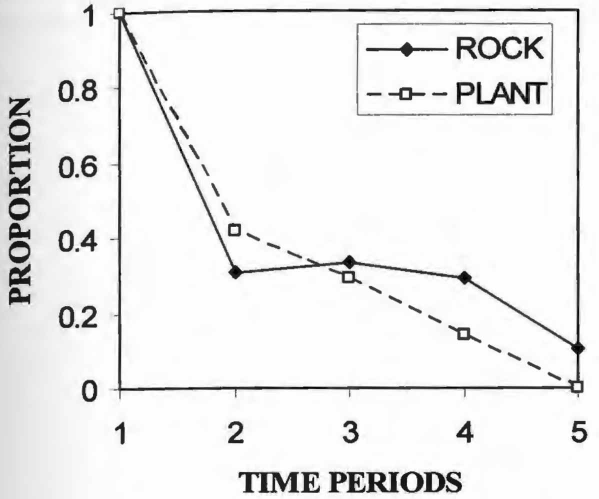
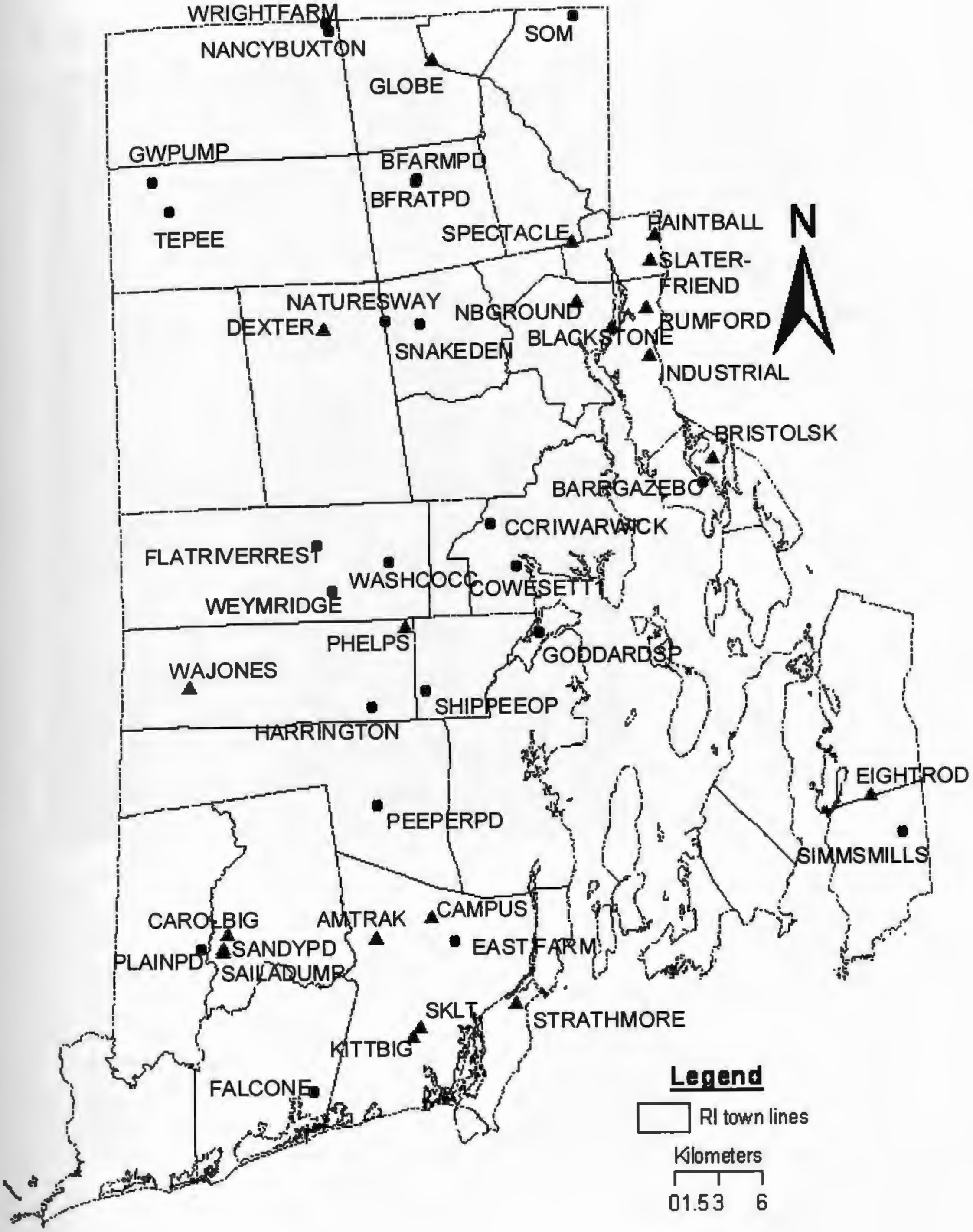


Figure 3.2. Overall proportion of exuviae remaining through time (number of 3-week periods after marking exuviae) on rock vs. vegetation substrates.

Appendix 1. Site pages.

This appendix contains two parts: Part A) map of Rhode Island with labeled sites; Part B) site pages. Specific information about each wetland is given on its site page, along with an aerial photo of the site (from RIGIS03/04 Digital Orthophotos of Rhode Island 2003-2004) and approximate sampling paths; the information includes town, area, classification, owner & contact, year(s) surveyed, fish, amphibians, sampling dates, wetland origin, site code and dragonfly species observed as nymph (N), exuviae (E) or adult (A).


WRIGHTFARM
NANCYBUXTON
SOM
GLOBE
GWPUMP
BFARMPD
BFRATPD
TEPEE
SPECTACLE
PAINTBALL
SLATER-FRIEND
N
NATURESWAY
DEXTER
NBGROUND
RUMFORD
BLACKSTONE
SNAKEDEN
INDUSTRIAL
BRISTOLSK
BARRGAZEBO
CCRIWARWICK
FLATRIVERREST
WASHCOCC
COWESETT1
WEYMRIDGE
PHELPS
GODDARDSP
WAJONES
SHIPPEEOP
HARRINGTON
EIGHTROD
PEEPERPD
SIMMSMILLS
CAROLBIG
AMTRAK
CAMPUS
SANDYPD
EAST FARM
PLAINPD
SAILADUMP
SKLT
STRATHMORE
KITTBIG
FALCONE
Legend
RI town lines
Kilometers
01.53 6

Site name: Amtrak

TOWN: South Kingstown

AREA: 0.11 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: Great Swamp WMA (DEM)

CONTACT: Brian Tefft

YR(S) SURVEYED:

2004, 2005

FISH: No

AMPHIBIANS: Wood Frog and Spring Peeper (tadpoles, metamorphs), Gray Tree Frog (eggs, tadpoles)

DATES SAMPLED: 2004: 24 May, 16 June, 8 July, 3 Aug, 19 Aug, 21 Sept 2005: 1 June, 20 June, 12 July, 1 Aug, 23 Aug (no water)

WETLAND ORIGIN? Inconclusive

SITE CODE: AMTRAK

Approximate sampling path

Dragonfly species documented at site:

ADULTS:
Anax junius
Erythemis simplicicollis
Leucorrhinia intacta
Libellula cyanea
Libellula incesta
Libellula semifasciata
Pachydiplax longipennis

EXUVIAE:
Anax junius
Aeshna clepsydra
Aeshna tuberculifera
Epitheca cynosura
Celithemis elisa
Erythemis simplicicollis
Libellula cyanea
Libellula incesta
Libellula luctuosa
Libellula pulchella
Libellula semifasciata
Leucorrhinia intacta
Pachydiplax longipennis
Sympetrum janae
Sympetrum vicinum/semicinctum

Site name: Barrington Gazebo

Approximate sampling path

TOWN: Barrington

AREA: 0.16 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed or unconsolidated?

OWNED BY: town of Barrington

CONTACT: Joseph Piccerelli, DPW

YR(S) SURVEYED: 2006

FISH: Yes – incl. dense goldfish population

AMPHIBIANS: none detected

DATES SAMPLED: 2006: 13 June, 6 July, 31 July, 21 Aug, 13 Sept

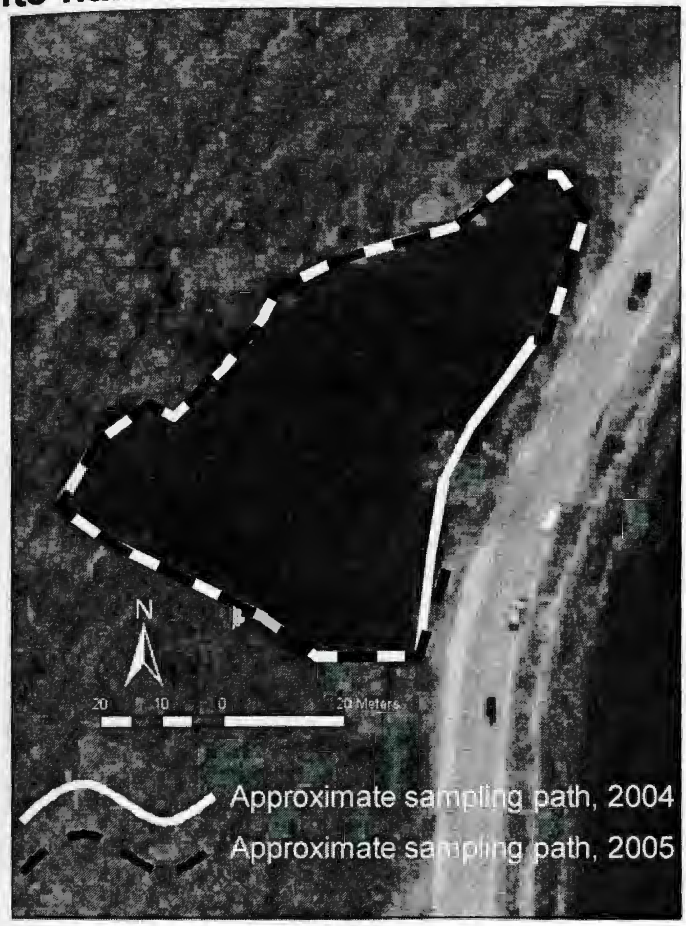
WETLAND ORIGIN? Culvert drainage, outflow: municipal design

SITE CODE: BARRGAZEBO

<u>Dragonfly species documented at site:</u>

ADULTS:	EXUVIAE:
Pachydiplax longipennis	*Anax junius*
	Epitheca cynosura
	Erythemis simplicicollis
	Libellula incesta
	Pachydiplax longipennis
	Perithemis tenera

Site name: Blackstone



TOWN: Providence

AREA: 0.32 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: City of Providence?

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes - sunfish

AMPHIBIANS: ?

REPTILES: painted turtles

DATES SAMPLED: 2004: 19 May, 16 June, 12 July, 5 Aug, 25 Aug, 24 Sept
2005: 15 June, 7 July, 27 July, 17 Aug, 12 Sept

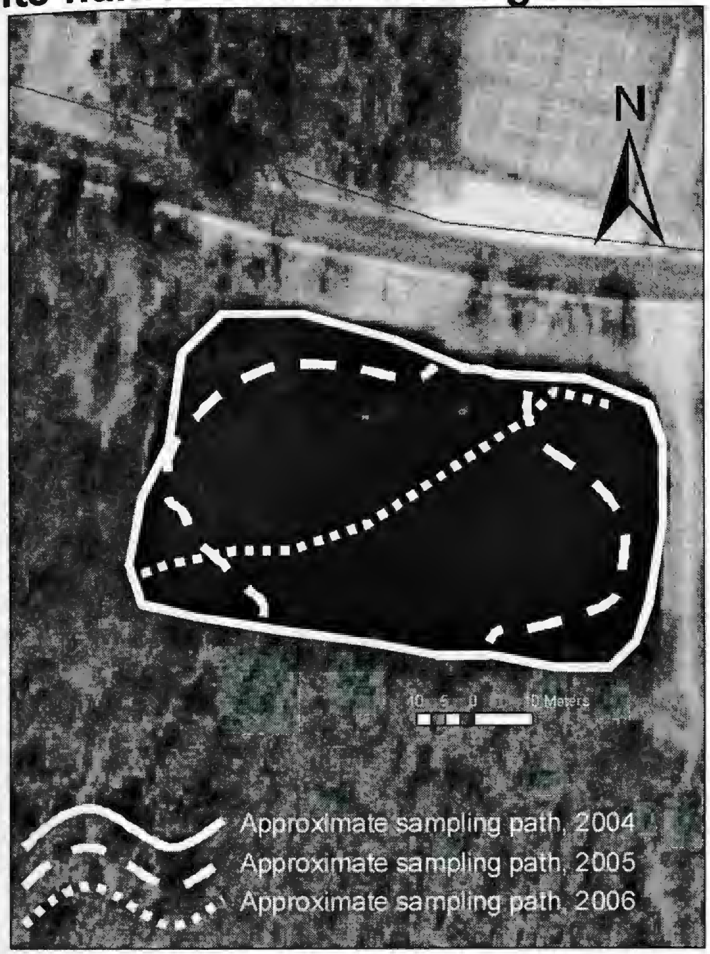
WETLAND ORIGIN? Inconclusive

SITE CODE: BLACKSTONE, BLKSTONE

Dragonfly species documented at site:

Anax junius	A, E
Epitheca cynosura	E
Epitheca princeps	A, E
Celithemis elisa	E
Celithemis eponina	A, E
Erythemis simplicicollis	A, E
Libellula incesta	A, E
Libellula luctuosa	A
Libellula pulchella	A
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A
Tramea lacerata	A
Tramea sp.	E

Site name: Bristol Skating Pd



TOWN: Barrington

AREA: 0.46 ha

CLASSIFICATION: POW, semipermanently flooded, emergent

OWNED BY: ?

CONTACT: ?

YR(S) SURVEYED: 2004, 2005, 2006

FISH: Yes – minnows, goldfish?

AMPHIBIANS: Bullfrog and Green Frog tadpoles & adults, Pickerel Frog adults, Spring Peeper and toad metamorphs
REPTILES: Painted Turtles (yoy), adult Snapping Turtles

WETLAND ORIGIN? Actively managed water; probably originally built for skating pond

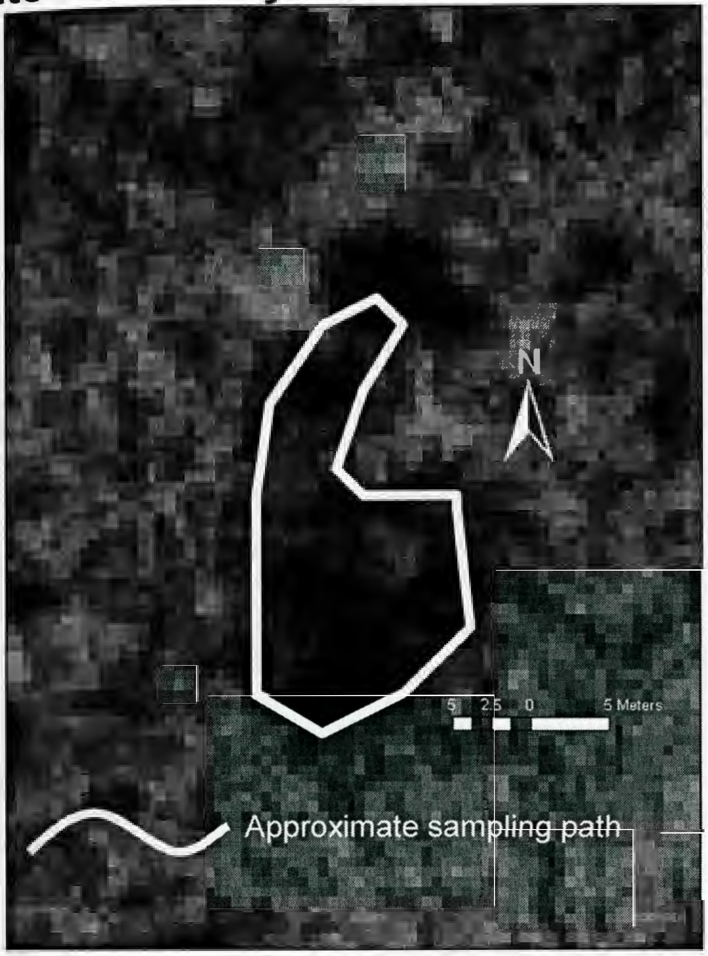
DATES SAMPLED: 2004: 27 May, 21 June, 21 July, 12 Aug, 30 Aug, 30 Sept
2005: 9 June, 29 June, 20 July, 4 Aug, 26 Aug*
2006: 23 June, 10 July, 31 July, 21 Aug, 13 Sept
*dry—dammed and dredged for *Phragmites* removal

SITE CODE: BRISTOLSK

Dragonfly species documented at site:

Anax junius	A, E	*Libellula (Plathemis) lydia*	A, E
Aeshna clepsydra	E	*Libellula pulchella*	A, E
Arigomphus villosipes	E	*Libellula needhami*	A
Epitheca cynosura	E	*Libellula semifasciata*	A, E
Celithemis elisa	A, E	*Libellula vibrans*	A
Celithemis eponina	E	*Pachydiplax longipennis*	A, E
Celithemis martha	A	*Pantala flavescens*	A
Erythemis simplicicollis	A, E	*Sympetrum sp.*	A
Erythrodiplax berenice	A	*Sympetrum janae*	E
Leucorrhinia intacta	A, E	*Sympetrum vicinum/semicinctum*	E
Leucorrhinia frigida	E	*Tramea carolina*	A
Libellula auripennis	E	*T. lacerata*	A
Libellula cyanea	A, E	*Tramea* sp.	E
Libellula incesta	A, E		
Libellula luctuosa	E		

Site name: Bryant Farm Pd



TOWN: Smithfield

AREA: 0.02 ha

CLASSIFICATION: POW, seasonally flooded

OWNED BY: Bryant University

CONTACT: Ken Person, Facilities Manager

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Wood Frog tadpoles and Spotted Salamander larvae

DATES SAMPLED: 2006: 1 June, 30 June, 27 July, 17 Aug, 12 Sept

WETLAND ORIGIN? Agricultural farm pond? (now abandoned)

SITE CODE: BFARMPD

Dragonfly species documented at site:

Pachydiplax longipennis A
Sympetrum janae E

Site name: Bryant Frat Pd

TOWN: Smithfield

AREA: 0.14 ha

CLASSIFICATION: POW, permanently flooded

OWNED BY: Bryant University

CONTACT: Ken Persons, Facilities Manager

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Spotted Salamander larvae, Bullfrog and Green Frog adults, Spring Peeper and Gray Tree Frog metamorphs

DATES SAMPLED: 2006: 1 June, 30 June, 27 July, 17 Aug, 12 Sept

WETLAND ORIGIN? Inconclusive

SITE CODE: BFRATPD

Dragonfly species documented at site:	
Anax junius	A
Aeshna tuberculifera	A
Aeshna umbrosa	A
Epitheca cynosura	A
Somatochlora sp.	N
Erythemis simplicicollis	A
Libellula incesta	E
Libellula (Plathemis) lydia	A, E
Libellula sp.	A
Pachydiplax longipennis	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Campus Pd

TOWN: South Kingstown

AREA: 0.32 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: URI

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes - sunfish

AMPHIBIANS:

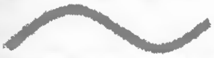
REPTILES: Painted Turtles

OTHER: beaver lodge

DATES SAMPLED: 2004: 24 May, 15 June, 1 July, 27 July, 17 Aug, 17 Sept 2005: 7 June, 23 June, 19 July, 1 Aug, 26 Aug

WETLAND ORIGIN? Impoundment—landscaping?

SITE CODE: CAMPUS



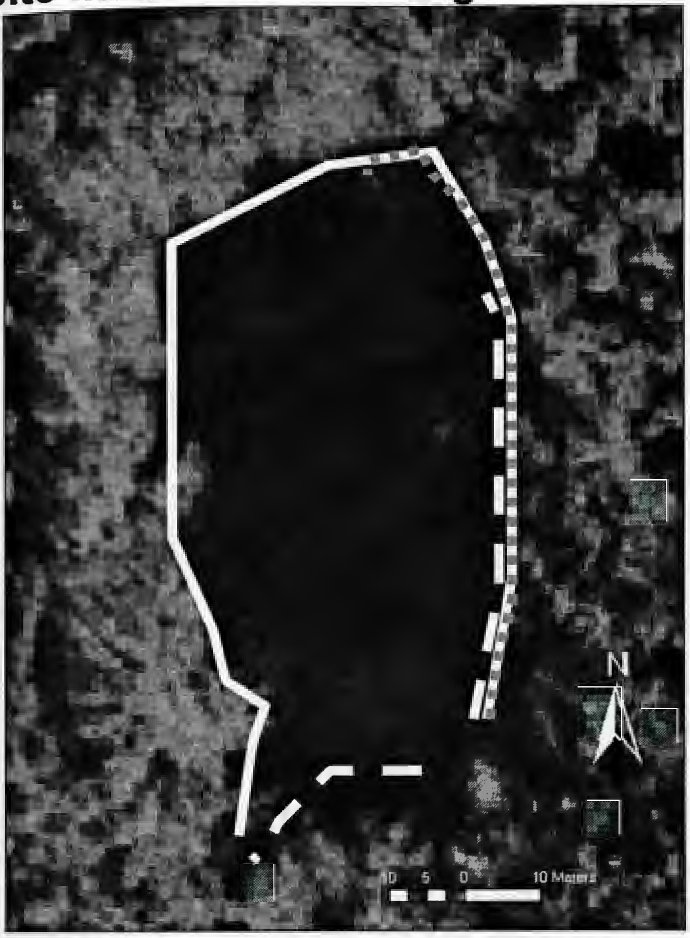
Approximate sampling path, 2004 & 2005

Additional path, 2004 only

Dragonfly species documented at site:

Anax junius	A
A. umbrosa	E
Nasiaeschna pentacantha	E
Arigomphus villosipes	E
Epitheca cynosura	E
E. semiaequea	E
Erythemis simplicicollis	A
Leucorrhinia intacta	E
Libellula incesta	A, E
Libellula luctuosa	A
Libellula (Plathemis) lydia	A, E
Libellula pulchella	A
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Tramea lacerata	A

Site name: Carolina Big



Approximate sampling path, 2004
Approximate sampling path, 2005
Approximate sampling path, 2006

TOWN: Richmond

AREA: 0.37 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: Carolina WMA (DEM)

CONTACT: Dr. Frank Golet

YR(S) SURVEYED: 2004, 2005, 2006

FISH: No

AMPHIBIANS: Gray Tree Frog adults, tadpoles & metamorphs; adult Bullfrogs & Green Frogs; Wood Frog tadpoles; Spotted Salamander larvae; Spring Peepers; Newts?

REPTILES: Painted Turtles

DATES SAMPLED: 2004: 25 May, 15 June, 8 July, 2 Aug, 20 Aug, 16 Sept
2005: 8 June, 28 June, 22 July, 15 Aug, 8 Sept (dry)
2006: 20 June, 12 July, 3 Aug, 23 Aug, 14 Sept

WETLAND ORIGIN? Natural?

SITE CODE: CAROLBIG

Dragonfly species documented at site:

Anax junius	A, E	*Epitheca cynosura*	E	*Pachydiplax longipennis*	A, E
Aeshna canadensis	A	*Epitheca semiaequea*	E	*Sympetrum janae*	E
Aeshna clepsydra	E	*Celithemis elisa*	A, E	*Sympetrum vicinum/* semicinctum	E
Aeshna tuberculifera	E	*Erythemis simplicicollis*	A, E	*Sympetrum* sp.	A
Aeshna umbrosa	A	*Leucorrhinia intacta*	E	*Tramea carolina*	A
Aeshna verticalis	E	*Libellula cyanea*	E	*Tramea* sp.	E
Aeshna sp.	A	*Libellula incesta*	A, E		
Dorocordulia lepida	E	*Libellula semifasciata*	A, E		

Site name: CCRI Warwick

TOWN: Warwick

AREA: 0.24

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: CCRI Warwick

CONTACT: ?

YR(S) SURVEYED: 2006

FISH: Yes

AMPHIBIANS:

REPTILES: Painted Turtle hatchlings

DATES SAMPLED: 2006: 31 May, 27 June, 25 July, 15 Aug, 7 Sept

WETLAND ORIGIN? Agricultural pond

SITE CODE: CCRIWARWICK

Approximate sampling path, 2006

Dragonfly species documented at site:	
Anax junius	A
Nasiaeschna pentacantha	E
Epitheca cynosura	E
Epitheca princeps	E
Epitheca semiaequea	E
Celithemis elisa	E
Libellula incesta	A, E
Libellula luctuosa	E
Libellula vibrans/axilena	E
Leucorrhinia intacta	E
Pachydiplax longipennis	A, E
Perithemis tenera	E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Cowesett I

Approximate sampling path, 2006

TOWN: Warwick

AREA: 1.07 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Cowesett Village, Piccone???

CONTACT: Sharon, others in office

YR(S) SURVEYED: 2006

FISH: Yes – perch, sunfish, bass
AMPHIBIANS: adult Bullfrogs

REPTILES: Snapping Turtles, large Painted Turtles

DATES SAMPLED: 2006: 25 May, 21 June, 18 July, 11 Aug, 5 Sept

WETLAND ORIGIN? Kettle pond, recent connection to other kettle pond

SITE CODE: COWESETT1

Dragonfly species documented at site:	
Anax junius	A
Epitheca cynosura	E
Erythemis simplicicollis	A
Libellula incesta	E
Libellula pulchella	A
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A
Tramea carolina	A
Tramea lacerata	A

Site name: Dexter Pd

TOWN: Scituate

AREA: 0.56 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Nelson King

CONTACT: Nelson King?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – sunfish, carp? (state stocks pond)

AMPHIBIANS: Adult Bullfrogs, Green and Pickerel Frogs; unk tadpoles

DATES SAMPLED: 2004: 28 May, 24 June, 20 July, 11 Aug, 26 Aug, 28 Sept 2005: 6 June, 22 June, 18 July, 3 Aug, 25 Aug

WETLAND ORIGIN? Built. A couple of inflows, largest at road

SITE CODE: DEXTER

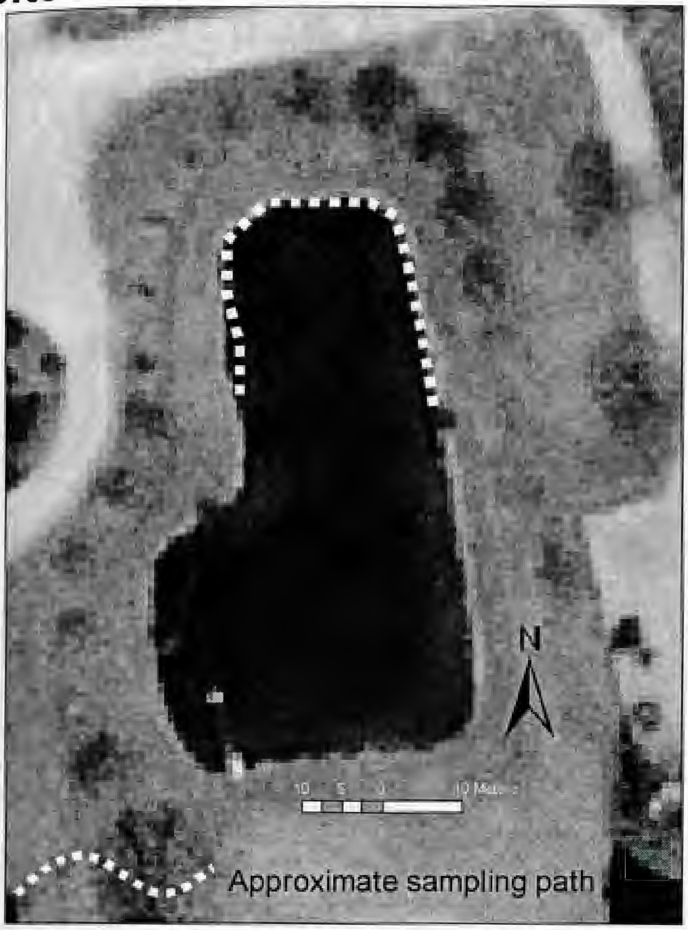
Approximate sampling path, 2005 & 2004

Additional sampling path, 2004

Dragonfly species documented at site:

Anax junius	A, E	*Libellula luctuosa*	E
Aeshna canadensis	E	*Libellula (Plathemis) lydia*	E
A. clepsydra	A, E	*Libellula pulchella*	A, E
Arigomphus villosipes	E	*Libellula vibrans/axilena*	E
Gomphus exilis	E	*Leucorrhinia intacta*	E
Epitheca cynosura	E	*Pachydiplax longipennis*	A, E
Epitheca princeps	E	*Perithemis tenera*	A, E
Celithemis elisa	A, E	*Sympetrum janae*	E
Celithemis eponina	E	*Sympetrum vicinum/semicinctum*	E
Erythemis simplicicollis	A, E	*Tramea* sp.	E
Libellula cyanea	E		
Libellula incesta	A, E		

Site name: East Farm Pd



TOWN: South Kingstown

AREA: 0.21 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: URI

CONTACT: ?

YR(S) SURVEYED: 2006

FISH: Yes – various, incl. Rainbow Trout & other salmonids (David Beutel)

AMPHIBIANS: tadpoles

REPTILES: Painted Turtles

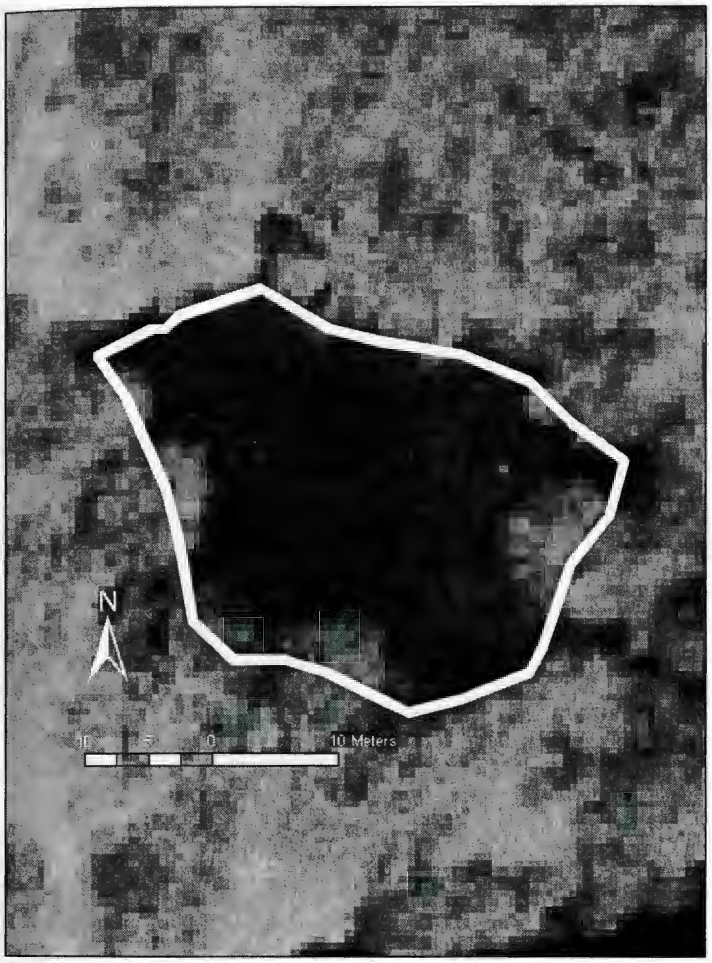
DATES SAMPLED: 2006: 23 May, 19 June, 14 July, 8 Aug, 29 Aug

WETLAND ORIGIN? Actively managed; built for landscaping, or outflow from labs?

SITE CODE: EASTFARM

Dragonfly species documented at site:	
Anax junius	A, E
Arigomphus villosipes	E
Epitheca cynosura	E
Erythemis simplicicollis	A, E
Libellula luctuosa	E
Libellula pulchella	E
Pachydiplax longipennis	A, E
Sympetrum vicinum/semicinctum	E
Tramea carolina	A
T. lacerata	A
Tramea sp.	E

Site name: Eight Rod Farm Pd



TOWN: Tiverton/ Little Compton

AREA: 0.07 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Eight Rod WMA (DEM)

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – small pickerel

AMPHIBIANS: Wood, Green, Pickerel Frogs, Spring Peepers

REPTILES: Painted Turtles, Spotted Turtle

DATES SAMPLED: 2004: 27 May, 29 June, 21 July, 12 Aug, 30 Aug, 8 Oct
2005: 2 June, 21 June, 13 July, 2 Aug, 24 Aug

WETLAND ORIGIN? Agricultural pond (abandoned)

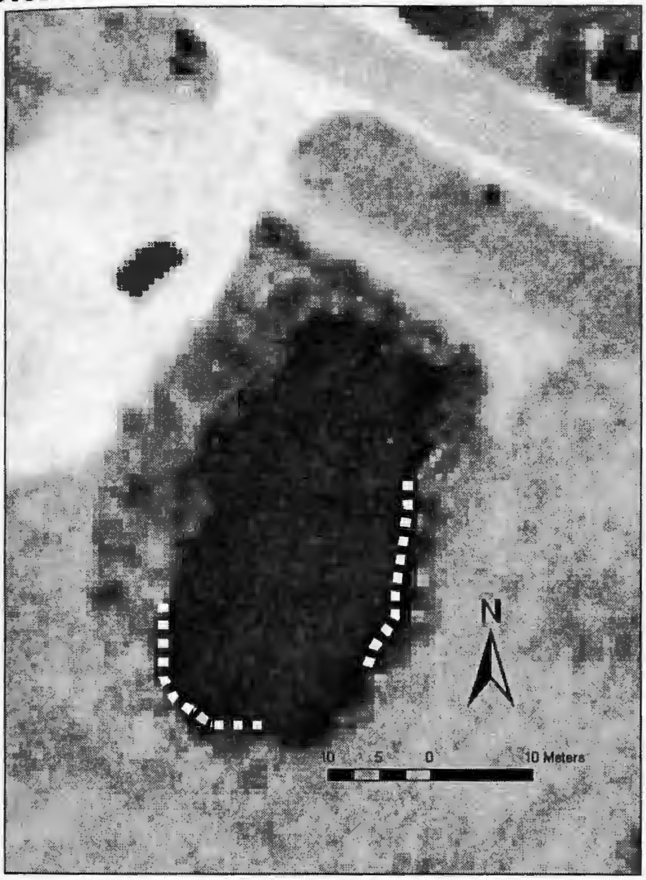
SITE CODE: EIGHTROD

Approximate sampling path

Dragonfly species documented at site:

Anax junius	E
Aeshna constricta	E
Aeshna tuberculifera	E
Aeshna umbrosa	E
Aeshna sp.	A
Epiaeschna heros	E
Erythemis simplicicollis	A, E
Libellula cyanea	A
Libellula pulchella	A
Libellula vibrans	A
Pachydiplax longipennis	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E

Site name: Falcone Pd



TOWN: Charlestown

AREA: 0.08 ha

CLASSIFICATION: POW, permanently flooded, unconsolidated?

OWNED BY: Mrs. Falcone

CONTACT: Mrs. Falcone

YR(S) SURVEYED: 2006

FISH: Yes – minnows? (found fry)

AMPHIBIANS: Green Frog adults & tadpoles; adult Bullfrogs

DATES SAMPLED: 2006: 24 May, 22 June, 14 July, 8 Aug, 23 Aug

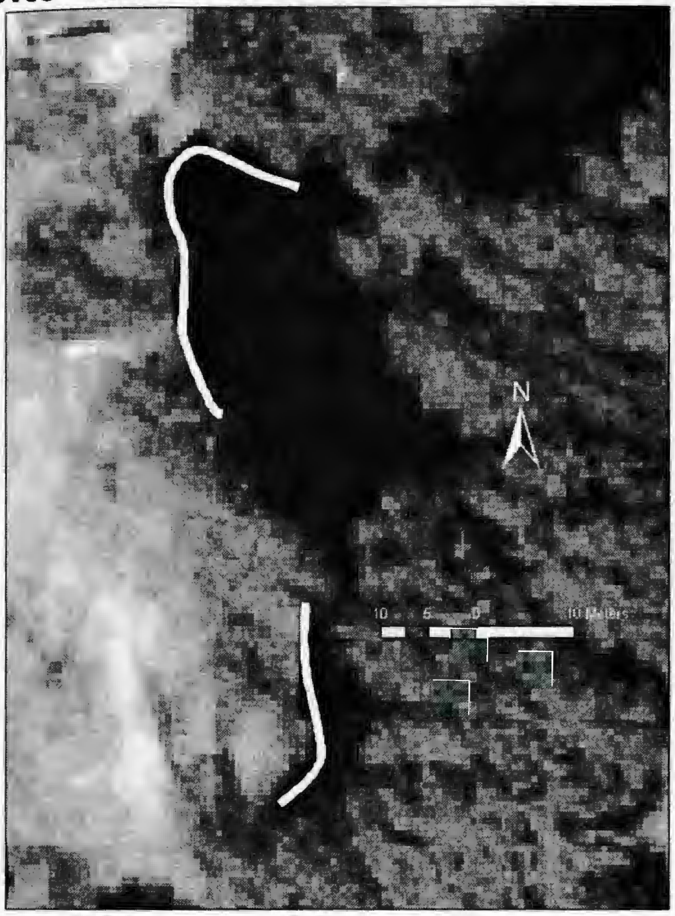
WETLAND ORIGIN? Inconclusive

SITE CODE: FALCONE

Approximate sampling path

Dragonfly species documented at site:	
Anax junius	A
Aeshna umbrosa	E
Celithemis elisa	A
Libellula incesta	E
Libellula (Plathemis) lydia	E
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A
Tramea lacerata	A

Site name: Flat River Reservoir I



Approximate sampling path

TOWN: Coventry

AREA: 0.08 ha

CLASSIFICATION: POW, permanently flooded

OWNED BY: Wayne Knight's family

CONTACT: Wayne Knight

YR(S) SURVEYED: 2006

FISH: Yes – "shiners" (baitfish?), bullheads

AMPHIBIANS:

DATES SAMPLED: 2006: 14 June, 5 July, 28 July, 18 Aug, 13 Sept

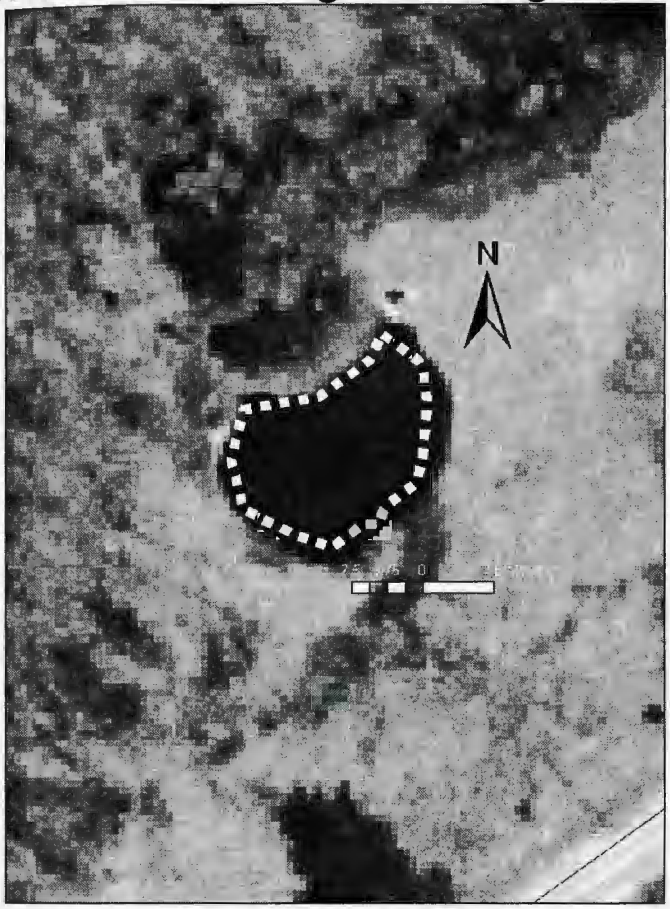
WETLAND ORIGIN? Inconclusive. (remnants of a cedar swamp? possible bait pond?)

SITE CODE: FLATRIVRES1

Dragonfly species documented at site:

Aeshna umbrosa	E
Aeshna sp.	A
Nasiaeschna pentacantha	E
Somatochlora williamsoni	A, E
Libellula incesta	A, E
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum janae	E

Site name: George Washington WMA Pump Pd



TOWN: Glocester

AREA: 0.04 ha

CLASSIFICATION: POW, semipermanently flooded?

OWNED BY: George Washington WMA (DEM)

CONTACT: Paul Riccard, Paul Wright

YR(S) SURVEYED: 2006

FISH: Hdqts staff say yes, but none observed

AMPHIBIANS: Green Frog and Bullfrog adults, Spring Peeper metamorphs

DATES SAMPLED: 2006: 29 May, 28 June, 19 July, 10 Aug, 4 Sept

WETLAND ORIGIN? Built for water supply for fighting forest fires

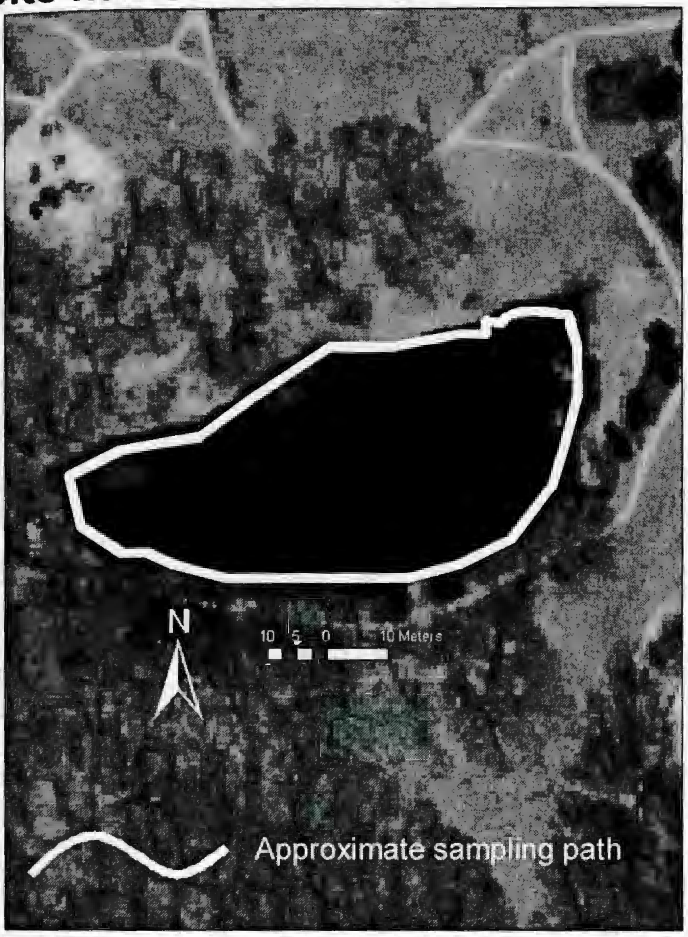
SITE CODE: GWPUMP

Approximate sampling path

Dragonfly species documented at site:

Anax junius	A	*Libellula cyanea*	A
Aeshna sp.	A	*Libellula incesta*	A, E
Dorocordulia lepida	E	*Libellula semifasciata*	E
Epitheca cynosura	E	*Pachydiplax longipennis*	A, E
Erythemis simplicicollis	E	*Perithemis tenera*	A
Celithemis elisa	A	*Sympetrum janae*	E
Ladona julia	E	*Sympetrum vicinum/semicinctum*	E
Leucorrhinia intacta	E	*Sympetrum sp.*	A

Site name: Globe Pd



TOWN: Woonsocket

AREA: 0.28 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Town of Woonsocket? (Globe Park)

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – minnows?

AMPHIBIANS: Green Frog adults & tadpoles, Bullfrog tadpoles

REPTILES: Painted Turtles

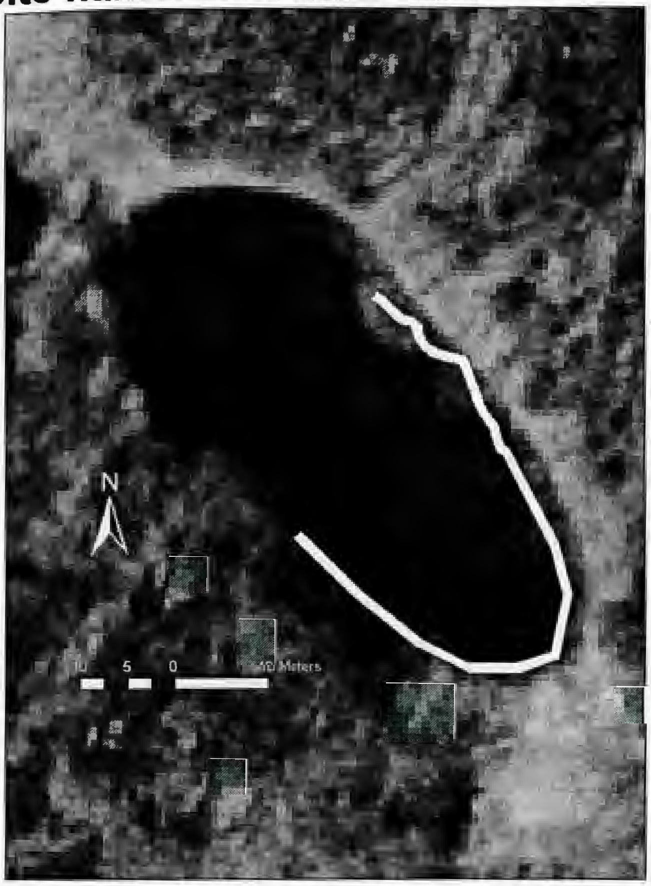
DATES SAMPLED: 2004: 28 May, 24 June, 20 July, 11 Aug, UNK, 5 Oct; 2005: 9 June, 27 June, 21 July, 11 Aug, 6 Sept

WETLAND ORIGIN? Landscape design (park pond)

SITE CODE: GLOBE

Dragonfly species documented at site:	
Anax junius	A, E
Aeshna umbrosa	E
Aeshna sp.	A
Arigomphus villosipes	E
Epitheca cynosura	E
Leucorrhinia intacta	A
Libellula cyanea	A
Libellula incesta	A
Libellula (Plathemis) lydia	A, E
Libellula pulchella	A, E
Pachydiplax longipennis	A, E
Perithemis tenera	A
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E

Site name: Goddard State Park



Approximate sampling path

TOWN: Warwick

AREA: 0.14 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Goddard Memorial State Park, RI DEM/Div. Parks & Rec

CONTACT: Bob Packart?

YR(S) SURVEYED: 2006

FISH: Yes – minnows, sunfish?

AMPHIBIANS: Bullfrogs; Spring Peeper metamorphs; Toad metamorphs?

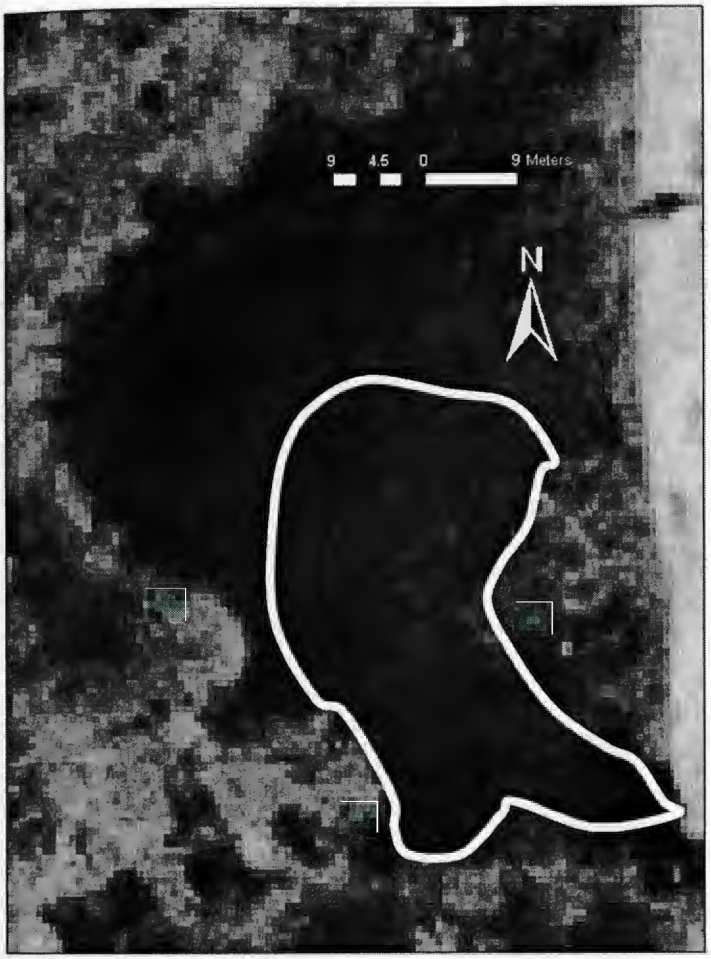
DATES SAMPLED: 2006: 25 May, 21 June, 25 July, 15 Aug, 7 Sept

WETLAND ORIGIN? Built for park landscaping? Maybe bait pond?

SITE CODE: GODDARDSP

Dragonfly species documented at site:	
Anax junius	A, E
Epitheca cynosura	E
Libellula incesta	A, E
Libellula pulchella	E
Libellula semifasciata	E
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Harrington Farm Pd



TOWN: West Greenwich?

AREA: 0.20 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: TNC?

CONTACT: Mary, Donald, Bernard Harrington

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Wood Frog metamorphs; Spotted Salamander larvae; Green Frog, Bullfrog, Gray Tree Frog tadpoles & adults

DATES SAMPLED: 2006: 1 June, 3 July, 26 July, 16 Aug, 11 Sept

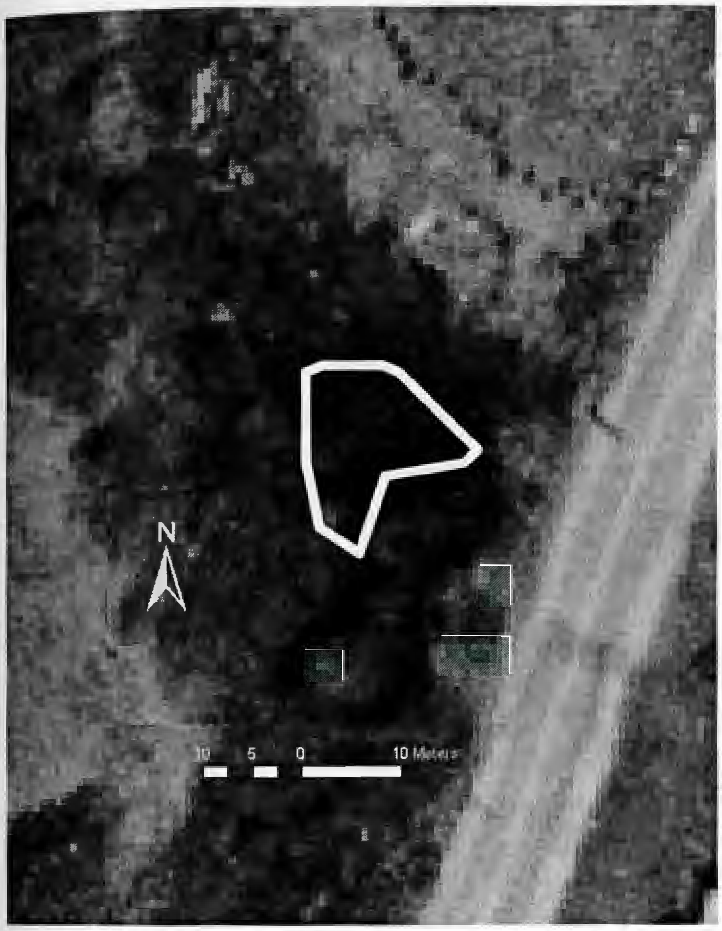
WETLAND ORIGIN? Farm pond

SITE CODE: HARRINGTON

Approximate sampling path

Dragonfly species documented at site:	
Anax junius	A
Aeshna canadensis	E
Aeshna verticalis	A
Aeshna sp.	A
Leucorrhinia intacta	A
Pachydiplax longipennis	A
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Industrial



Approximate sampling path

TOWN: East Providence

AREA: 0.13 ha

CLASSIFICATION: POW, semipermanently flooded, emergent

OWNED BY: ?

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – eels, pickerel

AMPHIBIANS: Green Frog adults, Bullfrog adults & tadpoles

DATES SAMPLED: 2004: 26 May, 21 June, 19 July, 10 Aug, 25 Aug, 24 Sept 2005: 9 June, 29 June, 20 July, 4 Aug, 26 Aug (dry)

WETLAND ORIGIN? Resulting wetland complex of mitigation work?

SITE CODE: INDUSTRIAL

Dragonfly species documented at site:	
Anax junius	A
Aeshna constricta	E
Erythemis simplicicollis	A
Leucorrhinia intacta	A, E
Libellula incesta	A
Libellula (Plathemis) lydia	A
Libellula pulchella	A
Libellula semifasciata	A
Libellula vibrans/axilena	E
Pachydiplax longipennis	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Pantala flavescens	A

Site name: Kitteridge Big

Approximate sampling path, 2004

Approximate sampling path, 2005

TOWN: South Kingstown

AREA: 0.42 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: TNC

CONTACT: TNC?

YR(S) SURVEYED: 2004, 2005

FISH: No

AMPHIBIANS: Toads, Spotted Salamander larvae, Wood Frogs, Gray Tree Frog metamorphs, Bullfrog tadpoles, Green Frogs

REPTILES: Painted Turtles
OTHER: otter droppings

DATES SAMPLED: 2004: 21 May, 15 June, 7 July, 27 July, 19 Aug, 20 Sept
2005: 14 June, 6 July, 26 July, 16 August, 9 Sept

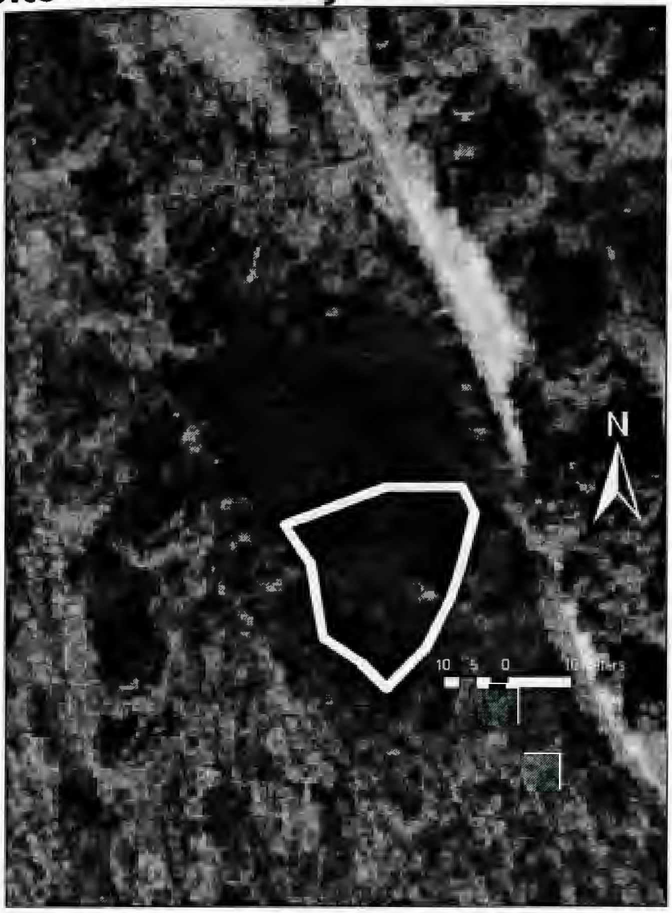
WETLAND ORIGIN? Kettle pond

SITE CODE: KITTBIG

Dragonfly species documented at site:

Anax junius	E	*Leucorrhinia intacta*	E
Anax longipes	A, E	*Libellula incesta*	A, E
Aeshna clepsydra	E	*Libellula semifasciata*	E
Aeshna mutata	E	*Pachydiplax longipennis*	A, E
Aeshna tuberculifera	E	*Sympetrum janae*	E
Aeshna umbrosa	E	*Sympetrum vicinum/semicinctum*	E
Dorocordulia lepida	E	*Tramea carolina*	A
Celithemis elisa	E	*Tramea* sp.	E
Celithemis eponina	E		
Erythemis simplicicollis	E		

Site name: Nancy-Buxton Pd



Approximate sampling path

TOWN: North Smithfield/ Burrillville

AREA: 0.09 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: The Wright family

CONTACT: Paul Wright

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Green Frog and Bullfrog adults; Gray Tree Frog tadpoles & metamorphs

DATES SAMPLED: 2006: 29 May, 28 June, 20 July, 14 Aug, 6 Sept

WETLAND ORIGIN? Inconclusive

SITE CODE: NANCYBUXTON

Dragonfly species documented at site:	
Anax junius	E
Aeshna constricta	E
Aeshna tuberculifera	E
Aeshna umbrosa	E
Dorocordulia lepida	E
Aeshna sp.	A
Libellula incesta	A
Pachydiplax longipennis	A
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Nature's Way

Approximate sampling path

TOWN: Johnston

AREA: 0.07 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed or unconsolidated?

OWNED BY: (at the time) Nature's Way Nursery

CONTACT: Anthony Rainone, and secretary

YR(S) SURVEYED: 2006

FISH: Yes – bluegills, bass

AMPHIBIANS: Green Frog adults

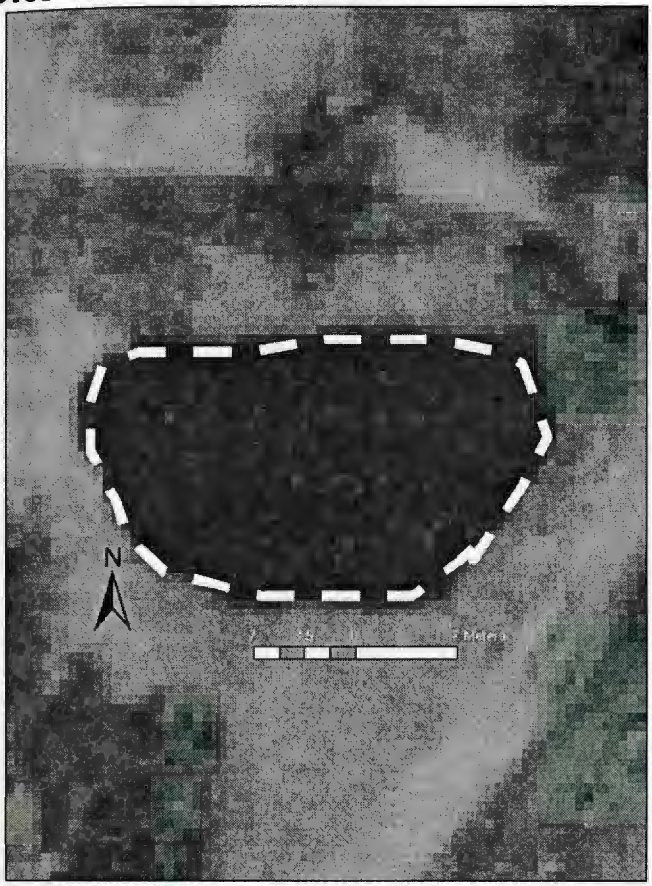
DATES SAMPLED: 2006: 22 May, 15 June, 11 July, 8 Aug, 28 Aug

WETLAND ORIGIN? Landscaping (commercial)

SITE CODE: NATURESWAY

Dragonfly species documented at site:	
Aeshna umbrosa	E
Epitheca cynosura	E
Dromogomphus spinosus	A
Erythemis simplicicollis	E
Libellula cyanea	A
Libellula incesta	A, E
Libellula (Plathemis) lydia	A, E
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E

Site name: North Burial Ground Ditch Pd



TOWN: Providence

AREA: 0.05 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: North Burial Ground Cemetary

CONTACT: (front office)

YR(S) SURVEYED: 2004, 2005

FISH: No

AMPHIBIANS: American Toad tadpoles & metamorphs

DATES SAMPLED: 2004: 19 May, 16 June, 6 July, 29 July, 18 Aug, 17 Sept
2005: 13 June, 29 June, 21 July, 12 Aug, 2 Sept

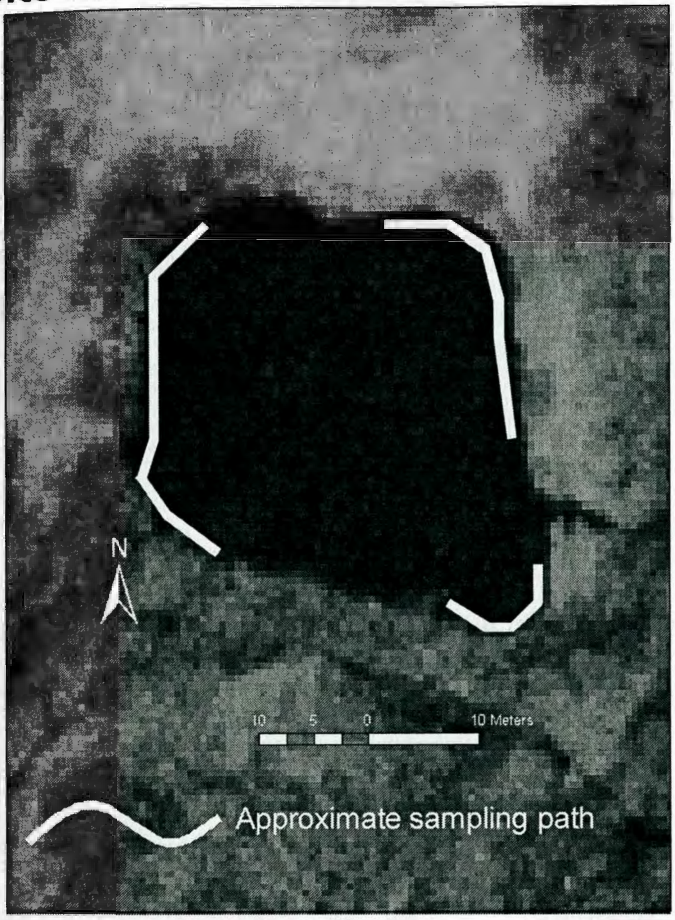
WETLAND ORIGIN? Resulting from clogged drainage ditch?

SITE CODE: NBGROUND

Approximate sampling path

Dragonfly species documented at site:	
Anax junius	A, E
Erythemis simplicicollis	E
Libellula (Plathemis) lydia	A, E
Libellula pulchella	A
Libellula semifasciata	E
Pachydiplax longipennis	E
Pantala flavescens	A
Pantala hymenaea	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Tramea lacerata	A
Tramea sp.	E

Site name: Paintball Pd



TOWN: Pawtucket

AREA: 0.11 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Daggett Park, Pawtucket Rec?

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – sunfish (bluegills?), small catfish

AMPHIBIANS: Pickerel Frog; various tadpoles, some with deformations

REPTILES: Painted Turtles

DATES SAMPLED: 2004: 26 May, 22 June, 15 July, 9 Aug, 25 Aug, 17 Sept 2005: 15 June, 7 July, 27 July, 17 Aug, 12 Sept

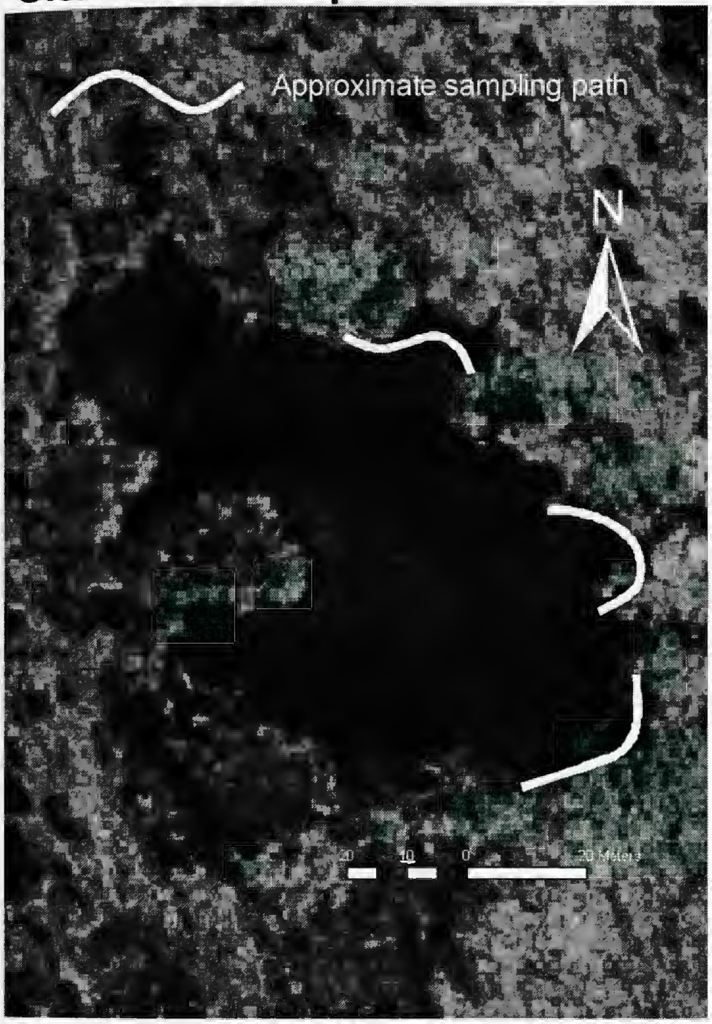
WETLAND ORIGIN? Impoundment; for recreation

SITE CODE: PAINTBALL

Dragonfly species documented at site:

Anax junius	A, E	*Libellula incesta*	A, E
Aeshna canadensis	E	*Libellula luctuosa*	A, E
Aeshna constricta	E	*Libellula (Plathemis) lydia*	A
Aeshna tuberculifera	E	*Libellula pulchella*	A, E
Aeshna umbrosa	E	*Pachydiplax longipennis*	A, E
Aeshna sp.	A	*Pantala hymenaea*	A
Gomphus exilis	E	*Perithemis tenera*	A, E
Epitheca cynosura	E	*Sympetrum janae*	E
Erythemis simplicicollis	A, E	*Sympetrum vicinum/semicinctum*	E
Leucorrhinia intacta	E	*Tramea lacerata*	A
Libellula cyanea	E	*Tramea* sp.	E

Site name: Peeper Pd



TOWN: Exeter

AREA: 0.45 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Peeper Pond Campground

CONTACT: (at the time) Phil & Gerry Quish

YR(S) SURVEYED: 2006

FISH: Yes - sunfish

AMPHIBIANS: adult Pickerel Frog; Toads, Spring Peepers, Green Frogs; salamander or newt larva

OTHER: active beavers, otters

DATES SAMPLED: 2006: 26 May, 22 June, 14 July, 9 Aug, 1 Sept

WETLAND ORIGIN? Beaver pond?

SITE CODE: PEEPERPD

Dragonfly species documented at site:

Anax junius	A, E	*Libellula incesta*	A, E
Gomphus exilis	E	*Libellula luctuosa*	A
Dorocordulia lepida	E	*Libellula (Plathemis) lydia*	A, E
Cordulia shurtleffi	E	*Libellula pulchella*	A, E
Epitheca cynosura	E	*Pachydiplax longipennis*	A, E
Erythemis simplicicollis	A, E	*Sympetrum janae*	E
Ladona julia	E	*Sympetrum vicinum/semicinctum*	E
Libellula cyanea	A		

Site name: Phelps Pd

TOWN: Exeter

AREA: 1.78 ha

CLASSIFICATION: POW, permanently flooded, unconsolidated?

OWNED BY: Big River WMA (DEM)

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes

AMPHIBIANS: Toads, Spring Peepers, Pickerel Frogs

DATES SAMPLED: 2004: 25 May, 23 June, 14 July, 6 Aug, 24 Aug, 25 Sept 2005: 14 June, 6 July, 25 July, 16 Aug, 9 Sept

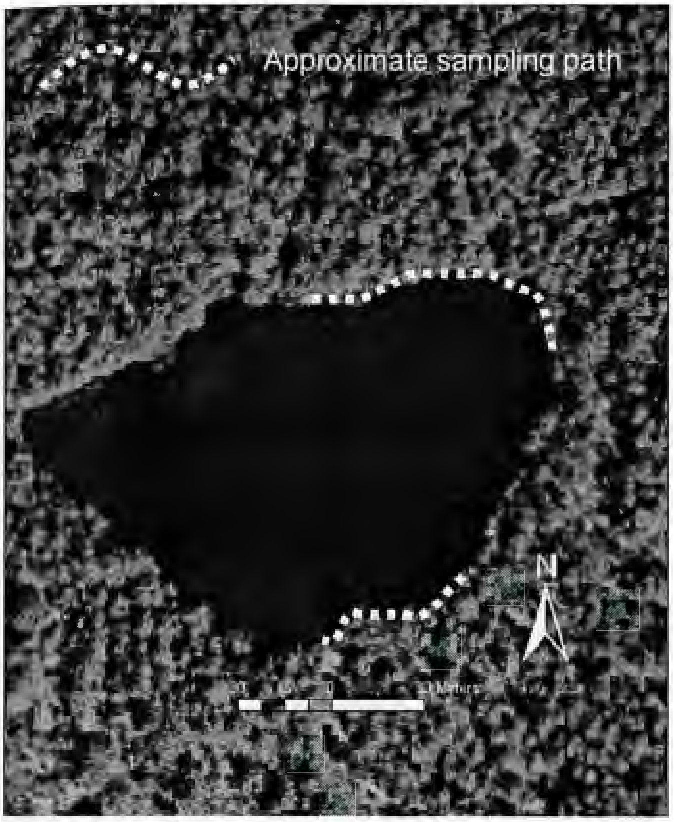
WETLAND ORIGIN? Flooded gravel or sand pit/mine

SITE CODE: PHELPS

Dragonfly species documented at site:

Anax junius	E	*Erythemis simplicicollis*	A, E
Aeshna clepsydra	E	*Libellula cyanea*	A
Aeshna umbrosa	E	*Libellula incesta*	A, E
Basiaeschna janata	E	*Libellula luctuosa*	A, E
Dromogomphus spinosus	E	*Libellula pulchella*	A
Gomphus exilis	E	*Libellula semifasciata*	A
Epitheca cynosura	E	*Pachydiplax longipennis*	A, E
Epitheca princeps	E	*Sympetrum janae*	E
Epitheca semiaequea	E	*Sympetrum vicinum/semicinctum*	E
Celithemis elisa	A, E	*Sympetrum* sp.	A
Celithemis eponina	E	*Tramea* sp.	E

Site name: Plain Pd



TOWN: Hopkinton

AREA: 1.38 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Black Farm WMA (DEM)

CONTACT: ?

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Bullfrog adults, tadpoles; Green Frog and Gray Tree Frog adults

REPTILES: Snapping Turtle

DATES SAMPLED: 2006: 17 May, 16 June, 12 July, 3 Aug, 23 Aug

WETLAND ORIGIN? Inconclusive

SITE CODE: PLAINPD

Dragonfly species documented at site:

Anax junius	E	*L.incesta*	A, E
Anax longipes	A, E	*Libellula vibrans/axilena*	E
Aeshna clepsydra	E	*Pachydiplax longipennis*	A, E
Aeshna tuberculifera	E	*Sympetrum vicinum/semicinctum*	E
Celithemis elisa	A, E	*Tramea lacerata*	A
Erythemis simplicicollis	A, E	*Tramea* sp.	E
Ladona julia	E		
Leucorrhinia intacta	E		
Leucorrhinia hudsonica	E		
Leucorrhinia proxima	E		

Site name: Rumford Pd

TOWN: East Providence

AREA: 0.32 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Lakeside Cemetary

CONTACT: Mike Seger, mgr

YR(S) SURVEYED: 2004, 2005, 2006

FISH: Yes – sunfish, goldfish, trout, catfish (according to manager)

AMPHIBIANS:

DATES SAMPLED: 2004: 26 May, 22 June, 12 July, 5 Aug, 25 Aug, 24 Sept
2005: 13 June, 5 July, 25 July, 12 Aug, 6 Sept
2006: 12 June, 3 July, 1 Aug, 21 Aug, 13 Sept

WETLAND ORIGIN? Ornamental landscaping

SITE CODE: RUMFORD

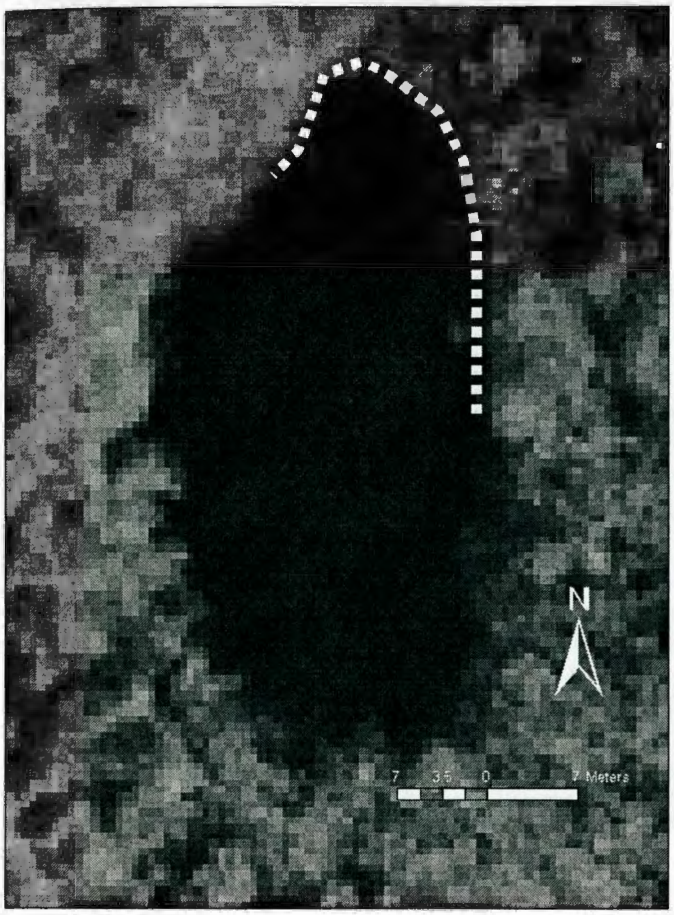
Approximate sampling path, 2004 & 2005

Approximate sampling path, 2006

Dragonfly species documented at site:

Anax junius	A, E	*Libellula (Plathemis) lydia*	E
Epitheca cynosura	E	*Libellula pulchella*	A, E
Epitheca princeps	E	*Pachydiplax longipennis*	A, E
Epitheca sp.	A	*Perithemis tenera*	A, E
Celithemis elisa	A, E	*Sympetrum vicinum/semicinctum*	E
Celithemis eponina	E	*Sympetrum* sp.	A
Erythemis simplicicollis	A, E	*Tramea lacerata*	A
Leucorrhinia intacta	E	*Tramea* sp.	E
Libellula incesta	A, E		
Libellula luctuosa	A, E		

Site name: Saila-Dump Pd



Approximate sampling path

TOWN: Richmond

AREA: 0.10 ha

CLASSIFICATION: POW, seasonally flooded?

OWNED BY: Dr. Saul Saila & neighbor

CONTACT: Dr. Saila

YR(S) SURVEYED: 2004, 2005

FISH: No

AMPHIBIANS: Wood, Green, Gray Tree and Bullfrogs, Spring Peepers, Spotted Salamander larvae; deformed/injured WF tadpoles?

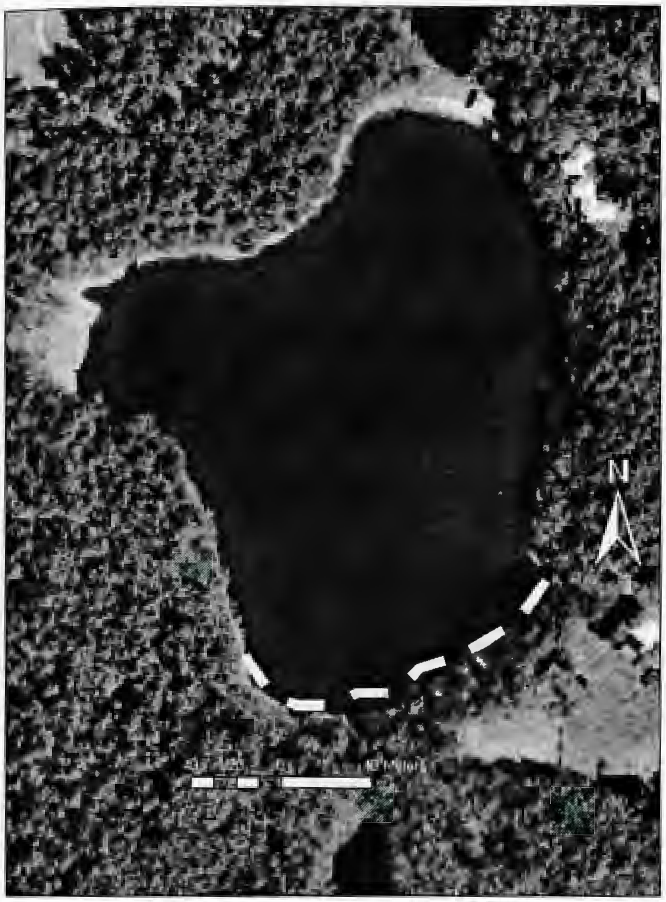
DATES SAMPLED: 2004: 21 May, 17 June, 7 July, 2 Aug, 24 Aug, 22 Sept 2005: 8 June, 28 June, 22 July, 15 Aug, 8 Sept

WETLAND ORIGIN? Inconclusive

SITE CODE: SAILADUMP

Dragonfly species documented at site:	
Anax junius	E
Aeshna umbrosa	E
Aeshna sp.	A
Nasiaeschna pentacantha	E
Dorocordulia lepida	E
Epitheca cynosura	E
Libellula incesta	A, E
Libellula vibrans/axilena	E
Pachydiplax longipennis	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E

Site name: Sandy Pd



TOWN: Richmond

AREA: 3.66 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed or unconsolidated?

OWNED BY: Dr. Saul Saila, Mr. & Mrs. Clancy, 1 other?

CONTACT: Dr. Saila

YR(S) SURVEYED: 2004, 2005

FISH: Yes - various

AMPHIBIANS: Bullfrog tadpoles, Spring Peepers, Toads

DATES SAMPLED: 2004: 21 May, 17 June, 7 July, 2 Aug, 24 Aug, 22 Sept
2005: 8 June, 28 June, 22 July, 15 Aug, 8 Sept

WETLAND ORIGIN? Natural coastal plain pond?

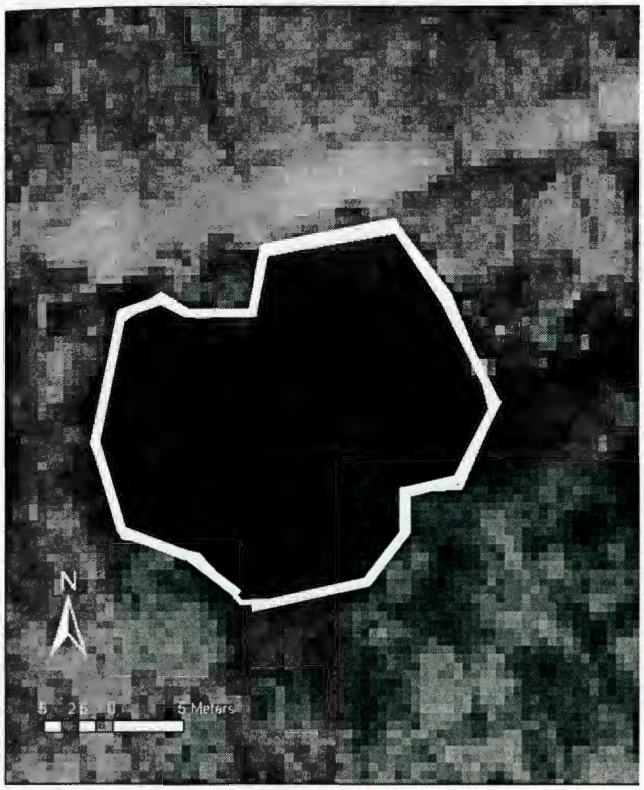
SITE CODE: SANDY

Approximate sampling path

Dragonfly species documented at site:

Anax longipes	A	*Celithemis* sp.	A
Aeshna clepsydra	E	*Erythemis simplicicollis*	A, E
Basiaeschna janata	E	*Libellula auripennis*	E
Dromogomphus spinosus	E	*Libellula incesta*	A, E
Gomphus exilis	E	*Libellula pulchella*	A
Hagenius brevistylus	N	*Libellula semifasciata*	A
Macromia sp.	N	*Pachydiplax longipennis*	E
Epitheca cynosura	E	*Perithemis tenera*	A, E
Epitheca princeps	A, E	*Sympetrum janae*	E
Epitheca semiaequea	E	*Sympetrum vicinum/semicinctum*	E
Celithemis elisa	A, E	*Tramea carolina*	A
Celithemis eponina	E		

Site name: Shippee-Opishinski Pd



Approximate sampling path

TOWN: East Greenwich

AREA: 0.05 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Kitty & Tom Opishinski

CONTACT: the Opishinskis

YR(S) SURVEYED: 2006

FISH: Yes -- bluegills, minnows

AMPHIBIANS: Green and Bullfrog adults, tadpoles, Bullfrog metamorphs; Pickerel Frog eggs

DATES SAMPLED: 2006: 30 May, 29 June, 26 July, 16 Aug, 11 Sept

WETLAND ORIGIN? Small impoundment; landscaping (residential)?

SITE CODE: SHIPPEEOP

Dragonfly species documented at site:	
Anax junius	A
Epitheca cynosura	E
Erythemis simplicicollis	E
Leucorrhinia intacta	E
Libellula incesta	A, E
Pachydiplax longipennis	A, E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Simmons Mill WMA Pd

Approximate sampling path

TOWN: Little Compton

AREA: 0.32 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Simmons Mill WMA (DEM)

CONTACT: ?

YR(S) SURVEYED: 2006

FISH: Yes

AMPHIBIANS: Pickerel Frogs

REPTILES: No. Water Snakes, turtles

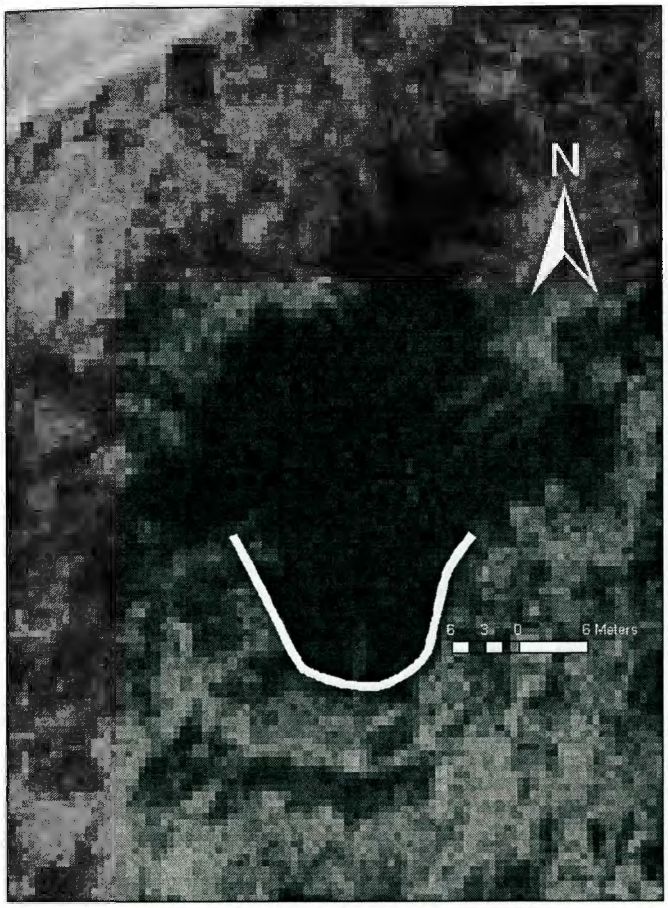
DATES SAMPLED: 2006: 13 June, 6 July, 2 Aug, 22 Aug, 14 Sept

WETLAND ORIGIN? Constructed/managed wetland complex; originally for mill operation

SITE CODE: SIMMSMILLS

<u>**Dragonfly species documented at site:**</u>	
Gomphus sp.	A
Epitheca cynosura	E
Epitheca semiaequea	E
Epitheca sp.	A
Erythemis simplicicollis	A, E
Libellula intacta	A
Libellula incesta	A
Libellula vibrans/axilena	E
Pachydiplax longipennis	A, E
Perithemis tenera	A, E
Sympetrum vicinum/semicinctum	E

Site name: Sisters-of-Mercy Pd



Approximate sampling path

TOWN: Cumberland

AREA: 0.06 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Sisters of Mercy

CONTACT: Sister Suzanne

YR(S) SURVEYED: 2006

FISH: Yes – minnows? (very tiny—maybe fry?)

AMPHIBIANS: Toad, Wood and Green Frog adults; Bullfrog tadpoles & adults; Spotted Salamander egg mass

REPTILES: No. Water Snake, Garter Snake

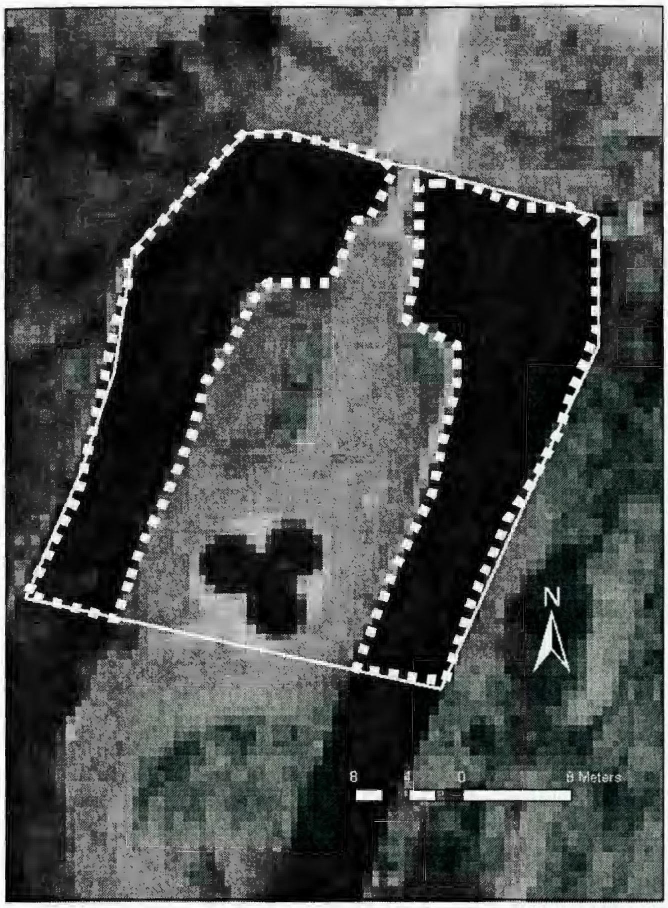
DATES SAMPLED: 2006: 24 May, 20 June, 13 July, 8 Aug, 31 Aug

WETLAND ORIGIN? Semi-constructed wetland impoundment?

SITE CODE: SOM

Dragonfly species documented at site:	
Anax junius	E
Aeshna umbrosa	E
Aeshna sp.	A
Anax junius	A, E
Nasiaeschna pentacantha	E
Cordulia shurtleffi	E
Libellula incesta	E
Pachydiplax longipennis	A, E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Slater-Friend Pd



Approximate sampling path

TOWN: Pawtucket

AREA: 0.12 ha

CLASSIFICATION: POW, permanently flooded, emergent?

OWNED BY: Slater Memorial Park

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes – at least on East side (minnows)

AMPHIBIANS: Green Frog and Bullfrog adults & tadpoles; Spring Peepers

REPTILES: No. Water Snake

DATES SAMPLED: 2004: 26 May, 22 June, 19 July, 9 Aug, 25 Aug, 17 Sept 2005: 13 June, 5 July, 25 July, 11 Aug, 31 Aug

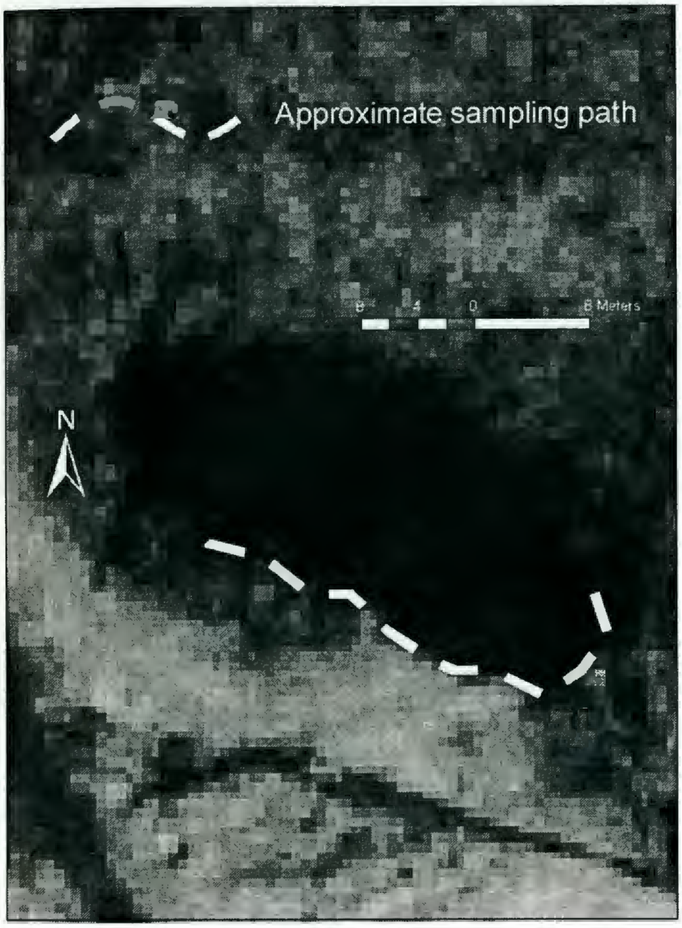
WETLAND ORIGIN? Ornamental landscaping– built > 100 years ago

SITE CODE: SLATERFRIEND

Dragonfly species documented at site:

Anax junius	A, E	*Libellula (Plathemis) lydia*	A, E
Aeshna canadensis	E	*Libellula pulchella*	A, E
Aeshna clepsydra	E	*Libellula semifasciata*	A, E
Aeshna verticalis	E	*Pachydiplax longipennis*	A, E
Arigomphus villosipes	A, E	*Pantala hymenaea*	E
Erythemis simplicicollis	A, E	*Perithemis tenera*	A
Leucorrhinia intacta	A, E	*Sympetrum vicinum/semicinctum*	E
Libellula cyanea	A, E		
Libellula incesta	A, E		
Libellula luctuosa	A, E		

Site name: Snake Den State Park Pd



TOWN: Johnston

AREA: 0.05 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Snake Den State Park (DEM/DEP Div. Parks & Rec????)

CONTACT: Belle (office)

YR(S) SURVEYED: 2006

FISH: Yes (even though folks at office told me there aren't)

AMPHIBIANS: Bullfrog adults, tadpoles & metamorphs; Green Frog adults & metamorphs

DATES SAMPLED: 2006: 1 June, 30 June, 19 July, 10 Aug, 5 Sept

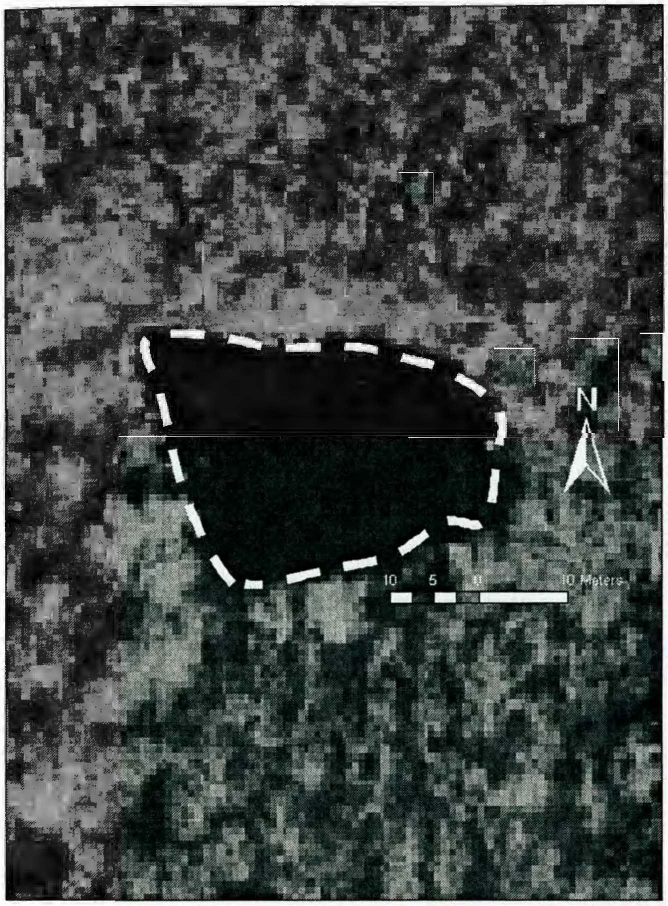
WETLAND ORIGIN? Agricultural farm pond; now maintained for state park

SITE CODE: SNAKEDEN

Dragonfly species documented at site:

Anax junius	E	*Libellula incesta*	A
Aeshna canadensis	E	*Libellula luctuosa*	A
Aeshna umbrosa	E	*Pachydiplax longipennis*	A, E
Aeshna sp.	A	*Sympetrum janae*	E
Epitheca cynosura	E	*Sympetrum vicinum/semicinctum*	E
Erythemis simplicicollis	A, E	*Sympetrum* sp.	A
Leucorrhinia intacta	A, E	*Tramea* sp.	E
Libellula cyanea	A		

Site name: South Kingstown Land Trust Pd



Approximate sampling path

TOWN: South Kingstown

AREA: 0.09 ha

CLASSIFICATION: POW, seasonally flooded, emergent

OWNED BY: South Kingstown Land Trust

CONTACT: ?????

YR(S) SURVEYED: 2004, 2005

FISH: No

AMPHIBIANS: Green Frog adults, Spring Peepers, Wood Frog and Gray Tree Frog tadpoles, Spotted Salamander larvae

DATES SAMPLED: 2004: 18 May, 14 June, 8 July, 29 July, 17 Aug, 24 Sept 2005: 1 June, 20 June, 12 July, 1 Aug, 23 Aug

WETLAND ORIGIN? Inconclusive

SITE CODE: SKLT

Dragonfly species documented at site:

Anax junius	E	*Libellula semifasciata*	A, E
Aeshna clepsydra	A, E	*Libellula vibrans*	A
Aeshna tuberculifera	E	*Pachydiplax longipennis*	A, E
Aeshna verticalis	E	*Sympetrum janae*	E
Aeshna sp.	A	*Sympetrum vicinum/semicinctum*	E
Anax junius	A, E	*Tramea carolina*	A
Erythemis simplicicollis	A, E		
Leucorrhinia intacta	A, E		
Libellula incesta	A		
Libellula pulchella	A		

Site name: Spectacle Pd

Approximate sampling path

TOWN: Lincoln

AREA: 1.66 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: town of Lincoln?

CONTACT: ?

YR(S) SURVEYED: 2004, 2005

FISH: Yes - minnows

AMPHIBIANS: Green Frogs; Bullfrog adults and tadpoles

REPTILES: Snapping Turtles

DATES SAMPLED: 2004: 28 May, 24 June, 20 July, 11 Aug, 26 Aug, 29 Sept 2005: 6 June, 22 June, 20 July, 4 Aug, 25 Aug

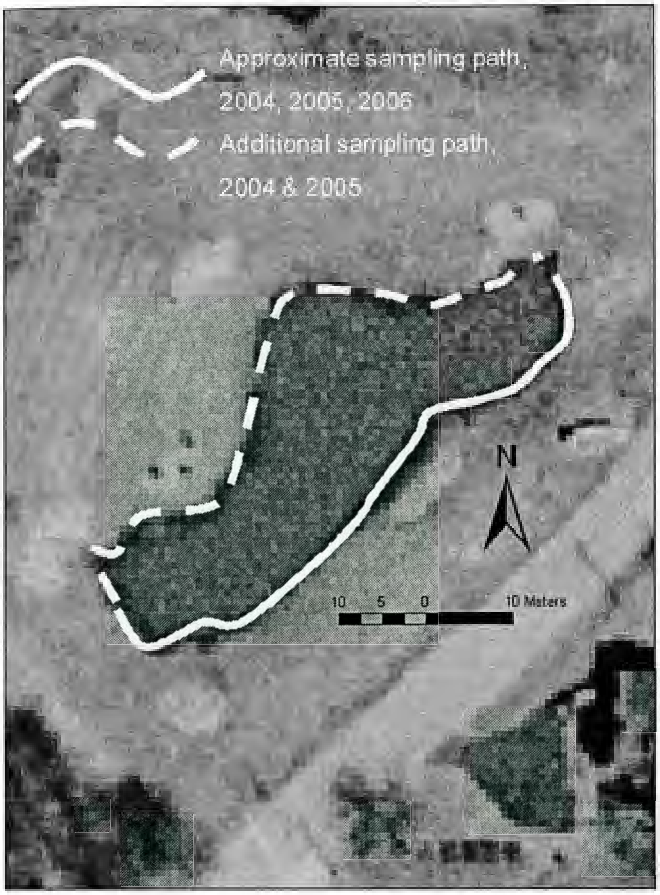
WETLAND ORIGIN? Inconclusive

SITE CODE: SPECTACLE

Dragonfly species documented at site:

Anax junius	A, E	*Perithemis tenera*	E
Aeshna mutata	E	*Sympetrum janae*	E
Epitheca cynosura	E	*Sympetrum vicinum/semicinctum*	E
Celithemis eponina	E	*Tramea lacerata*	A
Erythemis simplicicollis	A, E	*Tramea* sp.	E
Leucorrhinia intacta	A, E		
Libellula cyanea	A		
Libellula incesta	A		
Libellula pulchella	A		
Pachydiplax longipennis	A, E		

Site name: Strathmore Pd



TOWN: Narragansett

AREA: 0.09 ha

CLASSIFICATION: POW, seasonally flooded, aquatic bed?

OWNED BY: Canonchet Farms Association?

CONTACT: Don, CF Association?

YR(S) SURVEYED: 2004, 2005, 2006

FISH: No

AMPHIBIANS: Bullfrog adults; Green Frog adults & metamorphs; Gray Tree Frog tadpoles & metamorphs

REPTILES: Painted Turtles

DATES SAMPLED: 2004: 18 May, 14 June, 30 June, 26 July, 18 Aug, 13 Sept 2005: 31 May, 20 June, 12 July, 29 July, 23 Aug 2006: 15 June, 5 July, 29 July, 18 Aug, 12 Sept

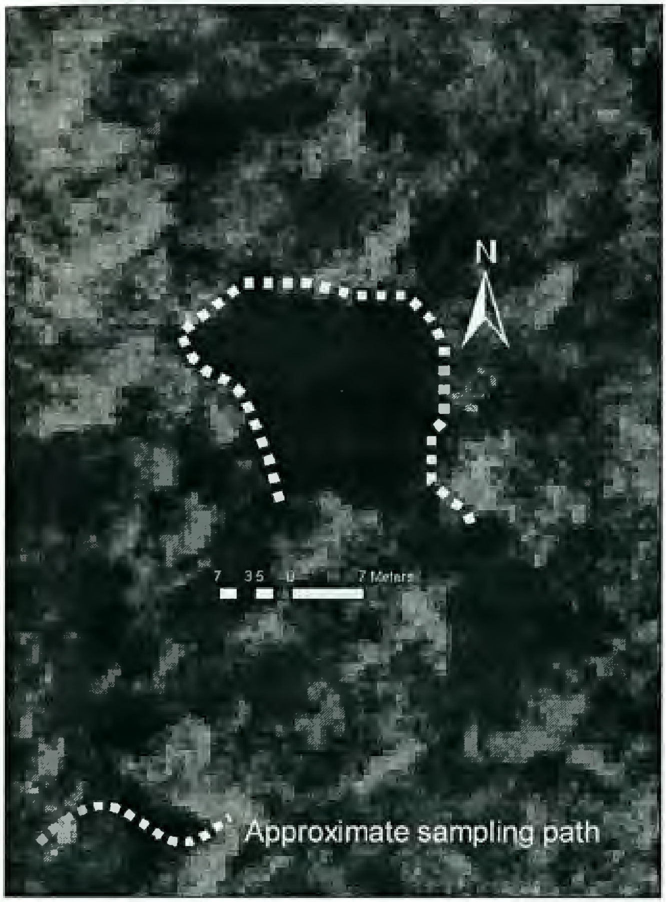
WETLAND ORIGIN? Landscape/mitigation in residential development

SITE CODE: STRATHMORE

Dragonfly species documented at site:

Anax junius	A, E	*Pachydiplax longipennis*	A, E
Anax longipes	A	*Pantala flavescens*	A, E
Celithemis elisa	A	*Pantala hymenaea*	E
Celithems eponina	A	*Perithemis tenera*	A
Erythemis simplicicollis	A	*Sympetrum janae*	E
Erythrodiplax berenice	A	*Sympetrum vicinum/ semicinctum*	E
Leucorrhinia intacta	A, E		
Libellula incesta	A	*Tramea carolina*	A
Libellula (Plathemis) lydia	A	*Tramea lacerata*	A
Libellula pulchella	A, E	*Tramea* sp.	E
Libellula semifasciata	A, E		

Site name: Tepee Pd



TOWN: Glocester

AREA: 0.05 ha

CLASSIFICATION: POW, semipermanently flooded?

OWNED BY: George Washington WMA (DEM) OR DEP???

CONTACT: Paul Riccard, Paul Wright

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Green and Pickerel Frog adults; Gray Tree Frog tadpoles

DATES SAMPLED: 2006: 29 May, 28 June, 19 July, 10 Aug, 4 Sept

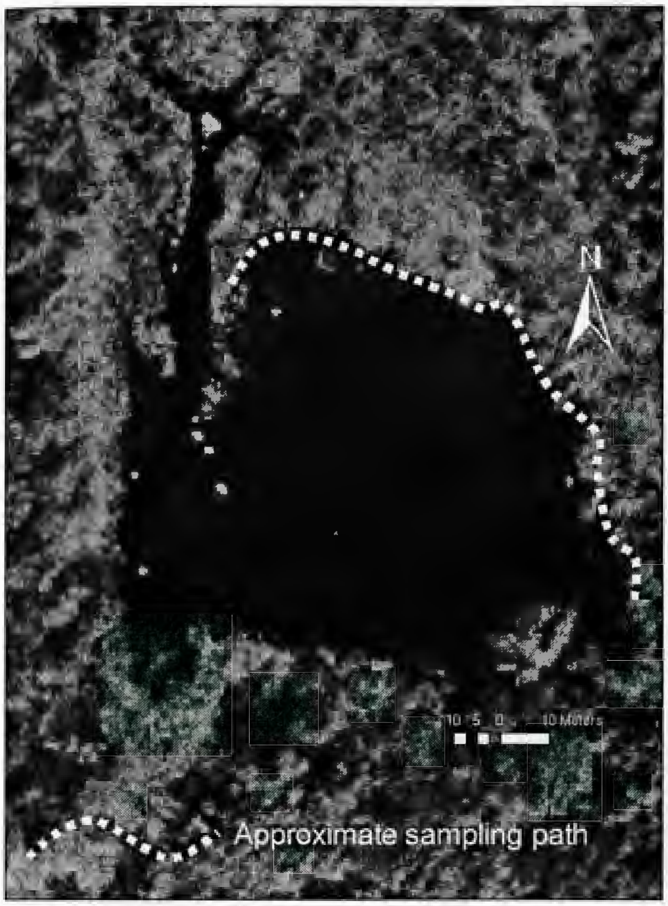
WETLAND ORIGIN? Industrial? (outflow is remnants of a mill/waterfall?)

SITE CODE: TEPEEPD

Dragonfly species documented at site:

Anax junius	E
Aeshna tuberculifera	E
Aeshna verticalis	E
Aeshna umbrosa	E
Aeshna sp.	A
Dorocordulia lepida	E
Cordulia shurtleffi	E
Erythemis simplicicollis	A, E
Ladona julia	E
Leucorrhinia frigida	A
Leucorrhinia intacta	E
Libellula incesta	E
Libellula (Plathemis) lydia	A
Pachydiplax longipennis	E
Sympetrum janae	E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: W. Alton Jones Campus Pd



TOWN: West Greenwich

AREA: 0.75 ha

CLASSIFICATION: POW, permanently flooded

OWNED BY: URI/WAJ campus

CONTACT: (Tom?) Mitchell

YR(S) SURVEYED: 2004, 2005

FISH: Yes – various

AMPHIBIANS: tadpoles; salamanders?; adult newt?

DATES SAMPLED: 2004: 25 May, 23 June, 14 July, 3 Aug, 20 Aug, 23 Sept
2005: 7 June, 22 June, 19 July, 3 Aug, 25 Aug

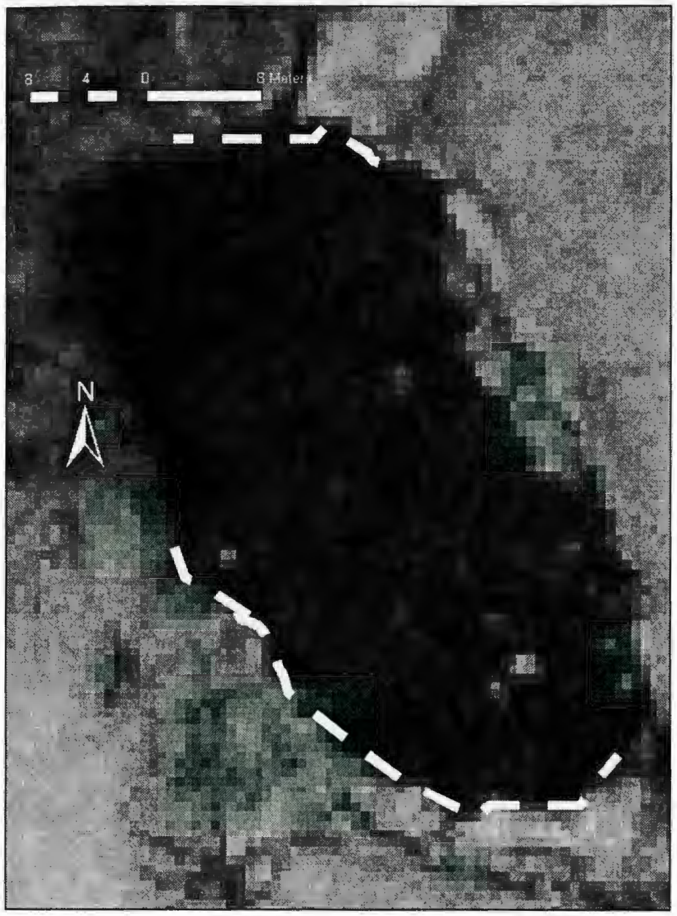
WETLAND ORIGIN? Stream impoundment—recreational?

SITE CODE: WAJONES

Dragonfly species documented at site:

Anax junius	A, E	*Erythemis simplicicollis*	A, E
Aeshna canadensis	E	*Ladona julia*	E
Aeshna clepsydra	E	*Leucorrhinia hudsonica*	A
Aeshna umbrosa	E	*Leucorrhinia intacta*	A, E
Basiaeschna janata	E	*Libellula cyanea*	A, E
Arigomphus villosipes	E	*Libellula incesta*	A, E
Gomphus exilis	A, E	*Libellula luctuosa*	A, E
Hagenius brevistylus	N	*Libellula (Plathemis) lydia*	A, E
Lanthus vernallis	E	*Libellula pulchella*	A
Cordulegaster diastatops	E	*Libellula semifasciata*	E
Didymops transversa	E	*Libellula vibrans/axilena*	E
Macromia illinoisensis	E	*Pachydiplax longipennis*	A
Macromia sp.	N	*Sympetrum janae*	E
Epitheca cynosura	E	*Sympetrum vicinum/* semicinctum	E
Celithemis elisa	A		

Site name: Washington County Country Club Pd



Approximate sampling path

TOWN: Coventry

AREA: 0.11 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Washington County Country Club

CONTACT: Jeremy Votolato

YR(S) SURVEYED: 2006

FISH: No

AMPHIBIANS: Green Frog adults & metamorphs; the most, and the largest, Bullfrog adults & tadpoles that I have ever seen

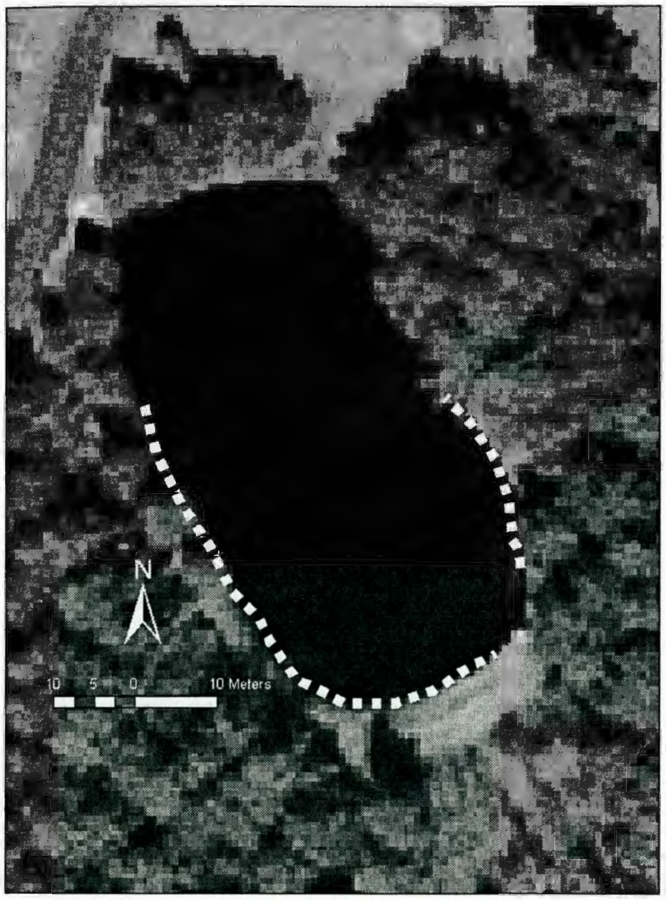
DATES SAMPLED: 2006: 30 May, 29 June, 26 July, 16 Aug, 11 Sept

WETLAND ORIGIN? Ornamental landscape; near or on a spring

SITE CODE: WASHCOCC

Dragonfly species documented at site:	
Anax junius	A, E
Epitheca cynosura	E
Erythemis simplicicollis	A, E
Leucorrhinia intacta	E
Libellula incesta	A
Libellula luctuosa	A
Libellula (Plathemis) lydia	A, E
Libellula pulchella	A
Pachydiplax longipennis	A, E
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A
Tramea lacerata	A
Tramea sp.	E

Site name: Weymouth Ridge Road Pd



Approximate sampling path

TOWN: Coventry

AREA: 0.22 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: Weym. Ridge Rd homeowners association?

CONTACT: Lauren Dwyer

YR(S) SURVEYED: 2006

FISH: Yes – incl. minnows, tesselated or swamp darter

AMPHIBIANS: Toad eggs & tadpoles; Green and Bullfrog adults; Spring Peeper metamorphs

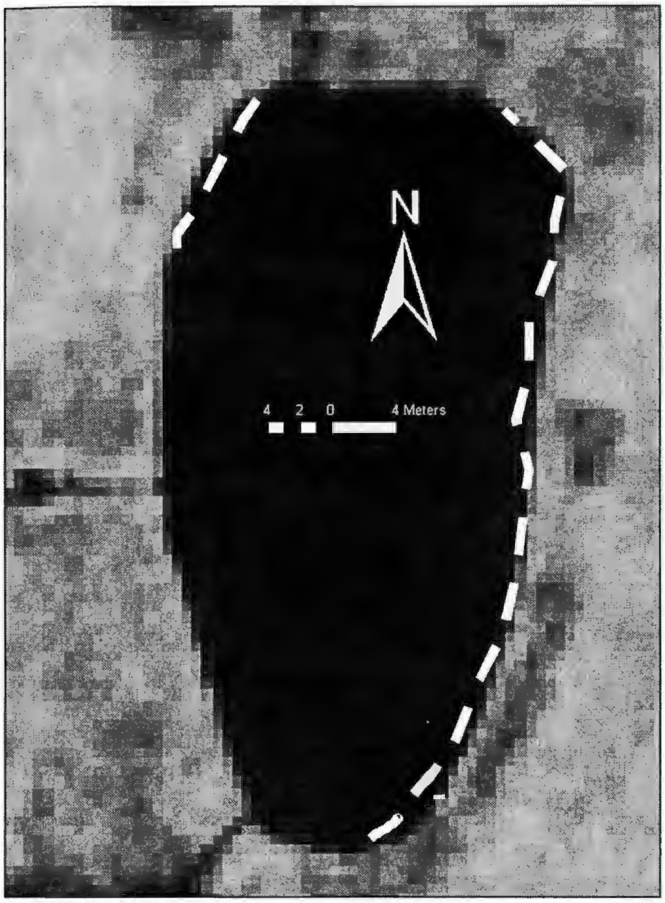
DATES SAMPLED: 2006: 22 May, 15 June, 11 July, 7 Aug, 29 Aug

WETLAND ORIGIN? Stream impoundment—ornamental landscape?

SITE CODE: WEYMRIDGE

Dragonfly species documented at site:	
Gomphus exilis	E
Epitheca cynosura	E
Celithemis elisa	A, E
Ladona julia	E
Libellula incesta	A, E
Pachydiplax longipennis	A
Sympetrum vicinum/semicinctum	E
Sympetrum sp.	A

Site name: Wright Farm Pd



Approximate sampling path

TOWN: North Smithfield/ Burrillville?

AREA: 0.09 ha

CLASSIFICATION: POW, permanently flooded, aquatic bed

OWNED BY: The Wright Family

CONTACT: Paul Wright

YR(S) SURVEYED: 2006

FISH: Yes – trout (stocked?), bluegills, bass

AMPHIBIANS: Green, Pickerel, Bullfrog adults

DATES SAMPLED: 2006: 29 May, 28 June, 20 July, 14 Aug, 6 Sept

WETLAND ORIGIN? Farm impoundment; extended and currently managed

SITE CODE: WRIGHTFARM

Dragonfly species documented at site:

Anax junius	A	*Ladona julia*	E
Aeshna sp.	A	*Leucorrhinia intacta*	A, E
Arigomphus villosipes	E	*Libellula cyanea*	A, E
Arigomphus sp.	A	*Libellula incesta*	A, E
Gomphus exilis	E	*Libellula luctuosa*	A, E
Macromia illinoisensis	E	*Libellula (Plathemis) lydia*	E
Epitheca cynosura	E	*Pachydiplax longipennis*	A
Gomphus exilis	A, E	*Perithemis tenera*	E
Celithemis elisa	E	*Sympetrum vicinum/semicinctum*	E
Erythemis simplicicollis	A, E	*Sympetrum* sp.	A

Initial sites (2004 & 2005)

pH	2004				2005			
Site	May	July	Sept	Value used[1]	Spring	Fall	Average	Value used[2]
AMTRAK	4.95	-	4.81	4.81	4.70	-	4.70	4.70
BLACKSTONE	7.33	6.54	6.97	6.54	6.43	6.74	6.58	6.58
BRISTOLSK	6.89	6.79	6.45	6.79	6.53	-	6.53	6.53
CAMPUS	8.80	7.32	6.56	7.32	7.06	7.60	7.33	7.33
CAROLBIG	5.15	5.95	-	5.95	5.09	-	5.09	5.09
DEXTER	7.43	7.23	6.81	7.23	6.91	8.70	7.80	7.80
EIGHTROD	5.89	5.83	5.73	5.83	5.69	5.99	5.84	5.84
GLOBE	6.54	8.65	6.34	8.65	5.88	5.98	5.93	5.93
INDUSTRIAL	6.73	5.85	6.50	5.85	6.85	-	6.85	6.85
KITTBIG	5.28	5.31	4.88	5.31	4.91	5.07	4.99	4.99
NBGROUND	6.67	6.56	6.62	6.56	6.27	6.90	6.58	6.58
PAINTBALL	6.50	6.45	6.42	6.45	6.48	7.86	7.17	7.17
PHELPS	6.60	6.37	6.78	6.37	6.63	6.55	6.59	6.59
RUMFORD	6.59	6.98	7.05	6.98	6.84	8.98	7.91	7.91
SAILADUMP	6.37	5.65	5.64	5.65	5.37	5.40	5.38	5.38
SANDY	6.52	6.92	6.48	6.92	6.37	6.38	6.37	6.37
SKLT	4.84	5.31	-	5.83	4.79	5.22	5.01	5.01
SLATERFRIEND	6.65	6.94	6.70	6.94	6.68	6.72	6.70	6.70
SPECTACLE	8.65	8.47	7.37	8.47	7.81	7.23	7.52	7.52
STRATHMORE	6.58	6.68	7.31	6.68	6.85	6.48	6.67	6.67
WAJONES	6.37	6.61	6.37	6.61	6.55	7.10	6.82	6.82

[1]Most values are from July measurements

[2]Most values are from average

Initial sites (2004 & 2005)

Chloride concentration

Site	Spring04	Fall04	2004 Value used*	Spring05	Fall05	2005 Value used*
AMTRAK	0.99	2.00	0.99	2.00	-	2.00
BLACKSTONE	120.96	268.00	120.96	159.00	232.50	159.00
BRISTOLSK	148.45	42.00	148.45	154.00	-	154.00
CAMPUS	115.00	20.00	115.00	159.00	49.00	159.00
CAROLBIG	2.50	-	2.50	6.00	-	6.00
DEXTER	29.49	27.00	29.49	41.50	46.00	41.50
EIGHTROD	-2.50	-	-2.50	4.00	6.00	4.00
GLOBE	17.49	13.00	17.49	10.50	8.00	10.50
INDUSTRIAL	23.49	15.00	23.49	33.00	-	33.00
KITTBIG	2.50	1.00	2.50	3.00	4.00	3.00
NBGROUND	30.49	17.50	30.49		4.00	4.00
PAINTBALL	25.49	38.00	25.49	49.00	40.00	49.00
PHELPS	125.46	119.00	125.46	288.25	162.50	288.25
RUMFORD	231.43	39.00	231.43	334.00	233.50	334.00
SAILADUMP	-0.50	4.00	-0.50	8.00	7.00	8.00
SANDY	41.49	45.00	41.49	53.00	58.00	53.00
SKLT	-0.50	-	-0.50	3.00	6.00	3.00
SLATERFRIEND	1.50	40.50	1.50	18.43	5.00	18.43
SPECTACLE	105.97	63.00	105.97	111.50	133.00	111.50
STRATHMORE	3.50	-	3.50	1.50	6.00	1.50
WAJONES	4.50	4.00	4.50	6.00	5.00	6.00

*Most values are from spring measurements

Replicate sites (2006)

Site	pH Spring	pH Fall	pH Average	Chloride concentation Spring	Chloride concentation Fall	Chloride concentation Average	Value used
BARRGAZEBO	6.41	6.75	6.58	28.64	21.00	24.82	24.82
BFARMPD	6.51	6.63	6.57	27.00	34.00	30.50	30.50
BFRATPD	6.62	6.44	6.53	22.00	28.00	25.00	25.00
CCRIWARWICK	6.54	6.69	6.61	14.85	12.00	13.43	13.43
COWESETT	6.64	6.26	6.45	32.32	13.00	22.66	22.66
EASTFARM	9.67	8.69	9.18	39.53	28.00	33.77	33.77
FALCONE	6.44	7.30	6.87	87.18	23.00	55.09	55.09
FLATRIVERRES	6.52	6.49	6.51	30.18	29.00	29.59	29.59
GODDARD1	6.36	6.11	6.23	33.77	29.00	31.39	31.39
GWPUMP	5.51	5.07	5.29	24.77	56.00	40.38	40.38
HARRINGTON	5.91	5.79	5.85	3.26	4.00	3.63	3.63
NANCYBUXTON	5.43	5.19	5.31	3.69	3.00	3.35	3.35
NATURESWAY	6.56	6.39	6.47	28.62	30.00	29.31	29.31
PEEPER	5.33	5.81	5.57	4.83	4.00	4.41	4.41
PLAINPD	4.91	4.71	4.81	-	3.00	-	3.00
SHIPPEE	5.98	6.33	6.16	7.03	7.00	7.02	7.02
SIMMONSMILL	6.33	6.52	6.43	26.75	34.00	30.37	30.37
SNAKEDEN	6.09	6.36	6.22	3.00	4.00	3.50	3.50
SOM	6.19	6.43	6.31	13.61	7.00	10.31	10.31
STRATHMORE	6.88	7.04	6.96	4.35	6.00	5.17	5.17
TEPEE	4.56	4.67	4.61	4.87	10.00	7.43	7.43
WASHCOCC	6.11	6.01	6.06	27.19	29.00	28.10	28.10
WEYMOUTHRIDGE	5.78	6.17	5.98	12.34	17.00	14.67	14.67
WRIGHTFARM	6.22	6.73	6.47	3.02	4.00	3.51	3.51

Appendix III. Data for construction of the urbanization variable (UV) from Principal Components Analysis with STATISTICA (6.0, StatSoft, Inc., Tulsa, OK 1984 - 2002). A) All sites in 2004; B) All sites in 2005; C) All sites in 2006; D) Graphical comparison of urbanization variable for 2004, 2005 and 2006.

A)

2004 - all sites

Site	Factor 1	Factor 2	UV score*
AMTRAK	0.7603	-0.2778	0.7603
BLACKSTONE	-0.2164	1.3442	-0.2164
BRISTOLSK	-0.9053	1.2507	-0.9053
CAMPUS	-1.7099	-0.2785	-1.7099
CAROLBIG	1.3016	0.2963	1.3016
DEXTER	-0.2524	-0.6731	-0.2524
EIGHTROD	0.4163	-0.6974	0.4163
GLOBE	0.0318	-0.6487	0.0318
INDUSTRIAL	0.3142	-0.2364	0.3142
KITTBIG	1.3958	0.3904	1.3958
NBGROUND	-0.8661	-1.2651	-0.8661
PAINTBALL	0.2002	-0.3071	0.2002
PHELPS	-1.3710	0.2870	-1.3710
RUMFORD	-3.0422	0.9110	-3.0422
SAILADUMP	1.2287	0.1584	1.2287
SANDY	0.7019	0.5411	0.7019
SKLT	1.6585	0.5882	1.6585
SLATERFRIEND	-0.5414	-1.5684	-0.5414
SPECTACLE	-1.1934	0.0423	-1.1934
STRATHMORE	0.8557	-0.1280	0.8557
WAJONES	1.2330	0.2710	1.2330

	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	1.4498	72.4883	1	72.4883
2	0.5502	27.5117	2	100.0000

Factor coordinates of the variables, based on correlations:

	Factor 1	Factor 2
FOREST	0.8514	0.5245
CL_04	-0.8514	0.5245

*UV score = Factor 1

B)

2005 - all sites

Site	Factor 1	Factor 2	UV score*
AMTRAK	-0.7271	-0.2446	0.7271
BLACKSTONE	0.0890	1.2168	-0.0890
BRISTOLSK	0.4439	0.7893	-0.4439
CAMPUS	1.6471	-0.3413	-1.6471
CAROLBIG	-1.2558	0.3421	1.2558
DEXTER	0.2634	-0.6621	-0.2634
EIGHTROD	-0.3308	-0.6119	0.3308
GLOBE	-0.1157	-0.7327	0.1157
INDUSTRIAL	-0.2999	-0.2221	0.2999
KITTBIG	-1.3717	0.4145	1.3717
NBGROUND	0.5943	-1.5370	-0.5943
PAINTBALL	-0.0915	-0.1984	0.0915
PHELPS	2.1323	1.0484	-2.1323
RUMFORD	2.9878	0.8566	-2.9878
SAILADUMP	-1.1359	0.2513	1.1359
SANDY	-0.7374	0.5056	0.7374
SKLT	-1.6020	0.6448	1.6020
SLATERFRIEND	0.6882	-1.4216	-0.6882
SPECTACLE	0.8839	-0.2672	-0.8839
STRATHMORE	-0.8534	-0.1256	0.8534
WAJONES	-1.2088	0.2951	1.2088

	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	1.4434	72.1699	1.4434	72.1699
2	0.5566	27.8301	2.0000	100.0000

Factor coordinates of the variables, based on correlations:

	Factor 1	Factor 2
CL_05	0.8495	0.5275
FOREST	-0.8495	0.5275

*UV score = Factor 1 x (-1)

C)

2006 - all sites

Site	Factor 1	Factor 2	UV score*
BARRGAZEBO	1.2354	-0.7434	-1.2354
BFARMPD	0.8816	0.1662	-0.8816
BFRATPD	-0.3388	0.8485	0.3388
CCRIWARWICK	-0.3695	-0.2534	0.3695
COWESETT	0.5033	-0.2229	-0.5033
EASTFARM	1.6731	-0.3058	-1.6731
FALCONE	2.3853	1.0683	-2.3853
FLATRIVRES	1.2947	-0.3361	-1.2947
GODDARDSP	-0.1922	1.3266	0.1922
GWPUMP	0.6804	1.3344	-0.6804
HARRINGTON	-0.7361	-0.8453	0.7361
NANCYBUXTON	-1.3962	-0.2131	1.3962
NATURESWAY	0.9327	-0.0016	-0.9327
PEEPER	-1.1434	-0.3614	1.1434
PLAINPD	-1.8079	0.1649	1.8079
SHIPPEEOP	-0.3142	-0.9359	0.3142
SIMMSMILL	0.3347	0.7006	-0.3347
SNAKEDEN	-1.0780	-0.5161	1.0780
SOM	-1.6472	0.7190	1.6472
TEPEEPD	-1.8981	0.6888	1.8981
WASHCOCC	1.3957	-0.5832	-1.3957
WEYMRIDGE	-0.4116	-0.0896	0.4116
WRIGHTFARM	0.0163	-1.6096	-0.0163

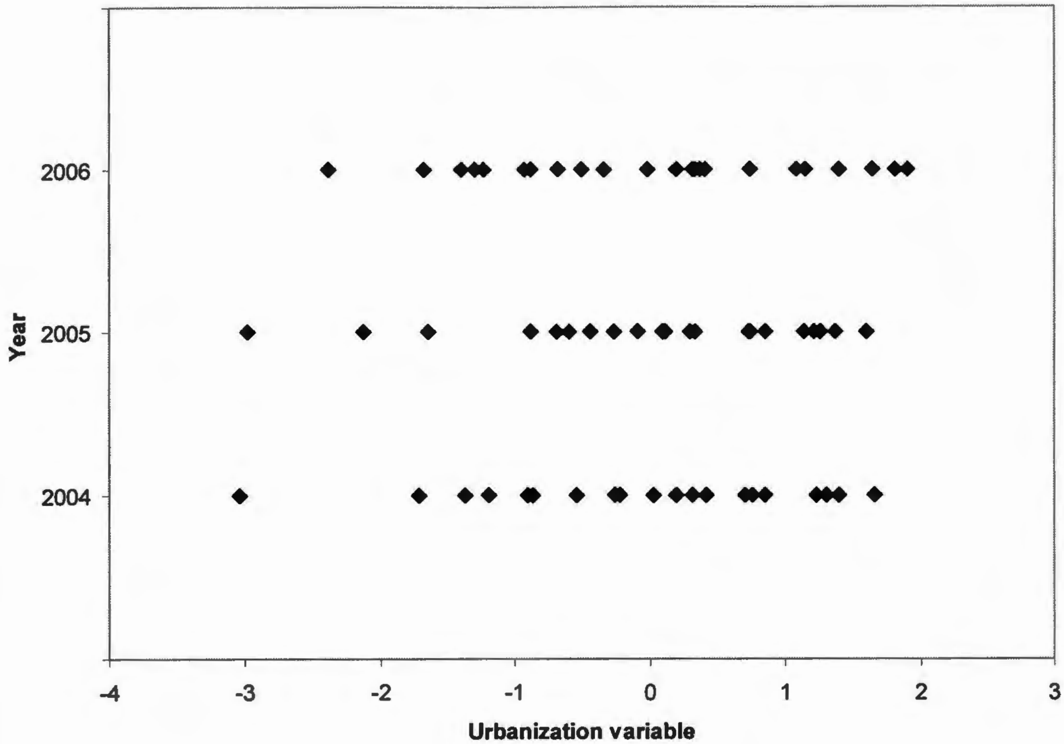
	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	1.4189	70.9459	1.4189	70.9459
2	0.5811	29.0541	2.0000	100.0000

Factor coordinates of the variables, based on correlations:

	Factor 1	Factor 2
CL	0.8423	0.5390
FOREST	-0.8423	0.5390

*UV score = Factor 1 x (-1)

D)



Appendix IV. Compendium of Anderson land-use code descriptions (in the RIGIS 1995 land-use data layer) that were included in the land-use categories of this study. Code descriptions are from: RIGIS (2005).

Anderson land-use codes merged into six land-use categories. (from Table 1.1)

	High-Medium Density Residential	Low-Medium Density Residential	Commercial/ Industrial	Forest	Open	Other/ Wetland
Anderson Land-Use Codes Included	111 112 113	114 115	120 130 150	310 320 330 340 400	141-147 161-163 170, 210 220, 230 250, 500 710, 720 730, 740	600

High-medium Density Residential
111 - High Density Residential (<1/8 acre lots)
112 - Medium Density Residential (1/4 - 1/8 acre lots)
113 - Medium Density Residential (1 to 1/4 acre lots)

Low-medium Density Residential
114 - Medium Low Density Residential (1 to 2 acre lots)
115 - Low Density Residential (>2 acre lots)

Commercial/Industrial
120 - Commercial (sale of products and services)
130 - Industrial (manufacturing, design, assembly, etc.)
150 - Commercial/Industrial Mixed(unseparable)

Forest
310 - Deciduous Forest (>80% deciduous)
320 - Evergreen Forest(>80% coniferous)
330 - Mixed Deciduous Forest (50 to 80% deciduous)
340 - Mixed Evergreen Forest (50 to 80% coniferous)
400 - Brush land (shrub and brush areas, reforested areas)

Open
141 - Roads (divided highways >200' plus related facilities)
142 - Airports (and associated facilities)
143 - Railroads (and associated facilities)
144 - Water and Sewage Treatment
145 - Waste Disposal (landfills, junkyards, etc.)
146 - Power Lines (100' or more width)
147 - Other Transportation (terminals, docks, tank farms, etc.)
161 - Developed Recreation (all recreation)
162 - Vacant Land
163 - Cemeteries

170 - Institutional (schools, hospitals, churches, etc.)
210 - Pasture (agricultural not suitable for tillage)
220 - Cropland (tillable)
230 - Orchards, Groves, Nurseries (Cranberry Bogs)
250 - Idle Agriculture (abandoned fields and orchards)
500 - Water
710 - Beaches (Fresh and Saltwater)
720 - Sandy Areas (excluding beaches)
730 - Rock Outcrops
740 - Mines, Quarries and Gravel Pits

Other/Wetland
600 - Wetland (from the RIGIS WETLANDS data layer)

Appendix V. Species data.

This appendix is given in two parts. Part A is the key to species codes used in Part B. Part B contains the final seasonal scores (number of individuals collected per hour per site visit, and summed across the season) for 2004, 2005 and 2006.

Part A

Family	Genus-species	Species code
Aeshnidae	*Anax junius*	ANJU
	Anax longipes	ANLO
	Aeshna canadensis	AECA
	Aeshna constricta	AECO
	Aeshna clepsydra	AECL
	Aeshna mutata	AEMU
	Aeshna tuberculifera	AETU
	Aeshna verticalis	AEVE
	Aeshna umbrosa	AEUM
	Nasiaeschna pentacantha	NAPE
	Basiaeschna janata	BAJA
	Epiaeschna heros	EPHE
Gomphidae	*Arigomphus villosipes*	ARVI
	Dromogomphus spinosus	DRSP
	Gomphus exilis	GOEX
	Lanthus vernallis	LAVE
Cordulegastridae	*Cordulegaster diastatops*	CODI
Macromiidae	*Didymops transversa*	DITR
	Macromia illinoisensis	MAIL
Corduliidae	*Cordulia shurtleffi*	COSH
	Dorocordulia lepida	DOLE
	Epitheca cynosura	EPCY
	Epitheca princeps	EPPR
	E. semiaequea	EPSE
	Somatochlora williamsoni	SOWI
	Celithemis elisa	CEEL
	Celithemis eponina	CEEP*
	Celithemis fasciata	CEFA*
	Erythemis simplicicollis	ERSI
	Ladona julia	LAJU
	Libellula auripennis	LIAU
	Libellula cyanea	LICY
	Libellula incesta	LIIN
	Libellula luctuosa	LILU
	Libellula pulchella	LIPU
	Libellula semifasciata	LISE
	Libellula vibrans/axilena	LIVIAX
	Leucorrhinia intacta	LEIN
	Leucorrhinia frigida	LEFR
	Leucorrhinia hudsonica	LEHU
	Leucorrhinia proxima	LEPR
	Pachydiplax longipennis	PALO
	Pantala hymenaea	PAHY
	Pantala flavescens	PAFL
	Perithemis tenera	PETE
	Plathemis (Libellula) lydia	PLLY
	Sympetrum janae	SYJA
	Sympetrum vicinum/semicinctum	SYVISE
	Tramea lacerata	TRLA
	Tramea carolina	TRCA
	Tramea sp.	TRAMEA

*CEFA/EP = combination of CEFA & CEEP, difficult to distinguish

PART B																															
YEAR:	SITE	ANJU	ANLO	AECA	AECO	AECL	AEMU	AETU	AEVE	AEUM	NAPE	BAJA	EPHE	DITR	CODI	ARVI	DRSP	GOEX	LAVE	MAIL	DOLE	COSH	SOWI	EPCY	EPPR	EPSE	CEEL	CEEP	ERSI	LAJU	LIAU
2004	AMTRAK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.14	0	0	4.00	0	2.00	0	0
	CAROLBIG	16.33	0	0	0	8.50	0	49.00	18.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	30.00	0	5.17	0	0
	KITTBIG	132.67	6.47	0	0	0	0.67	0.80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	184.30	0	2.72	0	0
	NBGROUND	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SAILADUMP	49.52	0	0	0	0	0	0	0	5.73	0	0	0	0	0	0	0	0	0	0	0	0	0	64.21	0	0	0	0	0	0	0
	SKLT	3.20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	STRATHMORE	71.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BLACKSTONE	7.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11.22	1.20	0	0	4.25	80.34	0	0
	BRISTOLSK	132.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	346.14	4.00	17.71	0	0.86
	CAMPUS	0	0	0	0	0	0	0	0	4.00	0	0	0	0	0	0	0	0	0	0	0	0	0	29.00	0	2.00	0	0	0	0	0
	DEXTER	28.95	0	0	0	4.86	0	0	0	0	0	0	0	0	0	40.89	0	2.86	0	0	0	0	0	30.00	13.96	0	18.57	0	58.00	0	0
	EIGHTROD	1.85	0	0	0	0	0	4.00	0	1.94	0	0	1.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.77	0	0
	GLOBE	18.14	0	0	0	0	0	0	0	3.99	0	0	0	0	0	6.00	0	0	0	0	0	0	0	2.40	0	0	0	0	0	0	0
	INDUSTRIAL	0	0	0	2.40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PAINTBALL	17.00	0	3.00	1.00	0	0	0	0	0	0	0	0	0	0	0	0	1.00	0	0	0	0	0	6.00	0	0	0	0	20.00	0	0
	PHELPS	8.07	0	0	0	4.82	0	0	0	1.00	0	0	0	0	0	0	1.50	4.00	0	0	0	0	0	19.96	3.00	0	171.25	18.21	28.14	0	0
	RUMFORD	5.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102.81	5.21	0	2.00	0	46.43	0	0
	SANDY	0	0	0	0	2.00	0	0	0	0	0	1.00	0	0	0	0	7.65	13.50	0	0	0	0	0	56.33	24.15	0	330.44	145.41	8.82	0	1.33
	SLATERFRIEND	27.01	0	0	0	1.20	0	0	0	0	0	0	0	0	0	6.00	0	0	0	0	0	0	0	0	0	0	0	0	3.27	0	0
	SPECTACLE	17.00	0	0	0	0	19.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.00	0	0	0	0	14.40	0	0
	WAJONES	3.45	0	5.18	0	5.18	0	0	0	8.92	0	0.86	0	0.79	0.79	0.86	0	70.22	0.79	0	0	0	0	2.51	0	0	0	0	1.66	0	0
2005	AMTRAK	31.84	0	0	0	34.09	0	1.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.40	0	0	0	0	0	0	0
	CAROLBIG	8.78	0	0	0	71.35	0	60.44	0	0	0	0	0	0	0	0	0	0	0	0	64.01	0	0	0	0	1.50	9.98	0	22.20	0	0
	KITTBIG	152.29	18.27	0	0	13.49	9.58	10.24	0	1.36	0	0	0	0	0	0	0	0	0	0	21.37	0	0	0	0	0	38.98	6.49	10.93	0	0
	NBGROUND	4.86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.86	0	0
	SAILADUMP	29.07	0	0	0	0	0	0	0	19.05	2.00	0	0	0	0	0	0	0	0	0	12.15	0	0	57.79	0	0	0	0	0	0	0
	SKLT	6.00	0	0	0	4.00	0	1.25	6.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.67	0	0
	STRATHMORE	24.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BLACKSTONE	2.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.36	3.76	0	1.40	0.97	92.78	0	0
	BRISTOLSK	36.14	0	0	0	6.43	0	0	0	0	0	0	0	0	0	3.27	0	0	0	0	0	0	0	1.09	0	0	119.35	0	44.00	0	1.15
	CAMPUS	0	0	0	0	0	0	0	0	4.11	1.43	0	0	0	0	7.14	0	0	0	0	0	0	0	46.79	0	0	0	0	0	0	0
	DEXTER	2.40	0	1.43	0	3.60	0	0	0	0	0	0	0	0	0	6.61	0	2.25	0	0	0	0	0	110.04	10.52	0	26.64	1.20	93.77	0	0
	EIGHTROD	0	0	0	1.50	0	0	2.86	0	7.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	GLOBE	0	0	0	0	0	0	0	0	1.00	0	0	0	0	0	27.14	0	0	0	0	0	0	0	1.18	0	0	0	0	0	0	0
	INDUSTRIAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PAINTBALL	6.43	0	0	0	0	0	1.33	0	1.33	0	0	0	0	0	0	0	0	0	0	0	0	0	2.53	0	0	0	0	21.61	0	0
	PHELPS	0	0	0	0	6.81	0	0	0	0	0	2.07	0	0	0	0	1.00	3.06	0	0	0	0	0	60.87	6.27	12.79	285.77	118.72	8.10	0	0
	RUMFORD	1.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75.35	19.57	0	1.46	1.46	13.74	0	0
	SANDY	0	0	0	0	5.07	0	0	0	0	0	0	0	0	0	0	12.91	14.48	0	0	0	0	0	41.50	39.03	1.46	658.96	82.67	2.53	0	0
	SLATERFRIEND	1.54	0	6.98	0	2.00	0	0	2.00	0	0	0	0	0	0	9.77	0	0	0	0	0	0	0	0	0	0	0	0	6.83	0	0
	SPECTACLE	8.78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.50	0	0	0	1.76	57.46	0	0
	WAJONES	1.00	0	0	0	0	0	0	0	12.73	0	3.20	0	0	0	0	0	236.76	0	2.25	0	0	0	1.00	0	0	0	0	0.70	3.40	0

PART B

YEAR:	SITE	LICY	LIIN	LILU	LIPU	LISE	LIVIAX	LEIN	LEFR	LEHU	LEPR	PALO	PAHY	PAFL	PETE	PLLY	SYJA	SYVISE	TRLA	TRCA	TRAMEA
2004	AMTRAK	2.00	0	4.00	0	1.00	0	42.76	0	0	0	256.11	0	0	0	0	20.67	28.59	0	0	0
	CAROLBIG	1.00	3.00	0	0	0.67	0	12.42	0	0	0	657.83	0	0	0	0	41.00	7.00	6.00	0	6.00
	KITTBIG	0	0	0	0	0	0	12.67	0	0	0	275.62	0	0	0	0	4.20	798.92	0	0	0
	NBGROUND	0	0	0	0	0	0	0	0	0	0	0	114.40	0	0	1.20	4.00	8.40	0	0	0
	SAILADUMP	0	0	0	0	0	0	0	0	0	0	1092.10	0	0	0	0	18.71	6.76	0	0	0
	SKLT	0	0	0	0	0	0	16.88	0	0	0	0	0	0	0	0	199.63	61.80	0	0	0
	STRATHMORE	0	0	0	5.29	0	0	3.43	0	0	0	0	10.77	20.00	0	0	13.24	0	4.62	6.86	11.47
	BLACKSTONE	0	1.67	0	0	0	0	0	0	0	0	63.70	0	0	35.90	0	1.75	171.91	0	9.30	9.30
	BRISTOLSK	1.00	0	0.86	3.00	0	0	30.86	0.86	0	0	63.43	0	0	0	0	5.86	393.00	32.00	23.00	55.00
	CAMPUS	0	0	0	0	0	0	1.20	0	0	0	113.25	0	0	234.92	0.97	0	29.10	0	0	0
	DEXTER	0.86	1.00	7.80	10.91	0	0	0	0	0	0	2.71	0	0	85.63	1.00	0	274.80	1.80	11.79	13.59
	EIGHTROD	0	0	0	0	0	0	0	0	0	0	295.93	0	0	0	0	60.41	1.94	0	0	0
	GLOBE	0	0	0	1.20	0	0	0	0	0	0	0	0	0	0	1.20	10.80	40.77	0	0	0
	INDUSTRIAL	0	0	0	0	0	1.20	4.00	0	0	0	49.50	0	0	0	0	26.62	12.00	0	0	0
	PAINTBALL	4.00	0	0	1.00	0	0	11.00	0	0	0	450.00	0	0	95.00	0	3.00	245.00	0	0	0
	PHELPS	0	0	3.50	0	0	0	0	0	0	0	5.25	0	0	0	0	2.25	68.43	8.25	2.71	10.96
	RUMFORD	0	8.36	16.29	0	0	0	0	0	0	0	696.88	0	0	20.50	0	0	22.07	6.92	74.42	81.35
	SANDY	0	0	0	0	0	0	0	0	0	0	1.00	0	0	204.12	0	0	27.60	0	0	0
	SLATERFRIEND	5.86	5.56	2.59	4.50	0	0	20.73	0	0	0	12.26	1.13	0	0	6.68	0	180.29	0	0	0
	SPECTACLE	0	0	0	0	0	0	1.00	0	0	0	115.60	0	0	0	0	1.20	5.00	6.86	38.97	45.83
	WAJONES	1.60	4.91	0	0	0	5.03	0.79	0	0	0	0	0	0	0	2.60	19.37	128.97	0	0	0
2005	AMTRAK	1.40	4.03	0	2.53	70.85	0	1.40	0	0	0	7.55	0	0	0	0	4.90	136.83	0	0	0
	CAROLBIG	7.98	3.40	0	0	54.74	0	10.34	0	0	0	105.55	0	0	0	0	22.33	19.46	0	1.40	1.40
	KITTBIG	0	1.02	0	0	4.44	0	1.36	0	0	0	573.68	0	0	0	0	1.36	52.35	0	1.20	1.20
	NBGROUND	0	0	0	0	2.00	0	0	0	0	0	186.00	0	0	0	9.47	2.86	9.23	22.86	0	22.86
	SAILADUMP	0	1.00	0	0	0	2.67	0	0	0	0	219.82	0	0	0	0	45.99	0	0	0	0
	SKLT	0	0	0	0	8.00	0	23.08	0	0	0	270.08	0	0	0	0	28.00	0	0	0	0
	STRATHMORE	0	0	0	5.73	3.97	0	1.36	0	0	0	12.82	0	0	0	0	0	39.55	4.09	0	4.09
	BLACKSTONE	0	0	0	0	0	0	0	0	0	0	145.13	0	0	139.93	0	4.30	183.98	3.27	0	3.27
	BRISTOLSK	27.46	36.39	0	4.19	93.27	0	34.67	0	0	0	103.04	0	0	0	2.73	2.55	59.89	2.79	0	2.79
	CAMPUS	0	8.33	0	0	0	0	0	0	0	0	169.47	0	0	223.68	0	1.20	60.51	0	0	0
	DEXTER	6.75	14.94	10.00	10.25	0	0.75	2.25	0	0	0	36.42	0	0	106.23	0	1.43	158.95	0	0	0
	EIGHTROD	0	0	0	0	0	0	0	0	0	0	236.96	0	0	0	0	19.21	0	0	0	0
	GLOBE	0	0	0	1.43	0	0	0	0	0	0	2.86	0	0	0	0	80.00	8.39	0	0	0
	INDUSTRIAL	0	0	0	0	0	0	0	0	0	0	8.11	0	0	0	0	6.49	0	0	0	0
	PAINTBALL	0	36.02	1.20	0	0	0	5.00	0	0	0	1062.20	0	0	60.82	0	1.20	147.04	1.20	0	1.20
	PHELPS	0	3.17	0	0	0	0	0	0	0	0	3.00	0	0	0	0	9.04	391.86	1.95	0	1.95
	RUMFORD	0	4.36	86.44	7.14	0	0	1.43	0	0	0	1437.07	0	0	3.34	1.46	0	26.52	25.71	0	25.71
	SANDY	0	5.72	0	0	0	0	0	0	0	0	0	0	0	51.43	0	2.53	81.01	0	0	0
	SLATERFRIEND	15.64	0	0	1.40	13.16	0	0	0	0	0	15.74	0	0	0	5.72	0	89.21	0	0	0
	SPECTACLE	0	0	0	0	0	0	44.50	0	0	0	114.41	0	0	1.46	0	3.53	85.01	17.64	0	17.64
	WAJONES	8.08	3.65	0	0	0.70	0	2.00	0	0	0	0	0	0	0	12.86	1.40	48.60	0	0	0

PART B																					
YEAR	SITE	ANJU	ANLO	AECA	AECO	AECL	AEMU	AETU	AEVE	AEUM	NAPE	BAJA	EPHE	DITR	CODI	ARVI	DRSP	GOEX	LAVE	MAIL	DOLE
2006	BARRGAZEBO	4.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BFARMPD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BFRATPD	4.19	0	0	0	0	0	12.50	0	8.36	0	0	0	0	0	0	0	0	0	0	0
	CCRIWARWICK	0	0	0	0	0	0	0	0	0	1.53	0	0	0	0	0	0	0	0	0	0
	COWESETT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EASTFARM	23.72	0	0	0	0	0	0	0	0	0	0	0	0	0	6.92	0	0	0	0	0
	FALCONE	0	0	0	0	0	0	0	0	5.00	0	0	0	0	0	0	0	0	0	0	0
	FLATRIVRES	0	0	0	0	0	0	0	0	2.56	3.11	0	0	0	0	0	0	0	0	0	0
	GODDARDSP	0.58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	GWPUMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.92
	HARRINGTON	0	0	4.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NANCYBUXTON	12.17	0	0	0.87	0	0	8.87	0	3.53	0	0	0	0	0	0	0	0	0	0	7.48
	NATURESWAY	0	0	0	0	0	0	0	0	7.25	0	0	0	0	0	0	0	0	0	0	0
	PEEPER	1.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.30	0	0	39.62
	PLAINPD	34.45	148.26	0	0	11.74	0	1.18	0	0	0	0	0	0	0	0	0	0	0	0	0
	SHIPPEEOP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SIMMSMILL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SNAKEDEN	2.31	0	1.11	0	0	0	0	0	2.30	0	0	0	0	0	0	0	0	0	0	0
	SOM	45.69	0	0	0	0	0	0	0	11.98	1.15	0	0	0	0	0	0	0	0	0	0
	TEPEEPD	1.20	0	0	0	0	0	2.35	1.20	33.24	0	0	0	0	0	0	0	0	0	0	9.13
	WASHCOCC	22.59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WEYMRIDGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23.25	0	0	0
	WRIGHTFARM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.63	0	118.84	0	2.00	0

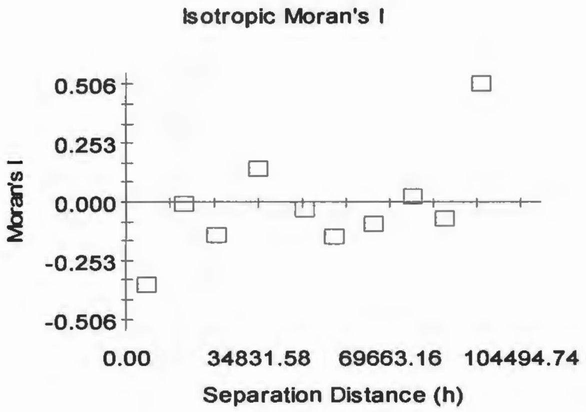
PART B																				
YEAR	SITE	COSH	SOWI	EPCY	EPPR	EPSE	CEEL	CEEP	ERSI	LAJU	LIAU	LICY	LIIN	LILU	LIPU	LISE	LIVIAX	LEIN	LEFR	LEHU
2006	BARRGAZEBO	0	0	2.37	0	0	0	0	1.58	0	0	0	1.28	0	0	0	0	0	0	0
	BFARMPD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BFRATPD	0	0	4.80	0	0	0	0	0	0	0	0	1.40	0	0	0	0	0	0	0
	CCRIWARWICK	0	0	255.88	0.72	16.50	91.27	0	0	0	0	0	16.28	0.72	0	0	3.29	0.72	0	0
	COWESETT	0	0	4.54	0	0	0	0	0	0	0	0	2.14	0	0	0	0	0	0	0
	EASTFARM	0	0	11.48	0	0	0	0	1.28	0	0	0	0	1.15	3.46	0	0	0	0	0
	FALCONE	0	0	0	0	0	0	0	0	0	0	0	4.84	0	0	0	0	0	0	0
	FLATRIVRES	0	1.94	0	0	0	0	0	0	0	0	0	6.87	0	0	0	0	0	0	0
	GODDARDSP	0	0	6.13	0	0	0	0	0	0	0	0	9.38	0	3.34	0.58	0	0	0	0
	GWPUMP	0	0	2.69	0	0	0	0	3.71	6.14	0	0	1.57	0	0	5.43	0	6.27	0	0
	HARRINGTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NANCYBUXTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NATURESWAY	0	0	63.31	0	0	0	0	5.93	0	0	0	3.81	0	0	0	0	0	0	0
	PEEPER	2.98	0	12.62	0	0	0	0	1.92	5.88	0	0	9.68	0	2.00	0	0	0	0	0
	PLAINPD	0	0	0	0	0	15.16	0	5.38	3.34	0	0	2.00	0	0	0	7.72	17.86	0	36.47
	SHIPPEEOP	0	0	7.78	0	0	0	0	5.56	0	0	0	0.82	0	0	0	0	5.71	0	0
	SIMMSMILL	0	0	6.00	0	1.20	0	0	15.71	0	0	0	0	0	0	0	2.67	0	0	0
	SNAKEDEN	0	0	26.75	0	0	0	0	2.00	0	0	0	0	0	0	0	0	21.91	0	0
	SOM	2.00	0	0	0	0	0	0	0	0	0	0	1.28	0	0	0	0	0	0	0
	TEPEEPD	1.34	0	0	0	0	0	0	1.15	1.20	0	0	3.60	0	0	0	0	12.57	0	0
	WASHCOCC	0	0	4.39	0	0	0	0	13.24	0	0	0	0	0	0	0	0	8.78	0	0
	WEYMRIDGE	0	0	1.17	0	0	1.98	0	0	1.17	0	0	3.68	0	0	0	0	0	0	0
	WRIGHTFARM	0	0	5.24	0	0	19.34	0	13.46	5.16	0	0.95	2.63	3.17	0	0	0	9.95	0	0

PART B										
YEAR	SITE	LEPR	PALO	PAHY	PAFL	PETE	PLLY	SYJA	SYVISE	TRAMEA
2006	BARRGAZEBO	0	88.79	0	0	47.93	0	0	0	0
	BFARMPD	0	0	0	0	0	0	15.45	0	0
	BFRATPD	0	112.36	0	0	0	5.00	48.73	2.86	0
	CCRIWARWICK	0	12.12	0	0	3.12	0	2.32	22.16	0
	COWESETT	0	13.19	0	0	1.20	0	0	23.30	0
	EASTFARM	0	19.38	0	0	0	0	0	4.19	126.54
	FALCONE	0	54.65	0	0	2.22	3.33	2.69	29.71	0
	FLATRIVRES	0	58.60	0	0	3.42	0	8.24	0	0
	GODDARDSP	0	691.16	0	0	16.92	0	0	3.85	0
	GWPUMP	0	3.43	0	0	0	0	1.71	139.66	0
	HARRINGTON	0	0	0	0	0	0	28.58	1.67	0
	NANCYBUXTON	0	0	0	0	0	0	294.51	23.13	0
	NATURESWAY	0	213.57	0	0	128.63	4.36	1.41	7.28	0
	PEEPER	0	197.24	0	0	0	2.00	4.36	212.92	0
	PLAINPD	83.72	14.75	0	0	0	0	0	99.48	3.32
	SHIPPEEOP	0	222.98	0	0	0	0	0	34.58	0
	SIMMSMILL	0	69.47	0	0	1.67	0	0	93.91	0
	SNAKEDEN	0	246.00	0	0	0	0	2.00	2.00	1.20
	SOM	0	155.39	0	0	0	0	51.57	21.99	0
	TEPEEPD	0	92.55	0	0	0	0	2.40	117.74	0
	WASHCOCC	0	12.00	0	0	0	4.39	0	1.83	36.33
	WEYMRIDGE	0	0	0	0	0	0	0	33.35	0
	WRIGHTFARM	0	6.95	0	0	1.15	1.11	0	66.45	0

Appendix VI. Output data from analysis for Moran's I, based on species richness (GS+: GeoStatistics for the Environmental Sciences, Version 7; 1989-2006, Gamma Design Software, Plainwell, Michigan); A) for all 21 sites, 2005 data; B) for 18 smaller sites, 2005 data; C) for all 23 sites surveyed in 2006.

A)
File 2005v1 - ALL 21 SITES

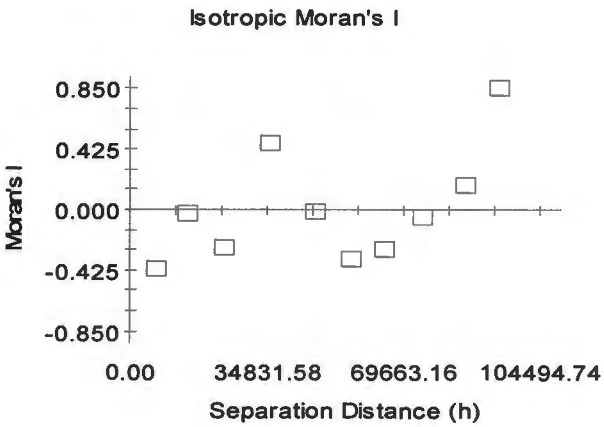
Lag	Dist	I	n
1	5581.36	-0.3566	8
2	15156.72	-0.0095	10
3	23584.8	-0.1464	16
4	34822.41	0.141	6
5	47064.25	-0.0286	12
6	55004	-0.1487	8
7	65149.02	-0.0994	12
8	75782.41	0.021	12
9	84291.86	-0.072	11
10	93696.85	0.5065	5



B)

File 2005v2 - W/O 3 AREA-OUTLIER SITES

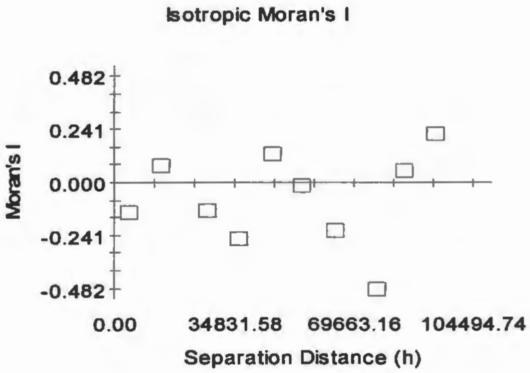
Lag	Dist	I	n
1	6779.71	-0.4143	6
2	14741.57	-0.0237	6
3	23731.09	-0.2728	11
4	35653.02	0.4611	2
5	46972.38	-0.0105	9
6	55992.46	-0.3414	3
7	64468.23	-0.2763	7
8	74425.43	-0.0568	8
9	85295.33	0.1705	4
10	93974.57	0.8504	3



C)

File 2006 - ALL 23 SITES

Lag	Dist	I	n
1	4414.64	-0.1375	4
2	13419.48	0.0756	6
3	26671.45	-0.1262	9
4	35950.64	-0.257	18
5	45998.56	0.1257	11
6	54363.25	-0.0163	27
7	64164.94	-0.2167	13
8	76416.3	-0.4819	11
9	84346.78	0.0497	17
10	93192.36	0.2207	9



Appendix VII. Dominance-diversity plots.

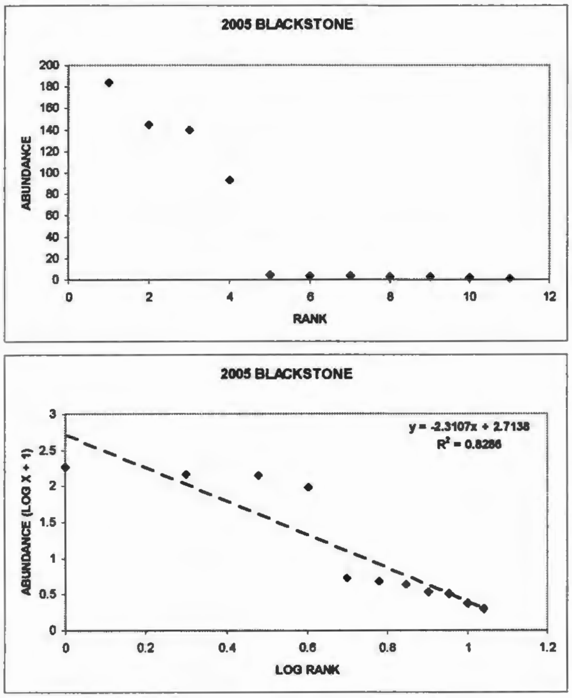
To assess evenness of species richness data at sites, I constructed dominance diversity plots for each site in 2005 ("model") and 2006 ("test" set). The original abundance vs. rank plot does not provide a linear relationship for comparison of evenness, so I also constructed log-abundance vs. log-rank plots, to evaluate linear measurements of slope as measurements of evenness along the urbanization gradient. There are two parts to this Appendix: Part A) table of the log-abundance-log rank slopes for 2005 and 2006 sites; Part B) graphs of the abundance-rank and log abundance-log rank plots of example sites, for comparison.

Part A - Slopes of the log abundance-log rank plots for species richness at sites surveyed in 2005 and 2006. NOTE: two sites are not included because they had only 1 or 2 species: INDUSTRIAL (2005) and BFARMPD (2006)

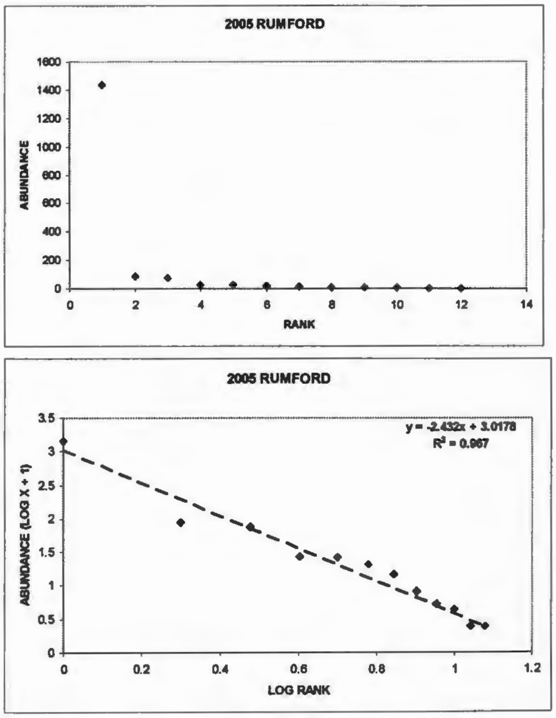
Site	Slope	Year
AMTRAK	-2.01	2005
BARRGAZEBO	-2.32	2006
BFRATPD	-1.71	2006
BLACKSTONE	-2.31	2005
BRISTOLSK	-1.65	2005
CAMPUS	-2.34	2005
CAROLBIG	-1.42	2005
CCRIWARWICK	-2.13	2006
COWESETT	-1.20	2006
DEXTER	-1.78	2005
EASTFARM	-1.87	2006
EIGHTROD	-2.82	2005
FALCONE	-1.58	2006
FLATRIVRES	-1.56	2006
GLOBE	-2.08	2005
GODDARDSP	-2.72	2006
GWPUMP	-1.50	2006
HARRINGTON	-2.22	2006
KITTBIG	-2.03	2005
NANCYBUXTON	-2.26	2006
NATURESWAY	-2.18	2006
NBGROUND	-2.03	2005
PAINTBALL	-2.75	2005
PEEPER	-2.06	2006
PHELPS	-2.13	2005
PLAINPD	-1.64	2006
RUMFORD	-2.43	2005
SAILADUMP	-2.07	2005
SANDY	-2.08	2005
SHIPPEEOP	-2.48	2006
SIMMSMILL	-2.00	2006
SKLT	-1.96	2005
SLATERFRIEND	-1.37	2005
SNAKEDEN	-2.26	2006
SOM	-2.18	2006
SPECTACLE	-1.83	2005
STRATHMORE	-1.42	2005
TEPEEPD	-1.96	2006
WAJONES	-1.81	2005
WASHCOCC	-0.93	2006
WEYMRIDGE	-1.84	2006
WRIGHTFARM	-1.61	2006

Part B – Examples of abundance-rank (top) and log abundance-log rank (bottom) plots for several wetlands: a) Blackstone (2005); Rumford (2005); Plain (2006).

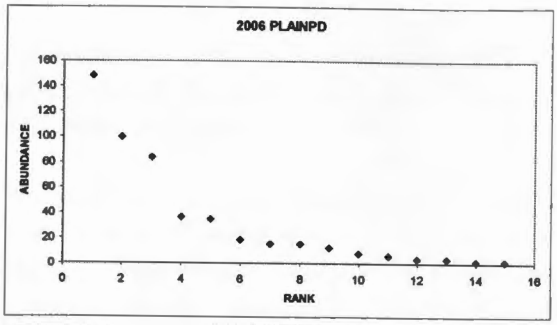
a)



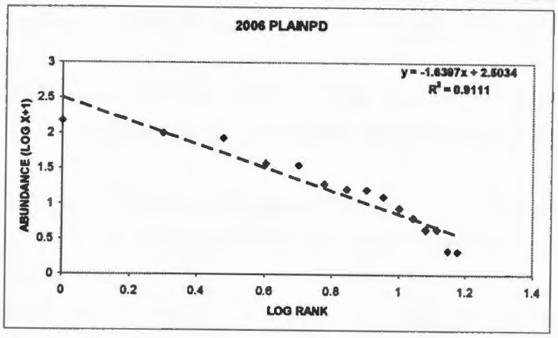
b)



c)



2006 PLAINPD
ABUNDANCE
RANK
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14
16



2006 PLAINPD
y = -1.6397x + 2.5034
R² = 0.9111
ABUNDANCE (LOG X+1)
LOG RANK
0
0.5
1
1.5
2
2.5
3
0
0.2
0.4
0.6
0.8
1
1.2
1.4

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