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Perspective

Conservation of herpetofauna in northern landscapes: Threats and challenges from a Canadian perspective

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ABSTRACT

The scientific community is increasingly aware that many amphibian and reptile species have experienced dramatic decreases in abundance and distribution, with at least 43% of amphibian species exhibiting population declines and 19% of all reptile species threatened with extinction since 2000. Species suffer from a suite of threats including habitat destruction, alteration and fragmentation, introduced species, over-exploitation, climate change, UV-B radiation, chemical contaminants, diseases and the synergisms among them. These worldwide threats are also present in northern landscapes and in Canada in particular where 20 amphibian and 37 reptile species are listed as at-risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In fact, with more than 80° in longitude and 40° in latitude, Canada presents both a diversity of northern ecosystems and a range of threats to its herpetofauna at least equal to other countries. The physical scale of Canada, its varied climate, its economic realities, and the legislative differences among levels of government and their respective mandates have long challenged traditional approaches to conservation. However, science and stewardship are leading forces in the conservation of emblematic species at risk in Canada and can serve to inform best practices elsewhere. Recent advances in data analysis and management have transformed our understanding of populations in northern landscapes. Canadian amphibians and reptiles, most of which are cold-adapted species at the northern edge of their distribution, can serve as case studies to improve modeling of population dynamics, create cogent, science-based policies, and prevent further declines of these taxa.

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1. Introduction

Modern amphibians and reptiles are the oldest extant groups of terrestrial vertebrates. They present vast diversity with more than 6800 amphibian species and 9700 reptile species currently known. These two groups occupy every terrestrial habitat apart from Antarctica and the high Arctic, but despite this they are in serious decline worldwide (Gibbons et al. 2000; Green, 2003; Wake, 2012; Böhm et al., 2013). According to the *International Union for Conservation of Nature* (IUCN), amphibians and reptiles have the highest proportions of threatened and Data Deficient species, and the lowest proportion of Least Concern species among vertebrate groups (Baillie et al., 2010; Böhm et al., 2013). Indeed, at the turn of the 21st Century, at least 43% of amphibian species showed evidence of decline, 32.5% were globally threatened, 37 species were confirmed extinct, with an additional 88 species also possibly extinct. Similarly, 19% of all reptile species were identified as threatened with extinction, including 12% that were critically endangered and 41% that were endangered. In Canada, these numbers are even higher with 42% of amphibian and 77% of reptile species currently diagnosed as at-risk by the Committee on the Status of Endangered Wildlife (COSEWIC).

There is now ample evidence of the vulnerability of northern ecosystems to climate and land-use change, increased human presence, and increased resource exploitation (Sala et al., 2000; Walther et al., 2002). Many northern species are at the periphery of their distribution in northern landscapes and peripheral populations may exhibit greater sensitivity to environmental changes because of reduced genetic variability (García-Ramos and Kirkpatrick, 1997). In Canada, where most amphibian and reptile species are at the northern limit of their range, understanding population declines is thus critical (Lesica and Allendorf, 1995; Eckert et al., 2008). Such knowledge will potentially help with design and implementation of conservation measures in other countries and benefit governmental and conservation agencies worldwide, especially in jurisdictions whose climate and governance are comparable to Canada. In this perspective article, we first discuss the different levels of governance in Canada, which like other countries may impede the success of conservation initiatives. We then present the threats and challenges associated with amphibian and reptile species in northern landscapes, allowing for better recommendations and adapted conservation measures in these areas.

2. Species conservation and legislation

Legislation is, or should be, the cornerstone of any effective framework for the conservation of endangered and threatened biota, including herpetofauna (amphibians and reptiles). Such legislation is typically complex and must represent a workable compromise between conserving wildlife and safeguarding the legitimate interests of landowners and other stakeholders. In Canada, the long and difficult political process (Freedman et al., 2001) that culminated in the *Canadian Species at Risk Act* (*SARA*) being passed into law in 2003 produced a bill with tangible strengths, but also with many weaknesses and abundant compromises (Mooers et al., 2010). For example, while 7 of the 8 turtle species in Ontario are considered to be at risk, only the endangered Wood Turtle (*Glyptemys insculpta*) has an approved provincial Recovery Strategy and Government Response Statement under which the species' habitat is regulated. Moreover, *SARA* applies mainly to federal lands and waters, and thus is unable to override numerous other statutes, including aboriginal land claim agreements. *SARA* is thus a classic Canadian compromise, relying on federal/provincial/territorial co-operation and good will. This compromise is both its greatest strength and its most profound vulnerability. Indeed at the federal level, critical habitat has thus far been identified for only one freshwater turtle, the Nova Scotia population of Blanding's Turtle (*Emydoidea blandingii*).

SARA has three primary components: assessing conservation status and legal listing of wildlife species at risk, planning and fostering actions to promote recovery of listed species, and ensuring compliance with the law's intentions by imposing prohibitions, penalties and other measures. In practice, formulation of remediation measures under *SARA* has been slow and implementation of recovery strategies for amphibians and reptiles has been even slower. The assessment provisions, though, remain effective and COSEWIC, which evaluates species' conservation status and makes recommendations for listing, is probably *SARA*'s most operational component. Such assessments are rigorous, consensual and proactive and based on the system of criteria established by the IUCN (Powles, 2011). To date, most species of amphibians and reptiles in Canada that might be at some risk have been assessed at the national level at least once (Mooers et al., 2010). However, assessment without remediation only suggests the potential for conservation rather than any real conservation.

In the northern hemisphere countries like Canada, amphibians and reptiles are most diverse and abundant at southern latitudes where the climate is warmest, but where anthropogenic development is typically intensive. With relatively few species' ranges extending as far north as the boreal forest in Canada (Cook, 1984), the geographic confluence of humans and herpetofauna in the south translates into many threats to the persistence of amphibians and reptiles (Green, 1997; Seburn and Bishop, 2007). Fortunately, the World Conservation Union and Conservation Measures Partnership (IUCN) has developed a threat classification system (Salafsky et al., 2008) providing a standardized way of classifying threats facing these species. The impact of each threat is an estimation of the interaction between the scope and severity of the threat to a species, which is generally based on expert opinion and rated in terms of its estimated proportional contribution to reduction in the species' total population size (Master et al., 2012). For instance, when applied to the 11 amphibians of conservation concern in British Columbia, the threat of invasive species emerges as having a high or very high impacts on 3 species, transportation corridors have a moderate to high impacts on 6 species, and agriculture, biological resource use (i.e. logging) and pollution have moderate impacts on nine species. Standardized threat assessments are useful as they identify species-specific high impact threats as well as common threats that affect multiple species. Although useful, this method should be applied with caution as much of the impact assessment may be based solely on expert opinion rather than on quantitative population data. Many elements are lacking for the procedure to be truly effective, such as baseline population data, quantification of the impacts of threats, and monitoring following conservation actions. The absence of such information poses significant barriers to the effective management of herpetofauna in Canada.

3. What are the threats in northern landscapes?

3.1. Habitat loss and fragmentation

As is true worldwide, habitat loss and fragmentation are likely the most serious threats to herpetofauna in northern areas. For species of amphibians and reptiles, the costs of fragmentation are often twofold: degradation or complete loss of key focal habitat patches needed for foraging and reproduction, and disconnection of seasonally crucial habitat elements, including hibernating sites. Reduction or elimination of movements of individuals among patches, in turn, affects the structure and dynamics of populations (Smith and Green, 2005). This is particularly problematic for populations of reptiles and amphibians that live at the edge of their global range in Canada where required vegetation, wetland types and thermal regimes may be limited and populations inherently small.

In Canada, historical and current natural resource-based industries have severely altered the country's landscapes. Based on the IUCN threat categories, industrial threats to the Canadian herpetofauna originate from agriculture, energy production and mining, forestry, and water management. As of January 2013, for 21 amphibian species for which there are COSEWIC status assessments (http://www.cosewic.gc.ca/eng/sct0/index_e.cfm#sar), identified habitat threats included agriculture in 10 cases, forestry in 9 cases, mining in 3 cases, and water management in 3 cases, whereas among 37 reptile species, agriculture was cited as a threat in 17 cases, water management in 7 cases, mining in 4 cases, and forestry in 4 cases. Threats from industrial activities do not act in isolation, and are best addressed and assessed at the landscape scale. For instance, the Alberta Biomonitoring Institute (ABMI) uses an integrated approach based on cumulative effects of human activities on landscapes; using GIS layers from 2007, ABMI reported that 29.1% of Alberta had been altered by human activities (http://www.abmi.ca/abmi/home/home.jsp).

The identity and severity of threats to habitat varies across Canada; however, lack of information on the location, size, and health of populations represents a pervasive and fundamental challenge for conservation. A subset of regions (e.g., grasslands of Manitoba, Saskatchewan and Alberta; southern interior and coastal regions of British Columbia; southwestern Ontario) stands out as "hot spots" of amphibian and reptile diversity and species at risk. Grasslands, including those in western Canada, originally comprised more than 40% of the Earth's land mass, yet have suffered the greatest conversion to human use and remains the planet's least protected biome (Hoekstra et al., 2005; Gallant et al., 2007). Approximately 20% of Canadian amphibians and reptiles inhabit grasslands; the majority of these species are at-risk, with most of the remaining species lacking sufficient information for assessment. Recent dramatic increases in activity of the oil and gas industries throughout the Canadian prairies are expected to further jeopardize populations of threatened species. To date, conservation efforts on the prairies, and elsewhere in Canada, have focused on the restoration of individual wetlands or protection of single species, often with some success; however, in a large, diverse country like Canada, a multi-species approach integrating a network of sites seems most promising in terms of costs and outcomes (see http://www.multi-sar.ca/ for a description of the Multiple Species at Risk program in the Milk River watershed of southeastern Alberta).

3.2. Roads

Roads threaten herpetofauna through loss and fragmentation of habitat, as well as direct mortality. Paved and unpaved roads in Canada currently span 1.04 million km (CIA, 2012). In southern Ontario, road networks have expanded tremendously in the past 50 years and are now the most extensive in Canada. Development of northern areas for natural resource extraction will soon expand road networks into isolated areas (Ministère des ressources naturelles du Québec, 2011; Ontario Ministry of Infrastructure and Ministry of Northern Development, Mines, and Forestry, 2011). Amphibians and reptiles exhibit traits that make them particularly vulnerable to direct and indirect impacts of roads. These traits include the use of different habitat types at different life stages, vulnerability to desiccation, low dispersal ability, and strong site fidelity (Pough et al., 2001). As a result, these taxa cannot easily counteract population isolation created by habitat fragmentation and high mortality (Lesbarrères et al., 2003).

Road construction itself directly affects herpetofauna through habitat loss and mortality. Many studies report negative effects of traffic intensity, as well as species-specific and sex-specific differences in mortality patterns (Fahrig et al., 1995; Steen et al., 2006; Row et al., 2007). However, mortality rates are often difficult to quantify due to poor detection of live and dead individuals on roads, lack of standard methods, and timing of surveys (Langen et al., 2007; Mazerolle et al., 2007; Brzezinski et al., 2012). Additionally, artificial light and traffic noise disturb amphibian and reptile behaviour on roads and alter their movements near roads (Mazerolle et al., 2005). Runoff of sediments, oil, heavy metals, and salt (used as a de-icing agent on Canada) from road surfaces into roadside ponds negatively impact embryonic and larval survival and development (Sanzo and Hecnar, 2006). Roads also indirectly influence herpetofaunal populations by facilitating the expansion of certain invasive animal and plant species (Seabrook and Dettmann, 1996; Jodoin et al., 2007). For instance, certain invasive plants thrive in roadside brackish conditions and disrupt wetland hydrology and communities (Jodoin et al., 2007). Even roads that are abandoned or closed to traffic can still exert negative effects on some herpetofauna (e.g. salamanders), although this requires further investigation for other groups (Semlitsch et al., 2007).

3.3. Pesticides and other contamination

COSEWIC lists 14 amphibians and 13 reptiles as being threatened by at least one form of pollution, including road-based contaminants (Hecnar, 1995; de Solla et al., 2007; Prugh et al., 2010). Exposure to environmental contamination has been quantified in Canadian herpetofauna but rarely have effects been measured. We do know that organochlorine pesticides, especially metabolites of dichlorodiphenyldichloroethylene (DDE), have been documented in amphibians at concentrations above those known to negatively affect their development (in areas of historically heavy use including national parks like Point Pelee in southwestern Ontario; see Russell et al., 1995). Endosulfan, another organochlorine pesticide, is highly toxic to amphibians, and one of a very persistent class of chemicals on the market in Canada. It has only been phased out in Canada within the past five years (Health Canada PMRA, 2011).

Industrial-based contaminants such as polychlorinated biphenyls (PCBs) and related dioxins and furan have been associated with reduced hatching success and deformities in snapping turtles in the Great Lakes (Bishop et al., 1998). Fire-retardant replacements for PCBs including polybrominated diphenyl ethers and perfluorooctanesulfonic acid (PFOs) have also been detected in snapping turtles from the Canadian Great Lakes at some of the highest levels detected in wildlife anywhere (de Solla et al., 2007, 2013) although, as yet, effects have not been measured.

Herbicides are among the most widely used pesticides in Canada. For example, glyphosate-based herbicides are used in both agriculture and forestry, and the development of glyphosate-resistant crops has resulted in increased glyphosate application over the last decade (Beckie et al., 2011). Although large-scale experiments in New Brunswick, Canada suggest that applications of some common glyphosate-based herbicides, including VisionMax™ and WeatherMax®, have little effect on amphibian growth, development or survival (Edge et al., 2011, 2012), these results conflict with small-scale toxicity studies done in laboratory conditions and indicating that glyphosate concentrations similar to those measured in the large-scale experiments are toxic (Relyea and Jones, 2009). These examples emphasize the need to improve our understanding of risk assessment for amphibians and reptiles by conducting studies in Canadian ecosystems and with native species.

3.4. Infectious diseases

Infectious diseases are present in all ecosystems but can sometimes threaten the long-term persistence of host populations. For example, recent changes in land cover and climate have been linked to emerging patterns in the occurrence and severity of infectious diseases in wild vertebrate populations throughout the world (Bielby et al., 2008). Conditions that compromise host immune defences can intensify or prolong the impacts of pathogens. Consequently, environmental stressors, such as contamination and altered environmental conditions interact with pathogens to alter disease dynamics and potentially lead to the collapse of host populations (St-Amour et al., 2008; Echaubard et al., 2010). Similarly, the spread or translocation of novel species or strains of pathogens into new geographic areas, including northern territories (Schock et al., 2010), can threaten host populations or entire species with no innate immune defences to a pathogen (e.g., Lips et al., 2006). Many amphibian pathogens show marked differences across host species in the levels of disease triggered by infection (Schock et al., 2009; Hoverman et al., 2011; Martel et al., 2013) and conservation challenges develop when widespread, resistant species harbour pathogens that cause lethal infections in rare host species (Smith et al., 2009). For example, some Canadian amphibian species, such as the American Bullfrog (*Lithobates catesbeianus*), may act as reservoirs of pathogenic strains of *Batrachochytrium dendrobatidis* that affect other species (Schloegel et al., 2012). Sublethal effects of pathogens are also important because they can affect growth rates, predator avoidance, fecundity rates, and competitive interactions in amphibians (Kiesecker and Blaustein, 1999; Garner et al., 2009; Kerby et al., 2012).

Amphibian pathogens documented in Canada include ranaviruses (Greer et al., 2005), the chytrid fungus *B. dendrobatidis* (Ouellet et al., 2005; Schock et al., 2010), opportunistic bacteria (e.g. *Aeromonas*), water molds (e.g. *Saprolegnia*), as well as a variety of relatively poorly understood parasites including trypanosomatids (Woo, 1969; Barta and Desser, 1984), and helminths, such as tapeworms and lungworms (McAlpine, 1997; Oluwayemisi et al., 2008). Mass die-offs due to pathogens that have been documented in Canadian amphibian populations have primarily involved ranaviruses (e.g., Bollinger et al., 1999; Greer et al., 2005; Schock et al., 2009) but the true extent of die-offs due to pathogens, including ranaviruses, is likely under-reported. A recently discovered species of pathogenic chytrid fungus in The Netherlands, *B. salamandrivorans*, and the narrative of how the authors came to identify the pathogen (Martel et al., 2013), underscores two broader issues associated with identifying pathogen-related threats to amphibians: gaps in knowledge about pathogen biology generally, and widely used diagnostic techniques that fail to detect the responsible pathogen. It is unclear how widely distributed *B. salamandrivorans* is, but attention in Canada is warranted given the serious level of disease caused in some amphibian species, its low thermal preferences relative to *B. dendrobatidis*, and how readily it can be missed diagnostically (Martel et al., 2013).

Successful management of wildlife pathogens requires knowledge of pathogens as well as properly funded regulatory mechanisms that prevent pathogen translocations (intra- and internationally). Importation of amphibian pathogens (or tissues that might contain them) into Canada is regulated by the Canadian Food Inspection Agency (http://www.inspection.gc.ca/), while importation of wildlife is regulated by a combination of federal and provincial/territorial agencies, depending on whether the species is recognized as a threatened species under legislation such as the federal *Species At Risk Act*. Accidental spread of amphibian pathogens within Canada is loosely managed though province-specific best practices and guidelines (e.g., British Columbia – http://www.env.gov.bc.ca/wld/BMP/herptile/HerptileBMP_final.pdf). However, management and intervention surrounding amphibian diseases is minimal relative to wildlife diseases with the potential to infect humans (i.e., zoonotic) or diseases that affect livestock or wildlife species that humans routinely consume for food.

3.5. Climate change

Climate is a pervasive factor that will shape the future of amphibian and reptile populations in northern landscapes indirectly through interactions with anthropogenic disturbances and natural habitat features discussed above, and directly, through effects on their biology because of their ectothermy and migration patterns. Climate change is predicted to cause increases in mean temperatures of 1.5–2.5 °C in summer and 2–4 °C in winter for six major Canadian cities over the next 50 years (compared with a 1971–2000 baseline) with even higher values in the Arctic (Feltmate and Thistlethwaite, 2012). Such changes could have both positive and negative consequences for herpetofauna. On the positive side, a warming climate should allow an earlier start to breeding seasons, faster growth rates of embryos, larvae, and juveniles, and an overall northward range expansion for many species, all of which could create more robust Canadian populations of many species. For instance, the present northern ranges of turtle species seem to be mainly limited by insufficient heat days to hatch eggs (Bobyn and Brooks, 1994) and hence global warming could allow northward expansion of turtle species in Canada. On the negative side, the comparable southern range limits of these and other herpetofauna may be adversely affected by a warming climate, perhaps more likely to affect U.S. or Mexican populations than Canadian. Local populations will also have to deal with multiple possible consequences of a warmer climate that could include altered availability of food, changes in water availability (due to altered precipitation or evaporation), availability of suitable egg-laying or overwintering sites, northward invasion of diseases and parasites, and changes in habitat availability as a result of altered land-use for human agriculture (Storey and Storey, 2012). The thermophysiology of some species will also be compromised; e.g. temperatures at or above the critical thermal maximum require heliotherms to retreat into shaded sites and thereby reduce the time available for foraging. Indeed, in montane areas, this plus the upward movement of lowland species appear to have contributed to the recent extinctions of some viviparous lizard species at high elevation sites in México (Sinervo et al., 2010). Reduced snowpack may also lower the insulation that is crucial to winter survival for terrestrially hibernating species, reduce the number and size of meltwater ponds for spring-breeding amphibians, and decrease the hydroperiod of wetlands thereby affecting larval development and survival (the latter has been documented for *Ambystoma tigrinum*; McMenamin and Hadly, 2010). Finally, climatic oscillations select for vagility and generalism (Dynesius and Jansson, 2000); hence, a lack of these attributes and insufficient time for adaptation could potentially marginalize or extirpate selected Canadian species, particularly if they are already geographically restricted. For example, in Eastern Ontario, relic populations of Wood turtles (*Clemmys guttata*) are restricted to isolated bogs (Cook et al., 1980); these will either prosper or die out depending on the cumulative effects of climate change on their local environment. However, many reptile and amphibian species living in Canada, such as Wood frogs (*Lithobates sylvaticus*) and Common garter snakes (*Thamnophis sirtalis*) already experience wide seasonal variations in environmental conditions and have large geographic distributions. So, whereas local populations may suffer in some cases, the overall impact on widely distributed species across Canada may be minimal. Hence, many Canadian reptiles and amphibians may be more successful at adapting to a changing climate than tropical species, provided that they can disperse and modify their ranges to compensate.

4. Addressing conservation challenges: distribution, communities, populations

4.1. Phylogenetic perspectives

Phylogeography, the study of historical and evolutionary processes that underpin contemporary genealogical patterns, can inform conservation policy and implementation. It provides insights into the impacts of mountains, rivers, sea levels, and vegetation shifts on rates and patterns of species diversification, and can reveal cryptic diversity. Over the last three decades, a sizeable literature has helped to quantify the effects of Pleistocene range fragmentation and post-glacial population dynamics on evolutionary relationships in temperate species (e.g. Austin et al., 2004), in turn providing key inputs into conservation strategies for listed species (e.g. Moritz, 1994), primarily in the prioritization of focal populations. In Canada, over 50% of the approximately 100 amphibian and reptile taxa have been included in phylogeographic surveys, although most Canadian locales are under-sampled relative to the USA, particularly towards northern range limits. Sampling biases often compromise our ability to establish the conservation value of Canadian populations in a range-wide context. An additional bias is the small number of loci employed in most studies, insufficient to capture genome-wide genetic diversity of focal species. Phylogenomic and Next-Generation Sequencing surveys of DNA sequences can address this deficit encompassing both putatively neutral and adaptive markers from across focal species' genomes (Diepeveen and Salzburger, 2012). This will provide insight as to whether recognized lineages actually reflect major axes of adaptive diversity or evolutionary potential in Canada, and will improve our understanding of processes that have produced present-day patterns. Detailed experiments and genetic surveys of secondary contact zones will reveal whether they are important in completing speciation (e.g. via reinforcement) or in generating new species (e.g. homoploid speciation) and thus merit conservation consideration. Finally, analytical advances like Approximate Bayesian computation and ecological niche modeling will help to evaluate how herpetofauna responded to past climate change and may respond in the future (Row et al., 2010, 2011).

4.2. Spatial and temporal dynamics of amphibians

One of the greatest challenges affecting the status assessment and conservation of Canadian herpetofauna is a lack of basic knowledge of species' distributions, and their spatial and temporal dynamics. A consequence of the vast size of the country, combined with a relatively small human population is that most areas beyond Canada's southern fringes have been inadequately surveyed for amphibians and reptiles, if at all. This is especially true in the northern territories and the northern portions of most provinces where many species reach their range limits. As a result, range maps are crude estimates at best and survey efforts in remote areas of Canada typically reveal new locality records and range extensions. An understanding of the details of geographic distribution and spatial (meta)population dynamics is needed to avoid the Wallacean Shortfall (species loss or decline before distribution and species geographic variation is even known; Lomolino et al., 2010) and is also fundamental to species assessment and conservation. Most species of amphibians (87%) and reptiles (90%) occurring in Canada also reach their northernmost range limits in the country with many extending well into the Boreal Forest or even reaching the Tundra Biome. Moreover, most Canadian species are cold-adapted, early post-glacial invaders (Bleakney, 1958; Seburn and Bishop 2007) making their distributions and dynamics interesting not just at the species level but for understanding factors that shape geographic ranges of amphibians and reptiles in general. Also, theory predicts that the spatial dynamics of peripheral species are more complex than in central portions of the range (Gaston, 2003). The harsh northern conditions affecting Canadian species provides an ideal system for empirical tests of theoretical predictions of distribution and spatial dynamics of ectothermic vertebrates especially considering changing climate. Despite growing recognition of the importance of scale, a lack of large-scale, long-term studies hampers our efforts to understand the spatial and temporal dynamics of amphibian and reptile populations and to accurately assess individual species statuses in Canada. Although the variable abundance inherent in most populations makes trend detection difficult, it can be done with sufficiently long time-series of accurate census data (Hecnar and M'Closkey, 1996; Greenberg and Green, 2013). Presence-absence studies, however, can reveal the underlying dynamics and spatial structure of populations at larger scales (Hecnar and M'Closkey, 1996). For instance, Fowler's Toads, *Anaxyrus fowleri*, are found only along the northern shore of Lake Erie in extreme southern Ontario, where they are threatened by loss and degradation of their shoreline beach and dune habitat. Recently, their declining abundance has been linked specifically to the loss of breeding habitats due to continuous spread of the invasive common reed, *Phragmites australis* (Greenberg and Green, 2013). Additionally, application of the metapopulation concept to understand amphibian spatial dynamics holds great promise but its usefulness remains largely untested. Ultimately, trends reflect species-specific responses to a legacy of human and natural landscape changes and there is still a need for basic inventories and long-term, large-scale studies for most Canadian species.

4.3. Species focus: common versus rare

What does abundance tell us about extinction risk and conservation priorities? Although it seems obvious that rare and/or declining species are in greater jeopardy than common and widespread species, many biological and political/economic factors can influence likelihood of extinction (see Section 2). In fact, there is a growing concern regarding the fate of common species because high abundance does not always reduce risk (Gaston, 2010). Common species also contribute more to ecosystem function than do rare, spatially-confined species. Indeed, common species may also be key to survival of many specialized, rare taxa. Reptiles are the vertebrate taxon with the highest percentage of at-risk species in Canada and provide an opportunity to investigate how our approach to maintaining biodiversity works, where it fails, and how political pressure to limit SARA is as pervasive and unrelenting as Darwinian selection. For example, many reptile species reach their northern range limits in Canada. Hence, many governmental attempts to reduce the number of at-risk species rest on the largely untested notion that "peripheral" populations can be "rescued" by immigration and should thus be overseen by other jurisdictions. Paradoxically, stakeholders often argue that common, widespread species are still secure and should not be listed even if declining. They argue that we should wait until species meet the quantitative criteria of small, restricted declining populations before we act. SARA and provincial endangered species acts have assessment processes that rely on best available evidence and eschew stakeholder biases and economic and political consequences. One way to rethink conservation is to protect common or "keystone" species, thus simultaneously helping to protect ecosystems and other rare or at-risk species that depend on common species (Gaston, 2010).

4.4. From descriptive habitat selection studies to fitness estimates

Although hundreds of habitat selection studies are published annually, most of them are descriptive, only compare habitat use to habitat availability, are conducted at small spatial scales, and are not replicated. Nevertheless, it is often possible, and almost always desirable, to go beyond simple descriptions of habitat association. In fact, making the link between habitat selection and fitness is paramount for conservation (Millar and Blouin-Demers, 2012). Failing to do so can lead us to define habitats for conservation (e.g. critical habitat under *SARA*) or to create wildlife reserves that are not suitable for target species because we have not identified source and sink populations. We propose the adoption of approaches that link habitat selection to fitness, and their application at larger spatial scales than most current studies cover. While documenting lifetime reproductive success is a monumental task for most reptiles, more proximal measures of fitness, such as growth rate or physiological performance (Dubois et al., 2009), may prove suitable until we reach our ultimate goal of linking fitness to habitat selection patterns. Ecophysiology, for instance, can serve to bridge this gap in ectotherms (Blouin-Demers and Weatherhead, 2008). In several reptile species, habitat selection, via its impact on thermoregulation, improves behavioural performances related to fitness (e.g. locomotion speed, food transit time). Ecophysiological approaches can quantify performance improvements resulting from habitat selection and compare mean performance in various habitats. Using energetics to study how variation in habitat selection affects fitness also offers a promising next step (Dubois et al., 2008) as we await the means to obtain more inclusive measures of fitness for reptiles (i.e. lifetime reproductive success and survival).

5. Conclusion: the future of herpetofauna conservation in northern landscapes

A hopeful future can only grow out of awareness, understanding and accommodation of the past. Success necessitates that we acknowledge that most northern amphibian and reptile species live on the periphery of their geographic ranges, and that most populations have been here only briefly in evolutionary time. Climate and habitat change are not new to our fauna, but the nature of present day disturbances (e.g. climate, habitat, invasive predators/competitors, collection, pollution) and their scale (both temporal and spatial) have fundamentally changed; what was previously experienced over generations at the population level is now in many species experienced in the lifetime and ambit of single individuals. This change has a profound impact on the ability of species to accommodate those disturbances, and on our ability to interpret and apply the "rules" that govern "edge-of-range" populations, as we search for conservation solutions. In Canada's "species-at-risk hotspots", solutions will differ between those areas where faunal diversity and human development are congruent, and thus the latter threatens the former (southern Ontario, southern British Columbia), and areas where faunal diversity and threats to it arise largely by accident of history and geography (Nova Scotia). There is clearly no "one size fits all" solution either within a single nation or among countries.

Although public policy frequently embraces the trend of rapid urbanization, the greatest large-scale industrial challenge that Canadian herpetofauna face is not urban, but actually agricultural. In fact, public policy and the legislation arising from it present significant risk to future herpetofaunal conservation. Pressures for legislative change at municipal, provincial and federal levels that encourage development and economic activity, also increase vulnerability of already compromised populations. Canada's (and indeed, the world's) obsession with unending economic growth has contributed to diminished science funding, diluted protection of aquatic ecosystems, "streamlined" environmental impact assessment criteria, and increased uncertainty around the future of species-at-risk acts and regulations, both provincial and federal, which threaten our biodiversity and erode public confidence. Choosing the appropriate scale and intensity of conservation in the future, and finding the right mix of science, legislation and stewardship will not be without controversy. Although the sheer magnitude of challenges to many species necessitates a growing role for citizen science, science will remain key to finding conservation solutions, and to furthering our understanding of the dynamics and evolutionary potential of edge-of-range populations. Exploration and description of genetic structuring in species on fine spatial scales will help resolve the distribution and value of diversity within species, and guide conservation and recovery efforts. It is difficult to predict what new analytical tools will be developed, but recent advances have transformed our understanding of populations by allowing us to reconstruct population histories, source/sink population dynamics and responses to past environmental change. It is essential that we apply these tools across far more populations and species. This in turn will guide us in modeling and managing the dynamics of amphibian and reptile populations in the future and, most importantly, in choosing the appropriate spatial and temporal scales at which to do so. If we misjudge the scale of the problem, our solutions are likely to be at best ineffective and at worst counter-productive; if we choose the right scale, the future is decidedly less bleak for northern herpetofauna.

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