An analysis of environmental features important to

amphibian distribution in Nova Scotia.

Can we overcome the challenge of acquiring long term, large scale data

by using volunteer collected data?

By
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ACKNOWLEDGEMENTS

AUTHOR STATEMENT

This thesis is organized into two chapters. I anticipate submitting Chapter 1:

"Classification trees: A method for describing environmental features important to

amphibian distribution appropriate for use with volunteer collected data" as one or more

manuscripts for peer-reviewed publication. I was responsible for data collection for

approximately half of the wetlands, with Ron Russell collecting most of the data for the

wetlands in the Herring Cove cluster. I visited all Herring Cove wetlands at least twice.

The analysis and writing is my own.

Chapter 2 "A review of citizen science and community-based environmental

monitoring: Issues and opportunities" was co-written with Cathy Conrad, and was

accepted for publication in Environmental Monitoring and Assessment on June 15, 2010.

It is included in this thesis with the permission of the aforementioned journal. As each

chapter is intended as a stand-alone document, repetition may occur.

ABSTRACT

An analysis of environmental features important to amphibian distribution
in Nova Scotia. Can we overcome the challenge of acquiring long term, large scale data
by using volunteer collected data?

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Because of world-wide declines in amphibian populations, it is important we have a
strong understanding of what features are most important to their distribution. In Chapter
1, 100 wetlands and adjacent upland habitat were assessed for amphibians and potential
habitat requirements or limitations. Classification and Regression Trees (CART) were
used to analyze the data. Although this method worked well with data collected by
professionals, a larger data set would allow us more confidence in our results. This could
be achieved through the use of trained volunteer citizen scientists. In Chapter 2, the last
ten years of relevant citizen science literature was reviewed for areas of consensus,
divergence and knowledge gaps. If amphibian volunteer monitoring programs are
designed based on the latest recommendations in the field of citizen science, the
additional data generated would provide statistical strength to CART analysis of
environmental features most important to amphibians.

April 9, 2013

Chapter 1: Classification trees: A method for describing environmental features important to amphibian distribution appropriate for use with volunteer collected data

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ABSTRACT

Given the many characteristics of amphibians that infer sensitivity to changes in their environment, and their relative ease of sampling; amphibians are often considered general indicators of environmental health. However, large scale (in both time and space) studies of environmental features most important for amphibians are scarce. This makes it challenging to make policy recommendations for the protection of amphibian habitat. I propose the following limitations to our understanding of environmental features important to amphibians: monitoring data availability, time scale and landscape scale of data collection. Monitoring data availability over both scales could be considerably increased by the use of trained volunteer amphibian monitors. In this study, I looked at data collected by professionals from 100 wetlands across central Nova Scotia. The objective of this study was to assess the suitability of Classification and Regression Tree (CART) models to explore which environmental features are most important for amphibian presence in central Nova Scotia, and to modify the display of the models so they are easier to interpret by laypersons and policy makers for future use with volunteer data. This is important if we are to recruit volunteers for amphibian monitoring. CART models were "validated" by displaying environmental features well known to be important to our most common and well studied species, the green frog (*Lithobates clamitans*). I then created a simplified classification tree that clearly displays the recommendations of each model. Based on the environmental features identified in the CART models, we make the following recommendations for the protection of amphibian habitat in central Nova Scotia:

      1. Where possible, protect a diversity of wetlands with long and short hydroperiods, of various sizes and within and outside of forests.

      2. When concerned about a particular species, management decisions should be determined by the requirements of that particular species, not the total amphibian community. Please note the following important species-specific observations:

- Wood frogs were negatively associated with newt presence.
- Spotted salamanders were negatively associated with green frog presence.
- American toads were particularly sensitive to clearings.
- Pickerel frogs were particularly sensitive to pasturelands.
- Newts were positively associated with long hydroperiods.

      3. In general, protect wetlands and surrounding upland area where species richness is already high.

      4. When occupancy is unknown, protect wetlands larger than 43 m^2, with conductivity lower than 52 μS/cm, circum-neutral pH, and near or within large wooded areas.

With future use of trained volunteer amphibian monitors, we can increase the availability of data and thus improve confidence in our recommendations to protect the habitat of these complex species.

INTRODUCTION

There has been increasing interest in the problem of global amphibian declines over the last two decades (Alford & Richards, 1999; Beebee & Griffiths, 2005). Declines and extinctions have been documented globally since the 1950s to present day (Houlahan et al., 2000). At least 30% of known amphibian species are currently under threat, with just over 7% critically endangered (Stuart et al., 2004; Beebee & Griffiths, 2005). This is a higher rate of endangerment than the estimates for birds (12%) and mammals (23%). However, our understanding of the causes of these declines is limited (Cushman, 2006; Gardner et al., 2007).

Amphibians are often referred to as indicators of environmental health (Blaustein et al., 2003; Beebee & Griffiths, 2005) as their presence or absence may be related to habitat quality, environmental contamination, or population trends in other species (Beebee & Griffiths, 2005). They also make good indicator species because of their relative ease of sampling (especially for North American species) (Beebee & Griffiths, 2005). Although our lack of understanding of the ecology (and thus responses to environmental disturbance) of some amphibians may limit their usefulness as indicators, the combination of apparent sensitivity and relative ease of sampling makes most amphibian species excellent indicator candidates. With a better understanding of their ecology, we may be able to more confidently draw conclusions about the environment as a whole based on the health of the amphibian community.

Amphibian declines and extinctions have been attributed to both "structural" and "non-structural" disturbances (Gardner et al., 2007). "Structural" disturbances include

habitat loss and fragmentation, over-exploitation, and the introduction of exotic species (Alford & Richards, 1999; Beebee & Griffiths, 2005; Gardner et al., 2007). "Non-structural" disturbance takes the forms of acidification, pollution or infectious disease (Alford & Richards, 1999; Gardner et al., 2007). This thesis will focus more on "structural" disturbance effects on amphibians, and in particular, habitat loss and fragmentation. Further rationale for the study of "structural" disturbance is fuelled by evidence that most amphibian declines in North America, although frequently associated with an interaction of causal factors, seem to be associated with habitat modification (Alford & Richards, 1999). Much evidence still exists for "non-structural" disturbance effects on amphibians; thus possible key non-structural disturbances such as acidification and salinization will be explored.

Amphibians often possess characteristics that infer sensitivity to habitat loss and fragmentation, specifically: 1) high philopatry and low vagility (Cushman, 2006), 2) high vulnerability to mortality by desiccation, predation and/or vehicular death while crossing roads and inhospitable terrain (Clawson et al., 1997; Houlahan & Findlay, 2003; Porej et al., 2004b; Cushman, 2006; Semlitsch et al., 2007), 3) specific habitat needs and narrow habitat tolerances (Cushman, 2006), and 4) sensitivity to disturbance in both aquatic and terrestrial habitat (Mitchell et al., 1997; Semlitsch, 1998; Semlitsch & Bodie, 2003; Gardner et al., 2007). These characteristics lend credence to the theory of amphibians as indicators.

Species with low vagility and high philopatry exhibit decreased population sizes when suitable habitat is lost, and are at risk for genetic isolation effects when habitat is

fragmented (Cushman, 2006). A protective "rescue effect" may exist for highly vagile species that exhibit metapopulation structure. In this case, a species with high dispersal ability are able to "rescue" extinct subpopulations through recolonization. This "rescue effect" is generally not present in species that are highly philopatric to their natal ponds (Henle et al., 2004). Spatially realistic metapopulation theory assumes that as both size of a habitat fragment and connectivity to other fragments increases, the likelihood of fragment occupation by a particular species increases (Hanski, 2001). Therefore, a species with high dispersal ability would be more resistant to local extinctions than a less vagile species by virtue of producing more individuals capable of immigrating. Although debate exists as to whether amphibians exhibit true metapopulation structure (Marsh & Trenham, 2001), it is likely that amphibian species with low vagility are sensitive to habitat fragmentation.

More vagile species such as American toads, green frogs and red-spotted newts have been shown to travel 1000-1600 m (Semlitsch & Bodie, 2003).Travelling long distances increases the risk of encountering roads and other anthropogenic barriers in fragmented landscapes. Anthropogenic barriers often prevent dispersal and result in physical and genetic isolation. Direct mortality is the most likely consequence of crossing roads (Cushman, 2006). At particular risk are juvenile amphibians that often travel the greatest distances from their natal ponds during dispersal (Cushman, 2006).

Many species rely on both aquatic and upland habitat and are thus sensitive to changes occurring in both (Semlitsch, 1998). Many amphibians have an aquatic phase of their life cycle, most often for larval development. During this sensitive phase,

amphibians may be exposed to many aquatic contaminants. Low pH (especially in combination with other stressors) (Alford & Richards, 1999), agricultural chemicals and fertilizers (Mann et al., 2009), and road de-icing salts (Collins & Russell, 2009) have all been proposed as particularly troublesome to breeding and larval amphibians.

Upland terrestrial habitat is also crucial to many species for foraging, juvenile development, and dispersal or migration (Semlitsch, 1998). Core upland habitat has been defined for many amphibian species to extend from 159 to 290 m from the wetland edge (Semlitsch & Bodie, 2003). Although many amphibian species are philopatric to their natal wetland, they may visit upland terrestrial habitat regularly for foraging, or annually for over-wintering (Semlitsch & Bodie, 2003). Amphibian species richness has been positively associated with forest cover up to 3 km (Houlahan & Findlay, 2003) from their natal or breeding wetland. In a recent review, most studies showed positive relationships between amphibian populations (both species richness and abundance studies) and forested upland habitat, and negative relationships between amphibian populations and areas that are fragmented by urbanization and roads (Cushman, 2006). Road construction, forest harvesting, urbanization, and agricultural development have been identified as significant causes of habitat loss and fragmentation for amphibians.

Amphibian presence has been negatively associated with road presence on scales from 35 m (Semlitsch et al., 2007) to 1 km (Houlahan & Findlay, 2003; Porej et al., 2004b). Increasing traffic density is associated with greater amphibian mortality, as well as decreased density of amphibians in nearby wetlands (as measured by choruses) (Fahrig, et al., 1995). Salamanders in particular seem to suffer from a larger "road effect

zone" (the distance at which negative road effects are seen) - even on narrow, low-use forest roads (Semlitsch et al., 2007). These road effects include limiting dispersal and causing direct mortality (yielding less genetically diverse populations) (Cushman, 2006). Roads also open the forest canopy and change drainage regimes, which may lead to decreased soil moisture and leaf litter along road margins (Clawson et al., 1997; Semlitsch et al., 2007).

A consensus on forestry impacts on amphibians has not been reached (Kroll, 2009). Intensive forestry operations that decrease habitat complexity and structure have been shown to negatively impact species richness (Mitchell et al., 1997; Gardner et al., 2007). However, selective logging has had a positive impact on the presence of some generalist and relatively tolerant species (Gardner et al., 2007); and some young, recently cleared forests demonstrated higher species richness than older, less disturbed forests (Loehle et al., 2005).

Many studies show positive relationships between amphibian populations and area of forest in surrounding landscape, and negative relationships with increasing area of urbanization (Knutson et al., 1999; Cushman, 2006). Wood frogs and spotted salamanders are known to avoid fields, pastures, clear cuts, and lawns; while juvenile American toads also avoid areas of open canopy (Cushman, 2006). It appears any large scale removal of habitat or impediment to movement is a risk to local amphibian populations.

Two recent review papers recommended the need to focus more research on habitat fragmentation and loss effects on amphibians (Cushman, 2006; Gardner et al.,

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2007). Some of the gaps in recent years were identified as: 1) lack of species-specific responses to habitat fragmentation and loss (Gardner et al., 2007), 2) not enough studies conducted at large landscape scales (Cushman, 2006; Gardner et al., 2007), 3) studies were too short; need for more multi-season field campaigns (Gardner et al., 2007), 4) need to focus on structural habitat change, not just water chemistry, disease and temperature effects (Gardner et al., 2007), 5) too much work focused in protected areas, and 6) need for more information about community dynamics in fragmented and disturbed landscapes (Cushman, 2006; Gardner et al., 2007).

Objectives

The overall goal of this thesis is to increase our understanding of the importance of different habitat variables to amphibian presence in Nova Scotia, so we can better manage and protect their habitat. I postulate there are three main factors that limit our ability to manage and protect amphibian habitat:

1) Monitoring Data Availability: The amphibian monitoring data required to assess large study areas over many years is expensive to acquire, especially as governments continue to cut programs devoted to monitoring (Conrad and Hilchey, 2010).

2) Scale of Data Collection: As suggested by the studies above (Cushman, 2006; Gardner et al., 2007), when amphibian monitoring data is available, it often covers a small geographic area for a few seasons.

3) Communication: Scientists do not always provide wildlife and habitat management recommendations to the public and policy makers in an easy-to-interpret manner.

I propose we can overcome the aforementioned challenges, and meet the main study objective by:

a) Exploring which anthropogenic or natural features contribute most to presence or absence of amphibians with a method of analysis (CART- Classification and Regression Trees (Breiman et al., 1984; Moore et al., 1991) that could, in the future, be used in analysis of large amounts of data collected by trained volunteer citizen scientists. As a large number of volunteer amphibian monitoring programs exist (deSolla et al., 2005), I propose utilizing data collected by "citizen scientists" as a method to overcome the challenges of data availability and scale of data collection. For more on the challenges and opportunities of working with citizen scientists see Chapter 2.

b) Proposing a method of displaying the CART results in a way that is easy for laypeople (including citizen scientists and policy-makers) to understand, interpret, and apply to management decisions. The results of this study can provide meaningful and easily interpreted biological recommendations for wetland and upland habitat protection policies and regulations in northeastern North America, while also providing a realistic method to utilize citizen-collected data.

METHODS

Study area

This study was conducted within one hundred wetlands distributed across the central third of the province of Nova Scotia. The study area spanned from Hubbards, NS (44°38'34''N 64°03'06''W) in the West, Middle Musquodoboit, NS (45°02'35''N

63°09'06''W) in the East and Pictou, NS (45°40'53''N 62°42'43''W) in the North (Figure 1).

Nova Scotia has a modified continental climate, with variable temperatures and precipitation influenced by proximity to the coast and elevation. The study area spans three climatic zones in mainland Nova Scotia (Figure 2) from North to South): A) the Northumberland shore experiences the least precipitation with cold winters, delayed springs and warm summers and falls, D) the central portion of the province from Truro to Halifax has high rainfall and cool temperatures, and H) the Atlantic Coast has the coolest summers and warmest winters. Wetlands 1-10 and 78 occur in zone A, 11-18, 25-37,52,58,60-61,65,67,80-100 occur in zone D and 19-24,38-51,53-57,59,62-64,66,68-77, and 79 occur in zone H. Temperatures range from an average January temperature of -7°C to an average July temperature of 19°C. Average annual precipitation ranges from 1250-1500 mm (on the mainland) with precipitation occurring on average from 122 to 189 days per year. Snowfall on mainland Nova Scotia varies from year to year with an average total snowfall of 150-400 cm (Museum of Natural History, 1992c).

Mainland Nova Scotia is divided into two geological zones, separated by a large fault which runs from Cobequid Bay to Chedabucto Bay (Figure 3). Wetlands 1-10 and 78 exist within the Avalon zone. This zone is characterized by: 1) Upper Carboniferous sandstone, shale, coal seams, and conglomerate, 2) Triassic to Jurassic sandstone, limestone, basalt and conglomerate, and 3) Precambrian to Devonian with a basement complex of schist, gneiss, marble, amphibolites, slate, quartzite, shale, limestone and volcanic rocks and younger volcanic rocks, sandstone, shale, conglomerate, and plutonic

rocks (Museum of Natural History, 1992b). The rest of the wetlands exist within the Meguma group. The area of this zone that was part of our study site is characterized by: 1) Meguma terrane plutonic rocks (granite, granodiorite and diorite), and 2) Cambrian to Devonian quartzite, slate, schist, gneiss, minor volcanic rocks and iron formation (Museum of Natural History, 1992b).

The study site covers five primary watersheds. Wetlands 1-10 and 78 occur in watershed 1DO (River John), 25-37,58,65 and 80-86 in watershed 1DG (Shubenacadie-Stewiacke), 52,60-61,67,87-100 in watershed 1DE (St. Croix), 11-20 in watershed 1EH (East/Indian River), and the rest (21-24,38-51,53-57,59,62-64,66,68-77,79) occur in watershed 1EJ (Sackville) (Figure 4) (Museum of Natural History, 1992d).

Upland forest types encountered during the study included: 1) red maple, red oak, and white birch, 2) sugar maple, yellow birch and beech, 3) red spruce and balsam fir, 4) black spruce and larch, 5) red spruce, hemlock, pine and 6) black spruce, balsam fir and maple (Museum of Natural History, 1992a). Most vegetation in the surveyed wetlands was found in communities defined by wetland type. Bogs were characterized by *Sphagnum* and other mosses, often with black spruce, larch, bulrush (*Scripus* spp.) and predacious plants like pitcher plant and sundew. Swamps were defined by the presence of standing shrubs (i.e. *Rhodora* spp.), trees (balsam fir, black spruce, red maple and larch) and *Carex* sedges, Cinnamon fern and mosses. Freshwater marsh species were most often clumps of cattails (*Typha* spp), grasses, sedges, bulrushes (*Scirpus* spp.) and reeds. Swamp-type species were most often present in vernal pools; whereas man-made and

roadside wetlands often presented with species typical of freshwater marshes, as well as swamps.

The following native amphibian species were encountered: American toad (*Anaxyrus americanus*), green frog (*Lithobates clamitans*), bull frog (*Lithobates catesbeianus*), mink frog (*Lithobates septentrionalis*), northern leopard frog (*Lithobates pipiens*), pickerel frog (*Lithobates palustris*), spring peeper (*Pseudacris crucifer*), wood frog (*Lithobates sylvaticus*), eastern red spotted newt (*Notophthalmus viridescens*), spotted salamander (*Ambystoma maculatum*), blue spotted salamander (*Ambystoma laterale*), four-toed salamander (*Hemidactylium scutatum*) and redback salamander (*Plethodon cinereus*).

Field methods

Wetlands that were already affected to some degree by habitat fragmentation or loss were chosen, as it was assumed amphibians encounter "suboptimal" habitat much more frequently than "optimal" habitat in Nova Scotia (at the time of this study, less than 9% of Nova Scotia's land mass was legally protected (Nova Scotia Environment, 2010)). Wetland locations were chosen based on accessibility and travel time in four clusters: Hammonds Plains to Hubley (wooded suburban area along a secondary road and divided highway), Herring Cove area (coastal suburban along a secondary road), Elmsdale to Middle Musquodoboit (wooded and agricultural rural area along a secondary highway), and Pictou area (rural agricultural area along a secondary highway). Wetlands were not included if: 1) they were in close proximity to large-scale agriculture (to limit agricultural runoff impact), 2) they were within protected areas (to limit the study to disturbed and

fragmented wetlands), and 3) predacious fish were present (some amphibian species present in the study site are known to not breed in wetlands with predacious fish (Hecnar & M'Closkey, 1997b). All wetlands were within 250 m of a road. Although much variability exists across the landscape, all wetlands chosen were close to patches of small-scale agriculture, forestry, roads and/or urban or rural residences (sometimes urban or industrial developments).

Both evening auditory surveys and daytime visual sampling methods were employed to determine amphibian species presence/absence and species richness of each wetland. All native species that require both aquatic and terrestrial habitat to complete their life cycles were sampled (that includes all native amphibian species except *P. cinereus* which is an entirely terrestrial species). All wetlands were visited a minimum of six times (at least three times during the day for visual observations and at least three times for nighttime calling) over two years (2008 and 2009). Timing of visits occurred at least once during the day and night for: April, May, and June (for nighttime calling species and larval observations of early breeders), and at least once during the day in July or August (for daytime calling species and larval observations of later breeders). During the day, a dip net was used to sample for adult frogs and newts, anuran and caudate larvae and aquatic eggs. Rocks and logs were lifted and replaced in search of terrestrial salamanders within 5 m of the pond. Nighttime visits involved approaching the pond quietly and listening for calling anurans, and looking for mating pairs for a minimum of 10 minutes. It has been demonstrated that 3 to 5 minutes is an adequate time to hear most species at a given site (Shirose et al., 1997; Crouch & Paton, 2002). Presence of

confidently identified eggs, larvae and/or adults was considered evidence of species presence. Species richness was defined as the number of amphibian species present at the site.

All anthropogenic or environmental factors measured were chosen based on possible relevance to habitat loss and fragmentation effects, as well as factors shown in other studies to impact amphibian decline or distribution. During field visits, triplicate water samples were collected and analyzed in situ with a Hydrolab® for pH, salinity, and chloride. Each wetland type was loosely assigned a type as bog, swamp, marsh (based on the plant community present - see study site descriptions above), constructed (most were farm or ornamental ponds), roadside (artificial pools from road/building construction or quarrying activity) or vernal (if the wetland dried at least once over a sampling season). All field and aerial photo methods were chosen based on the accessibility of the methods to citizen scientists.

Aerial photography methods

Using aerial photographs, the following parameters were approximated: climatic zone; geologic zone; watershed (from the Nova Scotia Museum of Natural History definitions in *Study Area* above); area of wetland (m^2); distance to nearest road (m); distance to nearest wetland visible on the aerial photograph (m); distance to nearest clearing (m); type of clearing (1) clear-cut or storm damage, 2) pasture, 3) subdivision, 4) industry or 5) lawn, (with up to two buildings present); size of clearing (m^2); distance to nearest area of undisturbed forest (m); and size of undisturbed forest (m^2).

If the area of a wetland was too small to estimate on an aerial photograph it was assigned a value of 25 m^2. Those wetlands not observed on the aerial photographs were confirmed to be small in size (and not just obscured by tree cover) during site visits. The nearest road was considered to be the nearest road of any type in metres of Euclidean distance. The nearest clearing was considered to be the nearest clearing of any of the 5 types listed above in m of Euclidean distance. Clear-cut and storm damage were not differentiated as it was difficult to differentiate the two without historical data on forestry practices. It is assumed a small clear-cut (like most of those near the sampled wetlands) and storm damage would represent equivalent barriers to amphibians. A subdivision was defined as an area with more than two houses in close proximity without a wooded area in between the properties. A clearing was defined as industrial if it represented a gravel pit, large area of buildings and pavement, quarry, dump, etc. A lawn was defined as an area of mowed grass that did not represent a pasture and had up to two large buildings on site. The distance to nearest area of undisturbed forest was measured in m of Euclidean distance, without having to cross a potential amphibian barrier (road, large river, clear-cut/storm or pasture). The size of undisturbed forest was estimated from the aerial photograph to be the largest contiguous area without potential amphibian barriers. See Table 1 for list of all measured variables.

Preliminary Analysis

One wetland was removed from the analysis as water chemistry samples were lost. A Pearson Correlation Matrix was conducted to determine if any variables were correlated with one another (Table 2). Variables were considered collinear if r > 0.80.

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Collinearity (r = 0.971) was found between conductivity and chloride. Because

conductivity would likely be measured by citizen scientists more often than chloride,

chloride was removed from the dataset and conductivity retained.

Nestedness Analysis

The first analysis chosen was a nestedness analysis, simply to describe the type of

relationship that exists between the species in the amphibian assemblage. Species

assemblages are defined as nested if the species present in species-poor sites are a proper

subset of those present in species-rich sites (Patterson & Atmar, 1986). A pattern of

nestedness indicates a high level of non-random organization of assemblages (Hecnar et

al., 2002). If our Nova Scotia amphibian assemblage was non-nested, we would not

expect strong CART models and another method of analysis would be required.

Three conditions for the development of nestedness are generally accepted as: a

common bio geographical history, similar habitats, and hierarchical niche relationships

(Patterson & Brown, 1991). Basically, the species must be comparable (the first two

conditions) - but also differ in their life histories or use of resources (the last condition)

(Hecnar et al., 2002). Nestedness was first popularized for describing patterns of species

assemblages on archipelagos islands. Perfectly nested archipelagos would have smaller

islands that contain only common species and larger islands that contain both common

species and rarer species (Figure 5). Nestedness has now been expanded to apply many

taxa, and to fragmented sites, as well as islands (Kolozvary & Swihart, 1999; Hecnar et

al., 2002; Almeide-Neto et al., 2007). Selective extinction and/or colonization appears to

drive the relationship (Hecnar et al., 2002).

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Atmar and Patterson describe the measure of nestedness in their Nestedness Calculator as ° T- heat of disorder. A highly nested archipelago would be described with a cold, or low, "disorder temperature" (completely replicable extinction order= 0°). In an un-nested archipelago, the disorder temperature would be higher (completely random extinction order= 100°) (Atmar & Patterson, 1995). Although I use the T statistic calculated from the Nestedness calculator in my analysis, I exclude the °, as the accuracy of temperature as a metaphor for nestedness has recently been disputed, and is arguably better represented as % disorder (Almeide-Neto et al., 2007). The higher the T, the higher the disorder, and the lower the nestedness of the community.

Three presence/absence matrices (1=present, 0=absent) were produced: 1) amphibian species present or absent at all wetlands, 2) anuran species present or absent at all wetlands and 3) caudate species present or absent at all wetlands. Species included were all native species in Nova Scotia (listed in *Study Area*, above). Columns represented species, rows represented wetlands. Matrices were loaded into a Nestedness Calculator (Atmar and Patterson, 1995) to determine the degree of nestedness in the dataset. Those matrices were maximally packed and then compared to random models generated by 3000 Monte Carlo simulations to achieve a p value. Models were run for the total amphibian community, anurans only and caudates only.

Classification and Regression Trees (CART)

All statistical analyses were conducted using SYSTAT 10 (SPSS, 2000). Classification trees were conducted using SYSTAT 10's TREE program. Classification and regression tree (CART) models (Breiman et al., 1984; Moore et al., 1991) represent a

relatively new and under-used statistical method to compare differences between groups. Classification and regression trees can offer descriptive models that more effectively describe complex data than other methods like linear regression and analysis of variance (De'ath & Fabricius, 2000). CART was chosen because it is a method that a) elegantly determines which factors are most important when comparing sites with and without the presence of a particular species and b) produces visual models that can be adapted to be understood and interpreted by laypeople and politicians.

CART recursively subdivides the data set into a tree-like structure that represents the factors that most often separate the two pre-defined groups (in this case the two groups are: a) conditions when amphibian species is present and b) conditions when absent) (McCune & Grace, 2002). I conducted a Classification (as opposed to a Regression) Tree because the dependant variable (species presence) is categorical. CART works well when comparing a range of habitat conditions for a species; as all variables are compared simultaneously in a statistical sense (McCune & Grace, 2002). The model first identifies the average or most typical case (McCune & Grace, 2002), and then iteratively revisits the cases that emerge as exceptions to the rule (McCune & Grace, 2002). The result is a hierarchical tree model where alternate habitats are different branches of the tree (McCune & Grace, 2002). The PRE (Percent Reduction in Error) is the goodness of fit statistic that represents the amount of variation in presence and absence of the species explained by the model. It represents the expression of a loss function. We used least-squared loss (AID) which minimizes the sum of squared

deviations. The higher the PRE the better fit of the model. PRE is rarely1.0 (see the condition below where PRE could = 1.0).

Branches were stopped or "pruned" for optimal representation of conditions. Pruning can be achieved by adjusting the: a) maximum number of splits, b) minimum proportion reduction in error for the tree allowed at any split, c) minimum split value allowed at any node, and d) the minimum count (objects) allowed at any node (branch). In our models the a) maximum number of splits was set to 100 (allowing up to one split for every wetland), b) minimum proportion reduction in error for the tree allowed at any split was set to 0.05, and c) minimum split value allowed at any node was set to 0.05. There is a relationship between pruning and PRE. In order to achieve a PRE of 1, maximum splits would have to be set to the maximum number of observations, minimum PRE and minimum split value would be set to 0, and minimum count would be set to 0. However, this model would be overly complicated and difficult to interpret in a biological context. Increasing the minimum count yields progressively more simplified models, however they represent fewer of the cases that represent presence (a lower PRE), and we risk missing important variables for presence. A balance must be struck between sufficiently high PRE and sufficiently simplified model. In our case, we chose adjusting the minimum count for pruning, however, the ideal minimum count (to preserve PRE and reduce complexity) was determined to be 5 for all models.

Steps of CART analysis

All variables were included in the data set untransformed, except pH which was log transformed to Normality. SYSTAT Classification trees were run for all species.

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However, a model was not included if PRE was < 0.35 or if the species was locally rare (occurred at 5% or less of the sites). Models not included were those for bullfrogs (4% incidence), mink frogs (3% incidence), four-toed salamanders (5% incidence), and blue spotted salamanders (5% incidence). Information on the presence or absence of these species was still retained in the data set in case other species were associated with their presence (see Figure 6 for incidence of all species).

The CART model raw print outs, although intuitive to those familiar with them, are not easily interpreted by non-scientists. I adapted the printouts for ease of interpretability with the following steps:

Step 1: Figure 7 displays a computer printout of a Classification Tree analysis. The "condition" (i.e. Area < 43.1 m^2) placement on the map is key to interpreting the model. Conditions displayed on a left "branch" of the tree represent a "greater than" positive relationship between the dependant variable and the splitting variable (i.e. green frogs are most often found when area is greater than 43 m^2). Note this is the reverse of what you would expect! Conditions displayed on a right "branch" represent a "less than" positive relationship between the dependant variable and the splitting variable (i.e. green frogs are most often found when the size of the nearest clearing is less than 391,192 m^2). The most important variables are found at the top of the tree, least important at the bottom of the tree. This is reaffirmed in the accompanying table, where the variables are ordered from the first to the last split, and each variable is associated with an Improvement to the PRE of the model. Thus the "Improvement" value is the partial r^2 of each variable. Displayed within the boxes or "leaves" of the tree is more information about the dataset. *N*

represents the number of wetlands in the study area for which the condition is true (i.e. Wetland Area < 43.100 and seen on left side, left side $N = 35$, right side $N = 64$. 35 of the wetlands in the study area are smaller than 43 m^2, 64 of the wetlands are larger than 43 m^2). This simply displays the *sample size* of the wetlands with said condition, *not* the number of wetlands with said condition **and** presence of the species. Impurity is again an indicator of the sample of wetlands with said condition, and represents an estimate of within-group heterogeneity (McCune & Grace, 2002).

Step 2: I re-display the model in a simplified manner in the final version (Figure 8), removing the information within the "leaves" and adding more descriptive conditions. It is important to note I "flipped" the tree in order to reduce the use of double negatives (eg. instead of Area < 43, I used Area > 43). Although N and impurity values are important for analysing the statistical validity of the model, they are difficult to interpret by a layperson. Because a variable that contributes < 0.1 partial r^2 matters very little to the model (and thus, theoretically, the species), they are italicized, and not discussed in the conclusions below. I still retained them in the model, as they are interesting observations that may be of value to a study with a larger overall sample size. I then adapted the printout table to be displayed as a summary in Table 3, again italicizing observations that added little value to the model. All trees included in the Figures below have been developed with the aforementioned procedure.

RESULTS

Nestedness analysis results

All three nestedness analyses (total amphibian community, anurans only and caudates only) were statistically significantly nested (Appendix 1). Both the total amphibian community ($T = 14.6$, where $T = \%$ disorder) and the anurans only ($T = 16.82$) community had p values < 0.0001. The salamander community ($T = 17.73$) had a significant p value < 0.001.

Total amphibian community

The Classification tree for the total amphibian community yields a relatively weak PRE of 0.362 (Table 4, Figure 9). Only one of the four variables had a partial $r^2 > 0.1$ - a positive association (partial $r^2 = 0.140$) between species richness and wetlands larger than 43 m^2. However, a negative association with conductivity > 52.23 µS/cm had a partial r^2 of 0.097 and is discussed in the conclusions below. Variables with partial $r^2 < 0.1$ were: pH > 6.58 and size of nearest wooded area $< 8,023,000$ m^2.

Green frogs

The Classification tree for the very common (73% incidence) green frogs yielded a PRE of 0.548 (Table 3, Figure 8). Two of the five variables in the model had partial $r^2 > 0.1$. The most important variable for green frogs was a positive association with area of the wetland (> 43 m^2, partial $r^2 = 0.222$). They were also positively associated with wetlands with more than 4 species (partial $r^2 = 0.111$). Variables with partial $r^2 < 0.1$ were: size of nearest clearing $< 392,192$ m^2, wood frogs absent.

Spring peepers

Only one of the five variables in the spring peeper model (72% incidence, PRE of 0.600 (Table 5, Figure 10) had a partial $r^2 > 0.1$. This was a positive association with wetlands with more than 3 species (partial $r^2 = 0.333$). Variables with partial $r^2 < 0.1$ were: size of nearest clearing $< 129,888$ m^2, > 2 other amphibian species present, wetland area > 36 m^2 and size of nearest wooded area $> 307, 819$ m^2.

Wood frogs

The Classification tree for wood frogs (present at 59% of sites) yielded a PRE of 0.504 (Table 6, Figure 11). All three variables in the model had partial r^2 values > 0.1. Yet again, most important variable for wood frogs was wetlands with more than 3 species (partial $r^2 = 0.260$). Also important was the absence of newts in the species-rich wetlands (partial $r^2 = 0.130$). When present in less species rich wetlands, wood frogs were most often found when average conductivity did not exceed 103 µS/cm (partial $r^2 = 0.114$).

Spotted salamanders

Two of the five variables in the spotted salamander model (present at 46% of sites PRE of 0.600 (Table 7, Figure 12) had partial $r^2 > 0.1$. The most important variable for spotted salamanders was a positive association with species richness (> 4 species, partial $r^2 = 0.244$). However, when found in wetlands with less than 4 species, they were found most often in wetlands where green frogs were absent (partial $r^2 = 0.139$). Variables with partial $r^2 < 0.1$ were: conductivity < 326 µS/cm, nearest road < 4 m from wetland, and nearest clearing > 119m away.

American toads

Only one of the four variables in the American toad model (20% incidence, PRE 0.361 (Table 8, Figure 13) had a partial $r^2 > 0.1$. That was a negative association with the size of the nearest clearing (> 896 m^2, partial $r^2 = 0.124$). Variables with partial $r^2 < 0.1$ were: pH > 5.91, area of nearest wooded area $> 1,291,305$ m^2, and conductivity > 769 μS/cm.

Pickerel frogs

Although uncommon (17% of sites), the Classification tree for pickerel frogs was the strongest, with a PRE of 0.627 (Table 9, Figure 14). All variables in the model had partial $r^2 > 0.1$. Pickerel frogs were positively associated with species richness (> 5 species, partial $r^2 = 0.491$). They were negatively associated with wetlands where the nearest clearing type was pasture (partial $r^2 = 0.136$).

Leopard frogs

Although very uncommon (present at 8% of the sites), the Classification tree for leopard frogs yielded a PRE of 0.428 (Table 10, Figure 15). All three variables in the model had partial r^2 values > 0.1. The most important variable for leopard frogs was wetlands that were further than 5.8 m from the nearest wooded area (partial $r^2 = 0.164$). Also important was isolation of at least 70.8 m from the nearest wetland (partial $r^2 = 0.132$) and species richness of > 4 (partial $r^2 = 0.132$).

Eastern red-spotted newts

Also an uncommon (7% incidence) species, the only two variables in the newt model (PRE of 0.366 (Table 11, Figure 16)) both had partial $r^2 > 0.1$. The most important

variable was a distance of > 4.9 m from the nearest wooded area (partial $r^2 = 0.189$). Also important was the length of hydroperiod, with newts most often occurring when the wetland was permanent (partial $r^2 = 0.176$).

DISCUSSION

Green frog Classification Tree: An example

Green frogs are a common, well studied species in North America. The results for the green frog classification tree were consistent with the results of other studies (Hecnar & M'Closkey, 1997d; Woodford & Meyer, 2003). The two most important variables for green frogs were wetland size (partial $r^2 = 0.222$) and species richness (partial $r^2 = 0.111$). Green frogs were most often found when wetland area was greater than 43 m^2. This is likely a function of green frogs most often occurring in semi-permanent and permanent ponds (Hecnar & M'Closkey, 1997d; Woodford & Meyer, 2003; Porej et al., 2004b) and less often in smaller wetlands with shorter hydroperiods (Herrmann, et al. 2005). Green frogs are also known to coexist with fish, and are thus more likely to occur in large wetlands capable of supporting fish (Hecnar & M'Closkey, 1997d). When green frogs occurred in small wetlands they also followed the pattern of positive association with more species rich wetlands (partial $r^2 = 0.111$) discussed below. Even the "less significant" factors (italicized in Figure 8) of negative associations with large clearings and wood frogs, have been described before. Green frogs are more often found in areas with less disruption of upland habitat (Woodford & Meyer, 2003; Eigenbrod, et al., 2008), and thus would be less likely to occur near large clearings. Wood frogs are more often associated with shorter hydroperiods (Herrmann et al., 2005), rather than the longer

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hydroperiods associated with green frogs; so this likely explains the negative association between the two species. As the CART model confirms what we already know about this common species, we believe this "validates" the model, and allows us to better accept the findings for rarer species.

Most important variables

Wetland area emerges as a positive indicator in both the green frog (see above) and the total amphibian community models. Average conductivity is a negative indicator of both the total amphibian community and the wood frog. Only two other variables were important to more than one model. Those variables were: species richness, and distance to forest.

Wetland area

Wetland area has been described in other studies as a positive indicator of both green frog (see above) and overall species richness (Findlay & Houlahan, 1997). This is in keeping with the species-area relationship - whereby the number of species encountered increase as the area of the region increases (including a constant or two depending on the version of the model used) (Brown et al., 1998). However, small, isolated wetlands have been described as critical habitat for amphibians in other parts of North America (Semlitsch & Bodie, 1998; Hecnar et al., 2002) and a relationship between wetland size and species richness is not always found (Snodgrass et al., 2000). It is important to note that green frogs occurred at 73% of sites, and the presence of green frogs in larger wetlands could be driving the total amphibian community relationship with wetland area. No other species exhibited the same positive association with wetland

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size in the individual models. This "masking" of species specific responses when studying the total amphibian community has been seen before (Knutson et al., 1999).

Average conductivity

Wetlands with higher conductivity were less likely to have as many amphibian species as those with lower conductivity, and in particular they were less likely to have wood frogs present. Due to the strong correlation between chloride and conductivity in the dataset, it is likely chloride contamination is the cause of elevated conductivity in these wetlands (caused both by natural impacts from saltwater intrusion and sea spray, and anthropogenic impacts from road de-icing salts). Numerous studies have found wood frogs to be sensitive to chloride (Sanzo & Hecnar, 2006; Eigenbrod et al., 2008; Karraker et al., 2008; Collins & Russell, 2009). Other studies have also found amphibian species richness negatively associated with chloride and/or conductivity (Hecnar & M'Closkey, 1996; Hecnar & M'Closkey, 1997a), but this may again be an example of common species preferences driving the model and "masking" the responses of less common species.

Species richness

A positive association between amphibian presence and species richness appears frequently in the models (pickerel frog, spotted salamander, spring peeper, green frog, wood frog, newt), and is likely a reflection of some variable that is an important habitat requirement for amphibians not measured in this study. This species-richness effect has been seen elsewhere (Francesco Ficetola & De Bernardi, 2004), where it was also considered to be some indication of unmeasured habitat quality.

Distance to forest

Two species (leopard frog and eastern newt) had positive associations with distance from wetland to forest. Both species are often described as vagile species (Hecnar & M'Closkey, 1997c; Carr & Fahrig, 2001; Patrick et al., 2006). Leopard frogs are a species associated with grasslands (Knutson et al., 1999) and may be less sensitive to forest disturbance (Kolozvary & Swihart, 1999) than other, more woodland associated species. Although newts require wooded areas for their red eft phase and terrestrial hibernation, they are a vagile species capable of travelling long distances (Gill, 1978). As newts are extremely philopatric to their natal pools (Gill, 1978), it is possible wood clearing around wetlands took place after the population was established.

Spring peepers

With a CART PRE of 0.600 and present in 72% of the wetlands, confidence in our findings for spring peepers is fairly high. However, the only predictor variable contributing more than 0.1 partial r^2 is species richness (partial $r^2 = 0.333$). Again, we are uncertain as to the meaning of this relationship.

Wood frogs

The wood frog model also has a moderately high PRE of 0.504 and species incidence of 59%. Other than the species richness and conductivity associations described above, wood frogs were also negatively associated with newt presence (partial $r^2 = 0.130$). Negative associations between wood frogs and newt presence have been described (Cortwright and Nelson, 1990), likely due to predation on wood frog eggs and larvae by newts.

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Spotted salamanders

The model for the relatively common (46% incidence) spotted salamanders was strong, with a PRE of 0.601. Again, we see a positive association with species richness (partial r^2 = 0.244) as the most important predictor variable. When present in wetlands with fewer species, spotted salamanders are most often found in wetlands where green frogs are absent (partial r^2 = 0.139). The negative association with green frogs could be again related to differing niches of the two species (spotted salamanders often occur in smaller wetlands with shorter hydroperiods and no fish present, while green frogs are often found in larger wetlands and can tolerate fish presence (Porej et al., 2004b).

American toads

American toads were most often found when the nearest clearing was less than 900 m^2 in size (partial r^2 = 0.124). In general, amphibian species richness is often positively correlated with forest cover (Findlay & Houlahan, 1997; Hecnar & M'Closkey, 1998; Herrmann et al., 2005). As one of Nova Scotia's most terrestrial amphibian species, it seems appropriate that American toads would be more sensitive to perturbations in their terrestrial, versus aquatic habitat. A related UK species, the common toad (*Bufo bufo*), is more common in areas with a large percentage of forest cover (Scribner et al., 2001). However, American toads have been described as generalist species tolerant of clear cuts (Gilhen, 1984) and during one year (but not both years) of a study in Ontario, American toads were found to be *negatively* associated with forest cover (Eigenbrod et al., 2008). Another bufonid, the southern toad (*Bufo terrestris*) seems to be present in clear cuts, but survivorship of juveniles may be low (Todd & Rothermel,

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2006). Any findings based on this model must be interpreted with caution, as the PRE is only 0.361 and toads were relatively uncommon (20% of sites).

Pickerel frog

With a PRE of 0.627, the pickerel frog model is the strongest CART model in this analysis. This is particularly interesting given the incidence of the species; only 17%. Only two predictor variables emerged in this model, a positive association with species richness (partial $r^2 = 0.491$) and a negative association with pasture (partial $r^2 = 0.136$). The negative association with pasture could be related to pasture representing a particular barrier to this species, or it could represent sensitivity to something related to pasture, such as manure or physical disturbance by grazing livestock. In a recent global meta-analysis, more amphibian species were found in plantations than pastureland (Felton et al., 2010).

Leopard frogs

With a PRE of 0.427 and an incidence of only 8%, our conclusions about leopard frogs are relatively weak compared to most of the models in this analysis. Other than the association with distance to forest described above, leopard frogs, when found near wooded areas, tend to be present in wetlands isolated from the nearest wetland by greater than 70 m (partial $r^2 = 0.132$). This "isolation effect" could be a function of the vagility of the species (Hecnar & M'Closkey, 1997c; Carr & Fahrig, 2001).

Eastern red-spotted newts

With a relatively weak PRE of 0.366 and a species incidence of only 7% - the conclusions we draw from the newt model must be interpreted with caution. In addition

to the positive association with distance to forest and species richness; newts were positively associated with longer hydroperiods in wetlands. This makes sense as newts are known to coexist with fish, and are thus more likely to occur in large wetlands capable of supporting fish (Porej et al., 2004b), and are often found in permanent wetlands (Herrmann et al., 2005).

CONCLUSIONS

CART as a method for volunteer collected data

By employing the method described above, it is apparent CART trees can provide an easy-to-understand visual tool that describes relationships between species presence and habitat variables. Many of the associations between amphibian species and habitat variables that emerged in the models have been previously described in the literature, and all are plausible based on the life history of the species explored. We believe CART is a model that appropriately describes the relationships between amphibian species and their environment and thus can be used to provide management recommendations for the protection of amphibian habitat. CART is a method that works well with large amounts of data collected by professional scientists (Brazner et al., 2007), but in this age of reduced budgets for monitoring efforts (Conrad & Hilchey, 2011), data sets that span many years and large geographical areas are difficult to find.

A logical next step is to recruit trained citizen scientist volunteers to collect data. This does not come without its challenges, concerns include issues of data use, collection and organization of volunteers (Conrad & Hilchey, 2011). A professional scientist can utilize CART to analyze data collected by volunteers easily, quickly and efficiently. By

utilizing the method above, the classification trees can be easy to interpret by both the volunteers who collected the data and policy makers, minimizing the challenge of data use. The additional challenges of data collection and organization of volunteers are discussed in more detail in Chapter 2.

Specific recommendations for amphibian habitat management

It is important to consider species specific responses to habitat variables, as looking at the total community may mask important variables for less common species. When concerned about a particular species, it is critical to manage habitat based on their specific requirements. However, the high degree of nestedness in this study implies that at least some habitat for rare species will be protected by protecting habitat most important to the total amphibian community. We make the following recommendations to policy makers:

1. Where possible, protect a diversity of wetlands with long and short hydroperiods, of various sizes, and within and outside of forests.

2. When concerned about a particular species, management decisions should be informed by the requirements of that particular species, not the total amphibian community. Please note the following important species-specific observations:

- Wood frogs were negatively associated with newt presence.

- Spotted salamanders were negatively associated with green frog presence.

- American toads were particularly sensitive to clearings.

- Pickerel frogs were particularly sensitive to pasturelands.

- Newts were positively associated with long hydroperiods.

3. In general, protect wetlands and surrounding upland area where species richness is already high.

4. When occupancy is unknown, protect wetlands larger than 43 m^2, with conductivity lower than 52 µS/cm, circum-neutral pH and near or within large wooded areas.

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    abundance. *Biological Conservation,* 110(2), 277-284.

TABLES

Table 1. List of all variables measured (+/- = presence or absence)

Species identified	Environmental variables	Geographic variables
species richness (# of species)	wetland area (m^2)	nearest road (m)
four-toed salamander (+/-)	size of clearing (m^2)	nearest wetland (m)
green frog (+/-)	wetland type	nearest area of undisturbed forest (m)
bull frog (+/-)	clearing type	nearest clearing (m)
wood frog (+/-)	hydroperiod	climatic zone
American toad (+/-)	log pH	geologic zone
spring peeper (+/-)	average conductivity(μS/cm)	watershed
leopard frog (+/-)		
spotted salamander (+/-)		
blue spotted salamander (+/-)		
eastern red spotted newt (+/-)		
mink frog (+/-)		

Table 2. Pearson Correlation Matrix for chloride and conductivity

	Chloride	Conductivity
Chloride	1.000	
Conductivity	0.971	1.000

Table 3. Table of classification tree results for green frogs. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Italicized variables below bold line indicate variables with partial $r^2 < 0.1$, variables above the bold line have partial $r^2 > 0.1$. Overall variance explained by model of 0.548.

Split	Predictor variable (partial r^2)	Threshold value
1	Wetland area (0.222)	43.1 m^2
2	Species richness (0.111)	4 species
3	*Wood frog presence (0.072)*	*1 (presence)*
4	*Species richness (0.075)*	*2 species*
5	*Size of nearest clearing (0.068)*	*392192 m^2*

Table 4. Table of classification tree results for the total amphibian community. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Italicized variables below bold line indicate variables with partial $r^2 < 0.1$, variables above the bold line have partial $r^2 > 0.1$.* Average conductivity included because $r^2 = 0.097$. Overall variance explained by model of 0.362.

Split	Predictor variable (partial r^2)	Threshold value
1	Wetland area (0.140)	43 m^2
2	Average conductivity (0.097)*	52.233 µS/cm
3	*Average log pH (0.053)*	*0.818= pH 6.58*
4	*Size of nearest wooded area (0.072)*	*8,023,000 m2*

Table 5. Table of classification tree results for spring peepers. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Italicized variables below bold line indicate variables with partial $r^2 < 0.1$, variables above the bold line have partial $r^2 > 0.1$. Overall variance explained by model of 0.600.

Split	Predictor variable(partial r^2)	Threshold value
1	Species richness (0.333)	3 species
2	*Size of nearest clearing (0.083)*	*129888 m^2*
3	*Species richness (0.076)*	*2 species*
4	*Size of nearest wooded area (0.053)*	*307819 m^2*
5	*Wetland area (0.053)*	*36 m^2*

Table 6. Table of classification tree results for wood frogs. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Overall variance explained by model of 0.504

Split	Predictor variable (partial r^2)	Threshold value
1	Species richness (0.260)	3 species
2	Average conductivity (0.114)	103.033 μS/cm
3	Newt presence (0.130)	1 (presence)

Table 7. Table of classification tree results for spotted salamanders. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Italicized variables below bold line indicate variables with partial r^2 < 0.1, variables above the bold line have partial r^2 > 0.1. Overall variance explained by model of 0.600.

Split	Predictor variable(partial r^2)	Threshold value
1	Species richness (0.244)	4 species
2	Green frog presence (0.139)	1 (presence)
3	*Distance to nearest road (0.076)*	*4 m*
4	*Distance to nearest clearing (0.072)*	*119 m*
5	*Average conductivity (0.069)*	*326.933 µS/cm*

Table 8. Table of classification tree results for American toads. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Italicized variables below bold line indicate variables with partial r^2 < 0.1, variables above the bold line have partial r^2 > 0.1. Overall variance explained by model of 0.361.

Split	Predictor variable (partial r^2)	Threshold value
1	Size of nearest clearing (0.124)	896 m^2
2	*Average log pH(0.093)*	*0.771= pH 5.91*
3	*Size of nearest wooded area (0.091)*	*1291305 m^2*
4	*Average conductivity (0.053)*	*769.67µS/cm*

Table 9. Table of classification tree results for pickerel frogs. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Overall variance explained by model of 0.627.

Split	Predictor variable (partial r^2)	Threshold value
1	Species richness (0.491)	5 species
2	Nearest clearing type: pasture (0.136)	1 (presence)

Table 10. Table of classification tree results for leopard frogs. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Overall variance explained by model of 0.428.

Split	Predictor variable (partial r^2)	Threshold value
1	Distance to nearest wooded area (0.164)	5.8 m
2	Distance to nearest wetland (0.132)	70.8 m
3	Species richness (0.132)	4 species

Table 11. Table of classification tree results for eastern red-spotted newts. Predictor variables ordered by entry position in tree and represent the most predictive variable at each node (branch) of the tree. Overall variance explained by model of 0.366.

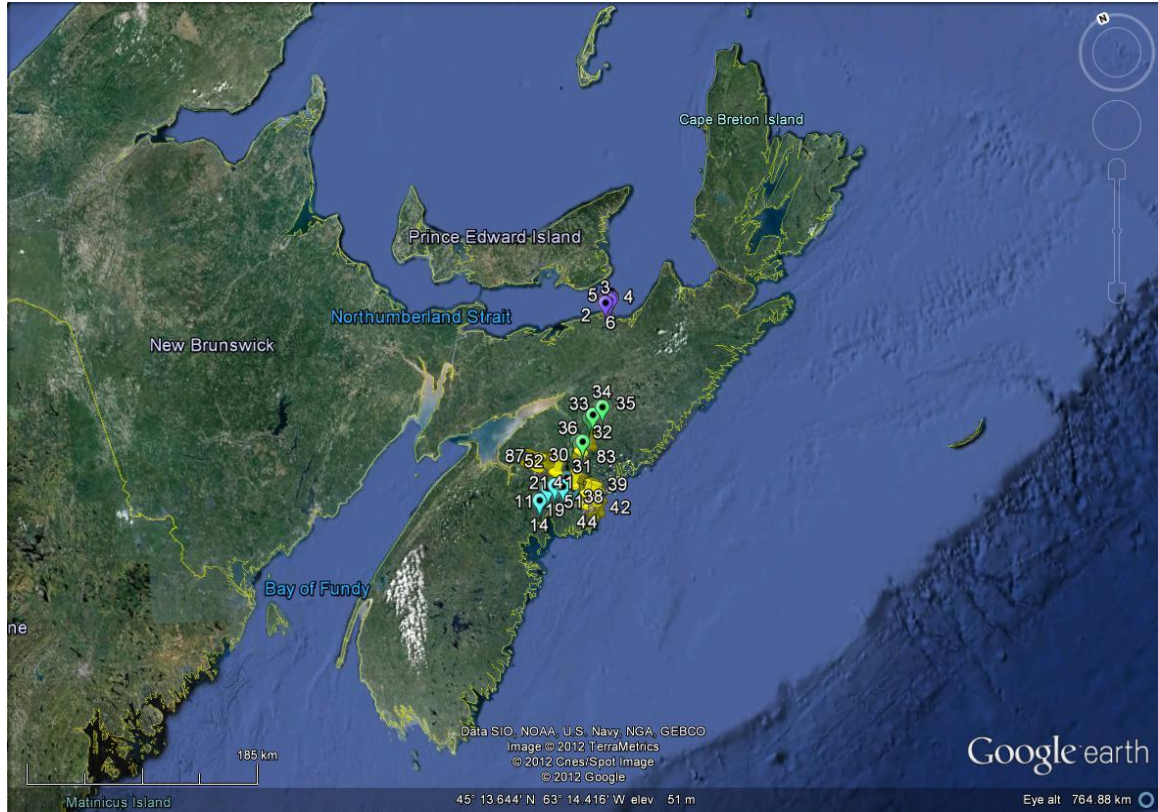| Split	Predictor variable (partial r^2)	Threshold value
1	Distance to nearest wooded area (0.189)	4.9 m
2	Hydroperiod (0.176)	3 (permanent)

FIGURES

Figure 1. Map of the study area and all wetland locations (*reproduced with permission from Google Earth*).
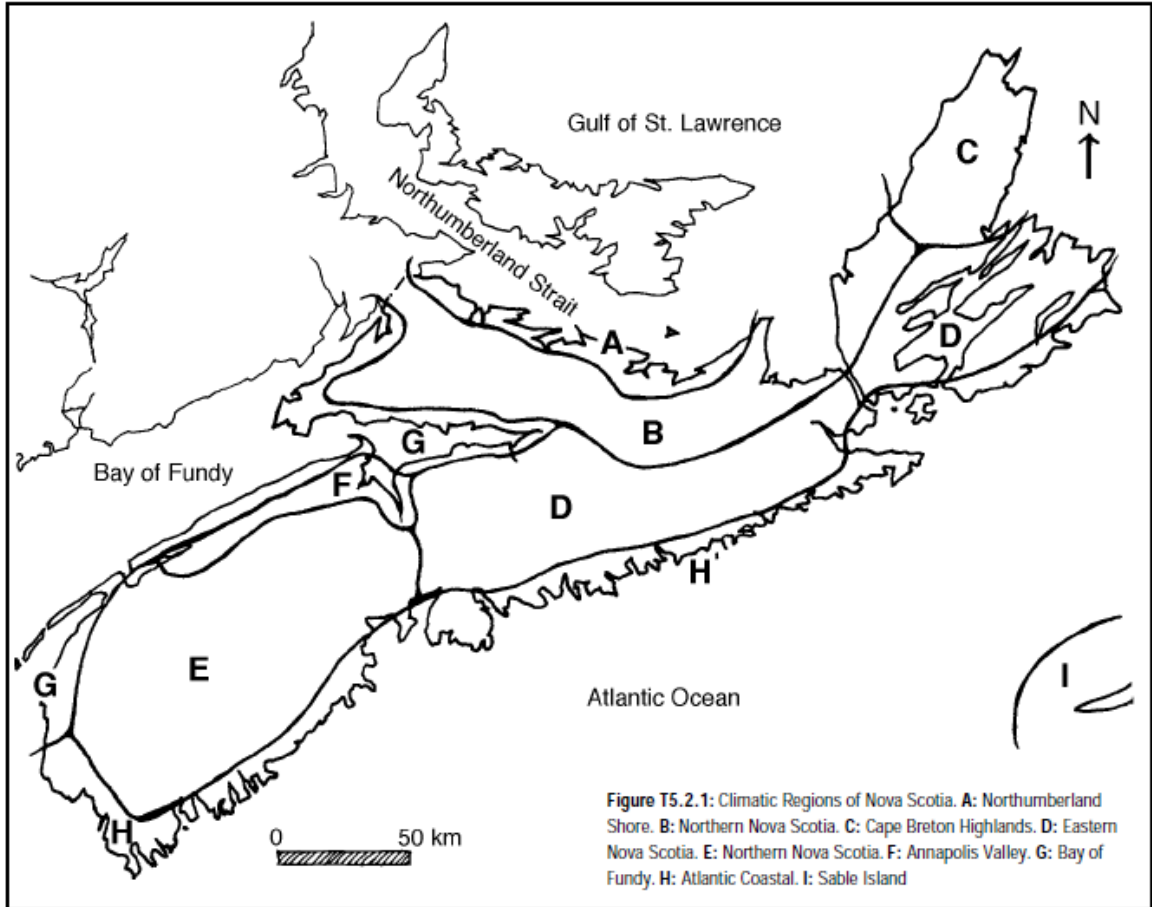
Figure 2. Climatic regions of Nova Scotia *(reproduced with permission from Nova Scotia Museum).*
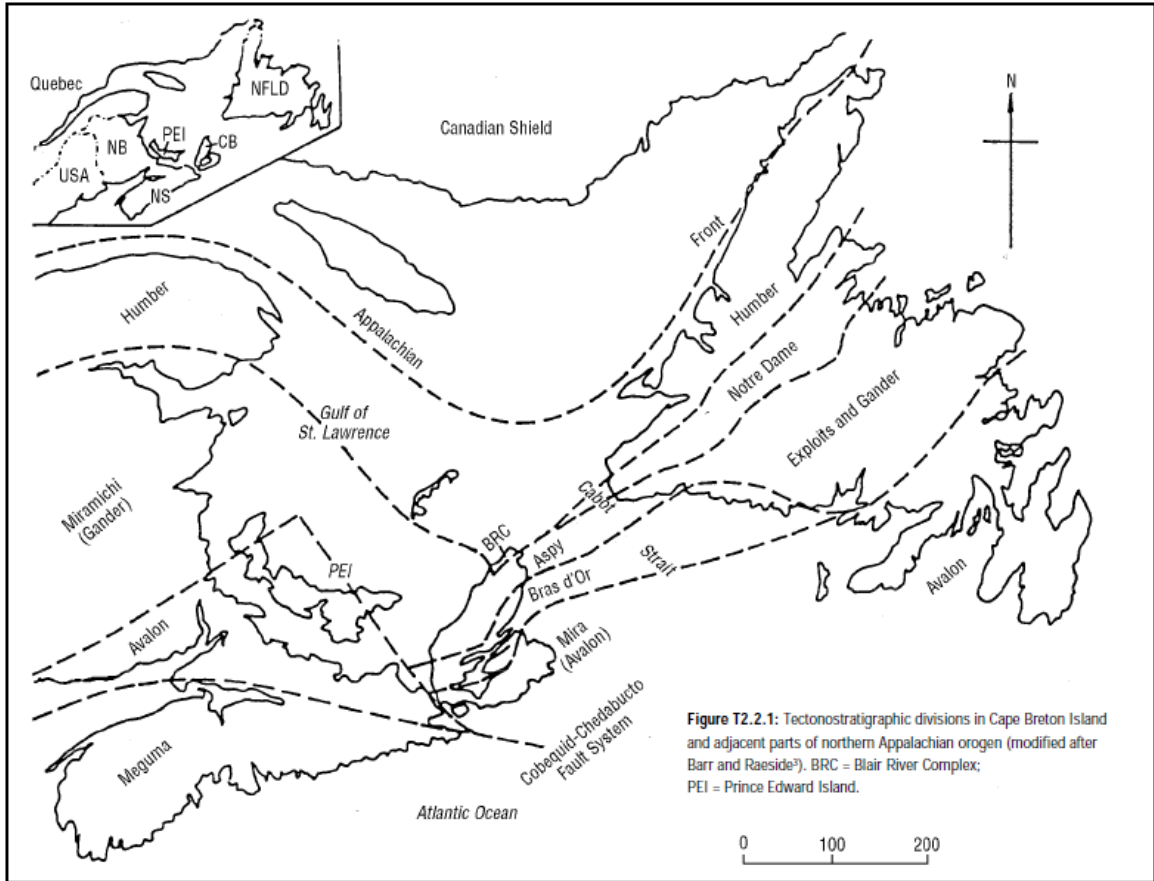
Figure T2.2.1: Tectonostratigraphic divisions in Cape Breton Island and adjacent parts of northern Appalachian orogen (modified after Barr and Raeside[3]). BRC = Blair River Complex; PEI = Prince Edward Island.

Figure 3. Tectonostratigraphic divisions in Cape Breton Island and adjacent parts of northern Appalachian orogen *(reproduced with permission from Nova Scotia Museum).*
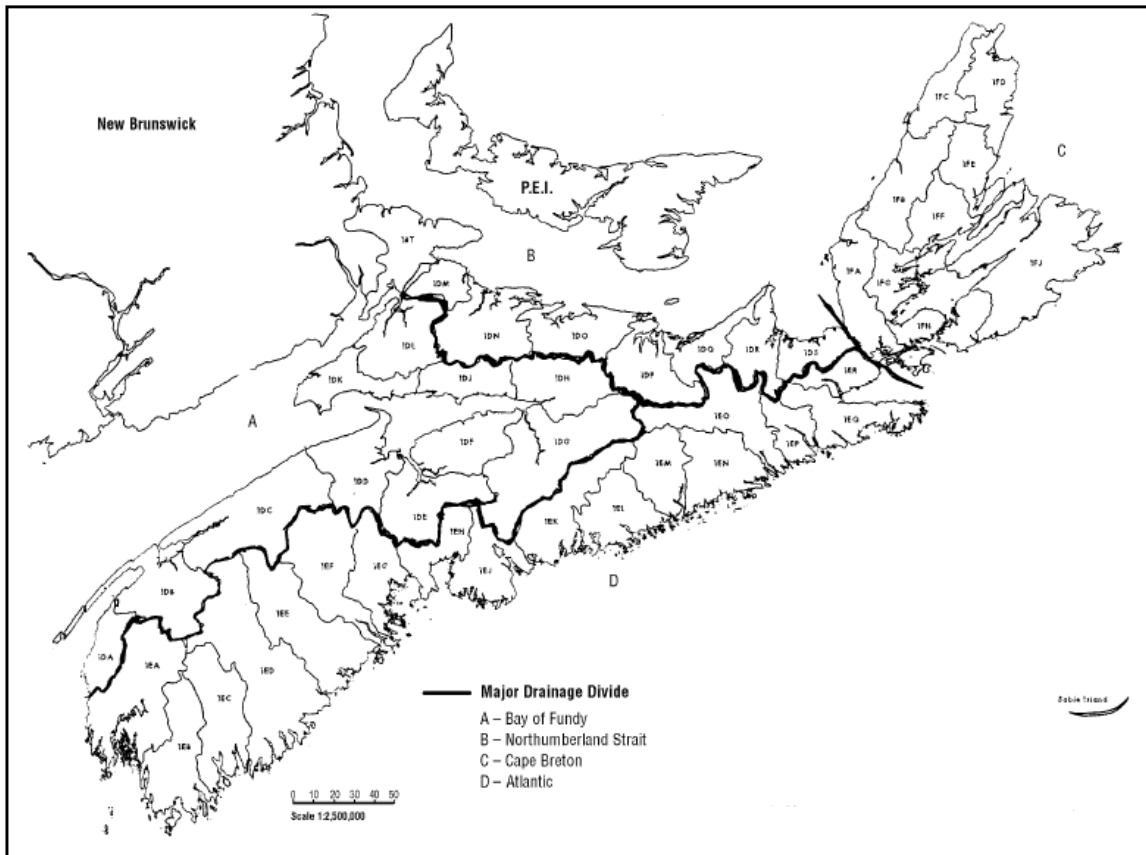
Figure 4. Primary watersheds of Nova Scotia *(reproduced with permission from Nova Scotia Museum).*

60
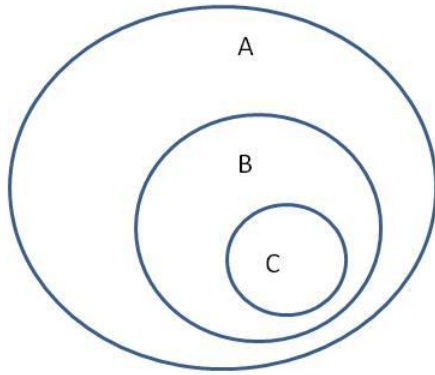
Figure 5. Nested vs. non-nested species assemblages. A, B and C represent species and circles represent size of habitat "island".
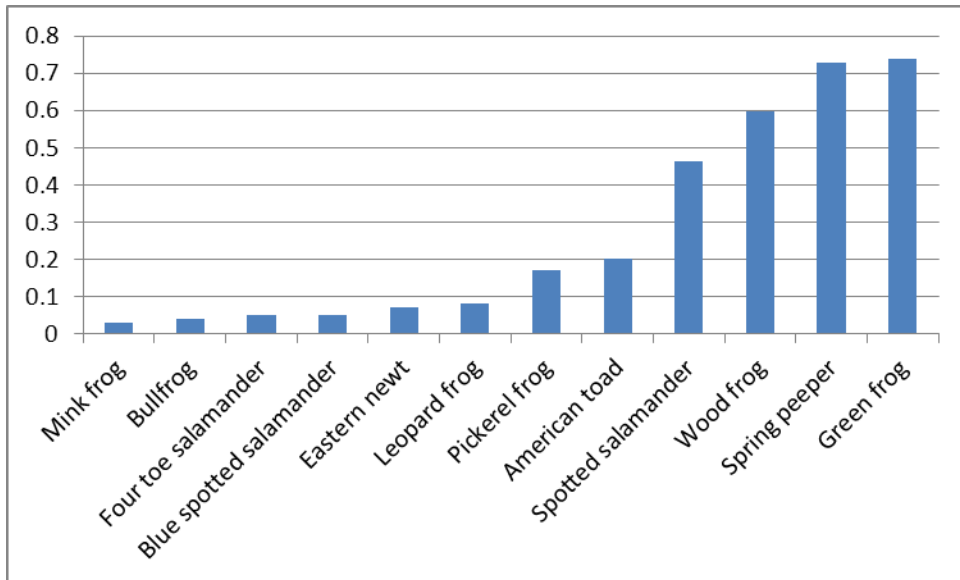
Figure 6. Overall incidence for each amphibian species in sampled wetlands (1.0 = 100% incidence in sampled wetlands).

GREENF

Split	Variable	PRE	Improvement
1	AREA	0.222	0.222
2	SPPRICH	0.333	0.111
3	WOODF	0.406	0.072
4	SPPRICH	0.480	0.075
5	SIZE_CLR	0.548	0.068

Fitting Method: Least Squares
Predicted variable: GREENF
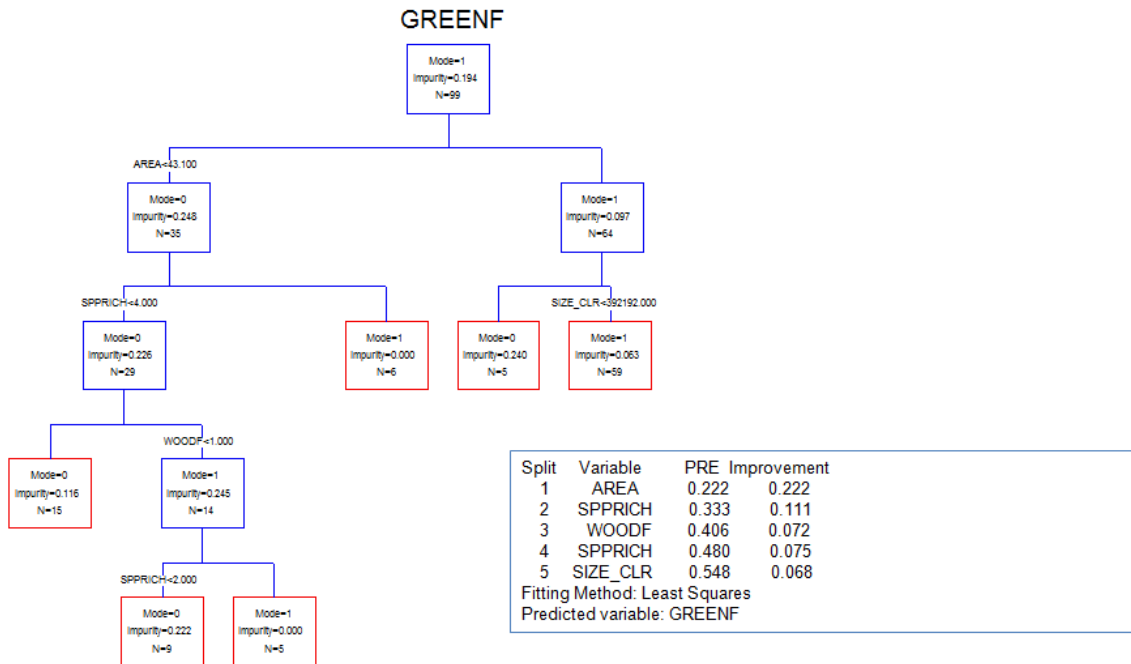
Figure 7. SYSTAT computer printout of Classification tree and table for green frogs.
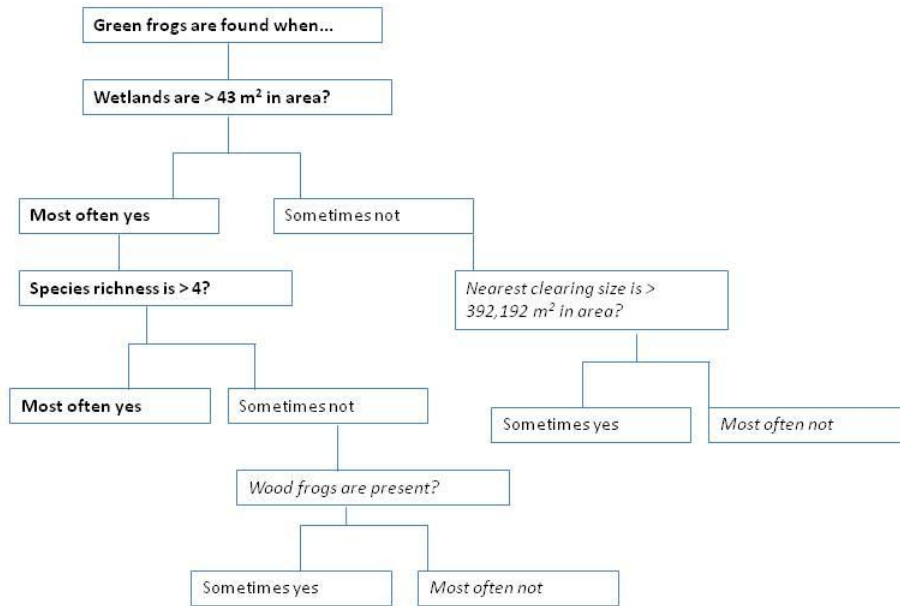
Figure 8. Classification tree for green frogs (Total PRE = 0.548). Italicized variables indicate variables with partial r^2 < 0.1.
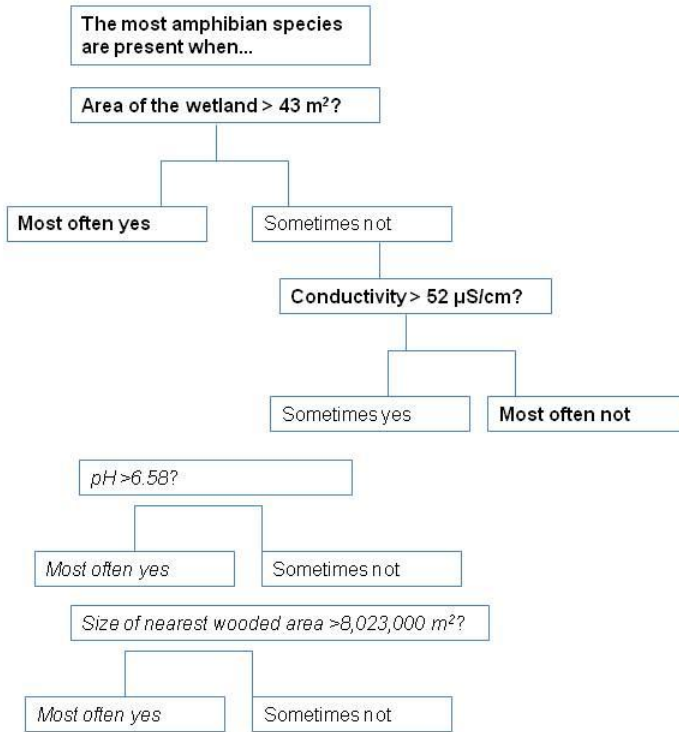
Figure 9. Classification tree for total amphibian community (Total PRE = 0.362). Italicized variables indicate variables with partial $r^2 < 0.1$.
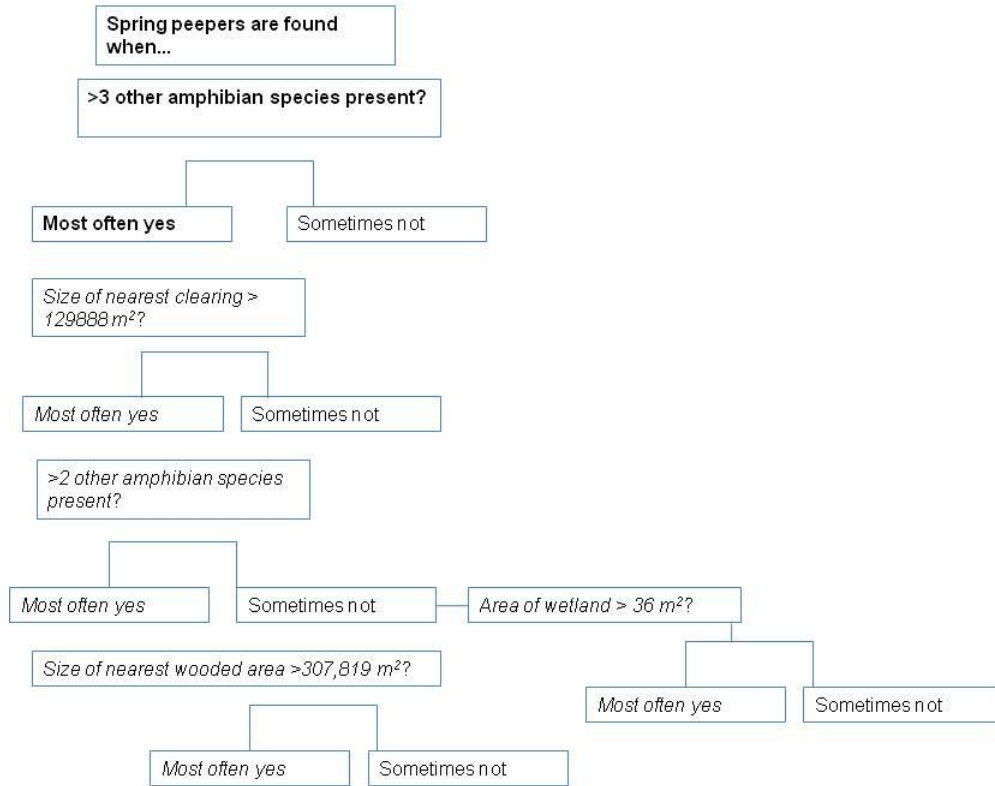
Figure 10. Classification tree for spring peepers (Total PRE = 0.600). Italicized variables indicate variables with partial $r^2 < 0.1$.
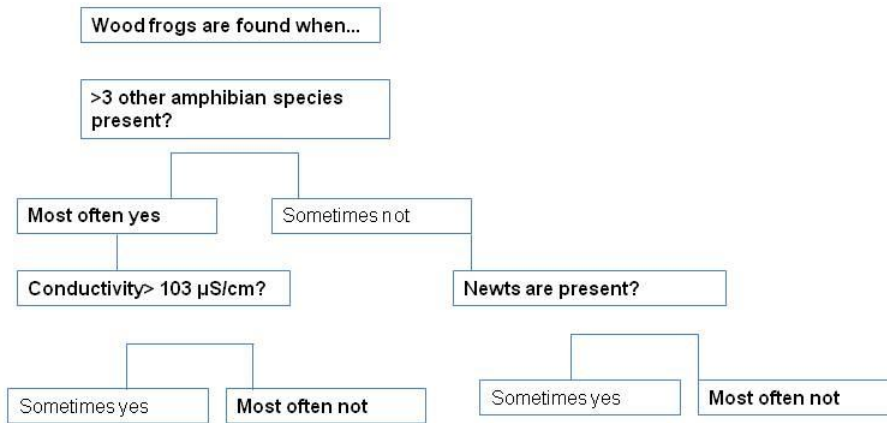
Figure 11. Classification tree for wood frogs (Total PRE = 0.504). Italicized variables indicate variables with partial $r^2 < 0.1$.

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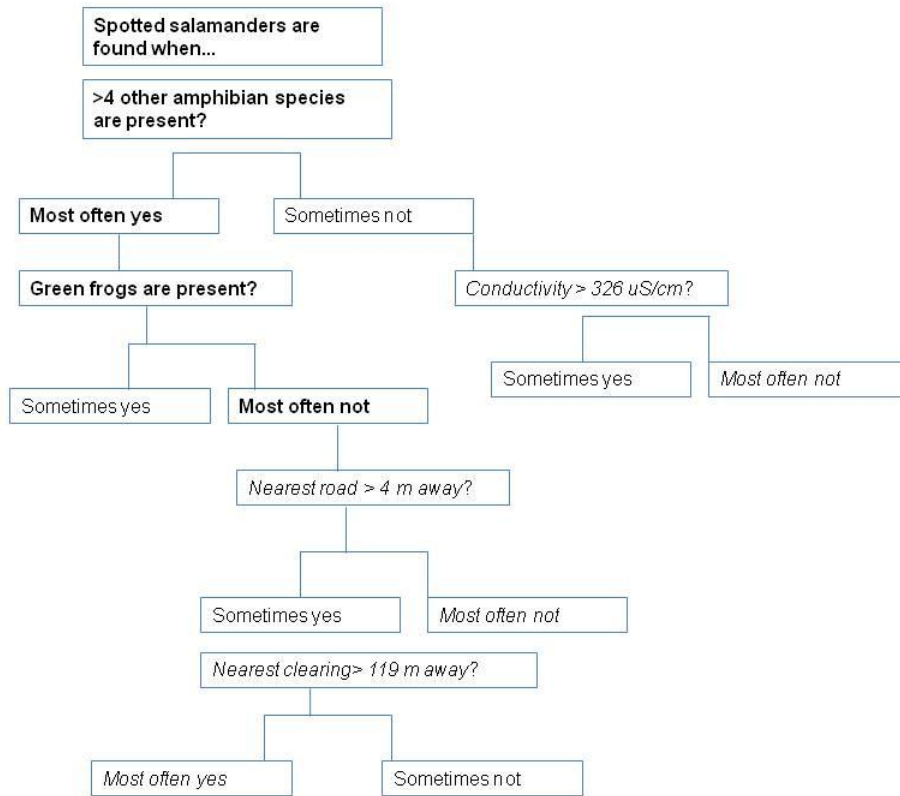
Figure 12. Classification tree for spotted salamanders (Total PRE = 0.600). Italicized

variables indicate variables with partial $r^2 < 0.1$.
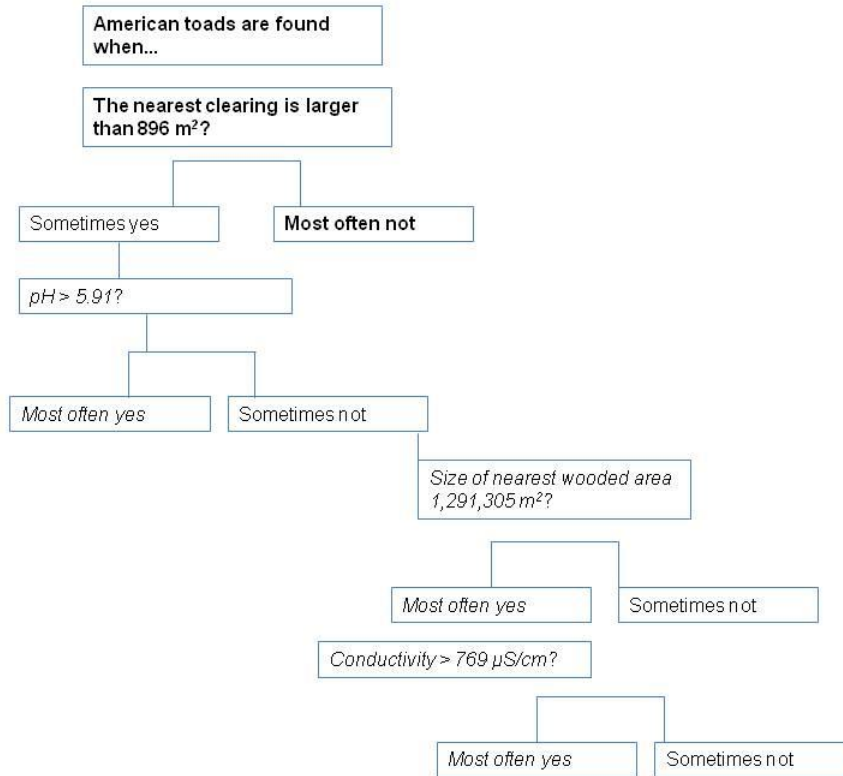
Figure 13. Classification tree for American toads (Total PRE=0.361). Italicized variables indicate variables with partial $r^2 < 0.1$.
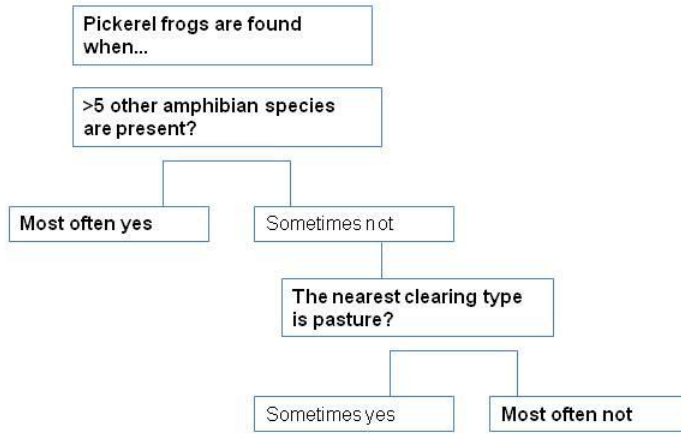
Figure 14. Classification tree for pickerel frogs (Total PRE=0.627). Italicized variables indicate variables with partial r^2 < 0.1.

70
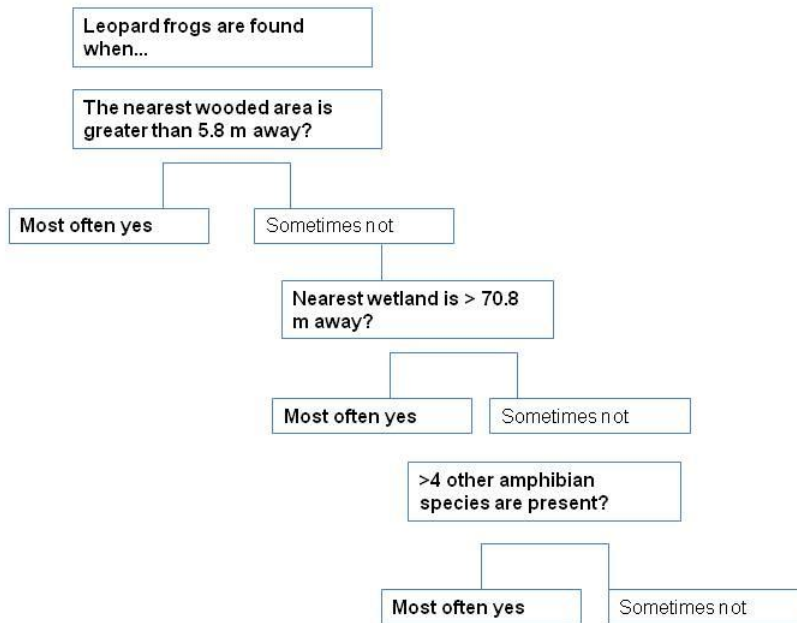
Figure 15. Classification tree for leopard frogs (Total PRE=0.428). Italicized variables indicate variables with partial $r^2 < 0.1$.

71
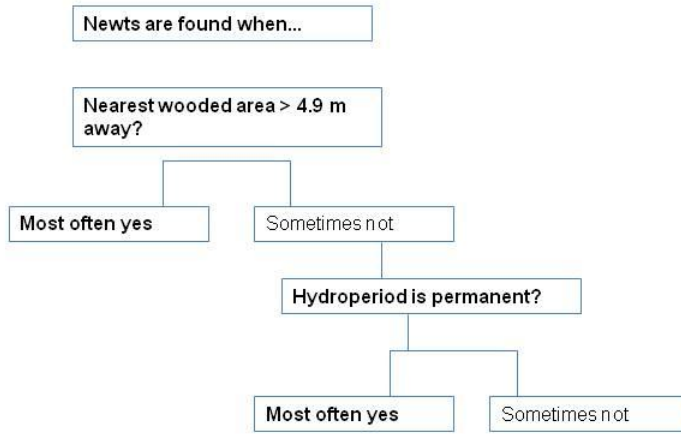
Figure 16. Classification tree for eastern red-spotted newts (Total PRE=0.366). Italicized variables indicate variables with partial $r^2 < 0.1$.

APPENDIX 1: Print outs for nestedness analysis
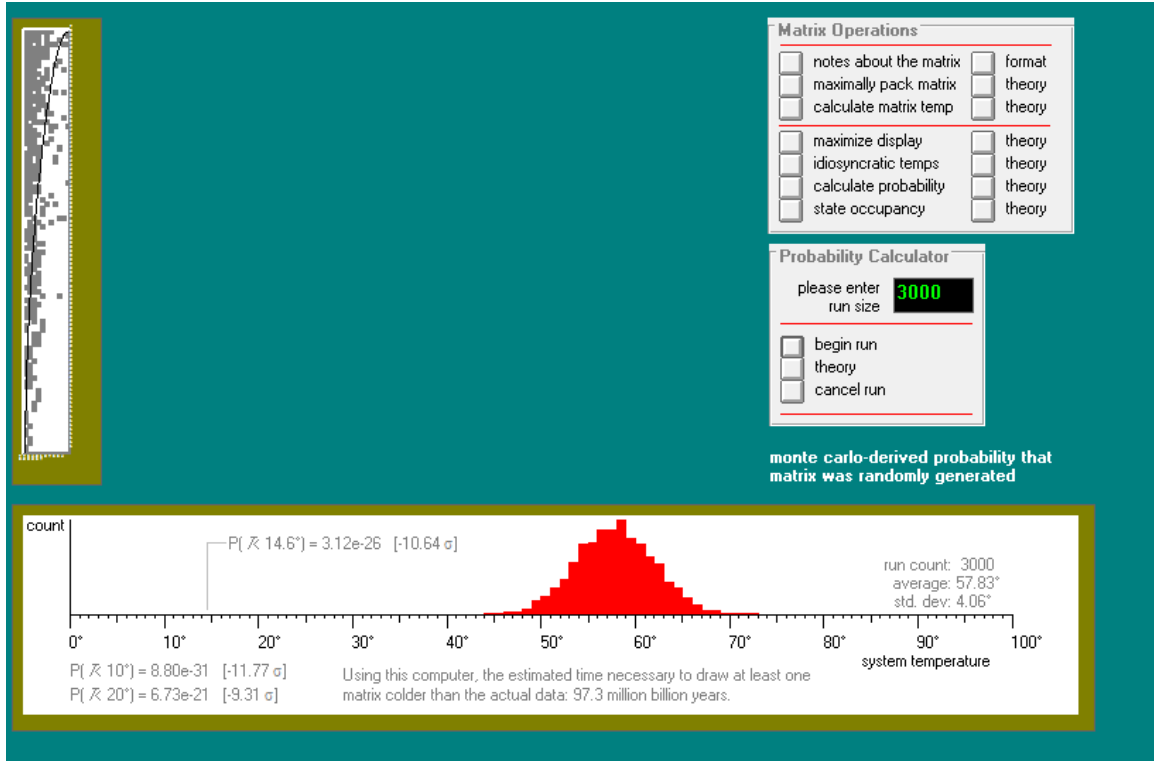
Nestedness of the total amphibian community (T = 14.6, p < 0.0001).
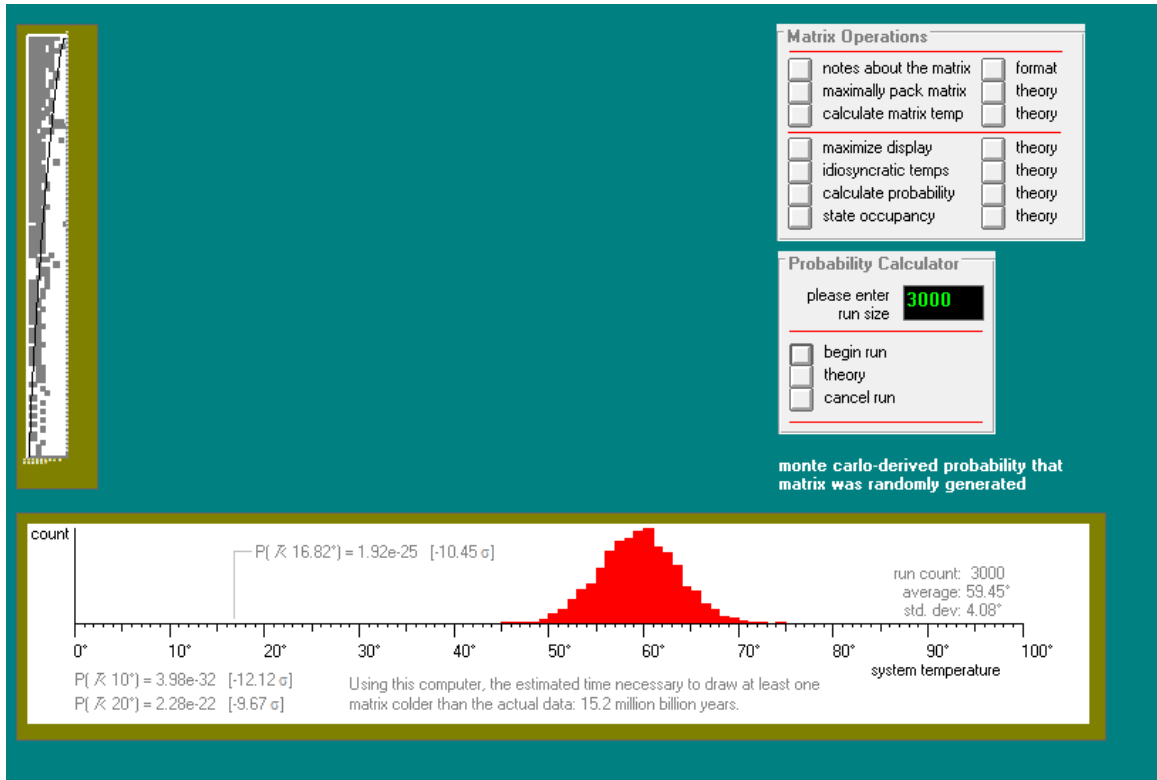
Nestedness of the anuran community only (T = 16.82, p < 0.0001).
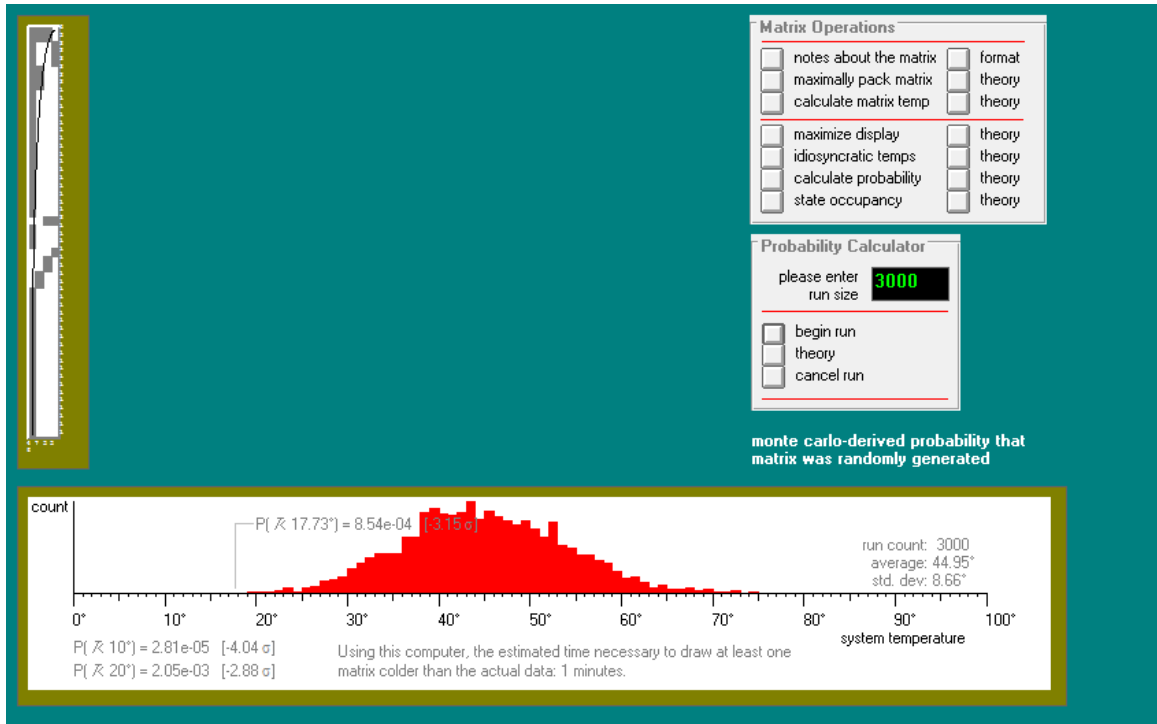
Nestedness of the caudate community only (T = 17.73, p < 0.001).

Chapter 2: A Review of citizen science and community-based environmental

monitoring: Issues and Opportunities

LIST OF TABLES

ABSTRACT

World-wide, decision-makers and non-government organizations (NGOs) are increasing their use of citizen volunteers to enhance their ability to monitor and manage natural resources, track species at risk and conserve protected areas. We reviewed the last ten years of relevant citizen science literature for areas of consensus, divergence and knowledge gaps. Different community-based monitoring (CBM) activities and governance structures were examined and contrasted. Literature was examined for evidence of common benefits, challenges and recommendations for successful citizen science. Two major gaps were identified: 1) a need to compare and contrast the success (and the situations that induce success) of CBM programmes which present sound evidence of citizen scientists influencing positive environmental changes in the local ecosystems they monitor and 2) more case studies showing use of CBM data by decision-makers or the barriers to linkages and how these might be overcome. If new research focuses on these gaps, and on the differences of opinions that exist, we will have a much better understanding of the social, economic and ecological benefits of citizen science.

Due to the increasing significance, utility and function of community-based

monitoring (CBM) initiatives, a review of status and trends is presented here. The need to

have a comprehensive understanding of ecosystem integrity, including function and

structure, is often confounded by a lack of, or inadequate and incomplete, data and

monitoring initiatives by professional scientists and government agencies. To fill the

void, non-professionals and citizen organizations have emerged the world over to track

trends, and to work towards effective and meaningful management planning,

management and stewardship. The following literature review examines consensus,

divergence and gaps in global citizen science literature. Many community-based

initiatives are not documented in the peer-reviewed literature and therefore reputable web

sites were examined in some cases. A comprehensive summary of types of monitoring,

ways CBM groups are governed, benefits provided by CBM, and challenges for CBM

groups is presented. As a result of this review, recommendations are suggested for

improving both the way CBM groups work and the way their data is collected and used.

Introduction to Citizen Science

Citizen science is the process whereby citizens are involved in science as

researchers (Kruger and Shannon 2000), and has also been referred to as *community*

science (Carr 2004). Citizen science can include community-based monitoring (CBM) "a

process where concerned citizens, government agencies, industry, academia, community

groups, and local institutions collaborate to monitor, track and respond to issues of

common community [environmental] concern" (Whitelaw et al. 2003) and/or community

based management, where citizens and stakeholders are included in the management of

natural resources and watersheds (Keough and Blahma 2006). This can also be referred to as voluntary biological monitoring (VBM; particularly in Britain) when the focus is on collecting data about species and habitats, although this is distinct from much of the CBM in North America which can also focus monitoring efforts on ecosystem functions and environmental quality. The focus of recent citizen science is not the traditional "scientists using citizens as data collectors", but rather, "citizens as scientists" (Lakshminarayanan 2007). For the purpose of this literature review CBM will refer to both aspects of citizen science: community-based monitoring and community-based management.

The nature of citizen science implies that in many cases, the work being undertaken is not documented in traditional journal articles, although there certainly are exceptions. In order to comprehensively review the state of citizen science, academic journal articles, as well as web sites and non-academic articles, were reviewed for examples of community-based monitoring. A wealth of CBM initiatives were discovered from around the globe. The Waterkeeper Alliance, for example, which includes so-called "Riverkeeper", "Lakekeeper", "Baykeeper" and "Coastkeeper" programs, and which works towards the goals of ecosystem and water quality protection and enhancement, has programs in fifteen nations. The majority of these are located in the United States, Australia, India, Canada and the Russian Federation. A review of the vast academic and non-academic based literature indicates that these nations are among those leading many community-based monitoring initiatives and that by all indications this movement of so-called citizen science is on the rise. This increase in monitoring activities by CBM groups

is documented in Canada (Savan et al. 2003; Whitelaw et al. 2003; Conrad and Daoust 2008), the US (Whitelaw, et al. 2003; Keough and Blahna 2006), and many other areas across the globe (Sultana and Abeyasekera 2008; Pattengill-Semmens and Semmens 2003; Nagendra et al. 2005). Kerr et al. (1994) indicated a near tripling of new monitoring programs between 1988 and 1992, all related to water monitoring. Pretty (2003) reported that since the 1990s, up to 500,000 new local groups were established in varying environmental and social contexts. The increase has been particularly dramatic in the US and Canada (Lawrence 2006). The cause for this has been attributed to an increase in public knowledge and concern about anthropogenic impacts on natural ecosystems (Whitelaw et al. 2003; Conrad 2006; Conrad and Daoust 2008) and recent public and non-government organization (NGO) concern about government monitoring of ecosystems (Pollock and Whitelaw 2005).

Concern about the effectiveness of government monitoring has been attributed to government cutbacks in funding and staffing for ecological monitoring (Stokes et al. 1990; Pollock and Whitelaw 2005; Conrad and Daoust 2008) as well as questions about government staff expertise when dealing with complex environmental challenges (Conrad and Daoust 2008). Despite cutbacks, governments still require monitoring data for decision-making processes; and recognize the need to include stakeholders in these processes (Lawrence and Deagan 2001; Whitelaw et al. 2003). Requirements for species data for regulations and conservation have led to an increase in the use of amateur naturalists in Europe (Lawrence 2006).

There are differences in the monitoring intent in different parts of the world as well. In North America, there is a predominance of monitoring varying aspects of environmental *quality*, whereas biological species monitoring is more common in parts of Europe, where nature tends to be more "micro-managed" (Lawrence 2006, p.281). The issue of monitoring interest often transcends government boundaries, and many NGOs responsible for cross-state, -province or -country concerns have increased their use of citizen scientists as well (Cline and Collins 2003). CBM relationships with universities have also increased, perhaps due to their capacity to provide training, lab facilities, free space and funding (Savan et al. 2003). Some examples of CBM initiatives linked with academic institutions include:

- The Community-Based Environmental Monitoring Network, housed within the Department of Geography at Saint Mary's University in Halifax, Nova Scotia, Canada (www.envnetwork.smu.ca)

- The Canadian *Nature Watch* programs, which are in partnership with the University of Guelph in Ontario, Canada (www.eman-rese.ca/eman/naturewatch.html)

- The *Citizens' Environmental Watch*, in Toronto, Canada, was founded by academics in response to government cuts in environmental monitoring (www.citizensenvironmentwatch.org/cewsite/)

- The Alliance for Aquatic Resource Monitoring (ALLARM), housed within the Environmental Studies Department at Dickinson College in Pennsylvania (www.dickinson.edu/about/sustainability/allarm/)

- The University of Rhode Island Watershed Watch (www.uri.edu/ce/wq/ww)

- The Florida LAKEWATCH coordinated though the University of Florida's Institute of Food and Agricultural Science and Fisheries and Aquatic Science programs (http://lakewatch.ifas.ufl.edu/)

Though sometimes thought of as a new idea, some CBM organizations have been monitoring ecosystems (and ecosystem components) for decades (i.e. Christmas Bird Count since 1900 (Audubon 2008) and the British Trust for Ornithology (BTO) for over 50 years). BTO volunteers are estimated to have annually contributed 1.5 million person hours to CBM efforts (Bibby 2003). The United Kingdoms' Breeding Bird Survey involves tens of thousands of participants annually (Sullivan et al. 2009). The majority of groups have only been monitoring for several decades or less, however.

Types of Monitoring

Monitoring is an important tool in citizen science: it "informs when the system is departing from the desired state, measures the success of management actions, and detects effects of perturbations and disturbances" (p. 194, Legg and Nagy 2006). Monitoring can differ in focus, approach or technique. A sample of CBM initiatives is found in Appendix A, where several trends emerge. The initiatives in Appendix A were chosen from a broad literature review conducted by the authors. This review is not intended to be inclusive of all types of CBM monitoring (especially given the enormous proliferation of CBM information available on-line); but instead be representative of a variety of CBM campaigns across the globe. Of the CBM groups sampled, most monitored water quality (11), with only a few devoted to monitoring birds (3), air quality

(2), amphibians (2), plants (2), fish (1), worms (1) and ice (1). These monitoring

programs will be discussed throughout the paper.

CBM initiatives have engaged both the resource sector (often referred to as

commodity-based monitoring; e.g. the resource fishery) and the non-resource sector

(often referred to as non-commodity-based monitoring; e.g. recreational fishery).

Commodity-based monitoring deals with issues of economic (as well as social and

environmental) importance. Examples include monitoring of fisheries (Sultana and

Abeyasekera 2008) and forestry activities (Nagendra et al. 2005). Historically,

commodity-based CBM has focused on economic issues, but in more recent years the

focus has shifted to include social and ecological outcomes as well (Water Science and

Technology Board 1992). Non-commodity-based monitoring focuses on issues that may

not seem to be directly economically important. This is often in the form of monitoring

water quality (Mullen and Allison 1999), air quality (Nali and Lorenzini 2007) or

indicator species (i.e. benthic macro invertebrates (Jones et al. 2006), nesting songbirds

(Evans et al. 2005) or calling amphibians (de Solla et al. 2005)). The present paper

focuses on research and examples of non-commodity-based monitoring.

CBM also differs in the types of monitoring activities the organization undertakes.

Monitoring activities include many different types of assessments of ecosystems: 1)

status assessment (i.e. population monitoring), 2) impact assessment (i.e. affect of

pollution) or 3) adaptive management (i.e. managing based on monitoring) (Stem et al.

2005). Monitoring activities also include different aspects of the ecosystem monitored:

ecosystem composition (i.e. indicator species or species at risk), structure (i.e.

biodiversity analysis, keystone species, predator-prey relations, etc.) or processes (i.e. linking species with environment, nutrient cycling, etc.) (Milne et al. 2006). Process-based monitoring is suggested as being most desirable in many studies (Milne et al. 2006; Stem et al. 2005).

Governance Structures

In June, 1998, The Aarhus Convention was signed with the intent to mandate participation by the public in environmental decision-making and access to justice in environmental matters. By 2008, it had been signed by 40 countries (most of which are European and Asian nations) (UNECE 2009). Although attempts have been made to engage the public in science and technology for many decades, there has been a more recent interest throughout western democracies (Chilvers 2008). With this interest, considerable debate and discussion surrounding the meaning of *participation* and the various forms it can take has emerged (Pretty et al. 1995; Lawrence and Turnhout 2005; Lawrence 2005; 2006; Chilvers 2008). There are varying scales of participation which have traditionally been categorized into so-called top-down and bottom-up governance structures. Some authors (e.g. Pretty et al. 1995) have developed scales that recognize the diversity of power relations in public engagement, including passive participation, participation by consultation, functional participation, interactive participation through to self-mobilization whereby people participate by taking initiatives that are independent of external (e.g. government) institutions. Lawrence (2006) argues that, regardless of the classification, the "…traditional ladder typology of participation missed key changes taking place in individuals and groups of participants. These changes require a different

way of thinking about participation, the environment and governance." (p.290). Lawrence (2006), on the basis of a synthesis of approaches in the literature, organizes participation into four forms: consultative (public contributes information to a central authority); functional (public contributes information and is also engaged in implementing decisions); collaborative (public works with government to decide what is needed and contributes knowledge) and transformative (local people make and implement decisions with support from "experts" where needed). For many CBM activities, it is difficult to clearly define which category the program falls within (Lawrence 2006). Acknowledging the fact that there are both internal values (contributions of the participatory process to personal learning and development and relationship to nature) and external values gained (public utility of data for decision-making purposes), the following categorization is not intended to imply that there is an either or situation with participation.

Consultative/ Functional Governance

Consultative and functional levels of participation imply that a central agency (government) is asking for information from the public or making decisions and then involving local people. The status quo is maintained and existing structures initiate consultation. The scale of participation is not limited to local scales (Lawrence 2006). This form of participation has been traditionally referred to as top-down. The purpose of monitoring by these groups is to provide early detection (by citizens) of issues of environmental concern, which can then be investigated by scientific experts (most often government) (Whitelaw et al. 2003; Conrad and Daoust 2008). Consultative monitoring has also been suggested for areas (often in developing countries) where illegal poaching

of endangered species is a concern (Datta et al. 2008). Citizen scientists can thus provide a "watch-dog" service for government or scientific experts. The data collected by these groups may be used to create long-term data sets that can be used by researchers (Whitelaw et al. 2003). Although often successful in the short term (Mullen and Allison 1999), consultative and functional groups are often funding-dependant, and cannot continue on their own without government assistance (Mullen and Allison 1999). Also, these groups may represent a less diverse stakeholder group (i.e. only fishers, only farmers) (Mullen and Allison 1999). There has been a recent shift in most areas from consultative to transformative governance (Pollock and Whitelaw 2005).

An example of the consultative/functional model is the Cornell Lab of Ornithology bird-monitoring project where teams of scientists determine the questions to be answered and decide what segment of the public will be targeted as participants (Ely 2008a). This author indicated both pros and cons of such a monitoring model, with strengths including the coordination of large numbers of volunteers, spanning a wide geographic area, and the collection and management of large datasets. These kinds of programs can also assist in answering scientific questions that would otherwise be difficult or impossible to determine without the presence of such vast resources. There is no conceivable way that paid professionals alone could gather the amount of data annually undertaken by volunteers of the British Trust for Ornithology (Bibby 2003). The downside to this monitoring structure is the limited role that volunteers usually play in the data collection. Most large-scale ecosystem monitoring programs (e.g. bird monitoring programs) tend to be consultative.

Collaborative Governance

Collaborative or so-called *multi-party* CBM groups (sometimes involved in co-management or adaptive management, if management is part of the goal of the organization (Cooper et al. 2007)), are often governed by a board or group representing as many facets of the community as possible: private landowners, the general public, businesses, government, universities, etc. (Conrad and Daoust 2008). It is on the rise based on its collaborative nature (Whitelaw et al. 2003) that often yields more decision-making power than other types of monitoring (Conrad and Daoust 2008). Many watershed authorities or councils are governed by multi-party organizations. These authorities are coordinated or appointed by a locally-selected board (Mullen and Allison 1999). They are common in Ontario, Canada (Milne et al. 2006) and in the US (Mullen and Allison 1999; Griffin 1999). In the US, they seem to suffer from less diverse stakeholders than top-down or bottom-up groups, but tend to have good short and long term success (Mullen and Allison 1999). The success of watershed councils in the US has been attributed to their environmentally (not politically) appropriate physical boundary-the local watershed, non-commodity based approach, and community-level decision making (Griffin 1999).

In Bangladesh, community based co-management of fisheries was associated with more economic, social and environmental successes than more simple, bottom-up approaches led by the fishers themselves (Sultana and Abeyasekera 2008). Fisher-led management groups were sometimes economically unrepresentative- with richer, more influential fishers more prevalent than more economically underprivileged fishers. In the

multi-party co-management groups, these poorer fishers felt more represented- and less intimidated. (Sultana and Abeyasekera 2008).

Transformative Governance

CBM groups that are governed from the "bottom-up" (also called transformative, community- based, grassroots or advocacy groups) are often born out of crisis. The group focuses on an issue with the hopes of initiating government action (Conrad and Daoust 2008). This type of CBM group often focuses on specific local issues and sometimes has no private sector or government support (Whitelaw et al. 2003). Initiation, organization, leadership and funding of the CBM group is provided by the local community (Mullen and Allison 1999). Some researchers believe that by transferring authority over decision-making to those most affected by it (the public), better, more sustainable management decisions will be made- thus making the bottom-up model a desirable type of governance (Bradshaw 2003). However, many failures of bottom-up CBM groups are mentioned in one study (Bradshaw 2003). These include lack of success due to little organization credibility and capacity (Bradshaw 2003). Others suggest bottom-up CBM groups tend to be unsuccessful on a more organizational level, perhaps due to monitoring an issue with no legislation or policy support (Conrad and Daoust 2008). One study (Mullen and Allison 1999) predicted high success for transformative CBM groups in the U.S. state of Alabama, but suggested that CBM activities (for any type of monitoring) may not continue after federal or state support is reduced or withdrawn (Mullen and Allison 1999).

The transformative or community-based model has the advantage of involving participants in every stage of the monitoring program, from defining the problem through communicating the results and taking action. In this case, the role of the scientist is to advise and guide community groups rather than to set their agendas (Ely 2008b). This author also notes that water monitoring initiatives are often "tailor-made" for the community-based approach in that you don't "…need thousands of far-flung volunteers to collect the needed data. What you want is a small group of local citizens" (p.4). The experiences from the Community-Based Environmental Monitoring Network in Halifax, Nova Scotia confirms this observation, with over 50 community organizations active in watershed stewardship and monitoring activities (Conrad 2006).

The so-called "Bucket Brigade" serves as a meaningful example of a transformative community monitoring initiative. This was started in 1995 by attorney Edward Masry (of Erin Brockovitch fame) when both were made ill from fumes from a petroleum refinery he was suing on behalf of citizens in California (The Bucket Brigade 2006). When federal and state environmental authorities were notified, their staff indicated that their monitoring equipment did not detect any air quality issues. Out of anger and frustration Masry had an engineer design a low cost device that citizens in the community could use to monitor their exposure for themselves. The Environmental Protection Agency subsequently undertook a quality assurance evaluation of the device and the monitoring results and accepted their validity. The program has spread across the US and "armed with their own data and information about the health effects of chemicals,

these communities are winning impressive reductions of pollution, safety improvements and increasing enforcement of environmental laws" (Bucket Brigade 2006).

The Global Community Monitor (GCM) also serves as an example of how transformative governance structures can best serve the concerns of a community, although it has evolved into a collaborative framework. The GCM was created to provide community-based tools for citizens to monitor the health of their neighborhoods, with a focus on air quality. One of the organizations in India is the SIPCOT Area Community Environmental Monitors (SACEM). Villagers have been trained in the science of pollution and have been engaged in environmental monitoring, which over time has led to published scientific reports. This work formed the basis for a Supreme Court order calling for the establishment of national standards for toxic gases in ambient air (Global Community Monitor 2006).

Also in India, the "People's Biodiversity Register" addresses concerns related to dwindling numbers of the Siberian crane. Residents suggested that national park regulations which prevented people from digging for roots of a particular grass actually resulted in soil compaction, making it harder for the cranes to access underground tubers and food sources that are important to their diet (Gadgil 2006). The subsequent creation of "Biodiversity Management Committees", legislated under a Biological Diversity Act, now serves to take science literally down to the grassroots. The main function of the BMC is to prepare biodiversity registers in consultation with the local people. This citizen based approach has now evolved into a collaborative initiative.

Governance Structure Summary

Some pros and cons have been suggested for most of the three governance structures (see Table I), with most positives being associated with collaborative governance. However, there is insufficient information on each type to determine if one is necessarily better than the other. At the same time, there is evidence that "…long-term economic and environmental success [comes about] when people's ideas and knowledge are valued, and power is given to them to make decisions independently of external agencies." (Pretty et al. 1995, p.60). It may be that certain governance structures suit different monitoring situations (and communities), with collaborative and transformative participation being associated with local scales of participation and consultative and functional participation being more feasible across broader geographic scales. Also, there is sometimes an over-lap in the governance structures of monitoring activities. The different approaches have been widely held to be mutually exclusive (e.g. Goodwin 1998), although others (e.g. Lawrence 2005) conclude that it is quite possible for more top-down structures to lead to "…more radical changes in personal outlook and values…" (p.2), while more bottom-up approaches can produce good quality data and change power relations. The Florida LAKEWATCH program, which is a collaborative initiative between the University of Florida, government agencies and communities, is an example of an integration of both the consultative and transformative governance structures. This program has been in existence since 1986 and in 1991 the Florida Legislature recognized the importance of the program and established Florida LAKEWATCH in the state statutes (Florida Statute 1004.49.). This is now one of the

largest lake monitoring programs in the U.S. with over 1800 trained citizens monitoring over 600 lakes, rivers and coastal sites (Florida Lakewatch 2008).

Reviewing the governance structures of CBM programs listed in Appendix A, there appears to be a relationship between governance structure and a link to decision-making or an influence on conservation. Of the twenty programs listed, nine have documented an influence on conservation efforts. Of the nine programs, the majority (6) are either collaborative or transformative, with the other three being consultative or functional. Although this can lead to a preliminary conclusion that collaborative and transformative governance structures in community-based monitoring will lead to a greater likelihood of influencing conservation efforts, this requires further evidence. It is also of equal importance to further consider the common characteristics of the three more consultative governance structures and investigate the reasons for their unique successes. It should also be noted that of the remaining eleven programs that do not have documented evidence of linkages to decision-making, five are collaborative or transformative and four are consultative or functional. It appears that governance structure alone does not provide a recipe for success when it comes to linking community-based monitoring to environmental management.

Benefits of Citizen Science

Many benefits to society, citizen scientists and local ecosystems have been attributed to CBM. These include increasing environmental democracy, scientific literacy, social capital, citizen inclusion in local issues, benefits to government and

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benefits to ecosystems being monitored. Democratization of the environment is a relatively new concept based on making environmental science and expertise more accessible to the public, while also making scientists more aware of local knowledge and expertise (Carolan 2006). CBM can help to democratize science through the sharing of information between scientists and non-scientists. This ties in with the growing move to pursue "public ecology" research; where conservation biology research includes more multi-disciplinary topics with the purpose of influencing legislation (Robertson and Hull, 2001). Some authors (e.g. Carr 2004) go so far as to state that it is "inappropriate to leave (environmental) science solely to institutions and that community science is necessary" (p. 842). CBM also plays an important educational role in communities. By participating actively in scientific projects, community members increase their scientific literacy. This can take the form of augmenting knowledge of scientific processes, or by an increased understanding of their role in the local environment (Evans et al. 2005). This "environmental education" can be fostered through volunteer CBM activities; or in a more traditional sense where students from local schools are included in CBM to complement their studies (Nali and Lorenzini 2007; Au et al. 2000).

It has been suggested that public support for conservation can be increased by building social capital (Schwartz 2006). Social capital has been measured by increases in levels of trust, harmony and co-operation in communities practicing CBM (Sultana and Abeyasekera 2008). Social capital seems to be increased by CBM through activities that lead to volunteer engagement, agency connection, leadership building, problem-solving and identification of resources (Whitelaw et al. 2003). This can lead to a more educated

community (Pollock and Whitelaw 2005; Cooper et al. 2007) and creation of a stewardship ethic (Whitelaw et al. 2003; Cooper et al. 2007). However, it has been recognized that in areas with little social capital and no motivation for change (i.e. no immediate threat to a water resource, etc.), long term financial and technical resources may be required to create social capital (Mullen and Allison 1999). Also, CBM does not always yield higher social capital, as seen in Bangladesh (Sultana and Abeyasekera 2008); and in some cases, increases only as a result of a catastrophe (Mullen and Allison 1999).

Citizen science has been recognized in many studies as a way to include stakeholders and the general public in the planning and management of local ecosystems (Pollock and Whitelaw 2005). Citizens in communities with CBM tend to be more engaged in local issues, participate more in community development and have more influence on policy-makers (Whitelaw et al. 2003; Pollock and Whitelaw 2005; Lynam et al. 2007). Also, CBM has been shown to encourage more sustainable communities (Whitelaw et al. 2003).

CBM is beneficial to government agencies as it offers a cost-effective alternative to government employee monitoring (Whitelaw et al. 2003; Conrad and Daoust 2008). Fieldwork can be undertaken over larger areas, and during non-office hours (Whitelaw, et al. 2003). Government desire to be more inclusive of stakeholders (Lawrence and Deagan 2001; Whitelaw et al. 2003) is met by CBM. In Martha's Vineyard (U.S.A.), neighborhood pond associations formed out of concerns for declining water quality, which was a particular issue in this region due to the importance of good water quality for

the local shellfish industry. The numerous dedicated water monitoring initiatives led by non-profit organizations and the partnerships forged with environmental managers in the area, has led to a great number of initiatives (e.g. pressuring the Board of Health to inspect and replace failed septic systems, address boat related pollution, distributing pamphlets and educating boaters, etc.) and consequently improvements to water quality. "Environmental managers who forge partnerships with these organizations have been rewarded with energy, commitment, and passion reserved for issues that hit close to home….With the vigilance and dedication of a Neighborhood Crime Watch, local pond associations are the eyes and ears that sound the first alerts of environmental pollution" (Karney 2009, p.2).

Benefits to the ecosystems being monitored by CBM groups are not commonly published. Most published articles on CBM *suggest* that CBM groups provide benefits to the environments they monitor (Evans et al. 2005; Au et al. 2000, Jones et al. 2006, etc.) but few state quantitative environmental success as a result of community monitoring (Legg and Nagy 2006). One author conducted an analysis on the results of surveys on the quantity of "environmental protection" provided by different watershed associations in West Virginia, United States of America (Cline and Collins 2003). However, "environmental protection" was defined as the number of "protective actions" (defined as: stream litter clean-ups, water-quality monitoring, fish stocking, education programs, river festivals, watershed studies and recreational access improvements) performed by the monitoring groups and the amount of funding directed towards protecting surface waters. Environmental protection was not measured as an actual improvement in water quality in

the areas monitored. The number of protective actions and the dollar amount of funding alone is not an adequate measure of the environmental success of such groups. Although there is much anecdotal discussion and web site documentation of the environmental benefits of citizen science, more peer-reviewed studies must actually show a relationship between CBM group efforts and environmental improvements to substantiate these claims.

Challenges for Citizen Science

Challenges for CBM groups have been well documented in academic journal articles (Conrad and Daoust 2008; Milne et al. 2006, Whitelaw et al. 2003) and tend to be related to three issues: 1) CBM organizational issues, 2) data collection issues and 3) data use issues.

Challenges for CBM at the organizational level include a lack of volunteer interest (Conrad and Daoust 2008) and networking opportunities (Milne et al. 2006), as well as funding (Whitelaw et al. 2003) and information access challenges (Milne et al. 2006).

Issues for CBM groups also arise during data collection. These include data fragmentation, data inaccuracy and lack of participant objectivity (Whitelaw et al. 2003). Studies are often lacking in experimental design and do not consider issues such as adequate sample size (through a priori power analysis, for example). This furthers the mistrust (by the scientific or government community) in the credibility and capacity of CBM data. It has been suggested that information collected by community groups is not

taken seriously by decision-makers due to questions regarding the credibility, non-comparability and completeness of the data (Gouveia et al. 2004; Bradshaw 2003). In 1994, the US Congress called for the National Biological Survey to exclude data gathered by volunteers because of the belief that their "environmentalist agenda" would lead to biased data collection (Root and Alpert 1994). Many researchers are not confident the level of training volunteers receive is adequate to prevent both false positive and false negative data (especially in the case of biological identification) (Royle 2004). Certainly some of this concern is related to disagreement in the conservation field of the value of monitoring in general (Vos et al. 2000; Legg and Nagy 2006), and this issue for CBM is not a small hurdle to overcome. The "wrong data" might also be collected; many CBM groups focus on monitoring tasks as opposed to processes (Conrad 2006). This could lead to the folly of "monitoring for the sake of monitoring" (Conrad and Daoust 2008).

Finally, one of the greatest challenges for CBM is the use of the data collected through the monitoring program. Many groups find their data is not used in the decision-making process (or published in scientific peer-reviewed journals), either due to data collection concerns or difficulty getting their data to the appropriate decision-maker or journal (Milne et al. 2006; Conrad and Daoust 2008). Journal articles using volunteer-collected data are not as common as expected, especially with the wealth of volunteer-collected data available (see Ely 2008a for a list of such journal articles). Many articles (Warren and Witter 2002; Kershaw and Cranswick 2003; James et al. 2006; Fore et al. 2001) use data collected by volunteers but do not cite any attempts at training or compensation for volunteer error. It is not uncommon to see statements like the

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following: "While no evaluation of the effectiveness of the participatory aspects of the plan has been made… (Contador 2005)". Inaccuracy in CBM data collection is a valid concern, with several studies (Kershaw and Cranswick 2003; de Solla et al. 2005) showing volunteer difficulty particularly when volunteers are estimating sizes of groups of individuals. However, some researchers select and train their volunteers thoroughly (Easa et al. 1997), and some have found through validation and calibration that volunteers collect data comparable to professional researchers (with limitations) (Newman et al. 2003; Foster-Smith and Evans 2003, Fore et al. 2001).

Recommendations for Citizen Science

Do the benefits of CBM outweigh the challenges? Table II lists both benefits and challenges that were reviewed in the previous section. The benefits are substantial and although the challenges need to be addressed comprehensively, and are not insignificant, they appear to be items that can be overcome if those who have the capacity to address them do. For example, if relevant government agencies have the foresight to acknowledge the multiple benefits of CBM programs and want to link their efforts to enhanced environmental management, they can make funding for CBM a priority. Linkages to information access and training, as well as enhanced skills of volunteers can be overcome by linking to Academic Institutions as well as building upon the many existing models that have proven successful. Recommendations to overcome challenges have been outlined by some researchers (Whitelaw et al. 2003; Legg and Negy 2006; Gouveia 2004, etc.). They include a few key recommendations for organization problems, and a list of best practices for overcoming issues of data collection and use.

Organizational framework guidelines have been developed by others (Milne et al. 2006; Stem et al. 2005; Conrad and Daoust 2008, etc.) to help prevent these challenges from occurring. So while the challenges can be addressed, the benefits are substantive. Challenges to effective CBM should not be used to devalue the significance of citizen-based initiatives, since the benefits far exceed the challenges that can be overcome. If challenges primarily relate to concerns such as scientific rigor, but benefits include societal changes, the decision need not be to engage citizens or not. The decisions need to surround solving challenges while building on social capital. With benefits to society and challenges to science, how exactly can the former be capitalized while not undermining the science? Consensus from the examples in Appendix A indicates that in all cases, the challenges are addressed and met.

When it comes to issues within the CBM organization itself, there have been several proposals that have yet to be tested for their effectiveness. Volunteer drop-out or dis-interest could be tackled with positive reinforcement (i.e. informing them how they are impacting conservation, recognizing them for their efforts) (Whitelaw et al. 2003; Legg and Negy 2006) or by matching monitoring protocols to the interests and skills of the volunteers (Whitelaw et al. 2003). Collaboration with other organizations (perhaps through a network of CBM groups) could help with access to information and networking. Finally, funding should be acquired before the monitoring begins to prevent budget issues (Whitelaw et al. 2003).

Best practices have also been described to deal with the problem of data credibility and capacity. Gouveia et al. (2004) provides detailed recommendations to

overcome and address issues of data credibility, non-comparability of results, and data completeness.

Other suggestions include: increase sample size and perform power analysis prior to monitoring plan design (Legg and Negy 2006), ensure monitoring methods are simple and scientifically appropriate and incorporate training into all aspects of CBM monitoring. In order to increase the likelihood of results being published or used by decision-makers, CBM groups should focus on outcomes that serve society, and ensure monitoring data will be relevant to the policies the CBM group is hoping to influence (Whitelaw et al. 2003).

Organizational frameworks are recommended by many researchers (Milne et al. 2006) as a tool to better improve CBM. A study in Nova Scotia, Canada (Conrad and Daoust 2008) found the majority of CBM groups surveyed did not feel the data they collected was used by decision makers. However, these same groups admitted to not using consistent monitoring protocols. A standardized framework could help reconcile many of the challenges to CBM organizations. A number of studies (Stem et al. 2005) suggested using the following basic framework outlined by Conrad and Daoust 2008:

- Step 1) Identify stakeholders (including governance analysis, consultation and outreach, identification of champions, partnership development, and selection of organizational structure (Whitelaw et al. 2003))

- Step 2) Identify skills and resources (including fundraising and securing adequate future funding (Whitelaw et al. 2003; Legg and Negy 2006), skills assessment, capacity building (Whitelaw et al. 2003))

- Step 3) Create a communication plan (including achieving influence (Whitelaw et al. 2003), feeding back results and management recommendations (Cooper et al. 2007))

- Step 4) Create a monitoring plan (including community visioning (Whitelaw et al. 2003), data collection and organization (Cooper et al. 2007; Legg and Negy 2006), basic research on monitoring topic (Stem et al. 2005)

Individual groups may find one tool or framework works better than another based on their individual purposes, and several studies have discussed how best to decide what tool or framework to use (Conrad and Daoust 2008; Lynam et al. 2007).

Discussion and Conclusions

Citizen science research is a relatively new subject of interest with a multi-disciplinary approach. Perhaps the wide range of researchers involved (biologists, watershed planners, environmental scientists, social scientists, etc.) explains some of the diverse opinions in the field. However, this blend of different backgrounds brings many perspectives to the field; and helps to lend credibility to areas of consensus.

Monitoring activities by CBM groups (and the numbers of CBM groups themselves) have increased world-wide, with a few shifts in focus over the last few years

(e.g. increase in relationships with universities, move from commodity to non-commodity based monitoring and move to process-based monitoring); which seem to have only strengthened the capability and capacity of these groups. Although many large-scale organizations have consultative and functional governance structures (e.g. the Cornell Lab of Ornithology), many groups have moved towards transformative governance with some outstanding successes (e.g. the Bucket Brigade), but also some documented struggles. Although collaborative governance may not be as common as consultative or transformative, it may have the potential to be very successful (see Table I). More research comparing the benefits of all types of monitoring and governance (or the situations when it is best to use one governance type over another), could help improve upon global CBM.

There is a general consensus in the field about many of the societal benefits of CBM: the creation of environmental democracy and social capital (although the ease with which these are acquired is debatable), increased scientific literacy and inclusion in local issues, and time and money saving benefits to government. Many researchers (Milne et al. 2006; Stem et al. 2005) agree that process-based monitoring is one of the most efficient forms of monitoring, and many (Whitelaw et al. 2003; Legg and Negy, 2006; Cooper et al. 2007; Stem et al. 2005; Conrad and Daoust 2008) recommend the use of a monitoring framework to encourage success. Although recommendations have been made to overcome the challenges of organizational struggles, improper data collection and data use; the success of the recommendations, best practices and associated framework should be identified and evaluated. Particular focus on increasing use of data

by decision makers and scientists; and how that use influences conservation, would be particularly valuable.

There is increasing evidence that community-based monitoring efforts are making an impact. The Florida LAKEWATCH program, the Bucket Brigades and the Waterkeepers in the United States as well as the Global Community Monitor and People's Biodiversity Register provide examples of direct linkages between the monitoring activities undertaken by community organizations and changes in policy and decision-making with respect to conservation, air and watersheds. However, there remains a need to enhance our understanding of community-based monitoring. We make the following recommendations for future research in the field:

- compare and contrast the success (and the situations that induce success) of CBM programmes which present sound evidence of citizen scientists influencing positive environmental changes in the local ecosystems they monitor
- more case studies showing use of CBM data by decision-makers or the barriers to linkages and how these might be overcome.

Some of these questions can begin to be answered by comparing the successes of a selection of CBM groups (Appendix A). Transformative groups (11 of 20) are more common than all other types, and many groups (11 of the 20) had unclear evidence of a link to changes in legislation or data use by scientists. Are there particular characteristics and common characteristics of the nine that have been linked to conservation, and improved environmental management? There doesn't appear to be, as they involve water, air and species monitoring, there are varying forms of governance, and some are local

(e.g. the Neighborhood Pond Associations of Martha's Vineyard) whereas others are

global (e.g. the Earthwatch). In the absence of an obvious profile that suggests success for

linkages between monitoring efforts and conservation, a deeper exploration of the

characteristics that make such linkages is warranted.

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TABLES

Table I. Summary of Pros and Cons of Governance Structures for CBM Groups

	Consultative/Functional	**Collaborative**	**Transformative**
Details	Gov. led, community run; Gov. recognizes problem and uses CBM group to monitor	Involves as many stakeholders, individuals, etc. as possible; Often based on a non-politically demarked area (i.e. watershed)	Community led, run and funded; Community recognizes problem-trying to get gov. attention
Pros	May lead to long-term data sets; Often successful in short term	Often more decision making power than other structures	Can be successful with community and stakeholder support
Cons	Dependant on gov. funding; Less diverse stakeholders	None published	May not be diverse (i.e. only activists), Problems with credibility and capacity Monitoring issues that are not governed by legislation

Table II. Summary of Benefits and Challenges of CBM

Benefits	Challenges
Increasing environmental democracy (sharing of information)	Lack of volunteer interest/lack of networking opportunities
Scientific literacy (Broader community/public education)	Lack of funding
Social capital (volunteer engagement, agency connection, leadership building, problem-solving and identification of resources)	Inability to access appropriate information/expertise
Citizen inclusion in local issues	Data fragmentation, inaccuracy, lack of objectivity
Data provided at no cost to government	Lack of experimental design
Ecosystems being monitored that otherwise wouldn't be	Insufficient monitoring expertise/quality assurance and quality control
Government desire to be more inclusive is met	Monitoring for the sake of monitoring
Support/drive proactive changes to policy and legislation	Utility if CBM data (for decision-making; environmental management; conservation)
Can provide an early warning/detection system	

Appendix A: A selection of CBM entities, their monitoring mandates, governance structures and influence on conservation.

Community Monitoring Initiative:	Monitoring Activity:	Governance Structure:	Influence on Conservation:
			Evidence of influence on conservation documented:
Cornell Lab of Ornithology (United States) and Bird Studies Canada (Canadian version)	Numerous seasonal and year-round bird monitoring programs, from FeederWatch to PigeonWatch and eBird	Consultative	By integrating public outreach and scientific data collection protocols, this form of citizen science has become an established method for advancing scientific knowledge in many areas, including population trends in wildlife (e.g., Hochachka et al. 1999, Hochachka and Dhondt, 2000, Oberhauser and Solensky, 2004, Cannon et al. 2005), avian life histories (e.g., Cooper et al. 2005), and management recommendations (e.g., Rosenberg et al.1999, 2003, Gregory et al. 2005). The eBird data is use to test models required to prioritize areas for conservation actions and for species management (Sullivan et al. 2009).
Waterkeeper Alliance	Water monitoring	Collaborative/ Transformative	An alliance of over 117 organizations world-wide with various forms of conservation successes. (www.waterkeeper.org)
The Bucket Brigade	Air quality monitoring	Transformative	Now recognized by the US Environmental Protection Agency and monitoring results have been linked to reductions in pollution, safety improvements and enhanced enforcement of environmental laws in several states. (www.gcmonitor.org)
Global Community Monitor (GCM)	Air and water quality monitoring	Transformative	The GCM has programs around the world, some of which have had documented success, including the SIPCOT Area Community Environmental Monitors in India, which assisted in the establishment of national standards for toxic gases in ambient air.

			(www.gcmonitor.org)
The North American Amphibian Monitoring Program (NAAMP)	Amphibian monitoring	Functional	The NAAMP is a collaborative effort among regional partners in the US, state agencies, educational institutions and nonprofit organizations and the USGS to monitor populations of calling amphibians. The USGS provides central coordination and database management.
University of Rhode Island Watershed Watch	Water monitoring	Collaborative/ Transformative	The URI Watershed Watch Program produces quality data for a broad range of parameters for over 200 monitoring sites statewide. Produced using well established methods, and processed in state certified laboratories; this information is used by the Rhode Island Department of Environmental Management for assessing the State's waters, as well as by municipal governments, associations, consulting firms and residents for more effective management of local resources. (http://www.uri.edu/ce/wq/ww/Data.htm)
Florida LAKEWATCH	Water monitoring	Collaborative/ Transformative	In 1991 the Florida Legislature recognized the importance of the program and established Florida LAKEWATCH in the state statutes (Florida Statute 1004.49.). LAKEWATCH is now one of the largest lake monitoring programs in the nation with over 1800 trained citizens monitoring 600+ lakes, rivers and coastal sites in more than 40 counties. Volunteers take samples to collection sites located in 38 counties.
Neighborhood Pond Associations of Martha's Vineyard	Water monitoring	Collaborative/ Transformative	The environmental accomplishments of the various pond associations have been impressive. One funded a water quality study resulting in the establishment of a free septage pump out facility for boaters; another provided the leadership to coordinate a local, state, and federal partnership to complete a major dredging project which restored shellfish habitat; others have addressed farm and roadway runoff with fencing, buffer strips and innovative catch basins; and all have

			conducted successful public educations programs, water quality monitoring studies and protective zoning initiatives (Karney 2009).
Earthwatch	Collection of field data in the areas of rainforest ecology, wildlife conservations, marine science	Consultative	Founded in 1971, Earthwatch supports scientific research by offering volunteers the opportunity to join research teams around the world. Earthwatch recruits close to 4000 volunteers every year to collect field data for a variety of purposes (www.earthwatch.org). Scientists engaged in Earthwatch initiatives have generally had very good things to say about the volunteer monitoring, including the very high quality of their data collection (e.g. "…no difference between the data collected by volunteers and the project staff ") (www.earthwatch.org/aboutus/research/scientistopps/scientistssay/). In reference to a leatherback turtle project, one scientist stated that their project would not have been possible without the assistance of the 1337 volunteers who was been assisting in the 23 years of monitoring, patrolling over 91, 024 miles of beach. The data for many of the studies would not have been possible without the volunteers' participation. Volunteers' impact on conservation appears equally impressive, with numerous results cited (http://www.earthwatch.org/browse.aspx?ContainerID=reaccomp).
			Evidence of influence on conservation lacking:
British Trust for Ornithology	Bird surveys	Consultative	The collaborative venture between volunteers, amateurs and professionals has proved an enduring success over two or three human generations. Surveys have returned unexpected values and the value of historic data has grown (Bibby, 2003). If substantive *conservation* measures haven't been documented, at the very least enhanced *understanding* is a consequence.

Citizen's Environment Watch (CEW)	Primarily water monitoring	Transformative	Launched in communities across Ontario in 1997, CEW has worked with hundreds of community groups and school youth to assess the health of local waters: an understanding of the link to conservation is incomplete.
Community-Based Environmental Monitoring Network	Primarily water monitoring	Transformative	Launched in 2003, the CBEMN has worked with dozens of community groups to enhance their understanding and stewardship capabilities. Efforts are being made to make linkages to decision-makers and to conservation efforts, but this remains a barrier.
Atlantic Coastal Action Program	Primarily water monitoring	Collaborative/ Transformative	Although this program, which includes multi-stakeholder groups across Atlantic Canada has been touted as having had a strong impact, direct evidence remains somewhat elusive (Sharp and Conrad, 2006)
The Alliance for Aquatic Resource monitoring (ALLARM)	Water monitoring	Transformative	Difficult to ascertain the impact on conservation, although this organization has been in existence since 1986 and has established programs both within and outside of the United States.
Pacific Streamkeepers	Water monitoring	Transformative	Although the mandates include the intent to foster co-operation amongst watershed stakeholders and promote local management of aquatic resources, concrete examples of links to decision-makers and impacts on conservation measures are elusive.
Shorekeepers	Water monitoring	Consultative	Although the Shorekeepers' Guide was developed by Fisheries and Oceans Canada and is a rigorous monitoring methodology, there is little evidence that this program has been linked to enhanced conservation measures.
Reef Environmental Education Foundation (REEF)	Fish monitoring	Transformative	The volunteer fish monitoring program and fish survey project produce data that are provided to scientists, marine park staff and the general public. To date, the National Oceanic and Atmospheric

			Association, the State of Florida and the Bahamas Government have utilized this data. (http://www.reef.org/programs/monitoring)
Nature Watch programs in Canada	Frog Watch, Plant Watch, Ice Watch, Worm Watch	Functional	There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.
USDA Forest Service Nature Watch		Consultative	There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.
US National Phenology Network	Project Budburst (plant monitoring)	Consultative	The USA National Phenology Network brings together citizen scientists, government agencies, non-profit groups, educators and students of all ages to monitor the impacts of climate change on plants and animals in the United States (http://www.usanpn.org/). There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.

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