

Herpetology in the North: a review of past, present and future herpetofaunal research and management in Alaska.

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Joshua T. Ream
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Introduction

Many Alaska residents are unaware that amphibians and reptiles (collectively herpetiles) exist in the north, which is not surprising given that so little is known about these species in the state (Anderson 2004). Some who have lived their entire lives in Alaska have never seen an amphibian on the landscape (Anderson 2004) despite their prevalence in many areas. Indeed, one lifelong resident of Kenai was astonished to learn that hundreds of frogs had been counted from several nearby wetlands, having previously declared, “We don’t have frogs in Alaska. I’ve never seen one.” This conclusion may derive from the fact that frogs are not typically sought after, that they are small and can easily go unnoticed, their calls are often mistaken for those of waterfowl (such is the case with Wood Frogs) and that they tend to frequent areas lacking fish. In actuality, six amphibians reach the northern limits of their natural ranges in Alaska, along with four sea turtles occasionally found in near-shore ocean areas (MacDonald and Cook 2007).

Herpetiles, which are commonly thought to inhabit more temperate and tropical climates, are indeed present in the far north, and in some cases, they occur abundantly on the landscape. Though species diversity for this group is somewhat limited compared to sister states to the south, several species have developed impressive adaptations for survival in the harsh climactic conditions of the arctic and subarctic reaches of North America. Their ecological importance should not be underestimated, as they often fill critical niches within faunal communities. This paper will explore the past, present, and future of the herpetological discipline in Alaska, especially as it pertains to our understanding of herpetofaunal species and effective means for management and conservation of their populations.

Both amphibians and reptiles are found North of the Arctic Circle, and to the southernmost landmasses of the southern hemisphere (Hodge 1976), excluding Antarctica. Distributions of these species extend farthest north where summers are the longest and warmest, yet Siberia and Canada have some of the coldest winter temperatures on earth, suggesting that cold may not be the limiting factor for these species, and that summer warmth and the existence of suitable hibernacula are critical (Hodge 1976). Herpetiles in Asia and North America are found farthest north where the major northward flowing rivers bring a somewhat moderate influence, such as the McKenzie River in Canada’s Yukon (Hodge 1976).

The northern limit may also be the latitude at which larvae and embryos fail to develop during one summer (Hodge 1976). For amphibians, the northern distribution is closely correlated with areas that exhibit 100 days without killing frosts, allowing for egg deposition, larval development and metamorphosis (Hodge 1976). In the Pacific Northwest, species diversity is greatest in northern California and Oregon (n=66 and 64 species, respectively), with the Klamath-Siskiyou herpetofauna being especially diverse (Bury and Pearl 1999), and the lowest diversity occurring in the Yukon Territory (n=4 species)(Olson 2009). A table borrowed from Olson (2009), representing the herpetofaunal diversity of this region, is included as table 1 in the appendix.

Generally, amphibians are more tolerant of cold and more dependent on water than reptiles (Hodge 1976) resulting in this group being more widely represented in Alaska. Only the extant Wood Frog, the Common Frog (an old world species whose ancestors presumably crossed the Bering Land Bridge during the Tertiary Period and gave rise to the Wood Frog), and the Siberian Salamander have adapted to the climatic conditions of the far north (latitudes above the arctic circle), by shortening their larval periods (Hodge 1976). The Wood Frog has the highest rate of larval development at any given temperature of any North American frog, it is the first to breed in the spring and all morphologic stages can tolerate minimum temperatures that are lower than most other amphibian species (Hodge 1976). Several species of salamander do overwinter as larvae in temperate SE Alaska, but only survive if pools and ponds do not freeze to the bottom (Hodge 1976).

Permafrost appears to restrict northward dispersal of many herpetiles, especially reptiles such as the garter snake whose northern range limit barely reaches regions with discontinuous permafrost (Hodge 1976). In the arctic regions of Scandinavia, two reptiles are common (the Viviparous Lizard and the European Adder), but permafrost is found only in the extreme northern reaches (Hodge 1976). At least six other herpetiles in Scandinavia have northern limits near the Arctic Circle and Gulf Stream occasionally carries Leatherback Sea Turtles to the coast of Norway north of the circle (Hodge 1976).

The Siberian Salamander, *Hynobius keyserlingi*, has an extensive range throughout northern Eurasia and is found farther north than any other salamander in world (Hodge 1976). Hodge (1976) suggests that this species could conceivably have reached North America during periods of intercontinental connectivity and that remnant populations may exist, though none have been found to date. The Wood Frog is North America's only known herpetile with a range well north of the Arctic Circle. A species of chorus frog is the only other species known to come close on the North American continent (Hodge 1976).

The Wood Frog is probably the best known herpetofaunal representative in Alaska as it occurs relatively abundantly throughout its range, which extends over most of the state, well into the Brooks Range and possibly onto the North Slope. Tadpoles of this species were reported in the spring of 2013 approximately 80 miles south of Barrow – a report that has yet to be validated but which would represent the northernmost record to date. All five of Alaska's other native amphibians occur within the temperate rainforests of southeast Alaska and Prince William Sound. There are also two introduced anurans that, for better or for worse, now call Alaska home. Additionally, several other amphibians are considered enigmatic given questionable reports and nearby ranges. All of these amphibians are listed in Table 2 of the appendix.

Justification

I have established that amphibians occur in Alaska but why do they warrant attention and directed management? Amphibians are among the taxonomic groups that are typically considered non-game in the arctic (though they do have importance as consumptive species elsewhere) but they are known to provide a number of significant ecosystem services. They

help to regulate insect pests, they are prey species for a number of animals, they are considered excellent indicators of environmental health and they play an important role in human history and modern indigenous and non-indigenous cultures.

Amphibians have successfully exploited most terrestrial habitats while remaining closely tied to water (Vitt and Caldwell 2009). Despite their evolutionary success, declines and developmental malformations have been prominent in scientific literature and the popular press for the past two decades. Amphibians have a number of characteristics that make them excellent bio-indicators, especially unprotected permeable skin and a lack of long-range dispersal capability (ADF&G 2006, Lannoo 2005, NatureNorth 2008). Their aquatic life histories are seen as valuable indicators of environmental health and they may be the first taxonomic group to respond to environmental degradation (Anderson 2004). Many of these species also serve as indicators for declines that are co-occurring in other nongame species (Lannoo 2005).

The First World Congress of Herpetology in 1989 acknowledged that a pervasive theme resonated throughout the proceedings: frogs, toads and other amphibians were in trouble around the world (Anderson 2004). The Global Amphibian Assessment in 2004 found that nearly one third of the world's 6,000+ species of frogs, toads and salamanders face extinction, a figure that is far greater than that of any other group of animals. Amphibian extinctions worldwide are increasing at an alarming rate (Blaustein et al. 1994, Houlahan et al. 2000) and some suggest that this may be hundreds or even thousands of times the background extinction rate (McCallum 2007).

Nearly half of all known amphibian species have experienced population declines, making them one of the most threatened vertebrate taxa, more so than birds and mammals (Alford and Richards 1999, Stuart et al. 2004) and this is even occurring in relatively undisturbed habitats and protected areas worldwide (Lips et al. 2006). In specific regions, amphibian losses are more severe than in other taxa (Stuart et al. 2004, Pounds et al. 1997, Pounds et al. 1999), including the American and Canadian west, where the population sizes and ranges of a high proportion of species have decreased in the last sixty years (Blaustein and Wake 1990, Weller and Green 1997). From an evolutionary prospective, amphibians may be part of a sixth major extinction event (Wake and Vredenburg 2008). These scenarios necessitate a comprehensive understanding of amphibian ecology (Bull and Hayes 2001), especially since there appears to be no single cause for their declines (Blaustein et al. 1995) but rather a complex network of interactions.

Several compounding factors are likely responsible for these declines (Pounds et al. 2006) including habitat degradation and loss (Brooks et al. 2002), introduced species (Adams 1999), pollution (Dunson et al. 1992), contaminants (Relyea et al. 2005), pathogens (Daszak et al. 2003), and climate change (Pounds and Crump 1994, Pounds et al. 1999), the latter of which is likely to exacerbate the other threats and pose a major challenge for conservation. The general trend in amphibian extinctions suggests catastrophic future losses and uncertain recovery potential (McCallum 2007). Information on the impacts of change on amphibians can often

serve as a proxy for declines occurring in other nongame species (Lannoo 2005) which lends to their status as the proverbial canary in the coal mine.

The National Park Service identified amphibians as a taxonomic group of concern for Southeast Alaska in April of 2000 while the Alaska Department of Fish and Game confirms that historical information is currently fragmented and must be obtained to inform the development of occupancy-based protocols. Other problems identified by ADF&G include: 1) lack of information on taxonomic and evolutionary relationships, distribution, abundance, trends, habitat associations and life history of AK populations, 2) lack of information to understand the impacts of climate change viability, 3) lack of information about occurrence, frequency, causation and magnitude of amphibian deformities, 4) populations are not monitored in a systematic fashion, 5) Alaska is potentially experiencing a loss of endemic taxa, distinct populations, and unique lineages, 6) Alaska is experiencing less snow, greater ground freeze, great UV radiation, drought expansion, glacial uplift and the occurrence and spread of chytrid fungus.

Unfortunately, amphibians living in marginal habitat show a high degree of population fluctuation (Heyer 1994) and therefore long term monitoring is essential to overcome the fluctuations and see larger trends. In Alaska this situation is coupled with the difficulty and expense of monitoring large expanses of wilderness that are in many parts uninhabited except by remote, mainly indigenous villages. Without a thorough understanding of the distribution and status of these species, it is difficult to make the appropriate land use decisions to conserve amphibians and their habitats. Monitoring to provide definitive knowledge on the ranges of these species and to amass a greater understanding of the status of their populations and habitat requirements is essential and could potentially be obtained using local knowledge instead of undertaking costly inventories in some areas. Use of these alternative information sources may increase human resilience at a time when resources are limited and change is rampant. Furthermore, an analysis of local knowledge availability for several species included in this group may enhance our knowledge and access to these resources for other non-game species.

The relatively few amphibians and reptiles in the state have never, to the best of our knowledge, had a significant economic value (Tessler 2009) though their cultural value has only been moderately documented. There is no known historical or current subsistence harvest in the state though it is theoretically permissible (Tessler 2009). According to ADF&G, reptiles are defined as “Game” and amphibians as “Fish” but since there is no established season for either, there is no legal take except under a Scientific-Educational Permit (Tessler 2009). For subsistence harvest to occur, no fishing license would be required for amphibians though a hunting license would be required to take reptiles (Tessler 2009).

Only through increased monitoring can we obtain an understanding of Alaska’s herpetofaunal roles in its ecosystem, their spatial distribution, their habitat requirements, their population trends and the causes underlying each of these (Anderson 2004). With the internet, Geographic Information Systems (GIS) and citizen based science at our fingertips, we must now increase our opportunities to gather the baseline information necessary to effectively manage wildlife

species (NatureNorth 2008). In Alaska the integration of local knowledge with western science and an increased emphasis on citizen science collaborations and public outreach may provide the resources necessary to better understand the state's amphibian populations.

Brief History

Herpetology is a relatively young science in the state of Alaska and has received comparatively little attention as compared to other fields of inquiry within wildlife biology. Periodic surges of herpetological research have occurred in the state over time, usually as a result of interested individuals temporarily residing in or visiting the region. Many of the studies that have taken place have been short-term and/or have been tangential to research priorities.

Alaska has no dedicated state or federal herpetologist on staff and for managerial purposes, has relied on the recommendations and insight of interested individuals. This is not to suggest that herpetofauna have received considerable attention from policy makers over time, as few protective measures for the species have been implemented or even addressed. Non-game wildlife species in general receive little attention from the state of Alaska whose governmental body concerned with wildlife management is specifically titled the "Alaska Department of Fish and Game (ADF&G)," explicitly using the term "game" over "wildlife." The work that is done however is accomplished under the auspices of the Wildlife Diversity Program (WDP), an entity of the Division of Wildlife Conservation (DWC) at ADF&G. The WDP's budget in 2011 was less than 5% of the DWC's budget and less than 1% of ADF&G's overall budget (Tessler, pers. com. 2011).

Since the WDP budget is provided for the study of all nongame, funds going specifically to herpetofauna were even less. The State Wildlife Grants Program (SWGP) has traditionally provided the funding for the WDP through federal appropriations (Tessler, pers. com. 2011). Despite providing Alaska with just under \$2.4 million in 2012 (USFWS 2012), the DWC's 2012 fiscal year report showed that no money was allocated to nongame species (ADF&G 2013). As of 2013, the SWGP has begun allocating available funds to specific project awards under a competitive grants program, no longer allocating funds directly to states. According to the U.S. Fish and Wildlife Service, no SWGP funds were awarded to Alaska for projects in the 2013 fiscal year (USFWS 2013), though it is unclear if proposals were even submitted by the state.

In 2004 a group of scientists and managers concerned about Alaska's amphibian gathered in Juneau to discuss the state of these species and a path forward for addressing conservation and research needs. This group organized as the informal Alaska Amphibian Working Group (AAWG), and subsequently met every few years to discuss needs and to disseminate research. The last meeting was held in Anchorage in 2010, and there are no additional meetings scheduled. Since that time, the Alaska Herpetological Society (AHS) has organized to serve the field more broadly and formally in the state. The AHS is recognized by the state as a non-profit organization and their application for federal recognition is currently pending review. According to the organization's website (www.akherpsociety.org):

“The Alaska Herpetological Society is a nonprofit organization dedicated to advancing the field of Herpetology in the State of Alaska. Our mission is to promote sound research and management of amphibians and reptiles in the North, to foster responsible pet ownership and to provide opportunities in outreach, education, and citizen science for individuals who are interested in these species.”

AHS holds an annual meeting and a biannual conference as stipulated in its bylaws. The organization also produces a biannual newsletter, the Northern Herp Chronicles, to report on herpetological issues and research in the state. They work closely with another group, the Midnight Sun Herpetoculture Society (MSHS), to address the concerns of herpetofaunal husbandry and the pet trade in Alaska. According to AHS, the organization hopes to join forces with the AAWG in pursuit of shared goals and interests moving forward. Perhaps the efforts of these organizations will permit the herpetological discipline to flourish in the state.

As mentioned, dedicated herpetologists have been few and far between, with most individuals having pursued these interests in combination with other responsibilities. Worth mentioning here are the contributions of Robert P. Hodge, among the first and most renowned herpetologists in the state of Alaska. Hodge came to Alaska from Tacoma, Washington in the fall of 1975 to accept a position as curator at the University of Alaska Museum (UAM) in Fairbanks (Foley 1976). He had previously served as curator of the Point Defiance Aquarium and worked the American Museum of Natural History, the Massachusetts Department of Wildlife, and the Washington State Game Department (Foley 1976). Hodge published his book, “Amphibians and Reptiles in Alaska, the Yukon, and the Northwest Territories” in 1976. His pioneering expeditions in Alaska and his dedication to advancing herpetological knowledge in the state laid the foundations for this field of inquiry in the American North. For this reason, he may be labeled the “Father of Herpetology in Alaska.” Other contributors to the field have periodically surfaced in Alaska, and much of their work is cited in this paper.

Biogeography

The first amphibians probably arose during the Devonian period (408-360 mya) and the first reptiles during the Carboniferous (360-286 mya)(Hodge 1976). Herpetiles have migrated over Beringia at various times and frogs of the genus *Rana* apparently reached North and South America via the Bering Land Bridge (Hodge 1976). As late as the tertiary period there was little temperature variation due to latitude, and the Pacific Rim supported a warm humid climate with a resulting forest extending from Japan through Siberia, Beringia, Alaska and south to Oregon (Hodge 1976). Up to the mid-Tertiary, plant and animal communities of Eurasia and North America were nearly identical (Hodge 1976). Subsequent geologic activity and ice ages however, had significant impacts on the distributions of these species.

Geologic activity greatly affects connectivity among populations in space and time and should therefore be considered when relating phylogeographic patterns (Da Silva and Patton 1998). The Pacific Northwest in North America has a unique complexity due to the region’s physiography (Shafer et al. 2010). The contemporary mountainous terrain of western North

America originated with the Laramide Uplift of the Rocky Mountains, and attained significant prominence in the landscape during the Eocene, 45-36 million years ago (Brunsfeld et al. 2001). There are two main contiguous north-south ranges today in this area – the Rocky Mountains, which define the extent of the northwest, and the Coast Mountains, which occur along the Pacific coast (Graham 1999, Brunsfeld et al. 2001). In addition, the Cascade/Sierra formation was recent enough to have detectable effects on today's species distributions (Graham 1999, Brunsfeld et al. 2001).

Other range adjustment factors such as glacial advances during the Oligocene and Miocene (Zachos et al. 1997) are also implicated in the history of extant species distributions (Dynesius and Jansson 2000). The Eocene and the Oligocene also resulted in a variety of geologic terrains due to episodes of folding, faulting, and mountain uplifting in the Pacific Northwest (Alt and Hyndman 1995). During this period the Blue Mountains were angled differently, the Cascade Mountains were not high enough to significantly disrupt the flow of Pacific moisture and the Pacific shoreline was further inland (Thompson and Russell 2005).

The most profound environmental change to affect range distributions has been the periodic advancement of continental glaciers (Green et al. 1996, Brunsfeld et al. 2001, Knowles 2001, Tsedakis et al. 2002, Webb and Bartlein 1992, Hewitt 1996). Pleistocene (1.8-0.01 mya) ice ages advanced on a 100 ka cycle and each time were interrupted with brief (10 ka) interglacial periods (Hewitt and Ibrahim 2001). The glacial advances in North America were some of the most extensive in the world (Velichko et al. 1997) and followed regular intervals known as the Croll-Milankovich cycle (Imbrie 1985, Muller and MacDonald 1997). The mammoth glaciers advanced over vast areas of the northern hemisphere, forcing flora and fauna to seek refuge south of the glacier or in isolated refugia (Hodge 1976). In fact, ice-sheets covered much of Canada during the Pleistocene and reached their largest extent approximately 20,000 years ago (Clark et al. 2009). The last ice age ended around 12 ka, marking the beginning of the Holocene (Thompson and Russell 2005).

The ice ages presented a significant challenge for species that had previously occupied terrestrial habitat subsequently covered in ice, especially for amphibians that are sensitive to local environmental changes because of their “moist permeable skin, eggs and gills; a requirement for both aquatic and terrestrial environments; a high degree of philopatry, and site fidelity; and relatively small home ranges and limited dispersal ability” (Lauck 2005). Species that were to survive needed to retreat north, south, or in both directions during the glacial advances (Shafer et al. 2010), and were eventually categorized as either Beringian or Southern in origin (Youngman 1975, Hoffman 1981). The glacial history of these ice ages left a profound signature on the ranges of herpetofauna throughout northwestern Canada and the United States (Nussbaum et al. 1983).

Both refugia and post-glacial colonization are evident in contemporary patterns of herpetofaunal distribution (Nussbaum et al. 1983). At the height of the last glacial maximum (22,000-18,000 years ago), the Laurentide and Cordilleran ice sheets covered much of Canada, southeastern Alaska, and the northern United States (Mann and Hamilton 1995). The

Cordilleran ice sheet reached its maximum extent in western North America 14,500-14,000 years ago, filling the Puget Trough and Strait of Juan de Fuca in present-day Washington State (Waitt and Thorson 1983). It rapidly retreated inland and by 10,000 years ago, large expanses of land were exposed and colonized by terrestrial organisms (Josenhans et al. 1995, Mann and Hamilton 1985).

For most northern biota, the large refuges of Beringia and the Pacific Northwest were available (Hulten 1937, Pielou 1991) as well as smaller pockets of habitat elsewhere, including the Haida Gwaii region of coastal British Columbia and Vancouver Island even further south (Barnosky et al. 1983, Demboski et al. 1999). The Coast ranges in the western US were largely unglaciated (Burke and Birkland 1983, Guyton 2001). Unglaciated parts of Alaska, Yukon and adjacent Northwest Territories (Eastern Beringia) formed an important refugium for vertebrates and other life during the Pleistocene (Hulten 1937, Hopkins et al. 1982, Guthrie 1990, Harington 2005). Furthermore, in areas where glaciation was incomplete, species could also have persisted in small within-ice refugia like that of nunataks (Pielou 1991). Beringia in particular was largely overlooked in earlier reviews of the northwest refugia (Shafer et al. 2010).

Interestingly, the Haida Gwaii Islands (also known as the Queen Charlotte Islands) have long been hypothesized as North American coastal refugium (Heusser 1989) and are widely included in biogeographic models (Shafer et al. 2010). This coastal refuge along with parts of the Alexander Archipelago of southeast Alaska, were important for surviving organisms (Shafer et al. 2010), possibly even including the Garter Snake, *Thamnophis sirtalis* (Janzen et al. 2002), which are thought to have subsequently dispersed southward along the Coast Mountains (Janzen et al. 2002). Geological evidence shows that portions of these areas were ice-free (Scudder and Gessler 1989, Josenhans et al. 1995, Carrara et al. 2007) and the existence of considerable vertebrate fossil evidence from the Alexander Archipelago supports the terrestrial habitat hypothesis (Heaton et al. 1996, Dixon et al. 1997, Heaton and Grady 2003).

During the Pleistocene, the Haida Gwaii Islands were connected to the ice-free coast by the Hecate Strait which was periodically exposed and contained freshwater lakes and terrestrial flora (Barrie et al. 1993, Josenhans et al. 1995, Hetherington et al. 2003, Hetherington et al. 2004, Lacourse et al. 2003, Lacourse et al. 2005). This exposed strait would have allowed gene flow to occur to the coast, southward, and potentially northward to the Alexander Archipelago (Shafer et al. 2010). A glacier was thought to have separated Haida Gwaii from Alaska (Bornhold and Barrie 1991, Barrie and Conway 1999) and open water stretches were substantially shorter (Barrie and Conway 1999).

Exactly where the refugia were for most herpetiles is not absolutely known, but that we can speculate that the Boreal Toad, Spotted Frog, Northwestern Salamander, Long-toed Salamander and Rough-skinned Newt survived the glaciation in the Pacific Refuge and subsequently dispersed northward along the coast and intermontane corridors (Hodge 1976). Boreal species such as the Chorus Frog, Leopard Frog, Canadian Toad and Garter Snakes probably survived in a broad belt of boreal forest south of the glacier and then moved northward following closely the retreat path of the ice (Hodge 1976).

Hodge (1976) suggested that the Wood Frog, which is widely distributed in boreal areas, survived the glaciation south of the glacier margins but also possibly in the Bering Refuge, moving east and south where it met frogs moving north after the ice retreat (Hodge 1976). To validate part of this claim, Harington (2011) reported a fossilized Wood Frog in the Yukon from the Sangamonian interglacial age. Nearly 30 vertebrate faunal localities were investigated by Harington, spanning a period of about 1.6 mya to the close of the Pleistocene some 10,000 BP (radiocarbon years before present, taken as 1950)(Harington 2011). This count included the single amphibian representative, an unusual find since neither frog teeth nor their skeletons readily fossilize, causing them to be relatively rare in the fossil record (Chantell 1972). Lee-Yaw et al. (2008) suggested that patterns of genetic diversity, such as complete homogeneity in Alaska, fail to support a western refugium for the Wood Frog, especially given that genetic diversity is greatest in Michigan, Ohio and Ontario.

Over the approximately 18,000 years since the last glacial maximum, the northward shift of climatic zones has allowed flora and fauna to expand their ranges to recolonize previously ice-covered areas in North America and Europe (Bennett 1986, Thompson 1988, Pielou 1991, Hewitt 1993a,b). As the glaciers retreated, newly available environments were rapidly occupied by pioneer species (Pielou 1991, Clague and James 2002, Walker and Pellatt 2003). Northern taxa are presumed to be the earliest species to re-invade previously glaciated terrain (Lee-Yaw et al. 2008). The Wood Frog in particular, which is known for its freeze tolerance capabilities (Storey 1984), high dispersal abilities (Berven and Grudzien 1990, Newman and Squire 2001), and use of a variety of habitats including tundra, is thought to have been among the earliest vertebrates to enter the north following glacial retreat (Holman 1992). Another anuran species complex, the North America Spotted Frogs, has expanded into formerly glaciated regions too, including areas of British Columbia, Washington, Idaho, Montana, and southwestern Yukon (Turner and Dumas 1972, Nussbaum et al. 1983, Stebbins 1985). Specimens observed by Green et al. (1996) in these locations were said to be “deposited at the Canadian Museum of Nature in Ottawa”, but curators there have no records of this accession. Figure 1 was borrowed from Green et al. (1996) and shows the genetic relationship among the collected individuals from this study.

Species that expanded along the ecological range margins after glacial retreats presumably exhibit small population sizes that result in genetic bottlenecks (Solstis et al. 1997, Hewitt and Ibrahim 2001) – a reduction in genetic diversity relative to genealogical origins (Knowles 2001). These reductions in genetic variation occurred as repeated long distance dispersal of individuals (known as founder events) took place and resulted in the structure of colonizing genomes (Hewitt 1996, Hewitt 1999, Hewitt 2000, Ibrahim et al. 1996, Hewitt and Ibrahim 1997). Taxa with limited dispersal abilities often have populations that strongly reflect their Pleistocene distributions too (Shafer et al. 2010). This is true for many herpetofauna where limited dispersal ability and habitat specialization acted together to limit the spread of these species after the Pleistocene (Nielson et al. 2001, Carstens et al. 2005, Carstens and Richards 2007, Funk et al. 2008). In contrast to colonization events, unglaciated regions that provided refugia may show higher levels of genetic variation and population structure (Kuchta and An-Ming Tan 2005).

The resulting patterns of genetic diversity or lack thereof following the ice ages have been studied for several species, including that of the Rough-skinned Newt, *Taricha granulosa*. Kutch and An-Ming Tan (2005) hypothesized that populations of this species inhabiting formerly glaciated regions in the north would harbor less genetic diversity than those found in known or suspected refugia. They also suggested that this species expanded north from northern California prior to the last glaciation, possibly using the Klamath-Siskiyou region as a refuge (Soltis et al. 1997, Kutch and An-Ming Tan 2005). Prior to and during the last glacial maximum, the Pacific coast of North America remained forested (Barnosky et al. 1987, Whitlock 1992, Hewitt and Ibrahim 1997) and this would have allowed *T. granulosa* to expand northward into coastal Washington State (Kutch and AN-Ming Tan 2005).

The cordilleran ice sheet began to recede about 14,500-14,000 years ago and *T. granulosa* may have expanded northward to Alaska as early as 10,000 years ago when large expanses of open land became available (Josenhans et al. 1995, Mann and Hamilton 1995). It isn't clear if the initial early-successional habitats were suitable for newts and if not, the expansion may have occurred even more recently (Kutch and An-Ming Tan 2005). Kutch and An-Ming Tan found that allozyme and mtDNA from the newts supports a rapid range expansion, including from southern British Columbia to southeast Alaska following the glacial retreat. An alternative explanation for the reduced diversity in these populations in the north is that "allelic diversity was lost during island colonization" (Kutch and An-Ming Tan 2005). Unfortunately, this study lacked inclusion of specimens from across the Alexander Archipelago, especially the outer islands, including Prince of Wales Island (MacDonald pers. com. 2013).

Cold Adaptations

Generally, amphibians are more tolerant of cold and more dependent on water than reptiles (Hodge 1976) resulting in this group being more widely represented in Alaska. Only the extant Wood Frog, the Common Frog (an old world species whose ancestors presumably crossed the Bering Land Bridge during the Tertiary Period and gave rise to the Wood Frog), and the Siberian Salamander have adapted to the climatic conditions of the far north (latitudes above the arctic circle) by shortening their larval periods (Hodge 1976). The Wood Frog has the highest rate of larval development at any given temperature of any North American frog, it is the first to breed in the spring and all morphologic stages can tolerate minimum temperatures that are lower than most other amphibian species (Hodge 1976). Several species of salamander do overwinter as larvae in temperate SE Alaska but only if pools and ponds do not freeze to the bottom will they survive (Hodge 1976). Terrestrial adult pond-breeding amphibians undergo round-trip breeding migrations that include movements to aquatic breeding habitats and return trips to nonbreeding habitat (Semlitsch et al. 2008).

Vitt (2009) describes the cellular and chemical adaptations of some herpetiles at high latitudes:

"Intracellular freezing is lethal for all animals. Some species of turtles and frogs are freeze tolerant and survive extracellular freezing. Ice crystals appear beneath the skin and interspersed among skeletal muscle; a large mass of ice develops in the body cavity.

As much as 35%-45% of the total body water becomes ice and yet the frogs survive. When frozen, a frog's life processes are suspended including breathing, blood flow and heartbeat. They tolerate the large volume of body ice by producing and accumulating cryoprotectants (antifreeze) within the cells. These are generally either glycerol (Copes Gray Tree Frog ex) or glucose (Wood Frog ex). These species also possess specialized proteins that control extracellular freezing and adjust cellular metabolism to function at low temperatures and under aerobic conditions. Ice forms peripherally and triggers synthesis of cryoprotectants."

Other amphibian adaptations in northern regions noted by Hodge (1976) include:

- Increased diurnal activity
- Marked tendency toward submerged egg masses
- Eggs tend to be larger and darker, increasing absorption of radiant energy
- Tend to be considerably smaller than southern counterparts
- Tend to have shortened limbs
- Tend to be more vividly marked, darker colors presumably absorbing more heat

Wood frogs in the southeastern U.S. breed in January, those in Minnesota breed in early March and those in northern Alaska breed in June (Hodge 1976). In contrast, the boreal toad breeds earlier in southeastern Alaska than individuals of this species in sea level areas of Washington State (Hodge 1976). Amphibians that are early-spring breeders rely on fat reserves obtained during the previous fall for overwintering, movements to breeding sites, and breeding activities like calling and mating (Rittenhouse et al. 2009). The short breeding season of Wood Frogs may be limited by energy reserves because male frogs begin breeding with only enough stored energy in the form of glycogen to call for five hours per night for five nights (Wells and Bevier 1997).

Water temperatures are known to accelerate developmental rates for embryos and tadpoles (Brown 1975), which would promote earlier metamorphosis, longer post-transformation growth period before hibernation, and larger individuals less susceptible to starvation and desiccation (Schaub and Larsen 1978). This is one possible advantage to warmer temperatures occurring after oviposition. Some postulate that warming in the cooler northern ranges of species creates new opportunities for colonization, yet the limited dispersal ability of amphibians and the projected decreased availability of water may further increase their vulnerability.

Reptiles are generally more tolerant of aridity and dependent on warmth than amphibians and can also tolerate more salinity, causing them to be found with greater diversity in warm dry areas and on oceanic islands (Hodge 1976). Similar to amphibians though, northern reptiles hibernate during the winter months (Hodge 1976). Snakes often congregate in large numbers in dens located in deep fissures and rock outcroppings below the frost line (Hodge 1976). As will be discussed later, no terrestrial reptiles have been formally documented in Alaska to date.

Climate Change

Climate change has been influencing the planet at an increasing rate for more than 30 years and is projected to continue (Haufler 2010). Amphibians are likely to be increasingly valuable in understanding or monitoring the impacts of climate change on ecological communities (Todd et al. 2011). To develop a management plan for the conservation of Alaska's herpetofauna, an understanding of future climate projections and their impacts on these species is necessary since climate regimes will likely have a significant impact on species and habitats, particularly those at the edge of their range.

Warming may be a stressor for organisms that inhabit cool climates (Bernardo and Spotila 2006), including amphibians. Changes in ambient temperature and precipitation patterns on a global scale could disrupt, for herpetiles, the timing of breeding, periods of hibernation, ability to find food (Donnelly and Crump 1998, Blaustein et al. 2001) pathogen-host dynamics (Blaustein et al. 1995), food availability, predator prey interactions (Blaustein et al. 1995), survival, growth, reproduction, dispersal capabilities (Blaustein et al. 1995) and habitat variables such as vegetation, soils and hydrology (Blaustein et al. 1995) among others. In addition, other stressors such as UV-B radiation and contaminants may be present (Blaustein et al. 1995). It is the interaction among these factors that are probably driving some amphibian declines and extinctions, though few studies have attempted to model the potential future impacts of climate change on these species (Blaustein et al. 1995). A schema of potential temperature and precipitation change impacts on amphibians was borrowed from Blaustein et al. (2010) and is included as Figure 2 in the appendix.

The largest temperature increases are predicted for high northern latitudes where average annual temperatures may increase more than 7.5°C (Blaustein et al. 1995). A warming pattern is projected to be pronounced in the winter months (December-February), and a projected increase in annual precipitation is predicted at higher latitudes as well (Blaustein et al. 1995). In the Arctic, climates have warmed almost twice the global rate over the last several decades, making its ecosystems more sensitive than those in temperate regions (Ansimov et al. 2007). It is likely that climate change will force geographic range shifts or expansions for species that are closely tied to environmental conditions, such as amphibians (Moore et al. 2011). In some cases, shifts in amphibian populations are expected, including range expansions and contractions (Blaustein et al. 1995). Throughout the Pacific Northwest, evidence and concern for altered habitats in response to climate factors are being reported, especially at higher latitudes (Yukon, Alaska) and higher altitudes (Cascade Range, Rocky Mountains, Klamath Mountains)(Olson 2009).

Asymmetrical regional changes in weather patterns immediately impact amphibians, which are dependent on seasonal freshwater habitats for breeding and overwintering. All amphibians including those with nonaquatic eggs depend to some degree on the availability of freshwater for reproduction (Wells 2007). Effects on amphibians are probably correlated with the magnitude of change and on local morphology of wetlands (McCallum et al. 2009). Such perturbations likely have variable responses from ectotherms, but it can be anticipated that

many groups will be significantly impacted by the changes (McCallum et al. 2009). Decreased snowfall in parts of Alaska is a suspected cause for some amphibian die-offs in recent years and climate change may explain earlier anuran breeding choruses (Blaustein et al. 2001, Gibbs and Breisch 2001) and local range shifts to higher elevations (Seimon et al. 2007).

In North America, shorter winters include fluctuating spring and fall temperatures and drier conditions, which may alter amphibian breeding seasons and result in the desiccation or freezing of eggs (Lannoo 2005). In the summer, global warming impacts nighttime temperatures causing fewer nights with dew and constant evapotranspiration leading to a faster drying of wetlands and more frequent and prolonged droughts, which reduce or eliminate amphibian breeding and larval habitat (Lannoo 2005). Approximately 53% of wetlands in the continental U.S. have been lost or drained, 87% of that due to agriculture (Maltby 1986). “These losses are accompanied by the loss of ecological, hydrological, and cultural functions wetlands provide, including water purification, groundwater recharge/discharge, storm water storage/flood control, sediment and pollutant sequestering, carbon storage, cycling of sulfur, and wildlife habitat” as indicated by the Intergovernmental Panel on Climate Change (IPCC 2001).

Colonization and Breeding Habitat

On a regional scale, climate strongly influences the geographic distributions of species (Blaustein et al. 1995). Genetic differentiation among populations tends to be high in amphibians relative to other taxa, which suggest that gene flow and dispersal is limited in amphibians (Larson et al. 1984, Slatkin 1985, Gascon et al. 1996, Gascon et al. 1998). In light of this, it is necessary to determine if dispersal is great enough to allow the colonization of empty habitat patches at a rate equal or greater to the rate of population extinctions (Funk and Dunlap 1999). There is little empirical evidence concerning the capacity of amphibians to colonize empty habitat patches (Sjogren and Gulve 1993, Hecnar and M'Closkey 1996). Reptiles have been known to expand their ranges if climates are altered, especially by expanding their distribution latitudinally or altitudinally if cold temperature limitations are altered (Olson 2009).

The ability to easily permeate a variety of habitats and overcome potential barriers has important implications for range-margin populations under future climate regimes (Moore et al. 2011). Amphibians in general are thought to have limited capability for dispersal and are known to be highly philopatric toward natal breeding sites (Berven and Grudzien 1990, Meier 2007). Dispersal distances of up to 4km have been reported for amphibians (Lehtinen and Galatowitsch 2001), but for Wood Frogs 1.0-2.5km were recorded for several locations in the United States (Berven and Grudzien 1990, Baldwin et al. 2006, Rittenhouse and Semlitsch 2009).

Amphibian Breeding, Oviposition and Metamorphosis

In amphibians, temperature acts as a control for many physiological processes including rates of oxygen uptake, heart rate, locomotion, water balance, digestion, developmental rate, sex

determination, and immune function (Rome et al. 1992). Temperature and rainfall directly affect many species via physiological constraints pertaining to tolerances and seasonal timing of activities like growth and reproduction. These are critical too, to amphibian physiology and behavior, because of their role in gametogenesis and reproductive migrations (Beebee 1995, Noble 1931, Semlitsch 1985, Todd and Winne 2006).

Increases in temperature and climate extremes (Easterling et al. 2000), or a decrease in annual precipitation, might lead to regional declines in species abundance and local extinctions of amphibians (Caldwell et al. 1991, Daszak et al. 2005, Pounds et al. 2006, Church et al. 2007, Brodman 2009). Reduced precipitation or a precipitation-evaporation deficit resulting in earlier than normal seasonal drying of wetlands could result in recruitment failure for amphibians and desiccation of tadpoles (Skelly 1996, Brodman et al. 2006, Rittenhouse et al. 2009). There is also a significant relationship between the number of hours of blowing snow and how that snow was redistributed by wind into wetlands, ultimately contributing to the conditions that promote survival in Wood Frog eggs and tadpoles (Donald et al. 2011). Additionally, the height and distribution of vegetation near wetlands can influence capture of wind-driven snow (Donald et al. 2011).

Understanding the breeding biology and thermal requirements of ranids is essential to comprehend individual species and their abilities to adapt to environmental fluctuations during the breeding season (Bull and Shephard 2009). Shifts in phenology due to climate change have been observed in several species (Blaustein et al. 1995) but this has been variable between species, even within the same geographic area (Blaustein et al. 1995). Trends toward earlier breeding have been documented for several amphibian species in Japan (Kusano and Inoue 2008) and in at least three species of anurans from Britain (Blaustein et al. 1995). Other studies have documented earlier amphibian breeding in regions experiencing recent climate warming too (i.e. Beebee 1995, Beebee 2002, Gibbs and Breisch 2001).

Amphibians that breed in vernal ponds and isolated bodies of water are particularly vulnerable to changes in temperature and precipitation (Beebee 1995). Insufficient rainfall and shortened hydroperiods cause “catastrophic reproductive failure in pond-breeding amphibians” (Semlitsch 1987, Dodd 1993, Dodd 1994, Richter et al. 2003, Palis et al. 2006, Taylor et al. 2006) and probably is a factor in declines for several species (McMenamin et al. 2008, Daszak 2005). It also influences the number and size of metamorphosing frogs, the time to metamorphosis, and the effects of diseases (Semlitsch 1987, Semlitsch et al. 1998, Pechmann et al. 1989, Kiesecker and Skelly 2001). Temperature and precipitation can also change fire regimes, rates of evapotranspiration, and groundwater levels, all of which impact the availability of freshwater (Blaustein et al. 1995). The impact of precipitation on amphibian breeding phenology has been incorporated into models at least once (Corn 2003) but is frequently neglected despite its importance (Todd et al. 2011).

Todd et al. (2011) showed that responses to climate change will vary by populations and even by species within the same community. This may be partially explained by differences in physiology and ecology including the time of year that species breed and the type and degree

of climate change being experienced (Todd et al. 2011). Reproductive timing affects population trends and long-term persistence through larval interactions and impacts to juvenile recruitment (Wilbur 1997). A change in phenology of just two weeks in some species can alter the outcome of competitive interactions and predator-prey dynamics (Alford 1989, Boone et al. 2002, Gascon 1992, Lawler and Morin 1993).

Parmesan (2007) performed a meta-analysis of 203 phenology studies and found that amphibians exhibited the greatest phenological responses of all taxa studied. In one study (Todd et al. 2011) in Rainbow Bay, South Carolina, four study species (three urodeles and one anuran) exhibited significant changes in spring Mean Arrival Date (MAD) since 1979. Their estimated rate of phenological change was 5.9 to 37.2 days per decade, representing some of the greatest rates of change reported for vertebrates to date (Todd et al. 2011). This is particularly surprising since the findings occurred at relatively low latitudes – the effects of climate change are expected to be most pronounced at high latitudes where the growing season is shorter and where the species are at the colder limits of their ranges (Beebe 1995, IPCC 2007, Maxwell 1992). Another potential problem associated with shifting climates is that species that previously exhibited larval periods separate from one another may find each other inhabiting the same habitat at the same time (Blaustein et al. 1995). Changes in the timing of reproduction can also alter the temporal overlap between competitors, predators, and prey (Alford and Wilbur 1985, Wilbur and Alford 1985, Alford 1989, Morin et al. 1990, Lawler and Morin 1993).

Changes in precipitation patterns sometimes accompany changing temperatures (Allan and Soden 2008). In the northern plains of North America, the wetland breeding habitat of amphibians could be reduced by a change in climate that includes decreased precipitation (Donald et al. 2011), though precipitation is expected to increase in parts of the Pacific Northwest. Donald et al (2011) examined 29 wetlands distributed throughout central Saskatchewan, Canada that were dry for up to seven consecutive years. They found that tadpole occupancy was reduced to less than 40% for five consecutive years, that none of the wetlands had tadpoles during the severe drought of 2001 and 2002, that the drought had no observable long-term effect on either tadpole occupancy of wetlands or tadpole abundance, and that the principal determinant of tadpole abundance and occupancy in wetlands in late June was precipitation (Donald et al. 2011). Tadpole occupancy was related to winter and spring precipitation, with 67% of long-term variation attributed to snowfall between November and February, and 17% related to rainfall from March to June (Donald et al. 2011).

Temperature is the major factor influencing the developmental rate of amphibian embryos (Bull and Shephard 2009). Information on breeding ecology must be obtained to understand how disturbance factors influencing water temperature may affect the reproduction of amphibians (Bull and Shephard 2009). Embryos of the earliest breeding ranids, such as Wood Frogs, develop faster and tolerate lower temperatures than other species that breed during warmer conditions (Bull and Shephard 2009). General temperature limits (at which 50% or more of the embryos develop normally, Brown 1967) for several North American ranids have been documented, including for *R. aurora aurora* (4-21°C, Licht 1971), *R. sylvatica* (6-24°C, Herreid

and Kinney 1967), *R. pretiosa pretiosa* (6-28°C, Licht 1971), *R. luteiventris* (6-28°C, Johnson 1965) and *R. pipiens* (5-28°C, Moore 1939). Environmental cues such as temperature and precipitation are clearly linked to the onset of reproduction in many species (Blaustein et al. 1995).

The average water temperature on the first day of egg deposition in the Wood Frog was determined by one study to be 7-10°C (Herreid and Kinney 1967). Both *R. aurora* and *R. pretiosa* are known to breed when water temperature at breeding ponds reaches 6°C at a depth of 61cm (Licht 1971). In a study by Bull and Shephard (1991), egg deposition in Columbia Spotted Frogs began when mean water temperatures at the study sites were between 7.6-16.0°C and maximum water temperature was 9.8-20.2°C. Knowledge of water temperature at breeding sites can be used to determine the timing that monitoring populations for oviposition should occur (Bull and Shephard 2009).

Water in wetlands can originate from snowmelt and rain runoff, and from shallow and deep groundwater recharge (Donald et al. 2011). Donald et al. (2011) suggested that less than 45mm of winter precipitation for six consecutive years would probably cause regional extinction of populations of the Wood Frog, and they agree that amphibian populations may be particularly vulnerable to the effects of increased variability in seasonal and annual precipitation. Higher spring and summer temperatures could increase evaporation from wetlands, thereby reducing wetland area, volume, and seasonal persistence (Donald et al. 2011). In their study sites, suitable habitat for Wood Frog tadpoles were those wetlands that maintained a maximum depth less than 15 cm from April to at least the end of June. In a study by Werner et al. (2009), drought conditions reduced the density of aquatic predators of tadpoles, which led to increased colonization probability by Boreal Chorus Frogs (Donald et al. 2011). Drying also can affect terrestrial amphibians like Plethodontid salamanders that are desiccation-prone (Spotila 1972), and are well adapted to moist forest floors and cool oxygenated streams present in many mountainous areas (Blaustein et al. 1995).

Donald et al. (2011) found that, six years after the end of a severe drought, and with study sites having at least 15cm of water, Wood Frogs that had either survived or dispersed, but successfully relocated and bred in all 29 wetlands. They reported that severe drought did not have lasting effects on the occupancy of wetlands by tadpoles of the Wood Frog. In high snowfall years, Wood Frog tadpoles occupied most of their study sites, but many of these were also dry when precipitation from November to December was less than 60mm.

Temperature can influence the concentration of dissolved oxygen (DO) in aquatic habitats since warmer water generally has lower concentrations of DO (Blaustein et al. 1995). Most amphibians have highly vascularized permeable skin that acts as an organ for osmoregulation and respiration (Blaustein et al. 1995) and with the exception of a few “water-tight” species, water moves freely across the skin barrier, resulting in high evaporative water loss in dry or windy conditions (Hillyard 1999). A reduction in oxygen can negatively affect developing embryos and larvae, especially if increases in temperature increase oxygen consumption (Blaustein et al. 1995). Chronic hypoxia can delay development and hatching in Ambystomatids

(Mills and Barnhart 1999) and accelerate hatching in Ranids, causing tadpoles to be smaller (Mills and Barnhart 1999). The situation can also affect behavior of larvae and cause them to move to the surface to gulp air more frequently (Wassersug).

Development rate in tadpoles and larvae increases with temperature up to a threshold that can be species or population specific (Duellman and Trueb 1986, Morand et al. 1997). Higher temperatures can result in faster metamorphosis but also decreased size at the time of metamorphosis (Blaustein et al. 1995, Duellman and Trueb 1986, Morand et al. 1997, Wilbur and Collins 1973, Werner 1986). In seasonal pools where amphibians are at risk of desiccation prior to metamorphosis, increased developmental rates may be beneficial (Blaustein et al. 1995). Tadpole and larva survival are dependent on density at higher temperatures, where higher temperatures tend to increase survival rates when tadpole density is low (Govindarajulu and Anholt 2006).

Feeding, Vegetation and Microorganisms

Reduced hydroperiods and water depths during droughts can lead to increases in grass, upland and woody species, especially at the shallower margins of wetlands (Stroh et al. 2008). Oppositely, increased hydroperiods can promote growth of aquatic and emergent species (Stroh et al. 2008). Above average rainfall can increase the terrestrial prey base for adult female amphibians and potentially lead to greater reproductive success in subsequent years due to greater fitness of offspring (Blaustein et al. 1995). Tadpoles themselves exhibit a variety of trophic modes from herbivory (grazers and scrapers of epilithon, to detritivory, carnivory (cannals, predators, scavengers), and oophagy (Altig et al. 2007). Higher water temperatures can also exacerbate water pollution though, and associated blooms of cyanobacteria, green algae, bacteria, protozoans and small metazoans (Schindler 1997, IPCC 2008). It can increase rates of primary production and nutrient cycling too (Meyer et al. 1999).

In areas that are close to the earth's oceans, sea level rise contributes to the loss of coastal wetlands while storm surges lead to salt water intrusion, greatly affecting amphibians in these areas (Blaustein et al. 1995). Surges and flooding can additionally cause the introduction of fish predators into previously fishless wetlands (Blaustein et al. 1995).

Pathogens

Particularly concerning are the effects of shifting climates on host-pathogen interactions and disease dynamics (Blaustein et al. 1995). Climate change may cause some pathogens to increase in prevalence and severity and others to decline (Blaustein et al. 1995). Amphibians are susceptible to many types of pathogens including trematodes, copepods, fungi, oomycetes, bacteria and viruses (Blaustein et al. 1995). Desiccation can lead to weaker immune systems of which even temporary suppression after metamorphosis can lead to greater pathogen susceptibility (Blaustein et al. 1995). Gervasi and Foufopoulos (2008) found that Wood Frog tadpoles experiencing desiccation and shorter development times had weaker immune system responses to disease and total leukocyte numbers. Overall, climate change effects on

amphibian pathogens and response are hard to predict given the complexity of the mechanisms involved (Blaustein et al. 1995).

The amphibian chytrid fungus is recognized as a major threat to worldwide amphibian populations (Skerratt et al. 2007) though the role of climate change in chytrid –related extinctions is disputed (Pounds et al. 2006, Rohr et al. 2008). The growth and impact of these infections is strongly related to temperature (Berger et al. 2004).

Climate Scenarios in Alaska

Over the past 50 years, Alaska has warmed more than twice the rate of the rest of the United States (Haufler 2010) and its impacts have been much more pronounced here than in other parts of the country (US Global Change Research Program 2009). Temperature is a major driver of ecosystem dynamics that regulates the rate of biological and chemical processes and produces physical structure in the water column (Wetzel 2001). In the far north, cold temperatures and shorter growing seasons limit lake productivity (Brylinski and Mann 1973) making these wetlands particularly vulnerable given the accelerated warming at high latitudes (Christensen et al. 2007). Key threats include “changes to sea levels, increased storm intensities, ocean acidification, warming ocean and stream temperatures, increased retreat of glaciers, changing precipitation amounts and patterns, changes to evapotranspiration rates, changing distributions of species, changing outbreaks of insects, changes to ecosystem productivity and changing fire regimes” (Haufler 2010).

The Pacific Decadal Oscillation, a shift in North Pacific sea temperatures and currents, went through a cool phase between 1947 and 1976 and a warm phase from 1977 to present (Mantua and Hare 2002), and is a primary contributor to climate in Southcentral and Southeast Alaska (Barrett et al. 2012). The fifty year historical warming trend in the Gulf of Alaska is consistent with most General Circulation Models (GCMs) which predict increased precipitation for the region (Barrett et al. 2012). The GCMs attempt to anticipate scenarios based on continued increases in greenhouse gasses (Haufler 2010).

In southeast Alaska, the mean winter temperature (December – February) has increased at a rate of 3.0°C per 50 years (Barrett et al. 2012). Precipitation rates are shifting too and several models suggest an increase in rainfall in coming decades. The Hadley Model predicts 50 year increases in average precipitation (121, 135, and 168mm) at Juneau (Barrett et al. 2012). Climate stations at Anchorage and Homer have shown relatively constant annual precipitation over the past 50 years (Barrett et al. 2012) though recent research by Berg et al. (2009) documented drying of lakes and wetlands – an indication that precipitation-evaporation rates are increasing too.

The Scenarios Network for Alaska Planning (SNAP), an organization that reviews GCM models for best-fit in Alaska, reported in 2008 a statewide increase in annual temperature of 2.69°F since 1971, though this has not been equal across the state (Haufler 2010). Juneau was reported to have had an increase of 3.54°F while Valdez experienced increases of 3.4°F and

Yakutat clocking in at increases of 6.4°F (Haufler 2010). The U.S. Global Change Research Program (USGCRP)(2009) reported that Alaska experienced a 3.4°F rise in mean annual temperatures over the past fifty years, with an increase in average winter temperature of 6.4°F (Haufler 2010). The USGCRP also reported that the average snow free days across Alaska have increased by an average of 10 days per year. Kelly (2007) predicted annual temperature increases of 6-9°F over the next 100 years for southern Alaska's coastal forests.

Chief Tidwell of the United States Forest Service (USFS) recently directed his agency to craft a "well-coordinated landscape conservation action plan for specific geographic areas and major landscapes" (Haufler 2010), a project that was subsequently undertaken in many areas, including the Tongass and Chugach National Forests in Alaska. The Tongass, located in southeast Alaska, includes approximately 17 million acres and 11,000 miles of coastline (Haufler 2010). The Chugach, located in southcentral Alaska, is the most northerly national forest in the United States and contains approximately 5 million acres (Haufler 2010). Due to their northerly setting, climate change has affected these forests more than any other with Alaska, recording the most rapid temperature increases over the last century, more than any of the other 11 USFS regions analyzed (Julius and West 2008).

The southcentral landscape in Alaska spans glacially dominated mountain ecosystems to the coastal area of Prince William Sound and the Copper River Delta. It is located near the most populous and most developed areas of the state (Haufler 2010). Southeastern Alaska is located primarily within the Alexander Archipelago, a series of islands occurring for hundreds of miles down the coast, but also includes mainland areas with glaciers and mountainous terrain (Haufler 2010). Here, highly productive coastal rainforests occur within both marine and freshwater environments, and human communities are generally isolated and self-reliant due to limited transportation infrastructure (Haufler 2010). Prince of Wales Island (POW) has considerable human development and infrastructure comparatively (Haufler 2010).

In both southcentral and southeast Alaska, summer and winter precipitation and temperatures are expected to increase, with the winter rate of increase continuing to be greater than the summer (Haufler 2010). The growing season is expected to increase substantially in these areas over the next 100 years too (Haufler 2010). Additionally, the effects of timing of snowmelt, timing of peak runoff, and occurrence of snow cover are important implications for local ecosystems.

A summary of predicted climate change effects for the Tongass and Chugach National Forests was offered by Haufler (2010):

- Temperatures will increase, with winter temperatures increasing at a higher rate than summer temperatures
- Length of growing seasons and frost free days will increase
- Temperatures in seasonal transition months in many locations will shift from below freezing to above freezing
- Precipitation will increase

- More precipitation will fall as rain rather than snow
- Evapotranspiration rates will increase
- P-PET ratios will decrease in summer, causing dryer conditions in summer for many locations
- Storm intensities will increase

Sea level rise, changes to ocean currents, and upwellings could have significant impacts on several estuarine ecosystems in Alaska, especially three with high ecological and economic importance – the Copper River Delta, the Yakutat Forelands, and the Stikine River Flats (Haufler 2010). These areas are all extremely important as stopover locations for migratory birds, especially shorebirds, are major spawning areas for many species of fish, and are important for shellfish production (Haufler 2010). Depending on the topography of some areas though, sea levels could create new estuarine areas, so the net impacts remain uncertain (Haufler 2010).

More northerly storm tracks and greater storm intensities are predicted (U.S. Global Change Program 2009), the latter of which have already been documented in Alaska (Haufler 2010). Wind throw is one major effect of this and can be a primary disturbance process in coastal rainforests, potentially altering wildlife habitat (Haufler 2010). Storm surge can also cause increased disturbance to coastlines via waves and wind (Haufler 2010).

Warming is expected to increase stream temperatures, which are projected to have variable impacts on salmonids, reducing the habitat quality for some and improving it for others (Haufler 2010). These fish are keystone species in many streams and rivers but also a food source for many terrestrial species (Haufler 2010). Overall salmon numbers in southern coastal areas may not experience major declines, although many unknowns remain (Haufler 2010).

As glaciers experience increased rates of melt, stream flows may change considerably, particularly in the summer months (Haufler 2010). In some areas, there will be changes in the timing of run-off as snow packs move higher and the timing of snowmelt occurs sooner in the spring (Haufler 2010). Winter is a critical time for amphibians in cold climates, but understanding of hibernation requirements for most species is fragmentary at best (Browne and Paszkowski 2010).

Yet another important component of changing conditions is the Precipitation minus Potential Evapotranspiration (P-PET) ratio, which may in some cases offset increased precipitation in Alaska (Haufler 2010). Increases in P-PER are expected (Haufler 2010) and impacts to wetlands have already been observed (Klein et al. 2005, Berg et al. 2009). On the Kenai Peninsula, more than 2/3rds of wetlands decreased in area between 1950 and 1996 (Klein et al. 2005). In this same region, Berg et al. (2009) reported an 11% decadal decrease in the herbaceous area of 11 wetlands between 1968 and 1996 (Haufler 2010).

Shifts in distributions as a result of temperature and precipitation can also be impacted by other related factors, examples of which include fire, avalanches, insects and pathogens (Haufler 2010). Altitude is important in these calculations too. Generally, a 30°F decrease in

temperature is associated with a gain of 1000ft in elevation, meaning that forest ecosystems could see a 2000ft – 3000ft upward shift in distribution if current trends continue (Haufler 2010). Such a shift would substantially change the landscape in Alaska's southern coastal forests, decreasing alpine and tundra vegetation (Haufler 2010).

On the Kenai Peninsula, fire has been increasing as a major disturbance and though these have occurred historically, especially in Black Spruce forests (Berg and Anderson 2006), the prevalence and size of fires has been increasing, particularly for White and Lutz Spruce forests (Haufler 2010). Increasing temperatures are causing dryer forest conditions in the summer in southcentral Alaska, resulting in more severe fire conditions, larger fires when they occur, and an expansion of tree-killing beetles (Haufler 2010). Fire has not generally been a concern in southeast Alaska's coastal forests, but climate predictions indicate that P-PET ratios could cause summer drying of those forests too, even with higher projected rates of precipitation (Haufler 2010). If coastal forests dry and are ignited, the fires are expected to be very intense (Murphy and Witten 2006).

The Yellow-cedar is predicted to experience major impacts as a result of climate change, with its decline primarily being caused by loss of snow at lower elevations (Haufler 2010). The decreased snow allows soils to be exposed during freezing and thawing events in late winter, which kills the tree's roots on all but deep soils (Haufler 2010). At higher elevations where snow cover occurs through the late winter, the trees appear healthier, but as snow levels increase and earlier snow melt occurs, more parts of its range will be exposed to unfavorable conditions (Haufler 2010).

Many acres of spruce forests have been killed by massive beetle outbreaks in Alaska (Haufler 2010). The Western Balsam Bark Beetle has impacted substantial areas of subalpine fir in southern coastal forests of the state in recent years, particularly in the Skagway area (Wittwer 2002, Kelly et al. 2007). This species is expected to have increasing impacts at higher elevations under future scenarios (Haufler 2010). Another insect, the Mountain Pine Beetle, are also showing increased activity at higher elevations (Williams and Liebold 2002) and are thought to be a threat to Lodgepole Pines in southeast Alaska (Haufler 2010).

Despite the shifts in vegetation, the landscape modifications, and the threats of new species and changing conditions, coastal forests are expected to see increases in productivity with climate change given increased growing seasons (Myneni et al. 1997). These changes may alter competition between species and cause shifts in species compositions or changes in distributions (Haufler 2010). Climate change may also create favorable conditions for the establishment and spread of invasive species, especially those associated with warmer climates (Haufler 2010). Native species may become stressed by the changing conditions too, providing increased opportunities for exotic species to take hold (Haufler 2010).

The effects of climate change on Alaska's amphibians have yet to be seen, though these will likely mirror changes observed elsewhere. These impacts will undoubtedly be variable from place to place as Alaska encompasses a vast amount of land (1,717,854 km²), a huge variation in

latitude (51°20'N to 71°50'N) and several climate zones (arctic, subarctic, boreal forest, and temperate rainforest). Since the Wood Frog is present throughout the state, it is likely to see the most variation in climate change impact, and will probably see range expansions and contractions depending on the region.

Since most of the state's amphibian species occur primarily or wholly within the southeastern temperate coastal forests of Alaska, impacts to these landscapes will have the most pronounced effect on their populations and will likely vary by species and population. While warmer temperatures and increased rainfall may increase suitable habitat, development rates and survival, these benefits may be countered by P-PET ratios, shifts in vegetation, predator introductions, invasive species, disease, competition, and stresses related to changes to timing of their breeding and other biological events. Understanding the effects of these is further compounded by the fact that distribution, life history, and habitat requirements for Alaska's amphibians are not well known (Hokit and Brown 2006).

HERPETOFAUNA OF ALASKA

Each of Alaska's herpetofauna species are briefly discussed in this section, including data pertaining to research conducted on each in Alaska, as well as selected life history characteristics. The information is by no means comprehensive, but is included to give managers a basic understanding of the species and the current state of available information on Alaska populations. A list of Alaska's herpetofauna can be found in Table 2 of the appendix.

Frogs

Three native species of frogs (including one toad) are known to occur naturally in Alaska. These include the Wood Frog (*Lithobates sylvaticus*), the Columbia Spotted Frog (*Lithobates luteiventris*) and the Western (Boreal) Toad (*Anaxyrus boreas*). Two additional species, the Red-legged Frog (*Rana aurora*) and the Pacific Chorus Frog (*Pseudacris regilla*), were introduced and have established viable populations in southeast Alaska. These introduced species are discussed later under the heading "Introduced Non-Native Species."

WOOD FROG

The Wood Frog (*Lithobates sylvaticus*) and the Eurasian Common Frog (*Rana temporaria*) are two similar species whose common ancestor presumably crossed the Bering Land Bridge sometime during the Tertiary Period, after originating in the tropics of the Old World (Hodge 1976). They are the only two anurans with the adaptations to survive in the Far North – a shortened larval period to deal with extremely short summers (Hodge 1976) and an ability to withstand frigid temperatures via freeze tolerance associated with cellular and molecular mechanisms (Storey and Storey 1999). They range further North in the Western hemisphere than any other poikilothermic tetrapod (Herreid and Kinney 1967), and they occupy 4X10⁶ miles², exceeded only in range extent by the Northern Leopard Frog, *Rana pipiens* (Hock 1956). They are widely distributed across the North American continent ranging from Georgia to northern Alaska and

Canada (Martof and Humphries 1959), and the northern and upper limit for breeding populations may be determined by the larval stage (Hokit and Brown 2006).

This species has the highest rate of larval development of any North American frog, all life stages can tolerate minimum temperatures lower than any other species of amphibian on the continent (Hodge 1976), and they are also the earliest breeding Ranid on the continent (Licht 1971). They are distributed across Alaska, having been observed north of the Brooks Range and in the southern stretches of the coastal temperate rainforests. In fact, reports in 2013 suggest that the species has been found farther North than ever previously recorded in the state – about 80 miles south of Barrow in the Arctic tundra. They have been identified as present on many federal lands within the state, including Katmai National Park and Preserve, Lake Clark National Park and Preserve, Yukon-Charley Rivers National Preserve, Kobuk Valley National Park, and Gates of the Arctic National Park and Preserve (Anderson 2004). They are apparently absent from Prince William Sound (MacDonald 2003). A localized population on Douglas Island near Juneau is thought to have been transplanted (MacDonald 2003). They can be found in forest, muskeg and tundra areas, and present distributions suggest survival during the last ice age both south and north of the glacial margins (Hodge 1976).

These frogs are smooth-skinned, highly variable in color and pattern (ranging from light brown to gray above and creamy white below), and many have numerous dark spots on their dorsal surface (MacDonald 2003). They usually have a dark eye mask, a white jaw stripe, and a light stripe running down the middle of the back (MacDonald 2003). They can be distinguished from other Ranids in Alaska by their smaller size, presence of a dark triangular patch behind the eye, a light vertebral stripe and by an absence of red color on the under parts (MacDonald 2003). There are generally considered to include two subspecies – *L. sylvatica sylvatica* Le Conte and *L. sylvatica cantabrigensis* Baird (Stebbing 1951), the latter being present in Alaska (Johansen 1962).

Compared with more southerly populations of Wood Frogs, those in Alaska exhibit a considerably higher weight-length ratio to supply energy for winter metabolic needs (Hodge 1976). They usually breed at age 2 and have a maximum life span of 4-6 years (Donald et al. 2011). This species is nocturnal in the more temperate parts of its range but tend toward diurnal activity in the North where the lengthened daylight periods are extreme (Hodge 1976). In Minnesota they are most active in the late evening and early morning, whereas at Fort Yukon they are most active during the brightest and warmest parts of the day (Hodge 1976).

This species occurs in shallow temporary ponds to permanent water bodies, but they prefer woodland ponds (Conant and Collins 1998, MacCulloch 2002). Adults have often been associated with woody areas, they spend a large period of their lifecycle in terrestrial habitat (Brehaut 2012), and they are known to hibernate under leaf litter and woody debris (Hokit and Brown 2006). Abundance of adults is positively associated with forest canopy cover (deMaynadier and Hunter 1998, Guerry and Hunter 2002, Homan et al. 2004), movement at breeding sites is correlated to closed-canopy forests (Vasconcelos and Calhoun 2004), and winter hibernacula are frequently associated with upland forest habitat (Regosin et al. 2003).

They have also been shown to have lower survival rates in areas harvested for timber (Rittenhouse et al. 2009).

Despite aforementioned habitat criteria, Wood Frogs in Denali National Park are apparently not obligated to closed-canopy forests, whereby woody shrubs dominated by willow, dwarf birch, and alder (in order of prevalence) were shown to be acceptable substitutes (Hokit and Brown 2006). A more complex microhabitat around a pond's perimeter provides greater availability of egg mass attachment locations and sufficient cover for metamorphs and juveniles (Egan and Paton 2004, Skidds et al. 2007, Brehaut 2012). Climate change is predicted to shift vegetation regimes in Alaska (Chapin et al. 1995, Arft et al. 1999), which may cause shifts in Wood Frog distributions based on their association with canopies and woody vegetation (Hokit and Brown 2006). The length of time that surface water remains present influences the growth of vegetation (Skidds et al. 2007, Egan and Paton 2004). Changes in evaporation could also impact Wood Frogs if pond desiccation occurs more frequently or earlier in the season (Brehaut 2012).

Brehaut (2012) found higher presence values for this species when large lakes were absent from the landscape buffer, and in smaller ponds dominated by sedges. In this study, local variables seemed to play a more significant role in habitat selection, especially dominant pond vegetation and pond perimeter (Brehaut 2012). Smaller ponds with non-woody sedge vegetation around the pond perimeter were selected over larger ponds with woody species or no vegetation at all (Brehaut 2012). They did not find open water to be a significant local variable but suggested that this could be influenced by the fact that seasonal desiccation of study sites could not be determined from a single visit (Brehaut 2012). Others have found that the distance to the nearest pond, pond density, and stream length were important to amphibian dispersal across the landscape, but not as significant as terrestrial variables (Rothermel and Semlitsch 2002).

Wood Frogs typically breed in shallow bodies of water but adults can be found considerable distances from wetlands (Hodge 1976). The shallow regions (<50cm deep) of lentic sites provide thermal environments that are ideal for rapid tadpole development (Hokit and Brown 2006). Smaller sites often have warmer temperatures and fewer aquatic predators (Rowe and Dunson 1995) but a greater likelihood of desiccation prior to metamorphosis (Hokit and Brown 2006, Egan and Paton 2004). Low levels of gene flow for Wood Frogs have been shown within 200m of wetlands (Meier 2007).

In Fairbanks, Alaska, Wood Frogs are known to hibernate terrestrially in shallow (about 1.4 inches) bowl shaped pockets dug by the frogs in the upper layer of the previous year's vegetation (Hodge 1976). These are overlaid with newly fallen vegetation that ranges from .6 to 1 inch thick, followed by an insulative layer of snow (Hodge 1976). The snow is particularly important and years with limited snowfall can cause high overwinter mortality in this species (Hodge 1976). Mortality is thought to be high in moist hibernation sites (Hodge 1976) but they have been shown to survive temperatures down to 21°F (-6°C) (Hodge 1976). In the interior of Alaska, snow cover of approximately two feet gives maximum insulation and maintains temperatures in the upper layers of soil at relatively consistent temperatures, despite extreme

fluctuations in air temperatures (Kessel 1965). In the spring, snow settles and becomes denser, thus losing its insulative value, but as long as some remains the soil cannot thaw (Kessel 1965). Johansen (1962) reported that Wood Frogs in Fairbanks entered hibernation within a period of three days in early October.

Variations in the timing of courtship each year are due to weather conditions (Kessel 1965). They cannot begin breeding until temperatures are above freezing, the upper few inches of ground are thawed, and some open water is available at breeding sites (Kessel 1965). Wood Frogs in interior Alaska breed as soon as physiologically possible and in some years ice may still be present in the ponds when males begin chorusing in the melted pond margins (Kessel 1965). Eggs of this species can tolerate lower temperatures than those of other Ranids tested, and are even able to survive a layer of ice over the water (Moore 1939). The eggs also have the highest rate of development at any given temperature (Moore 1939). Adults have been shown to retain high levels of functional behavior at temperatures near the freezing point of water (Johansen 1962). Breeding and development are considered the life cycle phases that are least resistant to environmental extremes (Herreid and Kinney 1967).

This species must select breeding locations that permit time for eggs to hatch, tadpoles to develop, and metamorphosis to occur prior to the return of winter conditions (Hokit and Brown 2006). Wood Frogs in Alaska breed explosively just after snow has melted, they lay their eggs in late April or early May, and they metamorphose in late June or early July (Herreid and Kinney 1976). Kessel (1965) reported on 12 years of Wood Frog observations in Fairbanks and found that in nine of those years, ten or more consecutive days with mean daily temperatures above freezing had elapsed before chorusing began (mean 14 days). In 1962 and in 1959, breeding appeared to have been retarded by a late snow cover (Kessel 1965). For all years, the average high temperature for the three days preceding vocalizations was 56°F and the average low temperature was 31°F (Kessel 1965). The timing of breeding appeared to be more directly related to the timing of thaw in the upper layers of the ground and on the pond margins than by snow cover and atmospheric temperatures (Kessel 1965).

Herreid and Kinney (1967) also reported on Wood Frog emergence and breeding in Fairbanks. They found that the dates of first appearance ranged from April 24th to May 22nd and that egg laying began 4-6 days later. Oviposition was completed in a pond 4-8 days after the first egg mass appeared (Herreid and Kinney 1967). Egg masses were laid in the same general area within a pond, and the average number of eggs per mass was 778, with an average egg diameter of 1.6mm (Herreid and Kinney 1967). The development of the eggs is directly related to water temperature (Ultsch et al. 1999) and occurred in this study at the same rate as Wood Frogs in New York (Herreid and Kinney 1967). They also found that temperature limits that permit at least 50% survival of eggs through hatching were 6-24°C, and that tadpoles preferred a range of 9 to 29°C (Herreid and Kinney 1967). The time to metamorphosis was 53 to 78 days.

In another study by Herreid (1966), an average of 96% of the eggs and larvae observed in four ponds died before metamorphosis was complete. Mortality in this study was high throughout the first month of development and declined by the time the hind legs emerged on the

tadpoles (Herreid 1966). Less than 10% (average 3.7%) of the original population was alive prior to climax metamorphosis in late July (Herreid 1966).

Hokit and Brown (2006) reported on a study of this species in Denali National Park and Preserve in 2003 and 2004. Of the 219 sites that they surveyed, eggs were observed at 98 sites (45%), but adults and juveniles at only 18 sites (8%), suggesting that “post-metamorphic individuals are cryptic and that monitoring protocols should focus on surveys for eggs and larvae.”

Breeding activity was more often observed at sites with more emergent and woody vegetation in the riparian zone, particularly those with spruce and alder (Hokit and Brown 2006). It was less often observed at deeper sites that were more permanently connected to streams, those where moss dominated the substrate and those with beaver activity (Hokit and Brown 2006). Given that most of the sites the frogs were observed at were within shrubby tundra less than 1000m from boreal forest, the authors suggest that the species may frequent non-canopied areas at higher elevations so long as the riparian areas include shrubby vegetation (Hokit and Brown 2006).

Wood Frogs and American Toads are two relatively common pond-breeding anurans in North America (Homan 2010) but the latter fails to occur in Alaska. In contrast to the American Toad, adult Wood Frogs appear to prefer forested upland and forested wetland habitats (Guerry and Hunter 2002, Regosin et al. 2003, Baldwin et al. 2006). The Wood Frog’s distribution has been positively correlated to the amount of forest canopy cover present (Guerry and Hunter 2002, Homan et al. 2004) and there may be a threshold level of forest cover below which populations are unlikely to exist (Homan et al. 2004). They have been shown to be negatively impacted by road edges (Gibbs 1998b) as well as new-growth forests up to 11 years old (deMaynadier and Hunter 1998). Juveniles of both species orient themselves toward forested habitats and selectively avoid open habitats (Bellis 1965, deMaynadier and Hunter 1999, Rothermel and Semlitsch 2002, Vasconcelos and Calhoun 2004).

Several studies have reported Wood Frogs with growth abnormalities, usually in the form of missing limbs or toes, from the Kenai Peninsula, the Koyukuk National Wildlife Refuge, and the Arctic National Wildlife Refuge (MacDonald 2003). The often lethal chytrid fungus has also been reported in Wood Frogs from the Kenai Peninsula (MacDonald 2003). Reeves (2008) reported on monitoring of this species at 219 sites in the area between 2000 and 2006. They examined 9,268 metamorphic Wood Frogs from 86 breeding sites at five Alaska Wildlife Refuges. Abnormalities were observed at all refuges sampled, with Kenai having the highest prevalence of abnormal individuals (7.9%), followed by Tetlin (5.9%), Innoko (3.0%), Arctic (2.0%) and Yukon Delta (1.5%). The overall prevalence of abnormal frogs was 6.2% (Reeves 2008). Higher rates of malformation were observed in sites closer to roads, which can contribute to malformations through chemical contamination of habitat (Parson 2001, Rocque 2007) or by facilitating introduction of predators, parasites or pathogens (Reeves 2008b, Urban 2006). Strikingly, the size and relative remoteness of the refuges does not make them immune from anthropogenic influences (Reeves 2008).

COLUMBIA SPOTTED FROG

The Columbia Spotted Frog, *Rana luteiventris*, is widespread throughout western North America and occurs from the southern stretches of Canada's Yukon Territory and northwestern British Columbia (Bennett Lake and its upper watershed close to the Alaska Border), southward through British Columbia to central Nevada and Utah (MacDonald 2003). They occur in the coastal rainforests of southeastern Alaska, though their northern range limits are not precisely known (Hodge 1976, MacDonald 2003). It was once considered the same species as the Oregon Spotted Frog, *Rana pretiosa*, but subsequently gained species recognition within the spotted frog complex. Their present distribution suggests that they survived glaciation in the Pacific Refuge east of the Cascade Mountains, entering Alaska via the intermontane corridor between the Coast Mountains and Rocky Mountains of British Columbia (Hodge 1976).

Columbia Spotted Frogs are disappearing from parts of their range in Nevada and Utah, but are listed as stable throughout much of their range (Bos and Sites 2001). They are still considered common in British Columbia but their status in Alaska is unknown (MacDonald 2003). They have been documented along the mainland of southeastern Alaska at Salmon River, Unuk River, Stikine River (including on several nearby coastal islands), Point Agassiz, Taku River, and possibly in the Haines area, though the latter requires verification (MacDonald 2003). They've been identified 100m above the Stikine River in a muskeg pond and Anderson (2004) reported observations by hikers on the Canadian side of the Chilkoot Pass. Their sister species, the Oregon Spotted Frog, has drastically declined throughout its range in California, western Oregon, Washington, and southwestern British Columbia (Green et al. 1997), and has been a candidate for listing under the U.S. Endangered Species Act (Funk et al. 2005).

These frogs have somewhat bumpy skin, are medium sized, have relatively short hind legs, inconspicuous dorsal folds, and fully webbed toes (MacDonald 2003). They are larger than the Wood Frog, they have bright salmon coloration on the ventral surfaces, and they lack a dark eye mask or light vertebral stripe (MacDonald 2003). Like most Ranids, females are larger than males and this is associated with increased fecundity (Salthe and Duellman 1973, Elmberg 1991). Information on their habitat requirements, movements, overwintering and activities during the summer is particularly sparse (Bull and Hayes 2001).

Columbia Spotted Frogs are one of the most common lentic-breeding amphibians found at high elevations throughout northwestern North America (Reaser and Pilliod 2003). They are found in a variety of habitats ranging from low elevation wetlands to high elevation lakes (Funk et al. 2005). They are closely associated with permanent water and the riparian habitats of backwater lakes, beaver ponds, river channels, and streams "where they breed, forage, and overwinter underwater in mud and under stream banks" (MacDonald 2003). In landscapes that offer few overwintering sites such as those at high altitudes or latitudes where lakes can remain frozen for nine months a year, fidelity to specific hibernacula may be common (Pilliod et al. 2002).

The species is extremely aquatic, rarely being found far from permanent water, and they frequent grassy margins, rivers, and lakes (Hodge 1976). A study by Pilliod et al. (2002) in Idaho found that the vast majority of frogs in the Skyhigh Basin were in fishless wetlands deeper than 3m that were surrounded by extensive mats of vegetation and algae covered by shallow water

flowing from numerous perennial springs. They are capable of extensive annual migrations to distant water bodies (Turner 1960, Hollenbeck 1974, Patla 1997), “even in steep, arid mountain ranges at the altitudinal limit of the species” (Pilliod et al. 2002). Maximum dispersal distance of less than 1.3 km have been reported (Turner 1960, Hollenbeck 1974, Patla 1991m Bull and Hayes 2001, Bull and Hayes 2002), but one study reported an individual 6.5km downstream from its natal pond in Idaho (Engle 2001). This species generally moves along riparian corridors but have been reported to move 400-500m across dry, grazed grasslands and sagebrush uplands (Reaser 1996, Bull and Hayes 2001). Movements away from breeding sites though could provide frogs with a survival advantage if new sites had fewer predators, better cover, more food, or less competition (Bull and Hayes 2011).

Females in particular have been documented engaging in long distance migrations and in one study, nearly half of the female frogs migrated over 500m to reach summer habitats, whereas males stayed close to the breeding ponds (Pilliod et al. 2002). This suggests that there may be physical limitations for males based on size or differing life history strategies (Pilliod et al. 2002). Pilliod et al. (2002) suggest that this is more related to behavioral differences between the sexes rather than morphological or physiological differences:

“For example, males may remain near breeding sites to compete for females each spring, causing them to forgo traveling to preferred foraging sites. Males may also require less energy than reproductive females because female Columbia Spotted Frogs lose 25-35% of their body mass during egg deposition (Engle 2001).”

It has been shown that females often do not return to breeding ponds for several years until they reach sexual maturity (Engle 2001). At higher elevations, females of this species are thought to reproduce ever 3-4 years (Turner 1960), though individuals that migrate to areas rich in prey may be able to reproduce with greater frequency (Pilliod et al. 2002). They communally lay globular, often floating egg masses in shallow water immediately after ice melt, which tends to be mid-April in the lower Stikine valley (MacDonald 2003).

Columbia Spotted Frogs have an explosive mating system lasting a few days to a couple of weeks at each breeding site (Turner 1958, Bull and Shephard 2003). Because of their scramble mating system and the duration of the breeding season, some believe that there is little opportunity or time for female choice (Wells 1977a), despite the fact that females arrive at breeding sites later and in smaller numbers at any given time, producing a male-skewed ratio at the sites (Turner 1960, Wells 1997a, Pough et al. 2004). Males typically congregate at breeding sites first and begin calling in search for the females (Green and Funk 2009). As with many explosive amphibian breeders in western North America, males can sometimes engage with other males to dislodge them from the female (Olson et al. 1986, Davis and Verrell 2005). Amplexus can last for several days in this species (Svihlia 1935, Turner 1958, bull 2005, Davis and Verrell 2005) and many males successfully remain attached to the female until oviposition (Green and Funk 2009).

Merely protecting breeding sites for montane populations of Columbia Spotted Frogs is unlikely to be sufficient protection for the species since in some areas, spatially separated breeding, summer, and winter habitats may all be essential for the persistence of populations (Pilliod et al. 2002). Where amphibian conservation is a priority, Pilliod et al. (2002) recommends “a shift in management focus from protecting only breeding ponds to protecting groups of diverse water bodies and surrounding uplands within 1km of breeding ponds.”

WESTERN TOAD

The Western (Boreal) Toad, *Anaxyrus boreas*, occurs from southeastern Alaska through Western Canada (including Vancouver and the Haida Gwaii islands) and to the western United States and Baja California (MacDonald, 2003). For unknown reasons, this species appears to be declining throughout much of its range, even in entirely pristine environments (MacDonald 2003). Populations of this species have been nearly extirpated in large portions of western continental North America with a major contributor being the pathogenic chytrid fungus (Carey 1993, Muths et al. 2003). Among the most severely impacted populations are those from New Mexico, Colorado and Wyoming (Carey 1993, Muths et al. 2003). In Alaska, declines have been reported and chytrid fungus has been verified in many populations (Adams et al. 2007). Their present distribution suggests that they survived glaciation in the Pacific Refuge and that they entered Alaska via the coastal corridor and perhaps via the Stikine River (Hodge 1976).

In Alaska, the distribution of toads is from the Tasnuna River, a tributary of the Copper River, in Prince William Sound (PWS) to the north, from the British Columbia border in the south (Hodge 1976) and as far west as the Columbia River Glacier. They are widespread both on the mainland and islands in the Alexander Archipelago and they have been found on Montague and Hawkins Islands in PWS (MacDonald 2003). Additionally, MacDonald (2003) reports unsubstantiated observations of toads on Green, Heather, Glacier and Growler islands near Columbia Bay, also in PWS (MacDonald 2003). They have been found to inhabit altitudes up to 3600m above sea level (Moore et al. 2011).

Boreal Toads are squat, with short legs, numerous warts, and obvious paratoid glands on the back of the head (MacDonald 2003). In some areas they can be very abundant and are often active during the day (Hodge 1976), especially during damp weather (MacDonald 2003). They may live greater than nine years (Carey et al. 2005) and adult survival can be high (Scherer 2008). Adult Boreal Toads are active 5-6 months of the year and may have body temperatures greater than 30°C during their active period (Carey 1978, Bartelt and Peterson 2005). They are sexually dimorphic and studies have shown that females travel farther from breeding ponds to reach foraging grounds than males (Bartelt et al. 2004, Browne 2010, Bull 2006, Goates et al. 2007, Muths 2003).

Their habitat is terrestrial and they are typically found in open, non-forested areas adjacent to freshwater, although they breed in muskeg ponds, streams, rain pools and ditches (Hodge 1976). They occupy three types of seasonal habitat throughout a given year including spring breeding ponds, summers in upland aquatic habitats near breeding ponds, and winter

hibernacula in terrestrial forest habitats (Pyare et al. 2004). Movement studies have shown that this species uses habitat between 600 and 2000m from breeding ponds on average (Muths 2003, Bartelt et al. 2004, Bull 2006). Mullally (1952) reported that this species in California is very sensitive to light and temperature, noting that individuals become active at the same time each evening and if temperatures fall below 30°C, they take shelter (Browne and Paszkowski 2010).

Survival probability in some areas of this species' range is known to be influenced by minimum daily winter air temperature, snow depth, and winter environmental moisture level (Scherer et al. 2008), suggesting that suitable hibernacula is the limiting factor at the northern edge of the species range and at high elevations (Browne and Paszkowski 2010). In the Yukon, the species has only been reported from valleys that receive high snowfall which prevents deep frost penetration (Cook 1977). Survival to sexual maturity is low, but this has a small effect on population growth rate, which is more sensitive to adult survival (Biek et al. 2002, Vonesh and De la Cruz 2002).

Toads in Alaska often hibernate communally in burrows below frostline in forested cover adjacent to wet areas (MacDonald 2003). In Minnesota, Canadian Toads were found to display fidelity to hibernation sites (Kelleher and Tester 1969). This is not a freeze tolerant species (Mullally 1952, Holzwart and Hall 1984) and thus individuals must find suitable hibernacula to survive (Brown and Paszkowski 2010). Western Toads in Colorado have been found to hibernate communally (but not in physical contact with one another) in underground cavities near flowing ground water and insulated by snow (Campbell 1970). One study found that 68% of radio-tracked toads hibernated communally and that the hibernacula contained up to 29 toads, with two to five toads per site being most common (Browne and Paszkowski 2010). Communal hibernation may occur because suitable hibernacula are limited, or there are benefits to the aggregation such as predator defense – “a predator may sample only one individual in a group as this genus is known to be toxic” (Licht and Low 1968).

In Oregon, Western toads were found to overwinter in rodent burrows, beaver and muskrat structures, crevices, under large rocks, logs or root wads, and in banks adjacent to streams and lakes within 180 to 6230m from breeding ponds (Bull 2006, Browne and Paszkowski 2010). Toads frequently select pre-existing tunnels and cavities (Browne and Paszkowski 2010) and locations that provide suitable microclimates (Long and Prepas 2012). Unlike Canadian toads, Western Toads do not seem to dig into sand or loose soil (Breckenridge and Tester 1961, Kuyt 1991, Browne and Paszkowski 2010). Natural sites typically have less bare ground and more vegetative structure that provide insulation from wind and freezing temperatures (Dolby and Grubb 1999), and they trap blowing snow for additional insulative properties (Ross et al. 1968). Deciduous forests dominated by aspen appear to provide poor hibernacula and tend to be less insulated from colder temperatures than spruce stands (Balland et al. 2006). Conifer forests have been shown to be strongly selected for hibernation, followed by dry scrublands (Browne and Paszkowski 2010).

Larger and probably older toads move to hibernation sites later in the year and move along straighter paths than younger and smaller individuals, probably because the former have superior navigational skills, and larger energy and/or water reserves that permit rapid, long-distance movements (Browne and Paszkowski 2010). Unlike populations of this species elsewhere (Manier and Arnold 2006), distance does not appear to be a major predictor of gene flow in Southeast Alaska (Moore et al. 2006). Despite the need for winter insulation, this species can tolerate swimming through the frigid saltwater of Glacier Bay, Alaska and are regularly found in areas that were recently covered by glaciers (Taylor 1983). They are surprisingly tolerant to the glacial moraine terrain in southeastern Alaska, much of which has only been ice-free for 30-100 years (American Geographic Society 1966, Anderson 2004). Glacial rebound though can have negative effects on wetlands since, when the extreme weight of the glacier is removed, land may rise and drain (Anderson 2004).

While not all females may breed each year (in Alaska they appear to breed once every 2-3 years, Pyare et al. 2004), a single adult may lay over 5000 eggs in the years that she oviposits (Carey et al. 2005). Unlike many toads, males actually lack a vocal sack and do not appear to signal breeding with a loud call, only an occasional soft chirp (Awbrey 1972). In southeast Alaska, toads often congregate and breed in warm, shallow (less than or equal to 15cm) ponds and lake margins with abundant aquatic vegetation (Carstensen et al. 2003). Breeding can take place in seasonal ponds though successful development of tadpoles usually requires more permanent water bodies (Pyare et al. 2004). Large numbers of metamorphosing toads can be readily observed July-August in small ponds in the Juneau area (Hodge 1976).

Even though toads are less sensitive to desiccation than other amphibians and can tolerate the higher temperatures and lower moisture levels in clearcuts (Stebbins and Cohen 1995), it has been suggested that clearcuts may be favorable during the early summer months (Deguise and Richardson 2009). Later in the season, the clearcut habitat would potentially be detrimental when temperatures are high and there is little precipitation, resulting in significant desiccation (Deguise and Richardson 2009). In southeast Alaska, the temperate rainforest averages 3-4m of precipitation annually so breeding ponds are not at high risk of drying up before larvae metamorphose (Cartensen et al. 2003). Others though have suggested that localized drying of wetlands in the area may be affecting toad numbers (Anderson 2004). In this region, Boreal Toads may exhibit more plasticity in breeding site selection and dispersal, even in altered habitats (Moore et al. 2011). Moore et al. (2011) found that toads are “robust to habitat heterogeneity, yet can be genetically differentiated on small geographic scales, which is probably due to breeding site philopatry and small effective population sizes.” This ability to tolerate and disperse across variable habitats may allow the species to colonize newly available habitats and be resilient during climactic change (Moore et al. 2011). Conservation of this species is perhaps the most critical among Alaska’s amphibians, especially since long-time residents from Haines to Ketchikan have noted sharp declines in toad populations (MacDonald 2003, Ream unpublished data), and they are listed as a species of conservation concern in North America (Hammerson et al. 2004). Many comments and observations from residents in Gustavus and Skagway have identified major declines since the 1970s (Anderson 2004). Carstensen et al. (2003) recorded 40 terrestrial local knowledge

observations from this species in the Juneau area with only three of these reported since 2003, the rest having been seen between the 1950s and the 1990s. In contrast, populations in Canada appear to be stable or expanding, especially within the country's boreal forests (Hammerson et al. 2004). Southeast Alaska though, is a rapidly changing landscape at the northern edge of the species' range (Moore et al. 2011). Grasping the current distribution patterns and connectivity of populations will better allow predictions on the future impacts of climate change as well as the potential for range expansion (Moore et al. 2011).

Roads have long been suspected barriers to movement and population connectivity for many species. A study by Moore et al (2011) did not find that roads significantly affected Boreal Toads, a variable that they suggested to be among the most prominent anthropogenic influences in southeastern Alaska. The populations that this group studied were along the Haines Highway, a remote two-lane wide roadway with little traffic (Moore et al. 2011). Traffic arriving from the south arrives on the Alaska Marine Highway and there is no other port of entry (Moore et al. 2011). In light of the minimal effect that this road appears to have on local Boreal Toads, the authors suggest that there are few barriers to dispersal and that the species may be well suited to a northward range expansion. Furthermore, populations in southeastern Alaska appear to be broadly tolerant of habitat, moisture, and temperature regimes that occur there (Moore et al. 2011). For instance:

“toads in this region are known to breed in extreme thermal environments ranging from glacially fed lakes to warm thermal pools whereas in other parts of their range dispersal and connectivity are strongly limited by cover and moisture (Bartelt et al. 2004, Murphy et al. 2010).”

Terrestrial habitat is clearly important for this species and efforts to protect their habitat should include these areas (MacDonald 2003), as well as winter refugia (Long and Prepas 2012). Unfortunately, occupancy rates for Western Toads in Alaska are generally low (<0.15%) and when coupled with the fact that little is known about their distributions and habitat, the ability to detect trends becomes limited (Pyare et al. 2004b). In the southern part of the species range, several decades old captive breeding programs have continually released captive-bred animals into the wild to boost population numbers and to establish new populations in previously inhabited locations (Johnson 1999, Spencer 1999, Jackson 2008, Ivey et al. 2000).

Pyare et al. (2004) offered that:

“Breeding ponds are obvious focal points for potentially understanding the natural history, distribution, status and trends in toad populations, given the critical role that ponds play in toad life history, the relative permanence of ponds on landscapes, and the efficiency with which individuals of various life stages can be sampled at ponds.”

Management strategies might also benefit from including habitat patches aimed at protecting an entire population (Browne and Paszkowski 2010). Browne and Paszkowski (2010) found that even if breeding wetlands remain intact, “the destruction and degradation of small patches of

key terrestrial habitat for Western Toads can potentially translate into large negative impacts on populations,” but also that “it is unrealistic to institute prescriptive measures to create protective barriers around ponds large enough to encompass hibernation sites.” They suggest that patches of spruce dominated conifer forests with complex habitat structures that create subterranean spaces and insulation on the ground be protected for this species.

Salamanders

Three species of salamander are known to occur in Alaska including the Rough-skinned Newt (*Taricha granulosa*), the Long-toed Salamander (*Ambystoma macrodactylum*), and the Northwestern Salamander (*Ambystoma gracile*). While these are all lentic system breeders, mountain stream-dwelling salamanders in other parts of the United States, such as the Dicamptodons, are often neotenic, suggesting that cold and high altitude may inhibit or prolong metamorphosis (Hodge 1976). In southeastern Alaska where similar conditions exist (such as short cool summers where egg deposition often does not begin until that time), salamanders that metamorphose in their second year farther south often do so in their natal year in Alaska to avoid complete freezing that can take place in the breeding pond (Hodge 1976). Deeper pools typically have longer hydroperiods (Brooks and Hayashi 2002, Wellborn et al. 1996) and are thus sometimes preferred, especially for the ambystomatids. A significant consideration for Alaska is that, according to Rubbo et al. (2011), salamander habitat is expected to improve under current climate projections.

ROUGH-SKINNED NEWT

The Rough-skinned Newt, *Taricha granulosa*, is the most abundant and most frequently encountered urodele in southeast Alaska (Hodge 1976) and the most abundant tailed amphibian in the state (MacDonald 2003). The species occurs along the Pacific Coast from southeast Alaska through western Canada including Vancouver Island (but not the Haida Gwaii Islands), south to California (MacDonald 2003, Oliver and McCurdy 1974). They have been reported on the mainland of southeast Alaska as far north as Juneau (where they were transplanted from Shelter Island in the 1960s) and on the islands of Admiralty and Shelter, as well as many islands within the Alexander Archipelago farther south (MacDonald 2003). They have also been seen in the Galankin Island group near Sitka but this population is also suspected to be a transplant, taken from Ketchikan stock around 1980 according to personal communication with J. Whitman in 2003 by MacDonald (2003).

A National Park Service (NPS) volunteer found a Rough-skinned Newt off the coast of Sitka on Rockwell Island, outside of the borders of the Sitka National Historic Park (Anderson 2004). Researchers speculate that Native peoples may have transplanted these amphibians long ago, especially since the Tlingit, Haida, and other peoples of the Pacific Northwest have many amphibians in their legends (Anderson 2004, Post 2004), that salt water dispersal is probably difficult for the species (ADF&G 2005), and that no records on Baranof Island existed prior. In 2005 however, a science experiment gone wrong resulted in the introduction of this species to Baranof when a high school student cleaning an aquarium outdoors accidentally dumped about

50 newts into a nearby wetland (ADF&G 2005). The student had illegally captured these Newts from Kiui Island and illegally held them in captivity without the proper permits (ADF&G 2005). Biologists believe that the newts will do well on Baranof since habitat conditions appear suitable (ADF&G 2005).

Rough-skinned Newts are found in coastal forests dominated by spruce and hemlock (Hodge 1976), occurring from sea level to high mountain lakes (MacDonald 2003). They are typically in or about small permanent water bodies with abundant vegetation (Hodge 1976). Studies outside of Alaska have shown that populations reach their highest densities in mature and old-growth forests (MacDonald 2003). They are more aquatic than other members of their genus, especially the California Newt (*T. torosa*) and the Red-bellied Newt (*T. rivularis*), which are only found in California (Oliver and McCurdy 1974), but *T. granulosa* avoids the fast-flowing water frequented by the other two (Stebbins 1966).

Rough-skinned Newts are plain brown to black dorsally and have contrasting bright yellow to reddish orange below (MacDonald 2003), aposematic coloration due to their high toxicity throughout parts of their range. Their eyes are pale yellow and crossed by a distinct dark bar (MacDonald 2003). Throughout much of the year their skin is dark and grainy though breeding males develop a smooth, slimy skin, swollen vent, flattened tail and dark pads on the feet (MacDonald 2003). Sexual maturity often occurs between 4 and 5 years of age and individuals have been known to live up to 26 years (MacDonald 2003).

Breeding in Alaska usually commences in April and continues through June (MacDonald 2003). During and after the breeding period from April to mid-September, females are mostly aquatic but males normally remain aquatic throughout the year except for occasional brief excursions on land (Oliver and McCurdy 1974). Adult males approach breeding condition as early as November with turgid skin, a swollen vent, and a developing tail crest, appearing in that order (Oliver and McCurdy 1974). By late February males have fully prepared for breeding and have developed cornified nuptial pads (Oliver and McCurdy 1974).

Though males remain aquatic indefinitely, females overwinter on land and only old, emaciated females remain in the water over winter – females that do not become gravid the next spring (Oliver and McCurdy 1974). The difference in winter hibernation locations between the sexes appears to be unique to this member of the *Taricha* genus (Stebbins 1966). Newts in eastern North America and Europe of the genera *Notophthalmus* and *Triturus* are permanently aquatic in both sexes. Oliver and McCurdy (1974) found that among the few adult male newts overwintering on land and the few female newts overwintering in water on Vancouver Island, none reproduced the next spring.

Rough-skinned newts migrate from terrestrial overwintering habitat to breeding ponds in mid-March to mid-April in B.C., usually during a wet period (Oliver and McCurdy 1974). Unlike other members of its genus, this species lays their eggs singly (Chandler 1918), but they are not released from the ovary until late April (Oliver and McCurdy 1974). A study at Marion Lake in southwestern British Columbia found that female newts breeding in the spring left the water by

mid-October to overwinter on land (Efford and Mathias 1969), but this is apparently inconsistent with findings in similar habitat on Vancouver Island (Oliver and McCurdy 1974).

A second female migration, this time including metamorphosed juveniles of both sexes, occurs back to the terrestrial overwintering habitat with the onset of fall rains, usually in mid-September in southern British Columbia (Oliver and McCurdy 1974). As the fall progresses migrant numbers decrease with the last few animals leaving breeding ponds in mid-November before the arrival of freezing weather (Oliver and McCurdy 1974). At higher latitudes and altitudes this probably occurs sooner.

Throughout much of the Rough-skinned Newt's range, the species produces tetrodotoxin (TTX), a potent neurotoxin, and related analogs as a predator defense mechanism (Brodie 1983, Daly 1995). These block ion conductance through voltage-gated sodium channels (Kao and Levinson 1986, Hille 2001). Birds and fish readily succumb to the newts' deadly neurotoxin (Brodie 1968, McAllister et al. 1997, Mobley and Stidham 2000) but at least three species of garter snake (*Thamnophis sirtalis*, *Thamnophis couchi*, and *Thamnophis atratus*) overcome the toxin and consume all four species of newts producing it (*Taricha granulosa*, *Taricha torosa*, *Taricha rivularis*, and *Taricha sierra*) (Brodie 1968, Brodie and Brodie 1990, Brodie et al. 2005, Edgehouse 2008, Feldman et al. 2009, Gregory and Nelson 1991, Twitty 1966, Williams et al. 2004, Wiseman and Pool 2007). The snakes do so through modifications of the amino acid sequence for the TTX molecule (Feldman et al. 2009, Geffeney et al. 2002, Geffeney et al. 2005), thus reducing the impairment of action potentials in nerve and muscle tissue that lead to asphyxiation and death (Kao 1966).

The importance of this toxin as an antipredator trait has been well documented and is thought to have evolved as part of an "evolutionary arms race" with garter snakes where the two occur sympatrically (Brodie 1968, Brodie and Brodie 1990, Brodie et al. 2002). The evolution of lethal defenses in prey represents a fundamental paradox in evolutionary biology whereby "lethality in prey can ameliorate an innate imbalance associated with predator-prey interactions" (Williams et al. 2010). This model suggests that the potential fitness costs associated with being eaten (ie. death), are significantly greater than those associated with failure to eat (loss of a meal) (Williams et al. 2010). One mechanism by which predators avoid lethal consequences is taste-rejection (Skelhorn and Rowe 2006), which allows both the predator and often the prey to survive an encounter (Williams et al. 2010). With the garter snakes occurring sympatrically with the newts though, those with high individual resistance are more likely to survive interactions with and successfully consume the otherwise deadly newts (Williams et al. 2010).

Interestingly, the production of TTX in newts may not follow that of other vertebrate species that produce it. Most higher taxa species producing TTX do so via symbiotic relationships with bacteria that produce the toxin for them (Nogushi et al. 1986, Yotsu et al. 1987, Yasumoto and Yotsu-Yamashita 1996) but this has been questioned for the newt (Shimuzu 2002, Hanifin et al. 2004, Lehman et al. 2004). Cardell et al. (2004) demonstrated that:

- *T. granulosa* secrete high levels of TTX from glands on the skin
- *T. granulosa* are capable of secreting remarkable levels of TTX
- *T. granulosa* appear capable of regenerating TTX toxicity over a 9-month period in captivity
- *T. granulosa* lack TTX as larvae (Twitty 1937, Hanifin unpublished data) and have low levels as juveniles (Hanifin unpublished data)

Across their phenotypic range, TTX levels are closely correlated with the resistance of sympatric snakes (Hanifin et al. 2008). In areas that newts occur but snakes do not, many populations have been found to lack TTX or produce it in low quantities, presumably because it is a large molecule and energetically costly to produce. Where *T. sirtalis* occurs and newts do not, *T. sirtalis* lacks resistance to TTX (Hanifin et al. 1999, Brodie and Brodie 1991). Since garter snakes are not known to occur in Alaska (even if they do, their abundance is probably quite low), it is unclear if newts in the state even produce TTX. Dr. Dietrich Mebs of the University of Frankfurt is currently testing for the toxin in individuals from several southeast Alaska populations.

LONG-TOED SALAMANDER

The Long-toed Salamander, *Ambystoma macrodactylum*, is one of two Ambystomatid salamanders known to occur in southeast Alaska. The species is widely distributed in mountain regions of western North America (Petranka 1998) and can be found from Alaska south to California and east through Montana. Since Baird's (1849) original description of the species from specimens at Astoria, Oregon, the validity of the species has been widely recognized (Ferguson 1961). It is the most widely distributed salamander in the Pacific Northwest, a geologically and ecologically complex region (Brunsfield et al. 2001, Matsuda et al. 2006). Unlike *A. gracile*, *A. macrodactylum* inhabits diverse habitats throughout its range (Ferguson 1961, Anderson 1967, Nussbaum et al. 1983, Howard and Wallace 1985, Leonard 1993) and is considered the most "adaptable and variable" salamander species in the Pacific Northwest (Ferguson 1961, Hoffman et al. 2003).

The distribution of Long-toed Salamanders in Alaska is restricted to the southeastern coastal rainforests, especially those adjacent to the Stikine and Taku Rivers (Hodge 1976) though they've been found on islands elsewhere in the state. Distribution along the western coast is not precisely understood but we know that discrete populations exist along river basins that drain from more interior areas of British Columbia where the species commonly occurs (Ferguson 1961). The coastal form of this salamander is found as far north as Kitimat, British Columbia, suggesting the possibility that they entered the state via two pathways (Hodge 1976). The present distribution indicates survival during the last glacial period in the Pacific Refuge, entering Alaska via the intermountain corridor and the Coast Mountains (Hodge 1976). Lee-Yaw and Irwin (2002) suggested that the distribution and degree of divergence among the Long-toed Salamander lineages indicate that several refugial populations contributed to the large contemporary range of the species.

In British Columbia the distribution of this species is not precisely known but it has been found in the Stikine and Taku watersheds within the province, with the northernmost record based on a specimen taken at Telegraph Creek, B.C. The species was first confirmed present in Alaska on 4 August 1972 when Fred Wigg Jr., Ed Kalkins, and Rod Brown collected an adult female from Twin Lakes (on maps as Figure Eight Lake but referred to herein by its locally established name) on the Stikine (Hodge 1973). The specimen was found on damp ground in tall grass thirty yards from the lake (Hodge 1973). Subsequent specimens were found at this locality, as well as at Mallard Slough, Cheliped Bay, Andrews Slough, Farm Island, and farther out on the river delta on Sokolof Island, as well as on the Alaska side of the Coast Range in the Taku River Valley (MacDonald 2003). In addition, several individuals have been positively identified in the Ward Lake area of Ketchikan on Revillagigedo Island (Ream unpublished data).

Anderson (1967) studied the life histories of coastal and montane populations of the three ambystomatids inhabiting western North America (*A. macrodactylum*, *A. gracile*, and *A. tigrinum*) and found that they are more variable in life history than most salamander species in the east. The family Ambystomatidae was apparently isolated in the southeast due to the Mid-Continental Seaway during the Cretaceous (Milner 1983, Duellman and Sweet 1999) and progenitor populations gained access to the western Cordillera after the Pleistocene with the loss of the seaway (Thompson and Russell 2005). The mountainous environment that they found to the west was typical of those within the current distribution of Long-toed Salamanders (Thompson and Russell 2005). The fossil record for the species is non-existent and the nature of the geological record in the west requires reconstruction though historical patterns of gene flow (Thompson and Russell 2005). The natural history of the species indicates that they are fairly resilient to extinction (Templeton and Georgiadis 1996) and they appear to be phenotypically and behaviorally plastic in response to climatic and ecological gradients (Anderson and Graham 1967, Howard and Wallace 1983, Howard and Wallace 1984, Williams and Larsen 1986).

The Long-toed Salamander is slender with a smooth body, 12-13 costal grooves, no paratoid glands, long legs and long hind toes, especially the fourth toe (MacDonald 2003). They typically are dark brown to black above with a distinctive yellow, tan, or light green stripe running down the back from the head to near the tip of the tail (MacDonald 2003), though this strip is not always uniform and may be patchy and broken. The sides of the salamander often have a sprinkling of white flecks and the belly is dark brown to sooty gray (MacDonald 2003). In Alberta, Canada, this species has been found to have an average life span of approximately six years (Russell et al. 1996), allowing relatively long-lived cohorts to repopulate areas after brief disturbances or droughts (Thompson and Russell 2005).

These salamanders are largely terrestrial with adults entering water only during the early spring breeding season (Hodge 1976). They are found under boards, logs and ground litter in forested areas that are adjacent to freshwater (Hodge 1976) but their range is topographically and ecologically diverse (Ohta 1992, Brodie et al. 2002). They are almost exclusively nocturnal, secretive, and subterranean though adults can be found during the breeding season under rocks, decaying logs, or other debris, usually close to their breeding ponds which tend to be

shallow (>1m) and fish-free, but not always permanent (Hodge 1976, MacDonald 2003). Montane populations of *A. macrodactylum* larvae can inhabit small seasonally ephemeral and permanent ponds but also large permanent lakes (Anderson 1967, Howard and Wallace 1985, Leonard et al. 1993). They do prefer naturally fish-less wetland types (Petranka 1998) and at locations where trout have been introduced to the northwestern U.S. and southern Canada, the salamanders tend to be absent or exist in very low densities (Tyler et al. 1998a, Funk and Dunlap 1999, Pilliod and Peterson 2001, Bull and Marx 2002, Pearson and Goater 2008).

Pearson and Goater (2008) studied the effects of rainbow trout (*Oncorhynchus mykiss*) on Long-toed Salamanders and confirmed that direct predation can be a significant cause of local declines. They found that trout in laboratory settings consume both hatchlings and larvae, often killing all individuals within an hour of exposure (Pearson and Goater 2009). They also reported that distributions of introduced trout and native Long-toed salamanders within 57 wetlands in the Rocky Mountains of southwestern Alberta, Canada were completely allopatric (Pearson and Goater 2009). Salamanders were found only at sites that lacked introduced rainbow trout, cutthroat trout (*Oncorhynchus clarkia*), or brook trout (*Salvinus fontinalis*), a similar result found in several other studies (Tyler et al. 1998a, Funk and Dunlap 1999, Pilliod and Peterson 2001, Bull and Marx 2002).

In yet another study (Welsh et al. 2006), it was reported that among eight species of amphibian that occurred in wetlands in northern California, the Long-toed Salamander was the most susceptible to predation by trout, influenced by the fact that the feeding habits of the salamanders require them to spend more time in deeper, benthic areas where they are more likely to encounter trout. Funk and Dunlap (1999) found that many salamander populations in the Bitterroot Mountains of Montana were extirpated as a result of trout introductions to historically fishless lakes earlier in the 20th century. Fathead minnows, a common baitfish in parts of North America, have also been shown to have deleterious effects when introduced, given that they are voracious feeders of zooplankton (Duff 1998) and have been shown to cause strong ecosystem-level effects on zooplankton community structure (Zimmer et al. 2000).

In Alaska, native rainbow trout and cutthroat trout are popular sport fish and there may be a risk of introductions to previously fishless ponds. In addition, brook trout were introduced to parts of southeastern Alaska in the early to mid 20th century and may have impacted Long-toed Salamander populations in those areas. While the state currently restricts the use of live bait, future regulatory scenarios could allow for invasive species introductions that would impact Long-toed Salamanders. Limiting the introduction and spread of both native and invasive species, including the brook trout, should be considered conservation priorities for these and other amphibians. There is also evidence that salamanders can recover from the introduction of trout if the fish are extirpated or removed (Funk and Dunlap 1999) but population size during colonization events can have long-term effects too (Allendorf and Leary 1986, Gilpen and Soule 1986, Mills and Smouse 1994, Hitchings and Beebe 1997, Newman and Pilson 1997, Saccheri et al. 1998).

Breeding and larval ponds are often shallow and in subalpine meadows at elevations that are typically higher than those utilized by Alaska's second Ambystomatid, the Northwestern Salamander – *Ambystoma gracile* (Hoffman et al. 2003). Long-toed Salamanders are often philopatric toward breeding ponds and they can persist in disturbed areas (Powell et al. 1997a), which limit haplotype loss due to contemporary declines (Templeton and Georgiadis 1996, Fisher and Shaffer 1996, Alford and Richards 1999, Houlahan et al. 2000). Restricted gene flow has been attributed to semi-prominent landscape features like glacial basins (Howard and Wallace 1981, Tallmon et al. 2000).

Long-toed Salamanders can be found in the water only during the early spring breeding season (mid April/May on the Stikine River), sometimes before ponds are ice-free (MacDonald 2003). Migration to these breeding sites usually occurs on rainy nights and the males arrive before females and remain longer (MacDonald 2003). The presence of free water in soil is often a significant stimulus for breeding migrations in the spring (Howard and Wallace 1985) and is usually accompanied by increased temperatures and frequent rainfall (Anderson 1967). Howard and Wallace (1985) observed migrations during heavy snowmelt and even collected several adults that were crossing extensive snowfields, having made movements in excess of 100m across or under the snow pack. All of their observations of migration (over snowfields and otherwise) occurred at night.

There is a strong positive correlation between Snout-Vent Length (SVL) and the number of eggs laid by a female (Howard and Wallace 1985). Females at lower elevations produce significantly more than their counterparts at higher elevations (Howard and Wallace 1985). This is likely attributed to shorter growing seasons, fewer energy reserves, decreased predation and increased larval survivorship at higher altitudes (Howard and Wallace 1985). Eggs also tend to be larger at higher elevations, which may improve survival and reduce the time to hatch (Howard and Wallace 1985). Individuals in shallow or ephemeral ponds can metamorphose in 80-90 days after hatching at a relatively small size of approximately 25-35mm SVL (Kezer and Farner 1955, Anderson 1967, Howard and Wallace 1985). In larger permanent ponds, larvae often metamorphose 14 months after hatching when they are approximately 38-47mm SVL (Kezer and Farner 1955, Anderson 1967, Howard and Wallace 1985).

Eggs of this species hatch about 3 weeks after being laid depending on the water temperature (MacDonald 2003). Larvae in Alaska overwinter before transforming, though neotenic forms have not been reported in Alaska (MacDonald 2003). Several eggs were collected from Sokolof Island, Alaska on 5 May 1992 that were attached to alder twigs in a vernal pool just beyond the tidal influence (MacDonald 2003). This is apparently a frequently utilized habitat type for breeding as nearly identical conditions were identified at Mallard Slough in May of 2012 (Ream unpublished data).

Water temperature has a major effect on larval growth rates (Howard and Wallace 1985). Time to metamorphosis can be highly variable depending on altitude (Howard and Wallace 1985), with lower elevation populations capable of metamorphosing in one season and those at higher elevations taking up to three seasons (Waters 1992). There is apparently increased survival as a result of an additional year of larval life and increased body size (Wilbur 1980), but what

determines the size at which metamorphosis occurs in high altitude populations is not known (Howard and Wallace 1985).

While this species is relatively common throughout much of its range, the restricted distribution in Alaska along with its island endemism may be factors of concern in conservation (MacDonald 2003). The destruction of wetlands in developed areas may be among the greatest threats to this species (MacDonald 2003).

NORTHWESTERN SALAMANDER

The Northwestern Salamander, *Ambystoma gracile*, is the second ambystomatid salamander to occur in Alaska, though Licht (1975) reported their range as only from southern B.C. to northern California. Stebbins (1951) did report that the species occurs from Alaska to California in humid forest habitats. The presence of the species in Alaska is an interesting topic and will be subsequently discussed. In the Pacific Northwest though, many stable populations of this species are believed to exist (MacDonald 2003).

Both the Northwestern Salamander and the Long-toed Salamander are considered common species distributed throughout the Pacific Northwest (Hoffman et al. 2003) and both occur in diverse habitats on the west side of the hydrologic crest of the Cascade Mountains, though the Long-toed Salamander is also present on the east side of this range (Nussbaum et al. 1983, Leonard et al. 1993, Corkran and Thoms 1996). The life history characteristics of Ambystomatids often vary considerably though, suggesting that each possess strategies suitable for the diverse habitats they occupy (Semlitsch et al. 1990).

The Northwestern Salamander is robust with a broad head, pronounced coastal grooves, and pitted areas along the rounded top edge on the tail and on the prominent parotoid glands behind each eye (MacDonald 2003). The skin is smooth, gray-brown above, lighter below, and with flecks of cream or yellow dorsally on some individuals (MacDonald 2003). They often inhabit large, deep lakes and ponds in forested subalpine basins at elevations relatively lower than ponds inhabited by *A. macrodactylum*, typically between sea level and 2500m (Hoffman et al. 2003). Hoffman et al. (2003) reported finding this species in lakes and ponds with soft, flocculent bottoms high in organic content, containing abundant coarse woody debris and low to moderate amounts of emergent and aquatic vegetation. Breeding populations are typically found in permanent small shallow ponds to large deep lakes (Eagleson 1976, Brown 1976, Corkran and Thoms 1996) but the species has also been known to breed in semi-permanent lentic habitats (Petranka 1998). Breeding takes place from January to July (Stebbins 1951), and females lay large gelatinous masses with 60 to 140 eggs (Knudson 1960, Lindsey 1966).

Ambystoma gracile are highly polymorphic with metamorphosis sometimes occurring, often depending on the nature of the habitat (Sprules 1974b). At sea level the species typically takes one or two years to transform after hatching (Snyder 1956). The larvae of both *A. gracile* and *A. macrodactylum* develop more slowly in montane systems than at lower elevations (Eagleson 1976, Petranka 1998), and exhibit life-history strategies in montane systems aligned with

slower development (Kezer and Farner 1955, Snyder 1956, Anderson 1967, Eagleson 1976, Howard and Wallace 1985). A large proportion of individual populations of *A. gracile* in mountain wetlands never transform (Snyder 1956, Efford and Mathias 1969, Eagleson 1976, Sprules 1974), resulting in a high frequency of neotones (gilled adults) in these areas (Hoffman et al. 2003). Those that do fully metamorphose may take up to three years to do so (Eagleson 1976). Metamorphosed adults have been known to travel at least 1.5km to reach suitable breeding sites (MacDonald 2003). Inhabiting permanent, stable and relatively deep lentic systems allows the slow developing larvae of this species in populations dominated by gilled adults to survive harsh montane climates (Hoffman et al. 2003).

Neotony is a condition of certain urodele amphibians where the adult terrestrial form is suppressed, and the animals reproduce as aquatic larvae” (Eagleson 1976). In many species neoteny is facultative and can exist in four forms 1) immature animals with larval characteristics 2) metamorphosed and terrestrial but sexually immature juveniles 3) sexually mature adults with larval characteristics, and 4) sexually mature, transformed adults (Eagleson 1976). Northwestern salamanders tend to exhibit the last two of these, mature adults with larval characteristics (remaining fully aquatic with gills), and actually transforming and leaving the water. Snyder (1965) reported that sexual maturity is attained during the second year when the animal reaches an SVL of approximately 70mm, but where seasons are short at high latitudes and elevations, they may require three or more years to attain this size (Eagleson 1976). Hoffman (2003) reported that neotones of *A. gracile* at study sites in Mount Ranier National Park (MORA) in Washington accounted for a relatively large proportion of the population and ranged in size from approximately 80mm SVL to greater than or equal to 94mm SVL.

The ponds at MORA are covered for seven to nine months per year by thin surface ice, slush, and thick snowpack greater than or equal to 3m deep (Larson 1973). These conditions would cause shallow ponds to be filled with ice from top to bottom and any standing water would be extremely cold (Hoffman et al. 2003.) Deeper ponds on the other hand allow unfrozen water to be present between the pond bottom and the bottom of the snowpack (Hoffman et al. 2003). The snowpack and water column provide an insulative layer and permit *A. gracile* larvae to survive during the winter months (Hoffman et al. 2003).

The eggs of this salamander are laid in early spring in a single, firm jelly-like mass “about the size and shape of an elongated grapefruit and attached underwater to submerged sticks and stems (MacDonald 2003). Masses are always attached to support structures such as aquatic plants and reeds, cattails, twigs, limbs, and the small branches of fallen trees (Slater 1936, Watney 1941, Knudson 1960, Petranks 1998). After hatching, rapid growth of *A. gracile* larvae occurs during warmer months (Licht 1975). Both *A. gracile* and *A. macrodactylum* exhibit similarities in their larval diet (Licht 1975, Anderson 1968). They feed on the same items throughout larval life, normally a diet consisting of dipteran larvae, small crustaceans, and small mollusks (Licht 1975). Larger individuals will sometimes consume Trichoptera and Plecoptera species that are too large for newly hatched larvae (Licht 1975). Because of their distasteful qualities, predation by introduced fishes and other predators is not considered a serious problem (MacDonald 2003), at least not as serious as for *A. macrodactylum* as discussed earlier.

When disturbed, this species assumes an elevated-tail pose and secretes a white, milky fluid from its glands (MacDonald 2003).

Records of this species in the state are particularly interesting and warrant expanded discussion on their distribution. Northwestern Salamanders have only been verified (via organismal or photographic vouchers) at two locations in Alaska— southeast of Ketchikan on Mary Island and northwest Chichagof Island near Pelican (Macdonald 2003). The first vouchered record of the species was collected on Mary Island on 12 September 1895 by the USS Albatross Expedition and subsequently transferred to the Smithsonian Institution in Washington, D.C. (USNM 36338; Jacobs pers. com. 2013). The specimen measured 78mm SVL and photographs are included as figures 3 and 4 in the Appendix (Jacobs pers. com. 2013). Though there is currently no reason to doubt the validity of this voucher, caution should be used since specimens of the Alaska Worm Salamander (*Batrachoseps caudatus*) are thought to have possibly been erroneously labeled (discussed later) and to have originated in California during the same time period as the Northwestern Salamander collection.

The second set of vouchers were identified by Parker Robert Hodge and published in the Herpetological Review in 1986. This included five adult specimens collected in Pelican (Lat. 57°57'N, Long. 136°13'W) on 14/7/81, 6/1982, 6/1985, and 9/1985 by residents and students of M.A. Davidson, a teacher at Pelican High School (Hodge 1986). The specimens were then sent to the Tongass Historical Society Museum (THSM P32, 101, 102, P33) and later transferred to the NOAA Auke Bay Laboratory and eventually UAM in Fairbanks.

The next report of a Northwestern Salamander in Alaska was made by Dana Waters in 1991 (Waters, 1992) and is the first time this species was encountered on the Stikine River. This was an unverified record of a globular egg mass seen (but not collected) at Figure Eight Lake (Twin Lakes) on the Stikine River on 12 June 1991. Norman and Hassler (1995) attempted to locate this species in the same areas in 1992 but were unsuccessful. In the latter case, minnow traps were baited with minced clams (Norman and Hassler 1995), given that Henderson (1993) demonstrated a feeding preference for mollusks in a Canadian population of this species.

The specimen from the Stikine was observed by a credible biologist with experience in herpetofaunal identification. Unfortunately, this record is problematic because 1) egg masses are notoriously difficult to positively identify 2) no eggs were collected as vouchers 3) no photographs were taken 4) the mass was described as partially consumed, 5) no individuals of the species in this area were found prior or since, despite subsequent surveys in 2012 and 2013 (Ream unpublished data) 6) no voucher museum specimens exist for the Stikine River in Canada (according to www.herpnet.org) and 7) the species typically inhabits more permanent bodies of water given their tendency to take several years to metamorphose and to be permanently neotenic. The farthest north that a voucher is known to have been collected in Canada is from the Bella Coola River Valley. In support of the record though, adults are often cryptic and subterranean, active on the surface only during rains and migrations to aquatic breeding sites, which in Alaska, include muskeg ponds (Mary Island, Pelican), and freshwater lakes (Stikine) if the record is valid (MacDonald 2003).

The next sighting of a Northwestern Salamander occurred at Graves Harbor, on the outer coast of Glacier Bay National Park in 2000 (Anderson 2004). The individual was sighted by park employee Philip Hooge, as noted by Anderson (2004):

"A single northwestern salamander was documented along the outer coast of GLBA in Graves Harbor under a log in a riparian needle-leaf and alder area in a stream on the SE arm, about 200m from shore. Though it was observed in 2000, before this project began, it is still an important find. A small crew from GLBA attempted to relocate the observation site in 2003, but did not have an accurate location description to use. This sighting is an interesting addition to the known range of the species (MacDonald, pers. comm., 2003). Stephen MacDonald, of the UA Museum, and other researchers are interested in this location and population."

A U.S. Park Service employee recently wrote regarding the Graves observation:

"That individual was not collected only photographed and then reported to the park. I kept turning up logs whenever I got to outer coast sites. In numerous good sights on Yakobi I never found one and then got the one at Graves. I went back afterwards in part to get a photo and could not find any in the same place. And as you said you could not find it either. It remains a solitary unconfirmed sighting (John Brooks and others were on the boat but lacked the excitement in amphibians to take a look). But on the other-hand there was no mistaking it either as *Ambystoma gracile decorticatum*. It's not like there is anything else like them. It certainly was not a Rough-skinned Newt. However, who knows if a fisherman could have brought it with a load of firewood from Chichagof or something. It can be a mystery for someone in the future."

A third sighting of this species was made near the town of Pelican on Chichagof Island on 28 September 2006 (Figure 5). One of the observers wrote the following on the Alaska Amphibian Working Group email list the next day:

"Last night Adrianna and I were leaving the school at about 9:30, and I spotted this cool creature on the boardwalk! Being from California, my first reaction was *lizard*. Being from San Diego, Adrianna's first reaction was *plastic lizard*. I couldn't believe how large this Salamander was. It was between 25 and 30cm overall, and the width of a chicken egg. I knew salamanders were around here, but I thought they would only be up in the muskeg ponds and slow river bends. Too cool."

An ecologist at Glacier Bay National Park and Preserve, responded:

"A Northwestern Salamander. Probably migrating this time of year. 25cm (10") would be big for this species - normally adults are 7-8.5" long. 30cm would be giant. Nevertheless, they are big. This is the species we think might be present in the park (Graves Harbor), but we have so far been unable to confirm its existence."

Followed by this from Philip Hooge:

“This is the species known to occur around Pelican. According to Trooper Scott Carson (who grew up there) an number of these are known to occupy woodsheds around the community. I have never found them very far away from Pelican?”

It is interesting that these sightings from Glacier Bay and Chichagof are relatively close to one another and that they are near the outer coast of the mainland and archipelago. Also interesting is the size of the Pelican individual, as local knowledge reports from Hydaburg and Wrangell have referred to “large lizard-like creatures” on Dall Island and the North Arm of the Stikine, respectively (Ream unpublished data). It is tempting to speculate that these are very large Northwestern Salamanders and if so, could further validate the Stikine egg mass record. Obviously addition work must be done to elucidate the true distribution and origin of this species in Alaska.

Turtles

Although no freshwater turtles occur naturally in Alaska, released pets are becoming a frequent occurrence in populated areas (Ream unpublished data). In 2013 alone, turtles (presumably red-eared sliders) were reported in Sand Lake and Goose Lake in Anchorage (Ream unpublished data). The individual found at Goose Lake by school children was originally thought dead as it was buried in mud at the side of the still ice-covered lake (Ream unpublished data). The turtle was dislodged, found to be alive, and transported to Anchorage Animal Control (Ream unpublished data). The assumption is that this turtle successfully overwintered at Goose Lake, a problematic scenario that could be the first step in the establishment of viable introduced populations. To our knowledge though, there is yet to be a viable population of freshwater turtles in Alaska.

There are four species of marine turtles that sometimes venture into the state’s waters, including the Loggerhead Sea Turtle (*Caretta caretta*), the Green Sea Turtle (*Chelonia midas*), the Olive-Ridley Sea Turtle (*Lepidochelys olivacea*) and the Leatherback Sea Turtle (*Dermochelys coriacea*). All four are listed as federally threatened or endangered under the Endangered Species Act (ESA), but occur in Alaska waters in non-breeding populations (MacDonald 2003). Hodge and Wing (2000) described an “Alaska Turtle Season” as July through October, with 75% of occurrences reported during this period (Hodge and Wing 2000). Their graph of seasonal distributions of occurrence is borrowed here as figure 6 of the appendix. Prior to 1993 most Alaska marine turtle sightings were of live Leatherback Sea Turtles, but since then, most observations have been of Green Sea Turtle carcasses (ADF&G 2008).

Bruce Wing at the Auke Bay Laboratory of the National Oceanic and Atmospheric Administration (NOAA) maintained a database of Sea Turtle observations in Alaska for several decades. These were derived from field notes, correspondence, newspaper articles and reporters, biologists and records from the Auke Bay Laboratory (Hodge and Wing 2000). After 47 years of federal service, Wing retired in 2011. Consequently, database updates have ceased and as of August 2013, all specimen collections of the laboratory have been transferred to UAM

in Fairbanks. This collection included amphibian vouchers obtained by Robert Parker Hodge as well.

The records compiled by Wing as of 1998 were published in 2000 with coauthor Robert Parker Hodge in the *Herpetological Review*. Wing's records were combined with those of Hodge, the latter of which were derived from museum records, interviews, and "questionnaires distributed to fishermen, biologists and school teachers in Alaska coastal communities" (Hodge and Wing 2000). These combined data are included here as table 3 of the appendix.

Given the vast expanse of marine waters off of the state's coast, including over 54,246 km of largely uninhabited coastline, the Hodge and Wing (2000) data likely captured only a small percentage of turtles that actually occurred – those that were found dead on shore or observed by fishermen at sea. Hodge and Wing (2000) suggested that "most cold-killed, grounded turtles are probably destroyed by wave action (pounding on rocks), and scavengers before anyone finds the evidence. Consequently, all reported Alaska marine turtle occurrences are in clusters near centers of human population" (Hodge and Wing 2000). Later, Norman and Hassler (1995) reported that they were unable to locate a sea turtle, even after many hours in boats and planes observing the Alexander Archipelago and the coastal waters of southeast Alaska.

The North Pacific Drift may be partially to blame for turtles arriving in Alaska since this warm current moves east from the west Pacific and eventually it splits at the latitude of Vancouver Island, B.C., heading both north and south from there. Consequently, it is likely that turtles arriving in Alaska simply made a wrong turn, or got caught in a current that they couldn't easily get out of. Wing postulates that most turtles arrive to the state in late summer and fall and are then caught in the eastern portion of the Gulf of Alaska gyre (ADF&G 2011).

Unfortunately, many of the Sea Turtles that end up in Alaska waters eventually die due to the cold water temperatures. They end up in the state by straying beyond their normal ranges and when the water temperatures drop in September and October, they become hypothermic and are not able to return to the warmer southerly waters (ADF&G 2011). Among the four known to occur in Alaska though, the Leatherback is considered large enough to be able to maintain higher body temperatures that permit survival and the return south (ADF&G 2011).

Some authors have suggested that marine turtle occurrences in the North Pacific are associated with warm-water years (Eckert 1993, MacDonald 2003). Hodge and Wing (2000) refute this claim. They reported that only 53% of Leatherback sightings in Alaska prior to 1998 occurred in warm-water years (Hodge and Wing 2000). Their compiled observations of Leatherbacks in the state included ten sightings in three warm-water years and nine sightings in four normal-water years, but no sightings in cool-water years (Hodge and Wing 2003). Likewise, "hard shell turtle occurrences (*Chelnoia*, *Caretta*, *Lepidochelys*) occurrences in Alaska do not reflect a warm-water year connection, with only 47% of occurrences in warm water years" (Hodge and Wing 2000). The graph of annual turtle occurrences by species provided in Hodge and Wing (2000) is included here as figure 7 of the appendix.

LEATHERBACK SEA TURTLES

Leatherback Sea Turtles, listed as critically endangered under the ESA, were the most frequently reported Sea Turtles in Alaska prior to 1993, with at least 19 records occurring between 1960 and 1998 from Southeast Alaska to the Alaska Peninsula (MacDonald 2003). They have also been reported at Cape Navarin, Russia, 450km northwest of Saint Mathew Island in the Bering Sea (MacDonald 2003). This species is primarily pelagic and seldom approach land except for nesting (MacDonald 2003). They forage in temperate waters and nest on beaches at tropical and subtropical latitudes (MacDonald 2003). They feed primarily on jellyfish, which are abundant in the Gulf of Alaska during late summer and fall (MacDonald 2003). They are considered uncommon in Alaska, but peak numbers have been reported in August in the 1970s and 1980s (MacDonald 2003).

GREEN SEA TURTLES

The second most commonly reported Sea Turtle in Alaska at the time of MacDonalds 2003 publication titled “The amphibians and reptiles of Alaska: a field handbook” was the Green Sea Turtle, which has been reported at least nine times between 1960 and 1998 (MacDonald 2003). This may no longer be the case however, as it may have surpassed the Leatherback with 20 sightings as of 2011, including five live turtles (ADF&G 2011). It was the only species to be reported between 1994 and 1998 (MacDonald 2003). Beached carcasses and sightings of live individuals have occurred from the Alexander Archipelago north and west to near Cordova, and near Seldovia, and Homer in Kachemak Bay (MacDonald 2003). Eight of the nine sightings prior to 1998 occurred from September through November (MacDonald 2003).

Green Sea Turtles are listed as endangered under the ESA, they typically range throughout tropical portions of the Atlantic, Pacific, and Indian oceans, and they are commonly found in shallow waters with an abundance of seagrass and algae (preferred foods) except when migrating (MacDonald 2003). Sexual maturity takes 20 to 30 years (MacDonald 2003). The species can withstand water temperatures as low as 46°F (but prefer temperatures above 60°F) and usually become stressed and die in colder waters (SitNews 2007, Hutchison 2000). Bruce Wing (Hutchison 2000) offered that, “When it starts getting down to about 50 degrees Fahrenheit, they’re in trouble, and anything below 50 degrees is usually lethal to them.”

The only turtle that Wing knows for sure to have been alive when found in Alaska was a male member of this species located by deer hunters Jerry and Pat O’Brien on Montague Island in Prince William Sound on 9 October 1996 (Associated Press 1996, Hutchison 2000). This turtle was subsequently reported to biologists and weighed in at 170 pounds (Associated Press 1996). The hunters originally thought the turtle was dead but after hauling it into their boat’s fish hold, it began to show signs of life (Associated Press 1996). It apparently hadn’t eaten in months, was 130 pounds underweight, and within two weeks of death, according to Scott Eckert, a research biologist at the Hubbs SeaWorld Research Institute in San Diego (Associated Press 1996). This specimen was brought back to Cordova where volunteers at the fire department, with the assistance of biologist Kathy Hough of the Prince William Sound Science Center, helped

to revive the animal by warming it very slowly to prevent a heart attack (Associated Press 1996). The recovering animal was then shipped to San Diego for rehabilitation (Figure 8 in Appendix), released with a satellite tracking device, and later known to be 600 miles off the coast of northern California before the device battery failed (Hutchison 2000).

On 2 December 2007 Mary Hert, a resident of Gravina Island near Ketchikan, contacted the NOAA Office for Enforcement to report a green sea turtle (see figure 9 of the appendix) on the beach near her residence (SitNews 2007). Special Agent Drew Mathews recovered the dead turtle and later shipped it to Hawaii for a necropsy (SitNews 2007). Apparently, this is the third dead sea turtle identified near Ketchikan since 1997 (Sit News 2007). Another specimen of *C. midas* was identified dead at Kelp Bay on the east side of Baranof Island near Sitka by Chris and Chuck McGraw in December of 2000 (Hutchison 2000). The corpse was of a female, about 30 inches long and weighing 130 pounds (Hutchison 2000). These two turtles did not make the deadline to be included in the Hodge and Wing (2000) paper.

More recently, another resident of Ketchikan, Dennis Diamond, located a dead Green Sea Turtle (see figures 10-12 in the appendix) approximately 10 miles northwest of the city at Bond Bay while fishing for winter kings on 3 December 2010 (ADF&G 2011). A squawking Steller's Jay alerted him to the turtle's location and he then found the specimen. Though dead, it was completely intact and so heavy that Diamond could barely pull it above the tideline (ADF&G 2011). He then checked the water temperature finding it to be 41-42°F (ADF&G 2011).

After returning to Ketchikan and calling the Alaska Department of Fish and Game (ADF&G), Diamond returned to the site the next day to collect the individual and noted that "there were a couple of eagles sitting there. The eyes had been pecked out, and the scavengers had begun pecking into the body cavity, but it was still in very good condition." A necropsy determined that the cause of death was bronchial obstruction and lung collapse (ADF&G 2011). There were two types of plastic bags and a wad of microfilament fishing line in the stomach (ADF&G 2011). The digestive tract had become infected and inflamed, but the animal was also likely freezing to death (ADF&G 2011). The ADF&G Veterinarian who performed the necropsy in Fairbanks, Kimberly Beckman, noted that "It was a lot of plastic, the irritation was considerable in the stomach and partial obstruction likely affected the turtle's foraging behavior and ability to properly digest" (ADF&G 2011). The turtle was determined to be a female weighing 171 pounds and spanning approximately three feet in length (ADF&G 2011).

OLIVE-RIDLEY SEA TURTLES

Olive-Ridley Sea Turtles, listed as threatened under the ESA, are the most abundant marine turtle in the world in terms of absolute numbers, they are found primarily in the warmer regions of the Pacific and Indian Oceans, and less frequently in the Atlantic Ocean (MacDonald 2003). Pacific populations nest from Mexico south to at least Columbia, but non-breeding individuals can be found in slightly cooler waters at higher latitudes (MacDonald 2003). Non-breeding populations can range well out to sea, but they typically seek shallow water in bays and lagoons to breed and forage (MacDonald 2003).

This species has been documented in southeastern Alaska three times, including a carcass found near Yakutat in January 1986 and another south of Ketchikan in June 1991 (MacDonald 2003, Steiner and Walder 2005, Hodge and Wing 2000). The possibility exists that the turtles died elsewhere or were injured and carried out of their normal range before being observed in more northerly climates (Steiner and Walder 2005).

LOGGERHEAD SEA TURTLE

The Loggerhead Sea Turtle, listed as threatened under the ESA, has also only been reported in Alaska twice – a carcass was found on Shuyak Island north of Kodiak and another individual that was sighted near Cape Georgena on Kruzof Island northwest of Sitka in July of 1993. They typically inhabit warmer regions in the Pacific, Atlantic and Indian Oceans as well as the Mediterranean and Caribbean seas (MacDonald 2003). They sometimes move into temperate zones in the summer and their diet consists of crabs, mollusks, sponges, jellyfish, fish, eelgrass and seaweed (MacDonald 2003). They can take up to 30 years to reach sexual maturity (MacDonald 2003).

The Shuyak specimen was found at the water's edge in a deep inlet on the north end of the island (58°33.9'N 152°32.2'W) on 31 December 1991 (Bane 1992). The 37.8kg juvenile female was towed to a residence on the island and later transported to Kodiak by plane where it was transferred to the National Marine Fisheries Service and later to Kodiak College (Bane 1992).

There is no question that Sea Turtles occur in Alaska albeit usually to their detriment. It is not known how migratory patterns will shift with climate change and whether the rate of occurrence will change in light of this. It is also unknown what the true occurrence rate is, corrected for those that go unobserved. Given that these species are threatened and endangered, it will be important to monitor their occurrence in Alaska if we are to determine the impact that cold water mortality is having on the populations. To this end, a centralized long-term database should be established, maintained, and publicized to continue to build on this knowledge. It may be beneficial too, to establish protocols to capture, relocate and rehabilitate individuals for sea turtle species other than the cold tolerant Leatherbacks.

Enigmatics

Several species represent enigmas in Alaska since sightings have been reported but are either unvouchered, or available vouchers are questionable. These species and their associated information regarding possible Alaska populations are reported here.

Snakes

Garter snakes of the genus *Thamnophis* are among the enigmatic species that are questionably present in Alaska, though a lack of voucher specimens or photographs has kept these from

being officially recognized as native to the state. There have however been several sightings by credible individuals over the years. Whether or not established breeding populations of snakes are present in Alaska is yet to be determined (Hodge 1976).

As discussed briefly in the introductory chapter, reptiles do hibernate in northern areas and snakes tend to congregate in large numbers in dens, deep fissures, and rock outcroppings below the frost line (Hodge 1976). Reduced foraging opportunities and precipitation events may serve as cues to induce hibernation in these species (Gregory 1982) but photoperiod is also important since, unlike temperature, which can fluctuate drastically, photoperiod “reliably reflects seasonal changes” (Lutterschmid et al. 2006). This is not to say that temperature is not included as a hibernation cue though, as several studies have documented its importance as well (Nussear et al. 2007, Sexton and Hunt 1980).

Hodge (1976) suggests that suitable habitat for Garter Snakes likely exist in southeast Alaska and he is confident that snake populations occur on mainland portions of this region (Foley 1976). The Stikine, Taku and Unuk rivers could provide snakes access to the coast from interior B.C., though it remains unclear if natural populations even occur on the Canada side of these drainages (MacDonald 2003). The herpetofauna of northwestern B.C. is poorly understood (MacDonald 2003), but even a long-time resident of Telegraph Creek, B.C. (the only major settlement on the Stikine proper) could not recall having ever seen a snake in the area (MacDonald 2003). This is also true of many residents of Wrangell and Petersburg, Alaskan communities near the Stikine delta (Ream unpublished data).

The first recorded sighting of a garter snake in Alaska occurred in 1957 when federal biologists conducting moose surveys on the Taku River collected a specimen and brought it back to Juneau (Foley 1976). The snake was reportedly deposited in the State Territorial Museum in Juneau, but was later lost due to an “oversight or cataloguing failure” (Foley 1976). At the request of Bradford Norman in 1992, museum staff searched for this specimen and associated data but could not locate any mention of its existence in their files (Norman and Hassler 1995). According to Norman and Hassler (1995), “extensive records from many other museums have been obtained and none to date validate the presence of naturally occurring garter snakes in Alaska. This finding is opposite of those expressed by Foley (1976) and Hodge (1976).”

All subsequent attempts to document their presence along these river corridors with an organismal or photographic voucher have been unsuccessful (Foley 1976, Waters 1992, Norman and Hassler 1995, Ream unpublished data). Norman and Hassler (1995) also spent considerable time searching for a snake on the Stikine in 1992 and reported the following:

“One area which was searched extensively in 1992 and which appeared ideal for garter snakes was the vicinity of Chief Shakes Hot Springs in the Stikine River Basin. The breeding amphibian populations there were large, amphibian and fish prey was abundant, temperatures there are tolerable for such snakes apparently all year round due to the thermal input of the hot springs, and the site lies within the Stikine River drainage which has been hypothesized to be a main corridor of dispersal for

herpetological species entering southeast Alaska from British Columbia (Hodge 1976; [Waters 1992]) where garter snakes of at least three species are known to occur (Nussbaum et al. 1983; Stebbins 1985). It is probably only a matter of time until the presence of garter snakes in the Stikine River area is documented.”

At least two additional sight records do exist for the garter snake in Alaska, again being made by federal biologists (Hodge 1976). The observations were from remote areas of the Taku and Stikine Rivers, far from human habitation, suggesting that the snakes may have arrived in Alaska naturally (Hodge 1976). An ecologist with the National Park Service made one of these observations and later wrote (Lewis Sharman pers. com. 2009):

“Incidentally, I hope there's no doubt in anyone's mind that *Thamnophis* does in fact occur in the Stikine drainage. It's surprising to me that no vouchers exist, but the snakes definitely do - I remember them clearly from when I worked for the USFS out of Petersburg in 1978 and 1979. Certainly [these were] not uncommon at the time”

Sharman followed up with additional context at a later date (Lewis Sharman pers. com. 2013):

“I think it was at (or near) the Chief Shakes Hot Springs bath house. It was 1978 or 1979, in the summer. The weather was warm and dry. We saw them in thick grass right along the riverbank, or perhaps the bank of a slough. I don't recall any context regarding flooding one-way or the other. I remember seeing several individuals (up to a half dozen?) within several lineal meters of bankside. Once we saw the first one, we spent a few minutes actively looking for them over the course of a half hour or so.”

References to snakes have periodically surfaced in media reports but they appear to have been located at or near human centers and to have been unintentionally released (Hodge 1976). Dr. Frank Ray, professor of arctic biology and marine science at the University of Alaska Fairbanks (UAF), reportedly followed up on several snake observations (Foley 1976). Ray worked previously for the Public Health Department in Anchorage and “received frequent calls of snake findings.” Most of these calls were during the summer months and the snakes, when captured, were determined to be Garter Snake varieties from the lower 48 (Foley 1976). “They definitely didn’t occur in Alaska naturally,” Ray said (Foley 1976).

Later, a Garter Snake was found in Haines, Alaska on 21 August 2005 (now located at UAM as Herpetology catalogue number 314; figure 13 in appendix), it was roughly 200mm in total length, and it was found flattened and dry on the road approximately 1.5km south of the city on Mud Bay Road (Neuman-Lee et al. 2011). The location was described as the “shoulder of a paved road through a low density residential area along a stretch of road abutting a wetland area stretching unbroken to the east” (Neuman-Lee et al. 2011). It was considered “badly damaged” but was identified by superficial morphology and collected, being the only preserved organismal voucher to date (Neuman-Lee et al. 2011).

Based on their natural histories and geographic distributions, *Thamnophis sirtalis*, the Common Garter Snake, and *Thamnophis elegans*, the Terrestrial Gartersnake, have been considered

likely candidates to occur naturally in Alaska (Hodge 1976). Both species have been found as far north as the Peace River District of B.C. The former has been reported north of Terrace, B.C. in the Nass and Skeena watersheds and along the eastern side of the province northward, while the latter is found along the B.C coast, including Vancouver Island, northward. *Thamnophis sirtalis* is considered common in the Coast Mountains as far north as Terrace, B.C and has been reported from mile 125 of the Alaska Highway, “just 200 miles as the crow flies south of the Yukon border”(Hodge 1976). Nevertheless, the reports of *T. sirtalis* from the Stikine River in Alaska were never confirmed despite three months of fieldwork in 1991 in areas that appeared to comprise excellent foraging habitat (Waters 1992), and subsequent herpetofaunal surveys in these areas in 2012 and 2013 (Ream unpublished data).

Genetic analysis showed that the dead snake found at Haines was neither of these species, but rather a third - *Thamnophis ordinoides*, the Northwestern Gartersnake, with the nearest known natural population of this species being greater than 1000 miles south of Haines where it was found (Neuman-Lee et al. 2011). Neuman-Lee et al. (2011) offered three hypotheses to explain the occurrence of this specimen in Alaska:

1. Environmental conditions in some areas could permit populations to have thrived as undiscovered relicts, separated by geological events like volcanoes and glaciers (Inger and Voris 2001), a pattern observed with a wide variety of taxa (Dowling 1956).
2. Colonization of the area as part of a natural range expansion, especially since there are well-documented cases of range expansions into higher latitudes as climates in those areas improve for some species (Parmesan and Yohe 2003, Crozer 2004).
3. The snake arrived as an accidental or intentional introduction as a result of transport and release. Intentional release of pets is common (Rodda et al. 2009).

The existence of a relict population near Haines is unlikely since no specimens have been found prior (or since), and genetic analysis showed close relationships with more southerly populations of the species (Neuman-Lee et al. 2011). The second hypothesis is somewhat more plausible since *Thamnophis* is an excellent candidate for range expansion, the genus is widespread throughout North America, and member species tend to be dietary and habitat generalists (Rossman et al. 1996). Still, natural movement northward would presumably have been documented elsewhere prior and subsequent to this collection (Neuman-Lee et al. 2011). The third scenario is perhaps the most likely given that there is substantial movement of both people and cargo between Haines and the lower 48 states. The Alaska Marine Highway is well travelled and connected southeast Alaska communities with its southernmost port of Bellingham, Washington, a locality within the known range of natural populations (Neuman-Lee et al. 2011).

So, while the existence of natural populations of Garter Snakes is questionable at the moment in Alaska, there remains the possibility that range expansions and introductions could permit the establishment of *Thamnophis* species in certain locations. Little is known about the

northern adaptations of these species, though they are the only North American reptile with ranges that reach the subarctic (Hodge 1976). The adaptations of the two European reptiles – the Viviparous Lizard, *Zootoca vivipara*, and the Common European Adder, *Vipera berus* – are well documented (Hodge 1976). Both of these are viviparous, as are the North American Garter Snakes, and this is an advantage in the North since the female can incubate the developing young by moving and basking until they are ready to emerge from her body (Hodge 1976).

Alaska Worm Salamanders

The first references to Alaska's herpetofauna appeared in the late 1800s when large east coast museums began receiving record specimens from explorers and naturalists. During this time, three Alaska Worm Salamanders, *Batrachoseps caudatus*, arrived in the Smithsonian Institution at Washington, D.C. with their origin listed as Yakutat Bay and Hassler Harbor (Annette Island), Alaska (Hodge 1976). In over 130 years there have been no additional sightings or specimens of this species, resulting in its listing as "enigmatic", causing scientists to question the reliability of the locality data.

Worm Salamanders are in the Plethodontidae family, comprised of the lungless salamanders, are almost confined to California (MacDonald 2003). There are no authenticated records north of the Columbia River (MacDonald 2003), except for those apparently collected in southeastern Alaska. These salamanders are subterranean (but can also be found under surface debris during rainy periods), they often lay their eggs in communal nests, and they lack an aquatic larval stage (MacDonald 2003).

The first two specimens of *B. caudatus* were collected by W.H. Dall in Yakutat Bay between May 5th and May 22nd and May 26th, 1874 (Wake 1998). Though Dall was in fact at Yakutat that year, the specimens were eventually sent to the Smithsonian (USNM 17260 & USNM 20489) where they received labels that include the wording "All Data Questionable" (Wake 1998). A note appears in the Smithsonian records for USNM 17260 as follows: "Locality dubious in Dall's notebook no 660(1311) refer to a marine crab, and he does not recollect having collected any salamanders at Yakutat Bay."

Lieutenant Commander Henry E. Nichols of the U.S Navy was in command of the Coast and Geodetic Survey steamer Hassler and undertook several surveys of southeast Alaska between 1881 and 1883. Nichols sent a third specimen of the species to the Smithsonian (USNM 13561) that he collected at "Hassler Harbor" (later mapped as being on the northeast side of Annette Island in southeast Alaska) in "December of 1881". Many questions surround this voucher because it was supposedly collected in December, an unlikely scenario for amphibians in the north that are typically in hibernation at that time, and because the locality data is problematic. Several individuals have weighed in on this ambiguity over time (Norman and Hassler 1995):

"Dr. David Wake, of the Museum of Vertebrate Zoology, Berkeley, California, had extensive conversations with B. Norman regarding that possibility and regarding the status of the Alaskan Slender Salamander in general over the course of the study period

and he has independently come to the conclusion that the type specimen in the U.S. National Museum (Number USNM 13561) is possibly a mislabeled specimen collected by Capt. Henry Ezra Nichols at Mare Island, San Francisco Bay, California during a period in the early 1880's that Nichols was between expeditions to southeast Alaska where he collected large series of fish which were subsequently sent to the National Museum. However, Dr. Tarleton Bean, the curator of fish at the National Museum at the time, in publishing on the collections sent to him by Nichols states the collections sent to him by Nichols were among the most carefully preserved that he had the pleasure to receive from field workers, thus the possibility that the type specimen of *Batrachoseps caudatus* was mislabeled, though not impossible, does not seem to correlate well with what Bean had to say about Nichols' efforts (Bean 1882; 1884)."

The *B. caudatus* specimen collected by Nichols was nearly identical to members of *Batrachoseps attenuatus* from near San Francisco, California where Nichols had visited between his trips to California (MacDonald 2003). In fact, the specimen was catalogued with other specimen of species known to occur in southeastern Alaska, but also with those that occur in the vicinity of Mare Island near San Francisco (Wake et al. 1998). Alaska Norman and Hassler (1995) pointed out that a "Hassler Island" also exists near the northwest shore of Revillagigedo Island and that there is a small "harbor" on the southern end of this. In fact, the Hassler was at Annette Island in August of that year as indicated on labels for Western Toads and Rough-skinned Newts collected there (MacDonald 2003), but it is unclear if it was also at Hassler Island.

So, was the salamander actually collected on Annette and the date mislabeled, was it collected at another "Hassler Harbor", or was it collected in California with the location mislabeled? Despite the questions surrounding the Nichols specimen, it was later described by Cope (1889) as the type specimen for the species (Figure 14). Wake et al. (1998) conducted a search for the elusive species between August 4 and August 10, 1996 but failed to find a specimen, despite the fact that the team found the conditions for such an occurrence favorable (Wake et al. 1998). Abundant habitat exists on Annette Island for Plethodontid salamanders and much of the flora and fauna associated of Plethodontids further south are found there (Wake et al. 1998). They found Western Toads and Rough-skinned Newts while searching, but local residents described a third species that was possibly an Ambystomatid (Wake et al. 1998). No one, including local amateur naturalists, described a salamander that might be a Plethodontid (Wake et al. 1998). Wake et al. (1998) concluded the following:

"In summary, we found no plethodontid salamanders on Annette Island, although conditions appeared to be favorable. Given the good conditions and the favorable environment, the fact that three experienced collectors failed to find any *Batrachoseps* seems significant. The geological evidence together with the great geographic separation from other *Batrachoseps* makes it unlikely that the genus occurred on Annette Island in 1882, and the virtual identity of the specimen to members of *Batrachoseps attenuatus* suggests that the holotype is a mislabeled specimen of that species. We conclude by concurring with other authors (e.g. Schmidt 1953) that

Batrachops caudatus Cope, 1889, should be considered a subjective junior synonym of *Batrachoseps attenuates* (Eschscholtz 1883)."

In 2010 Robert Thomson, a professor of biology at the University of Hawaii Manoa, successfully petitioned the Smithsonian Institute to provide DNA samples from all three specimens in their collection (Thomson pers. comm. 2013). Thomson's goal was to perform a comparative analysis of DNA sequences aimed at determining the genetic provenance of the specimens (Thomson pers. comm. 2013). Unfortunately, he was unable to replicate the DNA for analysis as noted in his follow-up with curatorial staff (Thomson pers. comm. 2013):

"I wanted to let you know how things have gone with those *B. caudatus* tissues that you sent a few months ago. Unfortunately, the news isn't good. We've done a series of careful extractions and can quantify DNA in the extracts, but we can't get amplification. It's possible that there are inhibitors in the sample (though we've tried serial dilutions, which normally work in those situations) or that the DNA is present but simply too degraded for PCR to be effective. We've tried amplifying very short stretches of DNA (a couple hundred basepairs), which has worked for us in the past with degraded specimens, no luck this time though. In short, we've tried all of our tricks to get difficult samples to work and we're now out of ideas, at least for the time being.

Anyway, I wanted to thank you again for letting us even try it. I guess we knew that the odds of success were low from the outset, though it would have been very nice to see it work."

While the existence of this species remains unclear, Hodge created a fictitious organization to honor the creature in the 1970s called the "Society of Alaska Worm Salamanders" (Foley 1976). Citizen scientists that assisted with herpetofaunal surveys were awarded a certificate from Hodge depicting "a worm salamander in a sweater because it is cold up here" (Foley 1976). Perhaps someday this mystery will be solved, or, it will remain an enigma of Alaska herpetology.

Canadian Species

Several species of amphibians occur naturally in Canada close enough to the Alaska border to warrant their designation as enigmatic species. Though they have not been verified within the state's borders, large areas of Alaska have not been sampled and they may be present but as of yet remain undetected. They warrant mention here too since, even if they do not occur in the state currently, future range expansions could bring them here naturally.

The distributions of amphibians in many parts of British Columbia and the Yukon are largely unknown and understudied. The first published report of amphibians in the Yukon was by Loomis and Jones (1953), reporting on a Wood Frog collected at Dezadeash Lake in 1948 by the University of Kansas Museum of Natural History (Slough and Mennell 2006). The Western Toad was first observed in the southeast Yukon in 1961 (Cook 1977), and the Columbia Spotted Frog

in southwest Yukon in 1993 (Mennell 1997). Each of these is already known to be present in Alaska. No other species are known to occur in the Yukon (Slough and Mennell 2006), but the list of herpetofaunal diversity grows substantially in British Columbia.

The Western Chorus Frog, *Pseudacris triseriata*, is widely distributed east of the Rocky Mountains and is with the Liard River watershed as far north as Fort Nelson, B.C. Since this is just a short distance from here to the Yukon River's headwaters, the species may currently be present, or expand its range in the future, along the Yukon corridor to Alaska (Hodge 1976). Another species, the Tailed Frog (*Ascaphus truei*) is a tiny, cold-adapted frog found along the coast of British Columbia as far north as Kitlope, Kitimat, and Terrace (Green 1999); just 120km from Alaska's southern border (MacDonald 2003). Other species of amphibians and reptiles occur at more southerly locations in the province.

Norman and Hassler (1995) exerted considerable effort in 1992 to locate Pacific Giant Salamanders and Tailed Frogs along the Stikine and elsewhere in southeast Alaska. While they were unable to document these species, they did offer the following:

“Waters [1992] postulated that the Pacific giant salamander genus *Dicamptodon* and the tailed frog, *Ascaphus truei*, might occur within the boundaries of the state of Alaska and most probably in the southeast Alaska panhandle. He based his postulation on the fact that both types of amphibian are widely distributed in the Pacific Northwest, occur north into coastal British Columbia often in disjunct relict populations (Nussbaum et al. 1983; Logier and Toner 1961; Stebbins 1985), are cryptic in their coloration and habits and are difficult to find unless experienced field workers search specific habitat, especially cold, lower order streams (Bury and Corn 1991). Special efforts were made to sample for these species in such habitats but with no success. The possibility that relict populations of these amphibians may occur in little-studied remote localities such as southeast Alaska remains very real in our opinion and continued efforts should be made to determine the presence and/or absence of these taxa there.”

While unknown occurrence and natural range expansions are likely to occur over time, managers should also consider the threat of anthropogenic introductions. Whether released accidentally or intentionally, as pets or traveling within cargo, introduced species are likely to be those that occur in the region. This necessitates that we have a basic understanding of western and northern Canada's herpetofauna.

Others

There are many uninhabited and unexplored areas left to investigate and species that are notoriously difficult to find. It is possible, though perhaps unlikely, that additional herpetofaunal species occur naturally in Alaska that have simply not been discovered to date. Hodge (1976), for instance, suggested that Asian Salamanders of the genus *Hynobius* could exist in the “vast herpetologically unexplored interior of Alaska.” Committed and passionate

herpetologists such as Bradford Norman have, as of yet, failed to locate these (Norman and Hassler 1995):

“Additional searches were conducted by B. Norman for these and other amphibians on Kodiak Island in 1989, on the Alaska Peninsula (Chignik, Egegik and Ugashik areas) in 1982, 1983, and 1984, and on the Aleutian Islands of Akutan in 1985, Unimak in 1984, and Unalaska in 1982. No *Hynobius* species and no amphibians of any species were encountered during these efforts.”

MANAGEMENT

Very little attention has been afforded herpetofauna in Alaska by state agencies, usually due to a lack of data, funding, time, personnel and expertise. As the herpetological discipline advances in the state, these issues must be addressed and gradually rectified. As a start, the following topics and background may be valuable to managers that oversee portions of the state where these species currently occur, or are expected to occur in the future. The conclusion section of this paper also offers several long-term goals that the state should consider implementing in the future.

Status

Protecting wetlands and the services they provide often has a net economic benefit (Costanza et al. 1999). The global decline of amphibians has generated a large body of research on amphibian habitat and species diversity conservation (Brehaut 2012), but some areas like Alaska have been largely absent from participation in these studies.

State conservation status ranks for the six amphibian species in Alaska range from imperiled (Columbia Spotted Frog) to widespread, abundant and secure (for example, the Wood Frog)(Olson 2009). Management hurdles in the region are primarily related to insufficient information and funds (Olson 2009). While insufficient species distribution information is an issue everywhere, there appears to be a particular deficit for herpetile occurrences in several regions, especially the states of Wyoming, Alberta, Yukon, Alaska and eastern Oregon (Olson 2009). As indicators of ecosystem health (Stebbins and Cohen 1997), the acquisition of baseline population data for amphibians is actually critical (Hokit and Brown 2006).

A confounding problem in addition to a lack of population data is a lack of databases to house locality information (Olson 2009). Furthermore, only one northwestern state – Wyoming – has a full-time State herpetologist though experts for other taxonomic groups are common and often duplicated (Olson 2009). In contrast, 19 other states have dedicated State Herpetologists with several of these having multiple positions that focus on amphibian and reptile concerns (Olson 1999).

There have been relatively few studies of amphibian populations in Alaska and even those that were completed were largely limited in space and time. The vastness of the state and its limited

infrastructure provide substantial logistical and financial challenges for non-game research. Still, several studies have provided the discipline with valuable datasets on herpetofaunal populations (see table 3 of the appendix). Each of the studies listed in Table 3 have provided important data for knowledge of herpetofauna in Alaska. This is not a comprehensive list as there have been contributions to other sub-disciplines of herpetology in the state, but it represents the prominent works dealing with basic population data on diversity, distribution and abundance.

The opportunistic National Park Service (NPS) survey in 2001-2003 was developed following recognition by staff that basic information on species abundance, population status, and habitat requirements for amphibians was significantly inadequate (Anderson 2004). The study resulted in 79 observations by 40 observers totaling 1600 individual amphibians at 65 different sites throughout ten of the 16 national park units in Alaska (Anderson 2004). This is an excellent example of how, in the course of one's regular daily activities, citizens can substantially enhance knowledge of amphibians by recording their observations. The NPS inventory resulted in an extension of the known geographic ranges of Wood Frogs, Boreal Toads, Rough-skinned Newts, and Northwestern Salamanders (Anderson 2004).

Discovery Southeast conducted another major study that significantly advanced our knowledge of amphibians in Southeast Alaska, particularly in the Juneau area, in 2002 and 2003 (Carstensen et al. 2003). To illustrate the statewide lack of knowledge regarding amphibian diversity and distributions, the following is quoted from their report to ADF&G (Carstensen et al. 2003):

“To gain a sense of how little is known about the distribution of amphibians in Southeast Alaska, consider our most populated region – the City and Borough of Juneau. About half of the residents of Southeast live here. Because it is the state capitol and headquarters to many federal, state and borough natural resource managers and researchers, Juneau has an exceptionally high per-capita level of expertise in field biology. Discovery Southeast alone employs more professional naturalists than are found in any of the region's smaller cities and villages. Juneau also has the most elaborate network of backcountry trails in Southeast, which conducts large numbers of humans throughout a wide variety of amphibian habitats. Groups like Juneau Audubon and the web-based Eaglechat provide regular forums for outdoorspeople to share their observations. We ourselves - Armstrong, Carstensen and Willson - have spent a combined 78 years of active fieldwork in Juneau. We are well tapped-into the “nature-gossip” network.

In spite of all of this, we were unaware that the Juneau vicinity had any amphibians other than western toad until about 4 years ago, when a student walked past one of us in Dzantik'i Heeni Middle School carrying a bowl of rough-skinned newts. At the outset of our study we knew of only one Juneau pond where toads still assembled in spring to breed. And as our study progressed, we were quite surprised to discover that Juneau had small (probably exotic) populations of wood frog, Columbia spotted frog, and Pacific

chorus frog. Although we spent a great deal of time in the field around Juneau in 2002 and 2003, we only located the spotted and tree frogs toward the end of the project, thanks entirely to the natural history grapevine.

Now contrast the above level of ignorance of Juneau's amphibian populations to the even cloudier situation near smaller communities or on remote and rarely traveled islands. Clearly, there is much work to be done before anyone can say with authority where amphibians occur, let alone whether populations are in trouble or why, or what kinds of human intervention might arrest population declines."

This study examined 352 ponds in northern Southeast Alaska and conducted "full assessments" on 95 of them (Carstensen et al. 2003). Twenty-five (7%) of the 352 ponds were occupied by amphibians and this included Western Toads in 17, Wood Frogs in one, Columbia Spotted Frogs in 7, Pacific Chorus Frogs in one, Long-toed Salamanders in one, and Rough-skinned Newts in 6 (Carstensen et al. 2003). Among the most beneficial methods and results of this study was the use of citizen science and local knowledge in trying to ascertain species diversity and abundance. Local knowledge observations over time were plotted using GIS technology and compared to the aforementioned results of the systematic survey.

While the 1990s and early 2000s saw considerable advances in herpetological research and knowledge in Alaska, this surge in research activity seems to have dropped off considerably. Long-term monitoring programs such as the Alaska Wood Frog Monitoring Program should be implemented and funded statewide, and research grants should support herpetological research whenever possible.

Considerations and Strategies

Amphibian populations are often small (Green 2003), and such populations are more vulnerable to the effects of environmental, demographic, and genetic stochasticity as well as natural catastrophes (Purvis et al. 2000, Schaffer 1987). Small populations are also more likely to go extinct than large populations (Gilpen and Soule 1986, Shaffer 1987). Habitat alterations, invasive species, and disease can exacerbate the risk (McCallum and Dobson 1995, Smith et al. 2009, Muths and Scherer 2011).

Amphibians often occur as metapopulations (Smith and Green 2005), exhibit limited dispersal ability and high site fidelity (Vasconcelos and Calhoun 2004, Blihovde 2006), and are sensitive to geographic barriers (Rittenhouse and Semlitsch 2006). Each of these characters promotes genetic structure in relation to the physical landscape (Lougheed et al. 1999, Funk et al. 2005, Kraaijeveld-Smit et al. 2005, Spear et al. 2005, Stevens et al. 2006, Giordano et al. 2007) and can lead to high genetic differentiation at small scales.

Many ecological and genetic studies of pond breeding amphibians have shown that lentic systems can define randomly mating populations (Gill 1978, Sjogren 1991, Hecnar and

M'Closkey 1996, Tallmon et al. 2000). This definition of the population is appealing because ponds and lakes are discrete physical units bounded by shoreline, but data showing substantial interpond movements suggest that populations sometimes include more than a single pond (Berven and Grudzien 1990, Alford and Richards 1999, Marsh and Trenham 2001, Trenham et al. 2001). In addition, recent attention has been given to the requirement of pond-breeding amphibians to have access to upland terrestrial habitats for foraging and overwintering (Funk et al. 2005). In combination, these considerations necessitate that geographical units larger than single ponds and lakes should be protected if amphibians are to persist at those localities (Semlitsch 2003).

Similarly, a growing body of evidence exists that amphibian conservation requires protection of groups of diverse water bodies and upland or riparian habitat that connects them (Semlitsch 2002, Pilliod et al. 2002). Pond breeding amphibians require both types of habitat and they regularly move between them (Homan 2010). Despite this, management still typically focuses on wetlands and offers little protection to surrounding uplands (Gibbons 2003). Managers are however beginning to recognize that the quantity and quality of terrestrial habitat surrounding amphibian-breeding ponds is a critically important determinant of amphibian species occurrence (Gibbs 1998a, Gibbs 1998b, Homan et al 2004, Porej et al 2004).

In one study, small ponds with a dominant sedge vegetation appeared to be selected by Wood Frogs over larger ponds, but less water volume can result in increased acidification (Brehaut 2012). Amphibians typically breed in the early spring and are thus susceptible to low pH values associated with melt water (Gascon and Planas 1985). Large lake area in the landscape buffers appears to have a significant negative relationship on habitat selection for Wood Frogs (Brehaut 2012). The larger lakes in combination with landscape variables like roads and the Alaska Highway represent areas that Wood Frogs cannot use during their entire lifecycle and can reduce the amount of forested habitat available (Brehaut 2012).

The impacts of local landscape features may be difficult to predict based on field studies alone (Moore et al. 2011). For example, small-order streams can serve as corridors or assist in movement of Western Toads (Adams et al. 2005, Schmetterling and Young 2008), but with increased flows and size they can become barriers to movement and dispersal (Moore et al. 2011). In another example, biogeographical evidence exists that the ranges of some amphibians are constrained by mountains (Lynch and Duellman 1997) and there are several reasons for this to be true. First, many amphibians are subject to high evaporative water loss due to their permeable skin (Duellman and Trueb 1994) and they may tend to move along riparian corridors rather than over drier mountain ridges (Funk et al. 2005). Secondly, if ridges are high enough, they may surpass the physiological limits of the species (Funk et al. 2005).

Shoo et al. (2011) suggest that three thematic areas of intervention can reduce exposure to heat and water stress in amphibians including 1) installation of microclimate and microhabitat refuges 2) enhancement and restoration of breeding sites and 3) manipulation of water levels at breeding sites. Aquatic breeding amphibians require minimum hydroperiods to reach metamorphosis and can often benefit from irrigation, filling of drainage ditches, and vegetation manipulation that limits evapotranspiration (Shoo et al. 2011).

These types of artificial interventions are becoming commonplace in some areas. For example, the U.S. Conservation Assessment for the Oregon Spotted Frog has prescribed retention, restoration and creation of lentic wetland and bog complexes (Cushman and Pearl 2007). Shoo et al (2011) reported from personal communications with C. Pearly of the U.S. Geological Survey that actions have thus far included 1) vegetation management at constructed ponds 2) pond creation through irrigation and ditch segmentation 3) reconstruction of a river weir to retain water in a marsh 4) pond excavation to enhance water retention and 5) reestablishment of dam building activity of the North American beaver to promote water retention.

Evolutionarily Significant Units vs. Management Units

The phrase “evolutionarily significant unit”, or ESU, was coined in 1995 at a conference of zoo biologists and systematists (Ryder 1986) when it was realized that current taxonomy does not reflect the biodiversity in need of protection (Pennock and Dimmick 1997). According to DeWeerd (2002), an ESU is “an important chunk of a species.” The concept has gained acceptance among conservation biologists, eventually being applied to the U.S. Endangered Species Act (ESA) (U.S. Department of Commerce 1991, Waples 1991, Waples 1995, U.S. Department of the Interior et al. 1996). The purpose of an ESU is to ensure protection of evolutionary heritage and its potential across a set of these units (Moritz 1994).

ESUs quickly became associated with the conservation of units below the species level and subsequent dialogue sought criteria for a formal definition (Pennock and Dimmick 1997). Most of the resulting proposals suggested that these units, presumably worthy of conservation, should be geographically discrete (Moritz 1994), but that genetic criteria be included as either significant divergence of allele frequencies (Waples 1991), varying degrees of genetic distance (Ryder 1986), or similarly structured phylogenies (Avice 1989).

Each definition attempts to attain the same outcome but vary according to biological and legislative context (Moritz 1994). Moritz (1994) argues that “this issue is at the interface of science and law, which varies across countries”, adding that the term ESU is primarily relevant to long-term management issues and should recognize that a set of populations has been historically isolated and may have distinct potential. Many geneticists agree that molecular information must be put into ecological context to be truly meaningful (DeWeerd 2002). Often, molecular diversity is correlated with adaptive diversity (but not always), the latter of which

reflects the present-day ecological differences between populations and represents the raw material for evolution (DeWeerd 2002).

The search for a definition ignited an intense debate, especially with reference to the implications for the ESA (DeWeerd 2002). Moritz (1994) suggested that ESUs focus reciprocal monophyly based on mitochondrial DNA, but Robert Wayne of the University of California argued that this lacked an ecological component (DeWeerd 2002). Crandall et al. (2000) noted “with increasing resolution of molecular techniques, significant differentiation can be found at very small scales, even down to the individual, and this can lead to inappropriate diagnoses of ESUs.”

At its core, an ESU is a population unit that merits separate management and has high priority for conservation (Crandall et al. 2000). In the United States, the unit is often defined as a consequence of listing, or proposal for listing, under the ESA, but it is also used in a variety of less formal contexts around the world (Crandall et al. 2000). According to Crandall et al. (2000):

“The designation forces just two categories (ESU or not) from the continuous distribution of genetic diversity, habitat types, and selective pressures across populations... The problem is that in the United States everything comes back around to the ESA. You’re in a legal conundrum.”

These authors suggest that a continuum of conservation management categories would be more useful in practice than creating a theoretical dichotomy of this nature.

Several authors have recognized that the ESU is often troubled by a “lack of applicability to the real world” (Moritz 1994, Newton 1999, Karl 1999). An example is that the goal is conserving populations with a history of reproductive isolation is frequently overemphasized (Crandall et al. 2000). Crandall et al. (2000) offered three alternative principles to govern management actions:

1. Management should attempt to preserve adaptive diversity and evolutionary processes across the geographic range of a species (Storfer 1996)
2. Management actions can depend on the nature and severity of recent disturbances. “In general, restoration (either of separate or single populations) should be attempted more often for populations that have become disjunct or mixed as a result of recent anthropogenic activities (like habitat degradation, unnatural barriers to dispersal and introductions of nonnative forms) (Crandall et al 2000).
3. When possible, management recommendations should be based on adequate sampling and analysis (Sites 1997)

At present, ESUs rely on measures that reflect genetic isolation rather than adaptive diversity, which is not appropriate if the intended outcome is to maintain evolutionary potential where,

occasionally, this could limit gene flow and adaptation via natural selection (Crandall et al. 2000). In contrast, Crandall et al (2000) suggest that units defined for conservation should be based on traits that enhance the potential survival and fitness, thus necessitating conservation based on functional diversity rather than historical legacy.

Unfortunately, biologists are often forced to ask whether a certain group of organisms is an ESU or not (DeWeerd 2002). This debate is less heated in Europe where conservation legislation is based on the protection of habitat rather than individual species or populations (DeWeerd 2002). Moritz (1994) recognized this and noted that international conservation prioritizes areas of high biodiversity. He also offered that two types of conservation unit be established: 1) management units (MUs), representing sets of populations that are currently demographically independent and 2) evolutionarily significant units (ESUs), which represent historically isolated sets of populations that together encompass the evolutionary diversity of a taxon (Moritz 1994a, Moritz 1994b, Moritz 1995). Both units should be considered significant for conservation, with the former focused on the short-term and the latter on more strategic, long-term issues (Moritz 1995).

MUs may be the most logical unit for monitoring responses of populations to impacts and management (Moritz 1995). They may serve as important functional components of the often larger entities being conserved and may essentially be the same as species defined under a phylogenetic species concept (Vogler and DeSalle 1994). Allele frequencies may best define the MU (Hudson et al. 1992) but genetic analysis can be expensive (DeWeerd 2002).

An example of ESU application can be seen in the management of Pacific salmon where the units have permitted more targeted application of the ESA (DeWeerd 2002). Fifty-five ESUs have been established to represent seven salmonids, five of which are currently listed as endangered, 21 of which are classified as threatened, and several more of which have been proposed for listing (DeWeerd 2002). Most of these ESUs occur in California and the Pacific Northwest and have been critical in supporting healthy fish runs in Alaska (DeWeerd 2002).

Though ESUs are considered more applicable to long-term management, some suggest that short-term goals should seek to avoid translocating individuals between ESUs (Ryman 1991, Avise 1994). For amphibians throughout Alaska, anthropogenic translocations and introductions appear to occur frequently on the landscape (Ream unpublished data). Management of these species should focus on curbing this practice, not only to ensure the maintenance of genetic structure within populations, but also to prevent population stress due to the removal of breeding adults and the introduction of disease.

In Alaska, managers should consider defining MUs and ESUs for Alaska's native herpetofauna. A lack of funding, lack of baseline data, and a lack of dedicated non-game managers have limited the development of concrete, science-based conservation plans for amphibians in the state. While the spatial extent of amphibian populations can often be resolved using genetic data to appropriately define the most appropriate geographical unit for management (Moritz 1994), proper genetic analysis takes time and money, both of which are rarely available in excess for

resource managers (Moritz 1995). Since ESUs contain a genetic component and genetic material for the state's amphibians is scarcely available, a program should be implemented to gradually acquire sufficient samples. The Fish Resource Permit (FRP) officer for the Alaska Department of Fish and Game (ADF&G), Scott Ayers, has informally suggested a program whereby permittees collecting amphibians (in Alaska amphibians are legally defined as fish) opportunistically, collect toe samples when able to do so (Ayers pers. comm. 2013). This program should be pursued and if possible, kits should be distributed to permittees to assist in toe sample collection. These could be relatively inexpensive to assemble and may include plastic vials filled with a buffered salt solution, a scalpel with several razors, and labels.

Obtaining the necessary information to establish ESUs in Alaska will likely take time and as mentioned previously, these units are most applicable to long-term conservation goals. The acquisition of genetic material will allow researchers to determine the degree of separation that isolated populations of amphibian species in Alaska have with members of the species in other parts of their range. To some degree we can speculate that adaptations to the severe climatic and geological conditions in Alaska are encoded within genes and that these reservoirs of adaptive capacity may be beneficial for future conservation.

Short-term MUs are perhaps more easily established and may have substantial long-term benefits too. These require that managers have baseline population data, especially regarding species distributions and abundance. Again, this data is also scarce in Alaska but is gradually being studied and reported. To supplement the data, researchers investigating other taxa should begin reporting herpetofauna encountered in the course of already established daily work assignments, similar to that which was done in the Anderson (2004) opportunistic study in Alaska's National Parks. In fact, both state and federal staff should be trained in this process and allow for long-term monitoring of species. An easily navigable central database should be established to record, compile, and transmit this information. Another valuable tool for obtaining population data on the state's amphibians is the use of citizen science and Local and Traditional Knowledge (LTK), which has already proven valuable in understanding populations along the Stikine (Ream unpublished data).

Southeast Alaska is a unique study location because of its varied and distinctive landscapes such as dynamic fiords and glaciers (Moore et al. 2011). These features are rare but may be important for terrestrial vertebrates in the region (Moore et al. 2011). According to Moore et al. (2011), "Southeast Alaska is relatively pristine with fewer anthropogenic stressors like large-scale habitat loss and widespread contamination." Amphibian populations here also exhibit higher occupancy rates than currently exist elsewhere (S Pyare unpublished data).

The Stikine is perhaps one area within Alaska where baseline data for amphibian populations has been established and periodically updated (more on this under "Stikine Case Study" below). Much of this region is within the Stikine LeConte Wilderness Area and thus amphibians are afforded protections indirectly through habitat conservation, though anthropogenic uses of the area, particularly for recreation, are often high. MUs here may benefit from being based more on species diversity, abundance and breeding activity at certain sites rather than individual

population units. So, like Europe, the state may consider protecting critical habitat rather than ESUs so long as genetic information remains unavailable.

In the Stikine region, several wetland sites appear incredibly important as amphibian breeding habitat as evidenced by diversity and productivity at these sites over time. In most of these, several species of amphibian occur and breed sympatrically, adding to the conservation benefit of protecting the site and recognizing it as a management unit. These sites and the associated species include:

- Cheliped Bay / Mallard Slough (Columbia Spotted Frogs, Wood Frogs, Long-toed Salamanders)
- Twin Lakes and Nearby Geothermal Spring (Rough-skinned Newts, Long-toed Salamanders, Columbia Spotted Frogs, Western Toads, Northwestern Salamanders?)
- Shakes Hot Springs (Rough-skinned Newts, Columbia Spotted Frogs, Wood Frogs, Western Toads)
- Barnes Lake & Nearby Paradise Slough (Rough-skinned Newts, Long-toed Salamanders, Columbia Spotted Frogs, Western Toads)
- Farm Island / Sergief Island Tidal Flats (Western Toads, Wood Frogs, Long-toed Salamanders)
- Mitkof, Wrangell, and Etolin Island (Rough-skinned Newts, Western Toads, Columbia Spotted Frogs)

There are many other sites in the Stikine Le-Conte Wilderness Area that have breeding populations of amphibians, though the above listed sites have historic and recent evidence of significant productivity and importance. Most productivity appears to occur either in tidally influenced areas of the delta receiving substantial sunlight and rainfall or on the northern side of the Stikine River that received more sun and warmth. Geothermal areas are particularly interesting given their incredible productivity and their ability to serve as winter refugia on a frozen landscape. Humans also enjoy the inviting character of the above listed sites and thus visit and recreate at them frequently. For this reason, special attention should be paid to public education, including signage and educational material placement. In addition, the presence of people at these sites may provide opportunities for the implementation of citizen science programs that record valuable observations.

Monitoring

Wildlife management often requires site-specific information that can only be obtained through natural history studies of the populations in question (Constible et al. 2010). If we are to

conserve amphibian populations, better information on their spatial ecology is required, and according to Pilliod et al. (2002), this should include:

1. The spatial distribution of resources critical to survival
2. The seasonal use and movement patterns of animals among these habitats
3. The factors that contribute to habitat loss and fragmentation

In the past 20 years, there has been increasing evidence of widespread amphibian declines and this has led to the development of programs like the North American Amphibian Monitoring Program (NAAMP) (Weir and Mossman 2005). These programs require that important decisions regarding monitoring be considered (Scherer and Tracey 2011), such as the selection of appropriate state variables (Noon and McKelvey 2006). The primary goal of these programs is to document declines and so the state variable should record changes in population status and they should have a high probability of detecting these changes (Gibbs 2000, Noon 2003, Maxwell and Jennings 2005, Noon and McKelvey 2006).

For Wood Frogs, egg mass counts have been proposed as a state variable for monitoring populations and one major benefit of this is relatively low costs (Scherer and Tracey 2011). Simulations indicate that this method requires a minimum of nine years of monitoring to acquire high statistical power for detecting a 10% decline per year (Scherer and Tracey 2011). Populations that exhibit annual declines less than 4% require two decades or more of monitoring to achieve this same goal (Scherer and Tracey 2011), an obvious disadvantage of this technique.

Managers monitoring amphibians at small scales often prefer abundance as a state variable (Scherer and Tracey 2011). At broader scales, such as regional populations, broader ranges of state variables are available (Scherer and Tracey 2011). Models developed by MacKenzie et al. (2006) can be used with data from repeated presence-absence surveys at wetlands to estimate the proportion of wetlands occupied by a species and to determine the processes that lead to occupancy changes over time (Scherer and Tracey 2011). Other models have been developed for call survey data collected from regional populations (Scherer and Tracey 2011), such as the model of Royle and Link (2005), which uses this type of data to develop an index of the distribution of abundances across wetlands.

Presence-absence models are perhaps the most promising methods for successful inventories and monitoring over large and complex landscapes (Pyare 2004b). These provide an estimation of site occupancy rates using a measure of the fraction of a landscape occupied by a species, a method called the Proportion of Area Occupied (PAO) (Pyare 2004b). The USGS Amphibian Research and Monitoring Initiative (ARMI) developed the PAO protocols “as a central component of its mid-level amphibian monitoring program” (Pyare et al. 2004). They are statistically robust and are used to assess changes in amphibian distribution while helping to identify areas where conservation action is necessary (Pyare et al. 2004b). A challenge to presence-absence based models is that a lack of detection does not necessarily equate to the

absence of a species (Strayer 1999, Mackenzie et al. 2002). An alternative method of detecting species is quickly emerging and includes species presence validation through DNA detection in site water. This may become an important tool in advancing herpetology in Alaska.

The most common reason that monitoring programs fail is insufficient duration of financial and institutional support (Elzinga et al. 2001, Field and Tracey 2011). For this reason, building long-term partnerships between government agencies, institutions and the general public are essential for effective conservation. By involving stakeholders in the collection of data for management of local resources, amphibians included, the ability to obtain otherwise costly information can often be achieved while increasing the capacity of participants to play a meaningful role in conservation.

Mosquito Benefits (An Example of Public Interest)

Garnering public support for research initiatives and conservation is critical if these programs are to succeed (Calhoun and Reilly 2008). One method of galvanizing the public is to explain the real world value and tangible benefits to individuals (Rubbo et al. 2011). For amphibians, one topic of importance is human health and pest control – demonstrating that the maintenance of amphibian populations in seasonal pools can limit mosquito production (Rubbo et al. 2011) – a topic that is sure to excite many Alaskans.

Forested wetlands provide ideal breeding habitat for mosquitos (Dale and Knight 2008) because they are characterized by standing water and a lack of fish predators (Rubbo et al. 2011). Amphibians utilize these pools too as breeding sites for these same reasons (Rubbo et al. 2011). Frog tadpoles may function as competitors with larval mosquitos since they utilize similar food resources, such as bacteria and algae (Rubbo et al. 2011, Blaustein and Margalit 1996, Mokany and Shine 2003) and they can also act as predators of mosquito larvae (Petranka and Kennedy 1999). Salamander larvae too are predators of mosquito larvae (Smith and Petranka 1987, Brodman and Dorton 2006, Durant and Hopkins 2008) and they may be able to limit production of mosquitos in wetlands (Brodman et al. 2003).

In a study by Rubbo et al. (2011) the survival of larval mosquitos was effected by the presence of larval amphibians and the insects even avoided oviposition in experimental chambers containing Wood Frog tadpoles and Spotted Salamander larvae (Rubbo et al. 2011). This suggests that there are costs to utilizing environments containing larval amphibians as breeding sites (Rubbo et al. 2011). The authors suggest that the physical interference of the water's surface by the amphibian larvae causes mosquitos to avoid oviposition. The effects of Wood Frog tadpoles on mosquito oviposition was especially strong, perhaps a bit less so for the salamander larvae that showed a positive association with water depth, whereas the mosquitos showed a negative association to depth (Rubbo et al. 2011). Oppositely however, introductions of mosquito larvae (and crayfish) have been shown to decrease amphibian populations through interference competition for limiting resources (Gamradt and Kats 1996, Mokany and Shine 2003).

THREATS

As the human footprint expands globally, habitat loss and fragmentation continue to increase (Vitousek et al. 1997, Sanderson et al. 2002). The process of identifying threats and integrating efforts across spatial scales for herpetological conservation in northwestern North America is only beginning (Olson 2009). Still, enough is known about the region to begin to identify key topics for consideration when it comes to amphibian conservation. Among these are disease, malformations, pollutants, habitat modification, and introduced non-native species (Stuart et al. 2004), each of which is discussed briefly here.

Disease

In amphibians, infectious diseases have been implicated in several population declines (Bielby et al. 2008, Daszak et al. 2003, Skerratt et al. 2007, Rodder et al. 2009), they are of significant concern to Alaska's amphibians (Olson 2009) and preliminary sampling has found that chytridiomycosis, an infectious disease caused by the chytrid fungus – *Batrachochytrium dendrobatidis* (Bd) - is present in frog and toad populations in the southeast and southcentral regions of the state (Reeves and Green 2006, Adams et al. 2007, Reeves 2008, Reeves 2008b). Emerging diseases such as Bd and Ranavirus have caused mass mortality events and even local extinctions worldwide (Carey 2000, Lips et al. 2006, Gray et al. 2009, Kilpatrick et al. 2010). Bd in particular is now known to be present on every continent where amphibians occur (Berger et al. 1998, Weldon et al. 2004, Bosch et al. 2007, Longcore et al. 2007, Kustrini et al. 2008, Lips et al. 2008) and it has played a significant role in global amphibian declines (Berget et al. 2001, Lips et al. 2006).

Chytridiomycosis results when Bd invades keratinized tissue of an amphibian and causes hyperkeratosis (Longcore et al. 1999, Pessier et al. 1999). In turn, hyperkeratosis disrupts cutaneous function (Voyles et al. 2009) and may compromise the host's immune system (Rosenblum et al. 2008). The pathology of chytridiomycosis in amphibians is complex and varies due to host resistance, disease pathogenicity, and environmental conditions (Pilliod et al. 2010). Mass die offs of amphibians have been attributed to this disease (Muths et al. 2003, Scherer et al. 2005). Metamorphosing tadpoles can be particularly at risk of fatal Bd infections. Metamorphosis and immune response to infection are energetically costly events (Lochmiller and Deerenberg 2000, Demas 2004, Martin et al. 2008, Warne et al. 2011). Tadpoles that are metamorphosing must commit substantial resources to development and simultaneous immune responses to infection often results in mortality (Warne et al. 2011).

Bd has been verified in Western Toad populations throughout the species' range (Pearl et al. 2007, Muths et al. 2008, Deguise and Richardson 2009b) and populations of this species have declined subsequent to detection (Muths et al. 2003b, Scherer et al. 2005). In Canada (as of 2001) there had only been one report of BD infection among Western Toads in northeastern British Columbia (Raverty and Reynolds 2001). Muths and Scherer (2011) failed to observe mass mortalities or sick toads at Spruce Lake in Rocky Mountain National Park and though Bd was

present, very low zoospore equivalents were measured (Kirshtein et al. 2007). On Vancouver Island however, Garner et al. (2006) found very high prevalence levels of Bd in Bullfrogs.

In another study by Deguise and Richardson (2009b) at Alice Lake Provincial Park near Squamish, British Columbia, nine out of 32 toads sampled were infected with Bd but none showed outward signs of infection. The mass of the infected individuals was not significantly different with uninfected toads and there was no relationship between body condition and infection prevalence (Deguise and Richardson 2009b). The lack of relationship between these factors suggests minimal consequence for the host fitness, but this has not been well explored in amphibians to date (Deguise and Richardson 2009b).

Infected toads are certainly more likely to die than uninfected toads but those that are infected have a substantial probability of survival to the next year (Pilliod et al. 2010). Models have shown that colder temperatures during the breeding season (more frost killing days) may create less favorable conditions for BS and thus increase toad survival (Pilliod et al. 2010), though climate projections for Alaska indicate warming trends rather than cooling. A web-based tool for mapping worldwide Bd infections in amphibians, called the Global Bd Mapping Project (www.spatialepidemiology.net/bd-maps) is now available to track the disease (Olson 2009).

Ranavirus (family Iridoviridae) can infect fish, reptiles and amphibians and is cause for concern in aquaculture operations (Schock et al. 2010). This virus has been isolated in Wood Frog populations, mostly from die-offs, in Saskatchewan (Schock et al. 2008), Ontario (Greer et al. 2005), North Carolina (Harp and Patranka 2006), and in North Dakota, Maine, and Massachusetts (Green et al. 2002). Schock et al. (2010) detected both Bd and ranavirus in the Northwest Territories and thereby extended the known range of both pathogens. Ranavirus was found widely but only among Wood Frogs at that northern locality (Schock et al. 2010).

Global climate change is expected to have several important implications for amphibian disease transmission that should be considered by managers in Alaska. With global temperatures on the rise, pathogens are expected to grow and reproduce more quickly and may increase in severity (McMenamin et al. 2008, Harvell et al. 2002). In addition, warmer winters and warmer nighttime temperatures can reduce normal pathogen die-offs (Burdon and Elmquist 1996, Dwyer and Elkinton 1993). Furthermore, since many amphibian pathogens are transmitted aquatically, increased precipitation could lead to greater rates of transmission (Blaustein et al. 1995). In areas where glaciers are melting and new habitat is forming, it is also possible that either the pathogen or the host could shift ranges without the other following (Blaustein et al. 1995). Areas that are drying could see decreased rates of chytrid infection since the fungus dies after three hours of desiccation (Johnson et al. 2003, Blaustein et al. 1995). However, less winter snow pack may result in lower spring water levels and expose tadpoles to higher levels of UV-B radiation and higher rates of mortality from oomycetes like *Saprolegnia ferax* (Kiesecker et al. 2001b).

Malformations

Concurrent with disease, amphibians are experiencing an increase in morphologic abnormalities (Hoppe 2000). The background rate of abnormalities has been shown to be between 0% and 5% (Converse et al. 2000, Eaton et al. 2004, Gurushankara et al. 2007, Hoppe 2000, Johnson et al. 2002, Ouellet 2000, Schoff et al. 2003, Taylor et al. 2005) but studies in some areas have documented malformation rates as high as 6% to 22% (Bacon et al. 2006, Levey 2003, McCallum and Trauth 2003, Reeves 2008).

The prevalence of abnormalities at road-accessible sites in the Tetlin and Kenai refuges of Alaska are among the highest reported in the published literature (Reeves et al., 2008) and the cause and extent of these remains elusive. Life history parameters provide the basis for establishing adequate conservation practices that we need to circumvent the negative impacts of climate change (Bury 2006, McCallum and McCallum 2006). These impacts are evidently compounded by human-amphibian interactions, which are poorly understood. Because of their sensitivity to global change and our relatively poor understanding of Alaska's herpetofauna, this group may serve as an appropriate taxon to investigate the utility of local knowledge in non-game species.

There are several suspected causes of amphibian malformations. One of these is a trematode parasite named *Ribeiroia ondatrae*, which sequentially infects, birds, snails and amphibian larvae (Blaustein et al. 1995). These trematodes often cause limb deformities and mortality (Blaustein and Johnson 2003). Eutrophication of wetlands can promote trematodes by increasing the density of snail hosts and by enhancing the per-snail production of these parasites (Johnson et al. 2007).

Pollutants

As worldwide agricultural demands continue to skyrocket, so will the use of pesticides on landscapes (Tilman et al. 2001). These pesticides have the potential to travel as aerosols (Davidson et al. 2001, Davidson and Knapp 2007), and to deposit in places where they can be taken up by biota, especially amphibians through their skin, and may also alter nutrient dynamics or increase water clarity allowing for greater penetration of UV radiation (Wright and Schindler 1995).

Habitat Modifications

Timber Harvest

A significant portion of habitat fragmentation in the Pacific coastal ecoregion occurs through timber harvest including clear cutting and the creation of roads for timber access (Deguise and Richardson 2009). Clearcuts in particular sometimes create hostile environments for amphibians and many species are negatively impacted by these land-use practices (deMaynadier and Hunter 1995, Knapp et al. 2003).

Amphibians can orient themselves toward their native ponds (Sinsch 1990, Mazerolle and Desrochers 2005) and towards forested habitat during migratory movements (Rittenhouse and Semlitsch 2006). Relatively little research has focused on the impacts of clearcuts on amphibian movements at the local scale (Pawson et al. 2006), but at least one study these effects were examined in the Western Toad. Deguise and Richardson (2009) found that small recent clearcuts did not act as movement barriers for toads during the breeding season. They also found that Western Toads entered and remained in clearcuts less than five years old with greater frequency than adjacent second-growth forests in the spring (Deguise and Richardson 2009). They moved through matrix environments indicating that permeability of clear-cut areas was high (Deguise and Richardson 2009).

Though Western Toads are thought to be a forest-associated species, they have been found in a variety of habitats, which is not necessarily the case for other species (Bartelt et al. 2004, Davis 2002). In addition, toad species are known to bask and burrow in sandy soils and recent clearcuts may present a suitable environment with ample sunlight, sandy soils, many potential refugia and a high abundance of invertebrate prey (Niemala et al. 1993, Pawson et al. 2006). Red-legged Frogs, one of Alaska's introduced anurans, have been reported moving through clear cuts but are influenced by temperature and precipitation (Chan-McLeod 2003). Other studies have shown decreased movement ability (Baldwin et al. 2006) or no movement, indicating matrix permeability is species specific (Ricketts 2001).

Forest fragmentation also occurs through the creation of logging roads to access clearcuts (Deguise and Richardson 2009). Diversity and abundance of amphibians declines in relation to proximity to roads (Fahrig et al. 1995, Marsh et al. 2005), even on low traffic and abandoned logging roads (Semlitsch et al. 2007). Studies have shown that amphibians use ditches for movement and prefer cement substrate if given a choice (Mazerolle 2004, Stevens et al. 2006). Road mortality can be high (Hels and Buchwald 2001) but it remains unclear if the risk outweighs movement ability and connectivity between populations (Deguise and Richardson 2009).

Temperature and precipitation are also strong determinants of anuran movements in disturbed landscapes (Mazerolle 2001, Johnston and Frid 2002) but Deguise and Richardson (2009) found no relationship between adult Western Toads and these factors. Several studies have reported that bufonids are more resistant to desiccation and may have greater tolerance than other amphibians to climatic conditions in recent clearcuts (Todd and Rothermel 2006). Moisture does appear to be more important for amphibians than temperature (Bartelt et al. 2004) due to their physiology, and several studies have noted the importance of moist refugia for a variety of anurans, including Wood Frogs (Long and Prepas 2012). Amphibian microsites are also an important consideration in relation to forestry practices. It is well documented that many amphibian species display high fidelity toward microsites and that these are important to poikilotherms because, they provide shelter and favorable microclimates for thermo and hydroregulation (Long and Prepas 2012).

In Alaska and specifically in the southeastern region of the state, habitat alteration and fragmentation are key issues (Olson 2009). The Tongass Land Management Plan does not consider the critical roles that forested habitat play in non-breeding life stages of amphibians, particularly for overwintering and migration to and from breeding sites (Olson 2009). As an example of the importance of forests, Western Toads spend greater than 95% of their lives in areas up to several kilometers from their breeding sites (S. Pyare unpublished data, Olson 2009). All of Alaska's amphibians require some degree of terrestrial habitat to persist.

Humans have impacted less than 1% of Alaska's land but these impacts are increasingly prevalent (Duffy et al. 1999). For instance, less than 12% of Alaska's temperate forest has been logged yet the impact on small mammals is concerning (Smith et al. 2004, Hokit and Brown 2006). A major anthropogenic disturbance to landscapes occupied by amphibians is timber harvest and this is a frequently undertaken economic activity in southeast Alaska. In addition to habitat destruction, deforestation can also expose amphibians to levels of solar radiation that they hadn't experienced prior (Blaustein et al. 1995). Blomquist and Hunter (2010) offer two recommendations for minimizing this type of impact on amphibians:

1. Partial harvest with retention of greater than 50% canopy cover may be a viable forest management strategy in ecologically sensitive areas such as those surrounding vernal pools and places with endangered species
2. Retention of coarse woody debris is probably important following timber harvesting to provide thermal and hydric refuges for amphibians and other ground-dwelling organisms.

Roads

A major premise of ecological theory is that animals select habitats that maximize their individual lifetime fitness through increased rates of reproduction and survival (Fretwell and Lucas 1970). Factors that influence this fitness can include behavioral interactions with conspecifics, predators and prey, as well as the avoidance of psychological stress (Blomquist and Hunter 2010). Species utilizing transient habitats usually have higher degrees of phenotypic plasticity in correlates of fitness (Rudolf and Rodel 2007) but this plasticity can also be costly (Blomquist and Hunter 2010). Roadways are one such factor that can influence fitness through habitat connectivity, habitat availability, population isolations, increased edged effects, noise pollution, collisions and environmental contaminants (Reh and Seitz 1990, deMaynadier and Hunter 1995, Forman and Alexander 1998, Ashley and Robinson 1996, Trombulak and Frissell 2000). In the continental United States nearly 80% of the land is within a kilometer of a road (Ritters and Wickham 2003).

In southern Ontario the average traffic volume on Highway 47 was found to be approximately 18,300 vehicles per day, and Wood Frogs in this area exhibited a significant negative relationship to noise generated from this roadway during the breeding period (Eigenbrod et al. 2008). The Alaska Highway, on the other hand, has a traffic volume of only 417 per day average

and may not have as substantial of an impact on Wood Frog populations (Brehaut 2012). Still, traffic volume is expected to continue to increase over time.

Road runoff typically includes several chemicals such as metals, hydrocarbons like rubber residues and petroleum products, and de-icing agents (Norrstrom and Jacks 1998). The background concentration of chloride in wetlands is usually only a few grams per liter with slight variability based on topography, geology, and geographic location (Wetzel 2001), but Environment Canada (2001) reported road runoff concentrations exceeding 18,000mg per liter (Sanzo and Hecnar). Persistence and seasonal input of salts result in elevated concentrations sometimes present during spring amphibian breeding (Sanzo and Hecnar 2006). Amphibian species richness has been shown to be negatively linked with chloride concentrations but richness increases with distance from the nearest road (Sanzo and Hecnar 2006).

Sanzo and Hecnar (2006) reported on acute and chronic exposure of Wood Frogs to sodium chloride (NaCl). The tadpoles of this species are potentially exposed to road salts for 6-15 weeks from oviposition to metamorphosis (Harding 1997). In the study, chronic road salt (NaCl) exposure resulted in decreased survivorship over time, decreased weight, decreased number of frogs that metamorphosed and decreased time to metamorphosis (Sanzo and Hecnar 2006). They also exhibited reduced activity and feeding, delayed responses, were visually emaciated and also developed bent and disintegrated tails (Sanzo and Hecnar 2006). In addition, tadpoles showed increased developmental abnormalities as NaCl concentrations were increased (Sanzo and Hecnar 2006).

The state uses 16,000 tons of salt to prep its winter road sand supply for the MatSu Borough, the Kenai Peninsula, Kodiak, the Aleutians, and southwest Alaska (Bryson 2008). In Anchorage, Alaska, road operations require about 40,000 tons of sand a year that is mixed with 4,000 tons of NaCl (Bryson 2008). Anchorage constructed a heated sand barn in 2007 to shelter 10,000 tons of sand and decrease the need for added salt (Bryson 2008). Still, magnesium chloride is used to pre-wet the sand and to make the grains more prone to stick to the ice on the road (Bryson 2008). In the downtown area of Anchorage, sand is not spread but intersections are sprayed with sodium acetate, which the state also uses on the Knik River Bridge (Bryson 2008).

Little is known about the effects of Alaska's road operations on local amphibian populations but it can be assumed that there is indeed an effect. Monitoring should be undertaken to track chloride concentrations in wetlands near treated roadways and associated amphibian populations. In general though, efforts to protect local amphibian populations should aim to reduce the application of road salts near wetlands with high conductivity levels (Dougherty and Smith 2006).

Predation and Amphibian Defense

Amphibians can serve as substantial prey sources for many animals including fish, birds, and small mammals. Many species do however have predator defense mechanisms, which are worth mentioning briefly here so that managers can have a basic understanding of these biological adaptations.

Amphibians have either smooth or rough skin that is usually rich in glands (Noble 1931) that produce secretions for a variety of defensive functions including antimicrobial and antifungal activities (Clarke 1997, Daly 1998, Apponyi et al. 2004, schadich 2009), antipredator strategies (Anderson 1964, Clarke 1997, Daly 1998, Hamning et al. 2000). These are sometimes coupled with defensive postures (Brodie and Gibson 1969, Brodie et al. 1979) or aposematic coloration (Carpenter 1955, Hensel and Brodie 1976, Daly et al. 1987, Summer and Clough 2001). Four major categories of skin secretions have been identified among amphibians including amines, alkaloids, steroids, and peptides/proteins (Daly 1998, Clarke 1997). Some salamanders primarily use compounds like tetrodotoxin (Brodie et al. 1974, Hanifin et al. 2008), while others use proteins (Jaussi and Kunz 1978, Hamning et al. 2000). In urodeles, glandular secretions are primarily on the skin of the tail and the paratoid regions (Brodie and Gibson 1969, Williams and Larson 1986, Williams and Anthony 1994, Grant and Evans 2007).

Long-toed Salamanders have been shown to produce proteinaceous skin secretions (Hopkins and Migabo 2010) similar to other ambystomatids. These allow them to defend against microbial and fungal pathogens (Clarke 1997, Daly 1998, Apponyi et al. 2004, Schadich 2009), and vertebrate and invertebrate predators (Anderson 1964, Clarke 1997, Daly 1998, Hamning et al. 2000, Williams and Larson 1986). In the northern parts of their range, Long-toed Salamanders have been shown to produce the secretions but only require small concentrations (.25mg/ml) for the desired effect (Hopkins and Migabo 2010). This adaptive strategy may allow the species to survive short summers and harsh winters despite the physiological costs of producing and storing chemical defenses (Longson and Joss 2006). In addition to antipredatory defense, these secretions may also serve as a protein nutrient storage depository (Williams and Larson 1986).

Introduced Non-Native Species

Invasive species are included as one of Alaska's herpetofaunal concerns, and habitats in Alaska fulfill two of the three predictors of biological invasion (Moulton and Pimm 1986), including relatively few species and no additional members of the same taxonomic group (Neuman-Lee et al. 2011). Invasives are a considerable force of change globally and they alter ecological systems and evolutionary trajectories in their introduced ranges (Haught and von Hippel 2011). In the United States, these introductions are considered a significant cause of native species extinction, second only to habitat loss (Wicove et al. 1998, Pimm and Raven 2000). Executive Order 13112 (1999) defines invasive species as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health."

Species introductions pose a multi-faceted threat to amphibians (Olson 2009), especially in terms of competition for local resources, predation, and disease transmission. Stocked fishes and non-native amphibians have often been implicated in declines (Olson 2009). Some introduced amphibians are of particular concern in North America since they can carry disease, prey upon other amphibians and tend to do well in a variety of habitats. Several of these include the Cuban Treefrog (*Osteopilus septentrionalis*), the American Bullfrog (*Lithobates catesbeianus*) and the Cane Toad (*Rhinella marina*) (Blaustein et al. 1995). Several invasive species, including the American Bullfrog and the Red-legged Frog, also fail to avoid heavily disturbed areas (Bulgar et al. 2003, Patrik et al. 2006).

In Alaska, the threat of invasive species introductions is real and few laws restrict import of pet species. A variety of exotic amphibians and reptiles have been reported in Alaska but these have often been determined to be escaped pets near populated areas (Wake 1998). Wake (1998) reported observations of rubber boas, garter snakes, bull snakes (near Juneau), and snapping turtles (near Anchorage) while Anderson (pers. com. 2013) noted an unverified introduction of Bull Frogs near Palmer. These introductions, to our knowledge, have not resulted in viable populations and most individuals are expected to have perished during their first winter in Alaska.

In 2013 alone, several non-native herpetofauna observations have been reported (Ream unpublished data). A Red-eared Slider was captured at Goose Lake in Anchorage during the spring by a group of students who encountered it buried in mud, presumably in a pre-emergence hibernation state that suggests the possibility that this animal overwintered at that location. Another Red-eared Slider was reported from Sand Lake in July. At least one Blue-spotted Salamander from a group of six released individuals in Chugiak was verified to have survived the winter there. In addition, a new, presumably viable, population of Pacific Chorus Frogs was identified in Sitka, Alaska. It is unclear if 2013 has thus far been a unique year for introductions or if the reports are being funneled more centrally than in previous years. Noteworthy too is the fact that the winter of 2012/2013 was relatively mild in south-central Alaska, perhaps permitting some released individuals to persist.

To date, only two species of herpetofauna are known to have established viable populations in Alaska. These include the Pacific Chorus Frog (*Pseudacris regilla*; formerly *Hyla regilla*) to Ketchikan, and the Red-Legged Frog (*Rana aurora*) to Chichagof Island near Hoonah. The impacts of these introductions on native herpetofauna have not been documented though additional information on the populations is reported below. It may be expected that, as Alaska's population continues to grow, trade increases, and habitats change with a warming climate, the ability of non-native populations to become established may increase. Managers should seek to educate the public on the risks to native flora and fauna by introduced exotic species. Law enforcement should actively investigate and prosecute reported introductions. In addition, ADF&G should seek to codify a list of restricted species that pose considerable threat to native Alaska herpetofauna, perhaps mirroring the lists established by sister state's in the Pacific Northwest.

Fish

The invasion or introduction of predatory fish into wetlands can have major effects on amphibian populations (Pearson and Goater 2009). Many studies indicate that fish prey on ranid eggs and tadpoles (Knapp and Mathews 2000, Pilliod and Peterson 2001) and that in the absence of fish, frog density and survival increase (Pope 2008). It has also been shown that the addition of fish predators can reduce the survival of larval amphibians, in some cases to zero, through direct consumption (Semlitsch 1993, Tyler et al. 1998b). In fact, amphibians and fish are often allopatric, especially for amphibians native to high-elevation ponds and lakes in the northwestern United States (Tyler et al. 1998b, Pilliod and Peterson 2001, Bull and Marx 2002, Knapp 2005, Welsh et al. 2006).

The introduction of nonpiscivorous fishes throughout the ranges of amphibians is also common (Scott and Crossman 1973) and can have effects on amphibian populations too. Tadpoles and larval salamanders have exhibited reduced foraging rates in the presence of fish (Kats et al. 1988, Werner and Anholt in 1996). The occurrence of introduced fish has also been shown to influence the oviposition preferences of adult amphibians (Resetarits and Wilbur 1989, Kats and Sih 1992). In one example, the introduction of exotic western mosquitofish (*Gambusia affinis*) has been documented to cause population declines for several amphibian species (Kats and Ferrer 2003, Zeiber et al. 2008) due to direct predation on amphibian larvae (Goodsall and Kats 1999, Walls et al. 2002), as well as negative effects on larvae foraging activities (Lawler et al. 1999).

The effects of trout introductions on ambystomatids was discussed previously, but the introduction of Northern Pike, *Esox lucius*, to parts of Alaska has also likely caused significant localized declines in anurans and poses a threat in other areas where they could devastate frog and salamander populations if they were to become established. Invasive pike often remodel the ecology of lakes by removing prey types in reflection of their own diets (Haught and von Hippel 2011). Studies have shown that pike switch to less desirable food types to more abundant macroinvertebrate prey when preferred items are eliminated (Haught and von Hippel 2011). Pike prefer to consume soft-rayed fish to spiny-rayed fish (Hoogland et al. 1957, Eklov and Hamrin 1989) and in south-central Alaska, juvenile salmon and trout is the preferred prey (Rutz 1996, Rutz 1999). Despite these preferences, pike are known to be trophically adaptable and can be sustained on a wide variety of prey types (Beaudoin et al 1999), which allows them to make rapid changes in prey selection in response to changes in prey abundance (Mann 1985).

In south-central Alaska, the introduction and spread of Northern Pike is substantially altering the ecology of wetlands in the Cool Inlet Basin (Rutz 1996, Rutz 1999, Patrankar et al. 2006). The species is native to northern Alaska (Morrow 1980) but it was illegally introduced to the Susitna Watershed during the 1950s (Fay 2002, ADF&G 2007). They subsequently spread, both naturally and by anthropogenic introductions, to the Matanuska Valley, the Anchorage Bowl, and the Kenai Peninsula (Haught and von Hippel 2011). A map depicting the approximated

spread of the species to southcentral Alaska over time (Haught and Von Hippel 2011) is included as figure 15 in the appendix.

In a study by Haught and von Hippel (2011), Wood Frogs were a rare prey item despite being abundant in the area. It is however known that amphibian distribution is affected by fish predators (Hecnar and M'Closkey 1997), and that frogs are likely highly susceptible to pike predation (Haught and von Hippel 2011). The fact that frogs were a rare prey item in the aforementioned study could be attributed to a reduction or elimination of the frogs in the wetlands during the initial years following pike introduction (Haught and von Hippel 2011), and that they were among the preferred prey items at that time. Samuel Ivey, an Area Management Biologist for ADF&G, provided a photograph of a Northern Pike at Alexander Creek, Alaska that had been dissected, with stomach contents containing five adult Wood Frogs in various stages of decay (figure 16 of appendix).

Amphibians

PACIFIC CHORUS FROG

The Pacific Chorus Frog, *Pseudacris regilla*, is the first species of amphibian known to have established a viable non-native population in Alaska. It is found within its natural range from southern British Columbia (B.C.), including Vancouver Island, to Baja California and east to Idaho and Utah (MacDonald 2003). The species has been introduced to the Haida Gwaii Islands in B.C. and to Revillagigedo Island near Ketchikan (MacDonald 2003), the mainland near Juneau (Carstensen et al. 2003) and Baranof Island near Sitka (Ream unpublished data) in Alaska. The Juneau and Sitka observations have been vouchered but it remains unclear if viable populations have been established.

Pseudacris regilla inhabits a variety of habitats in the Pacific Northwest (Schaub and Larsen 1978). They have a preference for warmer, more open ponds (Schaub and Larsen 1978), and have strong homing responses (Jameson 1957). These frogs do need to reach a temperature threshold before breeding commences in the spring (Licht 1969). White and Kolb (1974) found that the species is an important food item for garter snakes where they occur sympatrically, while *T. sirtalis* has been shown to be highly successful at capturing transforming PCFs (Wassersug and Sperry 1977).

The population at Revillagigedo Island near Ketchikan (Ward Lake Area) has been monitored periodically since becoming established and Dana Waters and Bradford Norman ascertained the context of the original introduction. According to these researchers, one Ernest Deboer, a Ketchikan resident of more than 45 years at the time of the conversation, reported to the Ketchikan Daily News and Bradford Norman that he has released the frogs as early as 1960 (Chase 1992a, Chase 1992b, Chase 1992c). Deboer collected both small (<4.0cm) and large (>4.0cm) tadpoles and some transformed frogs from Kirkland, King County, Washington and transported them in a 5-gallon bucket by plane to Ketchikan where he released them at the same muskeg pond that they are known to occur at today (Waters 1998). He also suggested

that there may have been at least one other species in the bucket but no additional non-native species have been documented at the site (Waters 1998).

A U.S. Forest Service employee, R. Hauver, observed the *P. regilla* population at Ward Lake and shipped two adult specimens collected on 21 June 1991 to Dana Waters for identification (Waters 1991, Waters 1992a, Waters 1992b). Six additional specimens were collected by R. Whitten in 2002 and were sent to Auke Bay Laboratory by ADF&G. On 24 and 16 May 1992, Bradford Norman visited the site and documented at chorusing by at least 30 males (Waters 1998, MacDonald 2003). Norman also examined 45 transects at 24 localities near the site of release and no additional populations or individuals of the species were discovered (Norman and Hassler 1995, Waters 1998).

In June of 1992, Paul Zellmer of the U.S. Forest Service documented mating pairs, individual frogs, and egg masses (MacDonald 2003). Zellmer also reported the following observations in 1993 and 1994 (Waters 1998):

1. The frogs are utilizing clumps of grasses (Family Gramineae) and sedges (*Carex* sp.) for cover adjacent to the pond system margins.
2. Males initiate calling as spring air temperatures approach 9.5-10.0°C at the site.
3. As darkness increases less perturbation is tolerated by calling males before they cease calling in response.
4. Both green-dominated and brown-dominated color phases of this extremely varied species of frog are present at the introduction site.

To date, the Revillagigedo population appears to remain confined to the same pond system where it was first introduced (MacDonald 2003). The Rough-skinned Newt and the Western Toad have also been documented on the island and apparently have bred successfully in the same pond as the introduced frogs (MacDonald 2003, Hodge 1976, Taylor 1979, Waters 1991, Waters 1992b). A population of Long-toed Salamanders was identified near the pond in 2010 and was the first verified record of this species on Revillagigedo Island (Ream unpublished data).

On 8 August 2003, Carstensen et al. (2003) captured the only specimen of this species found during their study. It was captured from a small pond in the Mendenhall Valley where local residents reported having heard it calling during most of July and early August of 2003 (Carstensen et al. 2003). No additional specimens have since been reported from the area. In June of 2013, Troy Tydingco, an area biologist with ADF&G, reported a new population of *Pseudacris regilla* near the State Trooper Academy in Sitka, Alaska. A specimen from the population was captured, preserved and sent to the UAM as a voucher. Tydingco reported hearing several individuals of the species calling in the spring. Ream visited the site in July of 2013 and despite call surveys and a search of the pond's margins was unsuccessful at locating

another individual (Ream unpublished data). The status of this population requires additional monitoring.

RED-LEGGED FROG

The Northern Red-legged Frog, *Rana aurora*, is a stout, medium-to-large frog measuring up to 13.6cm SVL with a broad head and rounded snout (MacDonald 2003). Its natural range is from southwestern British Columbia, including Vancouver Island, south to California (MacDonald 2003). The Red-legged Frogs of North America (*Rana aurora* and *Rana draytonii*) comprise two distinct species whose ranges narrowly overlap in coastal southern Mendocino County, California (Camp 1917, Shaffer et al. 2004), though Bradley et al. (2004) claim that they were reclassified as a single polytypic species with two subspecies. Either way, they comprise a wide-ranging species complex of western North America anurans that have been “a long standing source of confusion with respect to species boundaries and composition (Bradley et al. 2004). *Rana aurora* occurs on the mainland north to Sullivan Bay, B.C. (Stebbins 2003, Pearl 2005).

Red-legged Frogs occur sympatrically with Columbia Spotted Frogs in southwestern British Columbia (Carl and Cowan 1945, Licht 1974). Both breed very early in the year, usually in February or March soon after ice melts from the breeding sites (Licht 1969). The mating call unlike other North American ranids as it is very low in volume, has little carrying power, and is normally made underwater (Licht 1969). Sometimes no sound can be detected in the air and a hydrophone is necessary to detect them (Licht 1969). Adults of both sexes appear to find their way to breeding sites without the use of vocal cues (Licht 1969). Licht (1969) reported emergence in late February and early March in southern B.C. and suggested that air temperatures must reach 5°C for emergence and calling to commence, though males observed basking likely had higher body temperatures.

Serious declines and extirpations of local populations have been documented in Oregon and California due to habitat loss, introduced predators, and perhaps disease (MacDonald 2003, Chan-McLeod and Allaye 2003). *Rana draytonii* is listed as Threatened under the ESA, and *R. aurora* is considered a Species of Special Concern in British Columbia (COSEWIC 2002). The species has however, established viable populations on the Haida Gwaii Islands of B.C. (Ovaska et al. 2002), and on Chichagof Island in Alaska (MacDonald 2003), and was assigned a “High” invasive threat ranking by the Assessment of Invasive Species in Alaska and its National Forests (USFS 2005).

The Red-legged Frog has a surprisingly long history of introductions with the earliest occurring in 1857 when they were released on the island of Oahu in Hawaii (but disappeared after several months) (McKeown 1996). They were introduced more recently to multiple locations in Nevada as part of frog farming ventures in the 1930s and 1940s, and several populations became established from these releases (Linsdale 1940, Reaser 2003). In Alaska, introduced populations of this species now occur in the Kennel Creek and Pavlov River drainages of Freshwater Bay on Northwest Chichagof Island near the community of Hoonah, Alaska (MacDonald 2003), 850km north of the nearest recognized native population in Sullivan Bay, N.C. (Pauly et al. 2008). The

introduction first occurred when a schoolteacher in Hoonah purchased one or two egg masses from Powell Laboratories in Gladstone, Oregon (now Carolina Biological Supply Company) around 1982, and subsequently released the surviving metamorphs (one or two dozen) into a pond near Kennel Creek, approximately 30km southeast of Hoonah (Hodge 2004, Pauly et al. 2008). Powell Laboratories collected wild specimens from the northwestern United States (Nace et al. 1971) and documentation indicates that *R. aurora* egg masses from Oregon's Columbia River Gorge were collected at the time they were ordered (Hodge 2004).

The survival of the resulting population went undocumented until U.S. Forest Service biologists collected a single specimen in 2000, and another in 2001 (Lerum and Piehl 2007, Pauly et al. 2008). The individuals were photographed and originally suspected to be *Rana luteiventris* (Lerum and Piehl 2007), but Hodge later identified specimens collected by USFS Hoonah Ranger District fisheries staff in 2002 as *R. aurora* (Sargent et al. 2003). Surveys in 2002 confirmed the presence of this species at several ponds (Sargent et al. 2003).

A subsequent visual detection survey was conducted in 2006 (Lerum and Piehl 2007). Diurnal visual encounter surveys were the primary technique used though night surveys have been found to be more effective than diurnal surveys in locating California Red-legged Frogs (Bury and Major 1997, Fellers and Kleeman 2006, Lerum and Piehl 2007). They were conducted in this study during the breeding season so that both adults and egg masses could be detected; adults were very wary and cryptic (Lerum and Piehl 2007). This survey found significant population growth and rapid range expansion outward from the initial introduction site with 100% breeding habitat occupancy below 200m over 6000 continuous hectares of wetland and forested habitat from Freshwater Creek to Tenakee Inlet (Lerum and Piehl 2007). The species was found along a 30km corridor of contiguous wetland habitat and no native amphibians were encountered in this survey (Lerum and Piehl 2007). A map borrowed from Lerum and Piehl (2007), depicting the introduction site and subsequent range expansion as of 2006, is included as Figure 17 in the Appendix.

Genetic analysis has shown that the Chichagof population is most closely related to available samples from Oregon, which is consistent with Hodge's (2004) claim that the source population was from the Columbia River Gorge (Pauly et al. 2008). There was also a complete lack of variation among the twelve individuals sampled from Chichagof, suggesting a recent introduction and range expansion from a small source population, "as would be expected if the founding population only included metamorphs of one or two clutches (Pauly et al. 2008).

In contrast to declines throughout its native range, *R. aurora* on Chichagof Island appear to be doing well and are undergoing population expansion (Pauly et al. 2008). Pauly et al. (2008) examined habitat on Chichagof Island and applied an LPT (minimum suitability value) that identified regions that are predicted to be at least as suitable as the localities where the species has been recorded. They found that only 23% of randomly selected localities on Chichagof are greater than or equal to the LPT and suggested that the potential for additional expansion is limited on the island (Pauly et al. 2008). Under future climate scenarios, 86% of the random localities are expected to remain equally or less suitable for the species (Pauly et al. 2008), and

the eastern half of the island including Freshwater Bay and Tenakee Inlet areas provide the most suitable habitat (Pauly et al. 2008). Niche modeling suggested that the species will expand over a relatively small area and may even decline in the future (Pauly et al. 2008).

There are biotic factors not considered in the generated models that could lead to range expansion including adaptive response by the frogs themselves (Pauly et al. 2008). The predictions could be biased if two critical assumptions are not met: 1) the model accurately predicts ecological tolerances and requirements and 2) the niche of the species is conserved and they will not adapt to novel and changing conditions (Pauly et al. 2008). Local knowledge in Tenakee suggests that the species may be present nearby (Lerum and Piehl 2007), and in the Hoonah area residents have suggested that the frogs have been expanding their range since 2008 (Ream unpublished data 2013). If the species continues to expand, new localities can be used to further assess changes in ecological tolerances and requirements on Chichagof (Urban et al. 2007, Pauly et al. 2008).

The effects of this species on the local environment have not yet been documented though its ability to persist and spread across drainages may present a threat to local herpetofauna through interspecific competition and disease transmission (Lerum and Piehl 2007). *Rana aurora* may have adverse effects on the native Western Toad (which also occurs on Chichagof) (MacDonald and Cook 2007), and could be of greater concern if transported to the mainland where habitat is considered more suitable (Pauly et al. 2008). Niche modeling shows those areas of the mainland north of Chichagof within Glacier Bay National Park are suitable and are at particular risk of invasion by this species (Pauly et al. 2008). Disease transmission to Western Toad populations is particularly troubling since chytrid fungus has contributed to the decline of these toads in Colorado (Scherer et al. 2005). Red-legged Frogs are largely insectivorous (Licht 1986), though it has been known to consume vertebrates and other amphibians (Rabinowe et al. 2002). Oregon Spotted Frogs (*Rana pretiosa*) have been shown to consume newly metamorphosed juvenile toads (Pearl and Hayes 2001), and since *R. aurora* are likely to be present near *A. boreas* breeding sites, they could have a significant impact on toad viability if found to prey on toad larvae or metamorphs (Lerum and Piehl 2007). Several Hoonah residents have reported sharp declines in Western Toad populations in the past several decades (Ream unpublished data 2013), but it is unclear if these are related to the *R. aurora* introduction. Hodge indicated in personal communication with Lerum and Piehl (2007) that he predicts “*R. aurora* will become the Bullfrog of AK! *R. aurora* is a large, aggressive, prolific Ranid with a big appetite for amphibians, fishes & invertebrates.”

Pauly et al. (2008) suggest two options for managing the introduced frogs on Chichagof. The first is to attempt to eradicate the species, which would help to avoid a variety of threats to the native herpetofauna of the area (Pauly et al. 2008). Unfortunately, this method is expected to be costly and to have minimal chance of success due to the remote and relatively uninhabited landscapes where they now persist (Pauly et al. 2008). The second option is to allow the species to persist until the effects on native species are evaluated, but to keep the population isolated on Chichagof (Pauly et al. 2008). Interestingly, many *R. aurora* populations in their native range are declining which may make the Alaska population an asset for future conservation initiatives

(Pauly et al. 2008). Restricting anthropogenic translocation will likely be difficult though, given the frequency with which these types of events have been reported in the state (Pauly et al. 2008, Ream unpublished data). The task will require extensive public education (Pauly et al. 2008). So long as there is no evidence of significant ecological impacts, Pauly et al. (2008) suggest allowing the population to persist. Unfortunately, the status of the population is largely unknown and has not been formally evaluated in several years.

STIKINE CASE STUDY

Introduction

Since an important challenge in management and conservation is the ability to extrapolate from studies done elsewhere on other populations of the same species (Constible et al. 2010), managers in Alaska may wish to analyze and interpret data that is available for Stikine amphibians since these datasets are relatively extensive compared to other areas, and they include all known native amphibian species in the state. For this reason, a brief overview of the work on this river is included here, but more complete and updated information will be provided in a pending doctoral dissertation to be published in 2014 (Ream unpublished data). Still, it is important to remember that no two situations are identical and management options are frequently site specific (Constible 2010).

Several transmontane river systems in Southeast Alaska provide important corridors from Canada's dryer warmer interior to the coastal temperate rainforest, especially the Stikine, Taku, and Unuk. The Stikine in particular has received considerable attention among biologists due to its biodiversity, length and output. This river is thought to be home to all six of Alaska's known native amphibians and it provides excellent habitat for their survival, making it an excellent case study. Though opportunistic and systematic herpetofaunal surveys here have been infrequent, it is perhaps among the mostly completely and most frequently sampled watersheds in the state. Hodge sampled this river in 1973 and 1976 (Hodge 1976), Waters in 1991 (Waters 1992), Norman and Hassler in 1992 (Norman and Hassler 1995), and Ream in 2012 and 2013 (Ream unpublished data). An ongoing citizen science and local knowledge study with amphibians has also been occurring in the area since 2009 (Ream unpublished data). Still, the vast expanse of land and wetlands in the area coupled with the difficulty and expense of access has provided for many gaps, a situation common in herpetology across the state.

The Stikine River is the largest of six great rivers flowing from the interior of British Columbia through the Coast Mountains into the Alexander Archipelago of Southeast Alaska. From its headwaters at Tuaton Lake, in the Spatsizi Plateau of the Cassiar district, the Stikine River winds about 400 mi, draining a large glaciated area. The upper portion of the river runs through a semiarid plateau of up to 6,234 ft in elevation, while the lower portion of the river drains the Coast Mountains, a steep, rugged range characterized by high precipitation. Just above the community of Telegraph Creek, 200 mi downriver from the headwaters, the river flows through the Grand Canyon, where rapids block river vessel navigation as well as migrating salmon (AGS 1979).

As the river flows from the interior plateaus through the narrow valley of the Grand Canyon, the waters become muddy with glacial silt from the ice fields and glaciers flowing into the Stikine's many tributaries. In the last few decades, these glaciers have receded, resulting in important changes in vegetation, habitats and fauna. Alpine vegetation is found at the upper elevations, while the lower mountain slopes near salt water support a dense spruce-hemlock rainforest. Closer to the Canadian border, the rain decreases and the vegetation changes to stands of Sitka spruce, cottonwood, alder, Alaska cedar, white fir, and western hemlock. Cottonwood trees are also common on the many islands of the Stikine. The valley floor is a combination of muskegs and dense alder and willow thickets (AGS 1979).

The major tributaries of the Stikine include the Klappan, Chuckachida, Spatsizi, Pitman, Klastline, Tazilla, Tuya, Tahltan, Chutine, Choquette, and Iskut rivers, all in British Columbia. The main tributary, the Iskut River, joins the Stikine 7 mi upstream from the Alaska border and accounts for about 25% of the river's flow. One hot and 2 warm springs are found along the river (AGS 1979).

In its lower reaches, the river spreads out in a delta approximately 17 mi wide with 3 main navigation channels, numerous smaller shifting and shallow channels, grass flats, tidal marsh, and sand bars (USDA 2003b). The river delta is located in the Stikine-LeConte Wilderness Area within the USFS Tongass National Forest. The delta provides a resting place for more than half a million migrating birds each spring and fall, as well as ideal habitat for deer, black bears, wolves, river otters, mink and weasels, and, in the willow flats, moose. Mountain goats inhabit the higher elevations, and seals abound in the waters of the Stikine River delta (AGS 1979)

1990s Amphibian Sampling

Between 4 June and 30 August 1991, Dana Waters of California Cooperative Fishery Unit at Humboldt State University, conducted the first systematic herpetofaunal inventory of the Stikine and its associated wetland habitats. This major effort was the first to provide a solid baseline for many study sites on the portion of this river occurring in the United States, as well as nearby delta and coastal islands and watersheds. A total of 18,413 amphibian observations were made among 92 sites, 82% of which were of the Western Toad and 17% of which were of the Columbia Spotted Frog, leaving just 1% of the remaining observations to be divided between the Rough-skinned Newt and the Northwestern Salamander (Waters 1992).

Data from 86 of the sampled sites indicate that amphibians occur seasonally though out the Stikine River basin but are locally abundant in only a few areas, possibly due to the scarcity of breeding habitat – a critical limiting factor for amphibians in the region (Waters 1992). A phenological reconstruction borrowed from Waters (1992) is included as Table 4 of the Appendix. The study found that aquatic habitats, ranked from least to most suitable for amphibian breeding sites based on hydrologic-stability and water temperature were 1) the Stikine River proper 2) streams 3) backwater sloughs 4) mountain lakes 5) backwater lakes 6) beaver ponds 7) muskegs and 8) outwash ponds (Waters 1992). Amphibian breeding activity

appears to correlate with these rankings with no breeding activity observed in the most hydrologically active and coldest habitats (Waters 1992). With hydrologic stability comes a richness of aquatic vegetation, warmer temperatures and increased amphibian observations (Waters 1992).

Outwash ponds predominate in Mallard Slough, Cheliped Bay, and in the tidal flats of Sergief, Dry, and Farm Islands, and elsewhere along the coastline (Waters 1992). Few if any outwash ponds occur further up the river, indicating that amphibians are likely most abundant in downriver delta areas (Waters 1992). The availability of suitable wetlands farther upriver is variable, with clusters of breeding habitat distributed sparsely, causing the existence of pockets of substantial amphibian breeding populations (Waters 1992).

Waters (1992) suggested that future work concentrate on lentic habitats where aquatic plant diversity is greatest and the majority of amphibian observations were made, particularly outwash ponds, muskegs, beaver ponds, and backwater lakes. He reported on three notable range expansions as a result of this study including a Pacific Chorus Frog (*Pseudacris regilla*) near Ketchikan (not part of the Stikine), Columbia Spotted Frogs on Vank Island, and a Northwestern Salamander at Twin Lakes. The latter record is mentioned under the Northwestern Salamander section of this paper and was a partially destroyed egg mass found on land. The study also noted that Mallard Slough, Cheliped Bay, Crittenden Creek, Sergief Island, Dry Island, Twin Lakes, Andrews Creek, Hot Tubs Slough, Barnes Lake, and Red Slough were among the most highly productive areas for amphibians (Waters 1992). The author offered, "Barnes Lake represents the most difficult area to reach, but it is worth the time due to its productivity." Ream (unpublished data) also found these sites to be productive (having chosen many of them based on Waters' 1991 work), but has thus far been unable to access Andrews Creek or Barnes Lake.

Intercepting breeding on the Stikine can be difficult since the timing of ice break up and onset of spring is variable from year to year and by location, with sites farther up river retaining snow pack and wetland ice well after delta areas experience warm temperatures. This was experienced by Ream (unpublished data) when in 2012 breeding activity for several species was at its peak near the delta (tadpoles were already present at some locations) but upstream past the zone of tidal influence, amphibians remained in hibernation under several feet of snow, except at geothermal springs. Compounding the situation, low river levels in the early spring can prevent access to several shallow tributaries and sloughs (such as Andrew's Creek and Paradise Slough). Furthermore, sites within the zone of tidal influence are difficult to sample as one must be knowledgeable of tides and river levels, and it is often impossible to travel between sites until the subsequent high tide. The situation speaks to the utility of citizen science and Local and Traditional Knowledge (LTK), which can greatly expand the temporal and spatial scale of scientific observations (Ream unpublished data). According to Waters (1992) regarding his 1991 work:

"The project would have yielded more herpetofauna observations if the fieldwork had begun in April when amphibians were actively breeding. Data that are reported here are

biased in that they may give the possibly false impression that amphibians are scarce within the project area. Working in Alaska presents several limitations upon performing fieldwork within the Stikine River basin, such as foul weather during the early spring, and ice in the river. However, the Mallard Slough and Cheliped Bay areas are on the edge of the basin and are reachable throughout the spring. Fieldwork could begin there and progress upriver as conditions improve.”

Bradford Norman and Thomas Hassler (1995), also with the California Cooperative Fishery Unit of Humboldt State University, conducted extensive field surveys along the Stikine and nearby areas in 1992, “to augment work done by Waters during 1991... and independent investigation by B. Norman in 1991 (unpublished data).” This work provided critical additions to the Waters research and included a thorough review of previously published literature and museum collections. The survey was conducted at 285 transects throughout Southeast Alaska (predominantly in the Stikine region) between 28 March through 31 September 1992 (Norman and Hassler 1995). Most of the general areas visited by Waters in 1991 were revisited in 1992 with the exception of Crittenden Creek, the Alpine Lakes (Goat, Alpine, Government, and Andrews), Virginia Lake, and Paradise Creek (Norman and Hassler 1995).

Selected notes on the 1991 survey (Waters 1992) and the 1992 survey (Norman and Hassler 1995) for each species are provided here. Specific sites of identification are not included in this paper but will be reported in a subsequent publication that includes results from Ream’s most recent surveys, the data from which is currently pending publication, and its relationship to these past monitoring efforts. Until then, the original papers published by the authors can be used to obtain this information.

Western Toads

In 1991, toads were predominantly located at outwash ponds, a backwater slough, a backwater lake, and a beaver pond (Waters 1992). They breed in muskegs and were observed doing so in one such site on Wrangell Island, but none were observed doing so along the Stikine, “perhaps due to the small sample size” (Waters 1992). They were found to oviposition in May and early June, usually later in higher elevation and colder sites, and metamorphosis occurred in mid-July and proceeded through August (Waters 1992). The only eggmass actually observed was at Hot Tubs Slough on 4 June (Waters 1992). Norman and Hassler (1995) observed eggs at Hot Tubs Slough, Twin Lakes, Mitkof Island, Etolin Island, Onslow in 1992, as well as other life stages at other locations (31 of 285 transects) in the same year. Waters (1992) indicated that of the amphibians he observed, “the Western Toad demonstrated the most variability in habitat use and environmental tolerances.”

Interestingly, though the Western Toad was observed to have bred at a pond at Blind Slough on Mitkof Island both in 1991 and 1992, most of the 1992 eggs were unviable by the time they were discovered (Norman and Hassler 1995). In 1991 larvae were present at this location in July but few appeared to reach metamorphosis the following year (Norman and Hassler 1995). This site is known locally to have been incredible productive for Western Toads in past years, but

LTK and subsequent sampling in 2010 and 2012 failed to locate the species in the immediate area and suggests long-term declines (Ream unpublished data). Unlike most sites in these studies, Blind Slough is adjacent to the Mitkof highway and near the city of Petersburg.

Norman and Hassler (1995) identified a breeding site on Etolin Island where thousands of eggs and larvae were seen in April and May. The authors found few larvae, presumably due to predation pressure:

“At a later visit however, mallards *Anas platyrhynchos*, lesser yellowlegs *Tringa flavipes* and greater yellowlegs *Tringa melanolueca* were observed at the breeding site and only 11 larvae were observed from the entire perimeter of the breeding pond. At later visits, no larvae were observed at the site indicating that bird predation had resulted in virtually no reproductive success for toads at the site in 1992. Odonata (dragonfly) and water beetle larvae probably also had a smaller predatory impact on the larval toad population at the site.”

At another site on Etolin Island, Norman and Hassler observed a Red-tailed Hawk, *Buteo jamaicensis*, preying on and eviscerating two adult toads that they had recently been tagged and released. The hawk left the skin relatively intact, a method described in other studies (Corn 1993) as a means of avoiding the unpalatable and often toxic compounds secreted by amphibian skin. It is apparently a common practice of Ravens too (Norman and Hassler 1995), which are known to drop toads from the air and feed on their ejected viscera. Hodge (1976) reported that gulls prey on breeding toads too and sometimes hang them on tree branches, “similar to how shrikes *Lanius* spp. have been known to impale lizards for later use” (Norman and Hassler 1995).

Wood Frog

As suggested by Norman and Hassler (1995), though the Wood Frog is the most widely distributed frog in Alaska (Behler and King 1979, Stebbins 1985), it is known from fewer validated records and sites in southeast Alaska than the Columbia Spotted Frog. Waters (1992) found but one breeding site (Mallard Slough) for this species, though they were found in limited quantities at other locations (Waters 1992, Norman and Hassler 1995). He confirms that the distribution of Wood Frogs in the Stikine River basin remains unclear and that he was only able to locate them at Mallard Slough, Dry Island and Shakes Slough. Norman and Hassler (1995) found the species at the same locations but added Farm Island, Cheliped Bay and Little Dry Island to the list. Ream (unpublished data) recorded Wood Frogs at all of these sites in 2012 and/or 2013, except for Little Dry Island, which wasn't sampled extensively due to uncooperative tide schedules.

In 1992, individuals found at Farm Island and Little Dry Island represented previously unreported localities for the species (Norman and Hassler 1995). Both Wood Frogs and Columbia Spotted Frogs were reported by Stebbins (1951) as having been collected on Sergief Island by H.S. Swath and J. Dixon of the Museum of Vertebrate Zoology at Berkeley in 1919

(perhaps the oldest records of the species in the state). Interestingly, they have not been found there subsequently (Waters 1991, Norman and Hassler 1992, Ream unpublished data).

Columbia Spotted Frog

Waters (1992) found that Columbia Spotted Frogs were present throughout the study area. He suggested that they commenced breeding in April and continued through mid-May in 1991 and that metamorphosis began in late July and continued through August (Waters 1992). The frogs were always observed in close proximity to aquatic habitat and were present at one alpine lake (Government Lake). Norman and Hassler (1995) identified this species and breeding activity in 1992 at many sites including 56 of their 285 transects. They also reported several mortalities for the species at Chief Shakes Hot Springs where adults had apparently been crushed by skiffs of recreational users and at a small muskeg pool on northern Mitkof Island where Mallards were observed (Norman and Hassler 1995). While both of these surveys failed to identify this species on Wrangell Island, local knowledge has long suggested their presence there, and this was confirmed in 2012 from a photo taken at Muskeg Meadows Golf Course (Ream unpublished data).

Rough-skinned Newts

Newts were only observed at several of Waters' sites in 1991 including Government Lake, Twin Lakes, Andrews Creek, and Paradise Slough, but were also sighted at Sergief Island, Vank Island, Zarembo Island, Wrangell Island, Etolin Island and Mitkof Island (Waters 1992). The species is apparently widely distributed throughout the Stikine River basin and surrounding areas (Waters 1992). They were later found at Chief Shakes Hot Springs in 1992 (Norman and Hassler 1995) and again in 2013 (Ream unpublished data). None of these studies have located newts at Mallard Slough or Cheliped Bay. Norman and Hassler (1995) noted that the species was encountered less on the Stikine River than on the coastal islands. In 2012 and 2013 Ream identified a small geothermal spring near Twin Lakes with hundreds of adult breeding newts (Ream unpublished data).

Waters (1992) indicated that breeding for the species likely commenced in May of 1991 and continued into June. Eggs were not observed but are difficult to find given that they are laid singly among aquatic vegetation and each is about 8mm in diameter (Waters 1992). He observed amplexing pairs the last week of May on Wrangell Island and at Twin Lake the first week of June (Waters 1992). He also observed concentrations of newts at Government Lake (Waters 1992).

Northwest Salamanders

Waters observed the only record for this species in 1991, as discussed previously. Unfortunately no validating media was collected from the partially destroyed egg mass that Waters (1992) reported to contain approximately 150 eggs in a solid 3"X 5" globular mass, located at Twin Lakes on 12 June. According to Waters (1992):

“It was lying ashore next to a hot spring, apparently something had detached it from its submerged position, fragged it ashore, and had eaten part of the eggmass. We re-submerged the remaining eggs a short distance away. No specimen was collected. The embryos had reached stage 8-9... indicating it had recently been deposited, probably the first week of June.”

Neither the 1992 study or Ream’s 2012 and 2013 studies could locate another individual. Local knowledge suggests that the species may be present (Ream unpublished data), but apparently individuals are rarely seen. Confirmation has yet to be made.

Long-toed Salamanders

Long-toed Salamanders were not encountered in the Waters survey despite having been found previously at Twin Lakes by Parker Robert Hodge in July and August of 1973 (Norman 2004, Waters 1992, Hodge 1973). Waters (1992) noted the following:

“The nature of the salamander data could be construed as poor at best. This is probably due to their scarcity within the Stikine River basin. Hodge (1973) discovered the Long-toed Salamander at Twin Lakes, observing several in June-July. Specimens were brought from Mallard Slough in 1991 and showed to the author. We failed to observe any Long-toed Salamanders despite extensive surveys in Mallard Slough and elsewhere in the basin throughout the summer of 1991. This raises the possibility that Long-toed Salamanders have declined. Wrangell residents and long-employed USFS employees recall in the mid-1970s of seeing numerous amphibians at Twin Lakes, yet we only managed to observe a very limited number, possibly indicating that amphibian populations have been depressed.”

Both the 1991 and 1992 studies failed to relocate the species at Twin Lakes and suggested that they may have been extirpated from the area (Waters 1992, Norman and Hassler 1995). Subsequent research in 2012 and 2013 confirmed their presence nearby but not at the lakes proper (Ream unpublished data). Citizen scientists reported the species from the lakes in 2012 and apparently photographic evidence is pending (Ream unpublished data) suggesting that they were either missed in the other studies, or have since recolonized.

Norman and Hassler (1995) found this species at 13 of the 285 transects visited, including those at Sokolof Island, Andrews Slough, Cheliped Bay, Farm Island, Mallard Slough. All but Mallard Slough were new localities for the species (Norman and Hassler 1995) and the Sokolof Island record specifically “constitutes the southernmost and westernmost record for the species in Alaska and the first known insular record for the species outside of the state of Washington” (Norman and Hassler 1995). Ream (unpublished data) verified and collected a new locality record from Revillagigedo Island in 2010, again establishing the southernmost record. He also recorded new locality at Little Dry Island in 2012 and at Paradise Slough in 2013 (Ream unpublished data). A citizen scientist voucher photograph of an individual from Guerin Slough was verified in 2012 as well (Ream unpublished data). Ream also re-located the species at

Mallard Slough in both 2012 (adults and egg masses in early May) and in 2013 (adults only in late May) (Ream unpublished data).

CONCLUSION

There is clearly a lack of basic information for many of Alaska's amphibian populations. Limited funding and a lack of attention by state and federal agencies compound the situation. Still, the efforts of professional and amateur herpetologists have been crucial to our understanding of these species in the state over time. Until now, no comprehensive compilation of their herpetological research in Alaska existed. The results of many studies were only available in a multitude of disciplinary journals and publications, many of which were difficult to obtain. While this paper may not be exhaustive, it provides a novel means of acquiring Alaska's herpetological knowledge that was largely unavailable prior to its publication. It is the author's hope that the document will be useful to researchers and managers well into the future, perhaps assisting in the advancement of herpetology in the North.

With continued efforts by herpetological organizations such as the AAWG, AHS, and MSHS, herpetology in Alaska will hopefully continue to expand, gradually increasing the availability of knowledge necessary for proper management and conservation of these species. To conclude, the following recommendations and future goals may also support the discipline and its related taxa. Additionally, several more specific recommendations have been included throughout this paper.

- Research initiatives should focus on:
 - Clearly defining species diversity and ranges of herpetofauna in the state
 - Establishing baselines for population abundance and changes over time
 - Establishing appropriate ESUs and MUs
 - Population dynamics and the effects of changing climates and habitats
 - Role of disease among herpetiles in the state
 - Past, present, and future impacts of introduced species
- Increase research funding through federal grants, state appropriations, internal budget allocations and donations from private entities and individuals.
 - Specifically, ADF&G should pursue an annual competitive grant from the federal State Wildlife Grants Program, to address herpetofaunal population data needs. A similar grant was awarded to the Colorado Department of Natural Resources in 2013.
- State and federal agencies in Alaska, specifically ADF&G and the USFS, should partner to establish a long-term opportunistic amphibian monitoring program. Employees should be trained to:
 - report population characteristics
 - collect morphological measurements
 - collect non-lethal genetic samples

- collect chytrid fungus samples
 - properly disinfect field equipment
- The Alaska Department of Transportation (DOT) should limit the amount of salt and other compounds used on state roadways whenever possible. The DOT should conduct or fund studies to ascertain the impacts of current chemical application protocols.
- The state should seek to hire a full-time permanent Herpetologist at ADF&G to direct research, management and conservation efforts statewide.
- The state should consider creating a division or subdivision of ADF&G specifically committed to the study and management of non-game species. The resulting entity should receive a stable annual budget allocation and be tasked with long-term herpetofaunal monitoring.
- ADF&G should establish an efficient means of compiling and disseminating herpetological information. Fish Resource Permits (FRPs) already acquire significant quantities of information in annual permittee reports, but no system is in place to manage this information.
- ADF&G should formally recognize the ecological and cultural ecosystem services provided by amphibians, consequently enacting management plans to specifically address these taxa. Amphibians should be more widely utilized as bio-indicators in studies of ecosystem health and global change. Management of herpetofauna should be at least as intensive as management regimes in other states in the Pacific Northwest.
- The state legislator should redefine amphibians, removing their designation as “fish.” Many, if not most of the regulations developed for the protection of fish species are not applicable to herpetofauna.
- The Alaska Board of Fish and Board of Game should move to establish a “clean list” or a “prohibited list” to keep potentially harmful exotic species from entering the state by means of the pet trade. These lists should reflect those already established by other states in the Pacific Northwest.
- ADF&G should increase awareness of amphibians and reptiles through public education campaigns and citizen science initiatives.
- The University of Alaska system should offer periodic courses in Herpetology and hire directed staff committed to statewide herpetological research. In addition, students should be encouraged to undertake herpetofaunal research projects that enhance our understanding of related taxa in the state.

- AAWG, AHS, and MSHS should continue to expand their memberships and influence. The state should endorse and support their work when appropriate.

WORKS CITED

- Adams M. 1999. Correlated factors in amphibian decline: exotic species and habitat change in western Washington. *The Journal of Wildlife Management* 63: 1162-1171.
- Adams, M. J., et al. "Incidence of the fungus *Batrachochytrium dendrobatidis* in amphibian populations along the Northwest Coast of North America." *Herpetological Review* 38.4 (2007): 430.
- Adams, Susan B., David A. Schmetterling, and Michael K. Young. "Instream movements by boreal toads (*Bufo boreas boreas*)." *Herpetological Review* 36.1 (2005): 27-32.
- ADAMS MJ, GALVAN S, REINITZ D, COLE RA, PYARE S, HAHR M, GOVINDARAJULU P. 2007. Incidence of the fungus *Batrachochytrium dendrobatidis* in amphibian populations along the northwest coast of North America. *Herpetological Review* 38:430–431.
- Alaska Department of Fish and Game. (ADF&G). 2005. *Poisonous Newts Establish Beachhead on Baranof Newts Are Harmless - Just Don't Eat Them*. By Andrew Miller. *Alaska Fish and Game News*. Accessed 28 July 2013.
- Alaska Department of Fish and Game. (ADF&G). 2006. *Our Wealth Maintained: A Strategy for Conserving Alaska's Diverse Wildlife and Fish Resources*. xviii+824 p.
- Alaska Department of Fish and Game (2007) Management plan for invasive northern pike in Alaska. South-central Alaska Northern Pike Control Committee, Anchorage.
- Alaska Department of Fish and Game (ADF&G). *Turtle*. By Robert P. Hodge and Mary Rabe. N.p., 2008. Web. 1 Aug. 2013. <<http://www.adfg.alaska.gov/static/education/wns/turtles.pdf>>.
- Alaska Department of Fish and Game. (ADF&G). 2011. *Tropical Turtle Strays North to Alaska*. By Riley Woodford. *Alaska Fish and Game News*. Accessed 1 August 2013.
- Alaska Department of Fish and Game (ADF&G). Division of Wildlife Conservation. *FY12 Expenditure Report*. N.p., 2013. Web. 17 Aug. 2013. <http://www.adfg.alaska.gov/static/home/about/pdfs/wc_fy12_expenditures.pdf>.
- Alaska Geological Society (AGS). 1979. *The Stikine River*. Edmonds, WA.
- Alford, R.A.; Wilbur, H.M. Priority effects in experimental pond communities: competition between *Bufo* and *Rana*. *Ecology* 1985, 66, 1097-1105.
- Alford, R.A. Variation in predator phenology affects predator performance and prey community composition. *Ecology* 1989, 70, 206-219.
- Alford, R. A. "Ecology: resource use, competition, and predation." *Tadpoles: the biology of anuran larvae* (1999): 240-278.
- Alford, Ross A., and Stephen J. Richards. "Global amphibian declines: a problem in applied ecology." *Annual review of Ecology and Systematics* (1999): 133-165.
- Allan, R. P. & Soden, B. J. 2008 Atmospheric warming and the amplification of precipitation extremes. *Science* 321, 1481–1484.
- Allendorf, Fred W., and Robb F. Leary. "Heterozygosity and fitness in natural populations of animals." *Conservation biology: the science of scarcity and diversity* (1986): 57-76.

Alt D, Hyndman D (1995) Northwest Exposures: A Geological Story of the North West. Mountain Press Publishing Company, Missoula, Montana

Altig, R.; Whiles, M.R.; Taylor, C.L. What do tadpoles really eat? Assessing the trophic status of an understudied and imperiled group of consumers in freshwater habitats. *Freshwater Biol.* 2007, 52, 386-395.

Anderson, Blain. "Glacier Toads and Frozen Frogs: Alaska's Surprising Amphibian Diversity."

Anderson, Blain C. *An Opportunistic Amphibian Inventory in Alaska's National Parks, 2001-2003: Final Report*. National Park Service, Inventory & Monitoring Program, Alaska Region, 2004.

Anderson J, Graham R (1967) Vertical migration and stratification of larval *Ambystoma*. *Copeia* 1967: 371-374

Anderson, James D. "Reactions of the western mole to skin secretions of *Ambystoma macrodactylum croceum*." *Herpetologica* 19.4 (1964): 282-284.

Anderson, James D. "A comparison of the life histories of coastal and montane populations of *Ambystoma macrodactylum* in California." *American Midland Naturalist* (1967): 323-355.

Anderson, James D. "A comparison of the food habits of *Ambystoma macrodactylum sigillatum*, *Ambystoma macrodactylum croceum*, and *Ambystoma tigrinum californiense*." *Herpetologica* 24.4 (1968): 273-284.

Anisimov, O. A., D. G. Vaughan, T. V. Callaghan, C. Furgal, H. Marchant, T. D. Prowse, H. Vilhjálmsson, and J. E. Walsh. 2007. Polar regions (Arctic and Antarctic). Pages 653–685 in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

APPONYI, M. A., et al. 2004. Host-defense peptides of Australian anurans: structure, mechanism of action and evolutionary significance. *Peptides* 25: 1035–1054.

Araújo, M. B.; Thuiller, W.; Pearson, R.G. Climate warming and the decline of amphibians and reptiles in Europe. *J. Biogeogr.* 2006, 33, 1712-1728.

Arft, A. M., et al. "Responses of tundra plants to experimental warming: meta-analysis of the international tundra experiment." *Ecological monographs* 69.4 (1999): 491-511.

Ashley, E. Paul, and Jeffrey T. Robinson. "Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario." *Canadian Field Naturalist* 110.3 (1996): 403-412.

Associated Press. "Sea Turtle Rare Sight for Alaska." *The Register-Guard* [Eugene, Oregon] 19 Oct. 1996: 3A. Print.

Awbrey, F.T. 19972. Mating call of a *Bufo boreas* male. *Copeia* 579-581.

Bacon, Jamie P., Jennifer A. Gray, and Lisa Kitson. "Status and conservation of the reptiles and amphibians of the Bermuda islands." *Applied Herpetology* 3.4 (2006): 323-344.

Baldwin, Robert F., Aram JK Calhoun, and Phillip G. deMaynadier. "Conservation planning for amphibian species with complex habitat requirements: a case study using movements and habitat selection of the wood frog *Rana sylvatica*." *Journal of Herpetology* 40.4 (2006): 442-453.

Bane, Gil. "First Report of a Loggerhead Sea Turtle From Alaska." *Marine Turtle Newsletter* 58 (1992): 1-2. Turtle Island Restoration Network. Web. 1 Aug. 2013. <<http://www.seaturtle.org/mtn/archives/mtn58/mtn58p1.shtml>>.

- Barnosky, Cathy W., Patricia M. Anderson, and Patrick J. Bartlein. "The northwestern US during deglaciation; vegetational history and paleoclimatic implications." *North America and adjacent oceans during the last deglaciation* 3 (1987): 289-321.
- Barrett, Tara M., et al. "Host–parasite distributions under changing climate: *Tsuga heterophylla* and *Arceuthobium tsugense* in Alaska." *Canadian Journal of Forest Research* 42.4 (2012): 642-656.
- Barrie, Vaughn J., et al. "Submerged Late Quaternary terrestrial deposits and paleoenvironment of northern Hecate Strait, British Columbia continental shelf, Canada." *Quaternary International* 20 (1993): 123-129.
- Barrie, J. Vaughn, and Kim W. Conway. "Late Quaternary glaciation and postglacial stratigraphy of the northern Pacific margin of Canada." *Quaternary Research* 51.2 (1999): 113-123.
- Bartelt, Paul E., Charles R. Peterson, and Robert W. Klaver. "Sexual differences in the post-breeding movements and habitats selected by western toads (*Bufo boreas*) in southeastern Idaho." *Journal Information* 60.4 (2004).
- Bartelt, Paul E., and Charles R. Peterson. "Physically modeling operative temperatures and evaporation rates in amphibians." *Journal of Thermal Biology* 30.2 (2005): 93-102.
- Bean, T.H. 1882. Notes on a collection of fishes made by Captain Henry E. Nichols, U.S.N., in British Columbia and southern Alaska, with descriptions of new species and a new genus (*Delolepis*). Proceedings of the U.S. National Museum, Vol. IV for 1881. Washington, D.C.: Smithsonian Institution.
- Bean, T.H. 1884. Notes on a collection of fishes made in 1882 and 1883 by Captain Henry E. Nichols, U.S.N., in Alaska and British Columbia, with a description of a new genus and species *Prionistius macellus*. Proceedings of u.s. National Museum, Vol. VI, No. 23, Washington, D.C. for year 1883.
- Beaudoin, Catherine P., et al. "Individual specialization and trophic adaptability of northern pike (*Esox lucius*): an isotope and dietary analysis." *Oecologia* 120.3 (1999): 386-396.
- Beebee, T.J.C. Amphibian breeding and climate. *Nature* 1995, 374, 219-220.
- Beebee, T. J. C. 2002 Amphibian phenology and climate change. *Conserv. Biol.* 16, 1454.
- Behler, J. and F. King. 1979. The Audubon Society field guide to North American reptiles and amphibians. New York: Alfred A. Knopf.
- Bellis, Edward D. "Home range and movements of the wood frog in a northern bog." *Ecology* (1965): 90-98.
- Beneski J, Zalisko E, Larsen J (1986) Demography and migratory patterns of the eastern long-toed salamander, *Ambystoma macrodactylum columbianum*. *Copeia* 1986: 398-408
- Berg, Edward E., et al. "Recent woody invasion of wetlands on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18 000 years of wet Sphagnum-sedge peat recruitment." *Canadian Journal of Forest Research* 39.11 (2009): 2033-2046.
- Berger, Lee, et al. "Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America." *Proceedings of the National Academy of Sciences* 95.15 (1998): 9031-9036.
- Berger, L., Speare, R., Hines, H.B., Marantelli, G., Hyatt, A.D., McDonald, K.R., Skerratt, L.F., Olsen, V., Clarke, J.M., Gillespie, G., Mahony, M., Sheppard, N., Williams, C. & Tyler, M.J. (2004) Effect of season and temperature on mortality in amphibians due to chytridiomycosis. *Australian Veterinary Journal*, 82, 434–439.

Berger, Lee, Rick Speare, and Lee F. Skerratt. "Distribution of Batrachochytrium dendrobatidis and pathology in the skin of green tree frogs *Litoria caerulea* with severe chytridiomycosis." *Diseases of aquatic organisms* 68.1 (2005): 65-70.

Bernardo, J.; Spotila, J.R. Physiological constraints on organismal response to global warming: mechanistic insights from clinally varying populations and implications for assessing endangerment. *Biol. Lett.* 2006, 2,135-139.

Berven, Keith A., and Thaddeus A. Grudzien. "Dispersal in the wood frog (*Rana sylvatica*): implications for genetic population structure." *Evolution* (1990): 2047-2056.

Biek, Roman, et al. "What is missing in amphibian decline research: insights from ecological sensitivity analysis." *Conservation Biology* 16.3 (2002): 728-734.

Bielby, J.; Cooper, N.; Cunningham, A.A.; Garner, T.W.J.; Purvis, A. Predicting susceptibility to rapid declines in the world's frogs. *Conserv. Lett.* 2008, 1, 82-90.

Blaustein, Andrew R., David B. Wake, and Wayne P. Sousa. "Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions." *Conservation Biology* 8.1 (1994): 60-71.

Blaustein, Leon, Burt P. Kotler, and David Ward. "Direct and indirect effects of a predatory backswimmer (*Notonecta maculata*) on community structure of desert temporary pools." *Ecological Entomology* 20.4 (1995): 311-318.

Blaustein, Leon, and Joel Margalit. "Priority effects in temporary pools: nature and outcome of mosquito larva-toad tadpole interactions depend on order of entrance." *Journal of Animal Ecology* (1996): 77-84.

Blaustein, A.R.; Belden, L.K.; Olson, D.H.; Green, D.L.; Root, T.L.; Kiesecker, K.M. Amphibian breeding and climate change. *Conserv. Biol.* 2001, 15, 1804-1809.

Blaustein, A.R.; Johnson, P.T.J. Prevalence, causes, and implications of amphibian deformities. *Front. Ecol. Environ.* 2003, 1, 87-94.

Blaustein, A.R., Walls, S.C., Bancroft, B.A., Lawler, J.J., Searle, C.L. & Gervasi, S.S. (2010) Direct and indirect effects of climate change on amphibian populations. *Diversity*, 2, 281–313.

Blihovde, W. Boyd. "Terrestrial movements and upland habitat use of Gopher Frogs in central Florida." *Southeastern Naturalist* 5.2 (2006): 265-276.

Blomquist, Sean M., and Malcolm L. Hunter Jr. "A multi-scale assessment of amphibian habitat selection: wood frog response to timber harvesting." *Ecoscience* 17.3 (2010): 251-264.

Boone, M. D., Scott, D. E. & Niewiarowski, P. H. 2002 Effects of hatching time for larval ambystomatid salamanders. *Copeia* 2002, 511–517.

Bornhold, Brian D., and J. Vaughn Barrie. "Surficial sediments on the western Canadian continental shelf." *Continental Shelf Research* 11.8 (1991): 685-699.

Bos, David H., and Jack W. Sites. "Phylogeography and conservation genetics of the Columbia spotted frog (*Rana luteiventris*; Amphibia, Ranidae)." *Molecular Ecology* 10.6 (2001): 1499-1513.

Bosch, Jaime, Iñigo Martínez-Solano, and Mario García-París. "Evidence of a chytrid fungus infection involved in the decline of the common midwife toad (*Alytes obstetricans*) in protected areas of central Spain." *Biological conservation* 97.3 (2001): 331-337.

Bosch, Jaime, et al. "Climate change and outbreaks of amphibian chytridiomycosis in a montane area of Central Spain; is there a link?." *Proceedings of the Royal Society B: Biological Sciences* 274.1607 (2007): 253-260.

Bradley Shaffer, H., et al. "Species boundaries, phylogeography and conservation genetics of the red-legged frog (*Rana aurora/draytonii*) complex." *Molecular Ecology* 13.9 (2004): 2667-2677.

Breckenridge, Walter J., and John R. Tester. "Growth, local movements and hibernation of the Manitoba toad, *Bufo hemiophrys*." *Ecology* 42.4 (1961): 637-646.

Brehaut, Lucas. *Local and Landscape-scale Variables Influencing the use of Ponds by Wood Frogs (*Lithobates sylvaticus*) in the Shikwuk Valley, Yukon*. Diss. Queen's University, 2012.

Bradley Shaffer, H., et al. "Species boundaries, phylogeography and conservation genetics of the red-legged frog (*Rana aurora/draytonii*) complex." *Molecular Ecology* 13.9 (2004): 2667-2677.

Brodie III, Edmund D., and Edmund D. Brodie Jr. "Tetrodotoxin resistance in garter snakes: an evolutionary response of predators to dangerous prey." *Evolution* (1990): 651-659.

Brodie Jr, Edmund D. "Investigations on the skin toxin of the adult rough-skinned newt, *Taricha granulosa*." *Copeia* (1968): 307-313.

Brodie Jr, Edmund D., and Linda S. Gibson. "Defensive behavior and skin glands of the northwestern salamander, *Ambystoma gracile*." *Herpetologica* (1969): 187-194.

Brodie Jr, Edmund D., John L. Hensel Jr, and Judith A. Johnson. "Toxicity of the urodele amphibians *Taricha*, *Notophthalmus*, *Cynops* and *Paramesotriton* (salamandridae)." *Copeia* (1974): 506-511.

Brodie Jr, Edmund D., Robert T. Nowak, and William R. Harvey. "The effectiveness of antipredator secretions and behavior of selected salamanders against shrews." *Copeia* (1979): 270-274.

Brodie Jr, Edmund D. "Antipredator adaptations of salamanders: evolution and convergence among terrestrial species." *Adaptations to Terrestrial Environments*. Springer US, 1983. 109-133.

Brodie, Edmund D., B. J. Ridenhour, and E. D. Brodie. "The evolutionary response of predators to dangerous prey: hotspots and coldspots in the geographic mosaic of coevolution between garter snakes and newts." *Evolution* 56.10 (2002): 2067-2082.

Brodman, R., et al. "Mosquito control by pond-breeding salamander larvae." *Herpetological Review* 34.2 (2003): 116-118.

Brodman, Robert, and Ryan Dorton. "The effectiveness of pond-breeding salamanders as agents of larval mosquito control." *Journal of Freshwater Ecology* 21.3 (2006): 467-474.

Brodman, R., et al. "Amphibian biodiversity recovery in a large-scale ecosystem restoration." *Herpetological Conservation and Biology* 1.2 (2006): 101-108.

Brodman, R. "A 14-year study of amphibian populations and metacommunities." *Herpetological Conservation and Biology* 4.1 (2009): 106-119.

Brooks T, Mittermeier R, Mittermeier C, Da Fonseca G, Rylands A, Konstant W, Flick P, Pilgrim J, Oldfield S, Magin G. 2002. Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* 16: 909-923.

Browne, CONSTANCE L., and CYNTHIA A. Paszkowski. "Hibernation sites of western toads (*Anaxyrus boreas*): Characterization and management implications." *Herpetological Conservation and Biology* 5.1 (2010): 49-63.

Brown, Herbert A. "Embryonic temperature adaptations and genetic compatibility in two allopatric populations of the spadefoot toad, *Scaphiopus hammondi*." *Evolution* (1967): 742-761.

Brown, Herbert A. "The time-temperature relation of embryonic development in the northwestern salamander, *Ambystoma gracile*." *Canadian Journal of Zoology* 54.4 (1976): 552-558.

Brunsfeld, S. J., et al. "Comparative phylogeography of northwestern North America: a synthesis." *SPECIAL PUBLICATION-BRITISH ECOLOGICAL SOCIETY* 14 (2001): 319-340.

Brylinsky, M., and K_H Mann. *An analysis of factors governing productivity in lakes and reservoirs*. American Society of Limnology and Oceanography., 1973.

Bryson, George. "The Price of Fighting Roadway Ice." *Anchorage Daily News*. N.p., 28 Nov. 2008. Web. 15 May 2013.

Bull, Evelyn L., and Marc P. Hayes. "Post-breeding season movements of Columbia spotted frogs (*Rana luteiventris*) in northeastern Oregon." *Western North American Naturalist* 61.1 (2001): 119-123.

BULL, Evelyn L. "Influence of fish and habitat on amphibian communities in high elevation lakes in northeastern Oregon." *Northwest Science* 76.3 (2002): 240-248.

Bull, Evelyn L. "Sexual differences in the ecology and habitat selection of Western Toads (*Bufo boreas*) in northeastern Oregon." *Herpetological Conservation and Biology* 1.1 (2006): 27-38.

Bull, Evelyn L., and Jay F. Shepherd. "Water temperature at oviposition sites of *Rana luteiventris* in northeastern Oregon." *Western North American Naturalist* 63.1 (2009): 108-113.

Burdon, J.; Elmqvist, T. Selective sieves in the epidemiology of *Melampsora lini*. *Plant Pathol.* 1996, 45, 933-943.

Burke, R. M., and P. W. Birkeland. "Holocene glaciation in the mountain ranges of the western United States." *Late-Quaternary Environments of the United States* 2 (1983): 3-11.

Bury, R. and P. Corn. 1991. Sampling methods for amphibians instreams in the Pacific Northwest. u.s. Forest Service, General Technical Report PNWGTR-275.

Bury, B.R. and Major D.J. 1997. Integrated Sampling for Amphibian Communities in Montane Habitats. in Sampling Amphibians in Lentic Habitats. Northwest Fauna Number 4:75-82.

Bury R. 2006. Natural history, field ecology, conservation biology, and wildlife management: Time to connect the dots. *Herpetological Conservation and Biology* 1: 56-61.

CALDWELL, IANALEE P., LJ VITT, and J. W. Gibbons. "Declining amphibian populations: the problem of separating human impacts from natural fluctuations." *Science* 253 (1991): 892-895.

Calhoun, Aram JK, Nicholas A. Miller, and Michael W. Klemens. "Conserving pool-breeding amphibians in human-dominated landscapes through local implementation of Best Development Practices." *Wetlands Ecology and Management* 13.3 (2005): 291-304.

CALIFORNIA DEPARTMENT OF FISH AND GAME. 1994. Amphibian and Reptile Species of Special Concern in California, Northern Red-legged Frog. California Department of Fish and Game. Rancho Cordova, CA.

Camp, Charles Lewis. *Notes on the systematic status of the toads and frogs of California*. University of California Press, 1917.

Campbell, James B. "Hibernacula of a population of *Bufo boreas boreas* in the Colorado Front Range." *Herpetologica* (1970): 278-282.

Cardall, Brian L., et al. "Secretion and regeneration of tetrodotoxin in the rough-skin newt (*Taricha granulosa*)."

Toxicon 44.8 (2004): 933-938.

Carey, Cynthia. "Factors affecting body temperatures of toads." *Oecologia* 35.2 (1978): 197-219.

Carey, Cynthia, Nicholas Cohen, and Louise Rollins-Smith. "Amphibian declines: an immunological perspective." *Developmental & Comparative Immunology* 23.6 (1999): 459-472.

Carey, C., et al. "Factors limiting the recovery of boreal toads (*Bufo b. boreas*)."

Amphibian declines: the conservation status of United States species (2005): 222-236.

Carl, G. Clifford, and Ian McTaggart Cowan. "Notes on some frogs and toads of British Columbia." *Copeia* 1945.1 (1945): 52-53.

Carpenter, Charles C. "Aposematic behavior in the salamander *Ambystoma tigrinum melanostictum*."

Copeia 1955.4 (1955): 311-311.

Carrara, P. E., T. A. Ager, and J. F. Baichtal. "Possible refugia in the Alexander Archipelago of southeastern Alaska during the late Wisconsin glaciation." *Canadian Journal of Earth Sciences* 44.2 (2007): 229-244.

Carstens, Bryan C., et al. "INVESTIGATING THE EVOLUTIONARY HISTORY OF THE PACIFIC NORTHWEST MESIC FOREST ECOSYSTEM: HYPOTHESIS TESTING WITHIN A COMPARATIVE PHYLOGEOGRAPHIC FRAMEWORK." *Evolution* 59.8 (2005): 1639-1652.

Carstens, Bryan C., and Corinne L. Richards. "Integrating coalescent and ecological niche modeling in comparative phylogeography." *Evolution* 61.6 (2007): 1439-1454.

Carstensen, R., M. Willson, and R. Armstrong. "Habitat use of amphibians in northern southeast Alaska." *Unpublished report to Alaska Department of Fish and Game. Juneau, AK* (2003).

Chan-McLeod, Ann C. Allay. "Factors affecting the permeability of clearcuts to red-legged frogs." *The Journal of wildlife management* (2003): 663-671.

Chandler, Asa Crawford. "The western newt or water-dog (*Notophthalmus torosus*): a natural enemy of mosquitoes." (1918).

Chapin III, F. Stuart, et al. "Responses of arctic tundra to experimental and observed changes in climate." *Ecology* 76.3 (1995): 694-711.

Chase, B. 1992a. Frog new to Alaska, discovered. Ketchikan Daily News 57(136):l.

Chase, B. 1992b. Frogs not so new after all. Ketchikan Daily News 57(137):l.

Chase, B. 1992c. Nothing to croak about. Alaska Magazine 58(10):15.

Christensen, Jens Hesselbjerg, et al. "Regional climate projections." *Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press, Cambridge, Chapter 11* (2007): 847-940.

Church, Don R., et al. "Iteroparity in the variable environment of the salamander *Ambystoma tigrinum*." *Ecology* 88.4 (2007): 891-903.

Clague J, James T (2002) History and isostatic effects of the last ice sheet in southern British Columbia. *Quaternary Science Reviews* 21: 71–87

Clark, Peter U., et al. "The last glacial maximum." *science* 325.5941 (2009): 710-714.

Clarke, Barry T. "The natural history of amphibian skin secretions, their normal functioning and potential medical applications." *Biological Reviews* 72.3 (1997): 365-379.

Conant, Roger, and Joseph T. Collins. *Field guide to reptiles and amphibians*. Vol. 12. Houghton Mifflin Harcourt, 1998.

Constible, J. M., P. T. Gregory, and K. W. Larsen. "The pitfalls of extrapolation in conservation: movements and habitat use of a threatened toad are different in the boreal forest." *Animal Conservation* 13.1 (2010): 43-52.

Converse, KATHRYN A., J. A. M. E. S. Mattsson, and L. A. U. R. A. Eaton-Poole. "Field surveys of midwestern and northeastern Fish and Wildlife Service lands for the presence of abnormal frogs and toads." *JOURNAL-IOWA ACADEMY OF SCIENCE* 107.3/4 (2000): 160-167.

Cook, F.R. 1977. Records of the Boreal Toad from the Yukon and northern British Columbia. *Canadian Field-Naturalist* 91:185–186.

Cope, E. 1889. The Batrachia of North America. *Bulletin of the United States National Museum* 34:1-525.

Corkran, Charlotte C., and Chris Thoms. *Amphibians of Oregon, Washington and British Columbia: A field identification guide*. Lone Pine Pub, 2006.

Costanza, Robert, et al. "The value of the world's ecosystem services and natural capital." *nature* 387.6630 (1997): 253-260.

Corn, P.S. 1993. Life history note on *Bufo boreas* (Boreal toad predation). *SSAR Herpetological Review* 24(2):57.

Corn, P. S. 2003 Amphibian breeding and climate change: importance of snow in the mountains. *Conserv. Biol.* 17, 622–625.

Corn, P.S. (2005) Climate change and amphibians. *Animal Biodiversity and Conservation*, 28, 59–67.

COSEWIC. 2002. COSEWIC Assessment and Status Report on the Red-Legged Frog, *Rana aurora*. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario, Canada

Crandall, Keith A., et al. "Considering evolutionary processes in conservation biology." *Trends in ecology & evolution* 15.7 (2000): 290-295.

Crozier, Lisa. "Warmer winters drive butterfly range expansion by increasing survivorship." *Ecology* 85.1 (2004): 231-241.

Cushman, K.A. & Pearl, C.A. (2007) A Conservation Assessment for the Oregon Spotted Frog (*Rana pretiosa*). 46 pp. USDA Forest Service, Region 6, and Oregon BLM, Special Status Species Program. Available at: <http://www.fs.fed.us/r6/sfpnw/issssp/planning-documents/assessments.shtml>.

DA SILVA, MARIA NAZARETH F., and JAMES L. PATTON. "Molecular phylogeography and the evolution and conservation of Amazonian mammals." *Molecular Ecology* 7.4 (1998): 475-486.

Dale, P. E. R., and J. M. Knight. "Wetlands and mosquitoes: a review." *Wetlands Ecology and Management* 16.4 (2008): 255-276.

Daly, John W., Charles W. Myers, and Noel Whittaker. "Further classification of skin alkaloids from neotropical poison frogs (Dendrobatidae), with a general survey of toxic/noxious substances in the amphibia." *Toxicon* 25.10 (1987): 1023-1095.

Daly, John W. "The chemistry of poisons in amphibian skin." *Proceedings of the National Academy of Sciences* 92.1 (1995): 9-13.

Daly, John William. "Thirty years of discovering arthropod alkaloids in amphibian skin." *Journal of natural products* 61.1 (1998): 162-172.

Daszak, P.A.; Cunningham, A.; Hyatt, A.D. Infectious disease and amphibian population declines. *Divers. Distrib.* 2003, 9, 141-150.

Daszak, P., et al. "Amphibian population declines at Savannah River site are linked to climate, not chytridiomycosis." *Ecology* 86.12 (2005): 3232-3237.

Davidson, C.; Shaffer, H.B.; Jennings, M.R. Declines of the California red-legged frog: Climate, UV-B, habitat, and pesticides hypotheses. *Ecol. App.* 2001, 11, 464-479.

Davidson, C.; Knapp, R. Multiple stressors and amphibian declines: dual impacts of pesticides and fish on yellow-legged frogs. *Ecol. App.* 2007, 17, 587-597.

Davis, T. M. "Research priorities for the management of the western toad, *Bufo boreas*." *British Columbia. British Columbia Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria. Wildlife Working Report WR-106. Victoria, BC, Canada* (2002).

Deguisse, Isabelle, and John S. Richardson. "Movement behaviour of adult western toads in a fragmented, forest landscape." *Canadian Journal of Zoology* 87.12 (2009): 1184-1194.

(b) Deguisse, Isabelle, and John S. Richardson. "Prevalence of the chytrid fungus (*Batrachochytrium dendrobatidis*) in Western Toads in southwestern British Columbia, Canada." *Northwestern Naturalist* 90.1 (2009): 35-38.

Demas, Gregory E. "The energetics of immunity: a neuroendocrine link between energy balance and immune function." *Hormones and Behavior* 45.3 (2004): 173-180.

DeMaynadier, Phillip G., and Malcolm L. Hunter Jr. "The relationship between forest management and amphibian ecology: a review of the North American literature." *Environmental Reviews* 3.3-4 (1995): 230-261.

Demaynadier, Phillip G., and Malcolm L. Hunter. "Effects of silvicultural edges on the distribution and abundance of amphibians in Maine." *Conservation Biology* 12.2 (1998): 340-352.

DeMaynadier, Phillip G., and Malcolm L. Hunter Jr. "Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine." *The Journal of wildlife management* (1999): 441-450.

Demboski, John R., Karen D. Stone, and Joseph A. Cook. "Further perspectives on the Haida Gwaii glacial refugium." *Evolution* 53.6 (1999): 2008-2012.

DeWeerd, Sarah. "What really is an evolutionarily significant unit? The debate over integrating genetics and ecology in conservation biology." *Conservation in Practice* 3.1 (2002): 10-19.

Dixon, E. James, et al. "Late Quaternary regional geoarchaeology of southeast Alaska karst: a progress report." *Geoarchaeology* 12.6 (1997): 689-712.

Dodd, C.K., Jr. Cost of living in an unpredictable environment: the ecology of striped newts *Notophthalmus perstriatus* during a prolonged drought. *Copeia* 1993, 1, 605-614.

Dolby, Andrew S., and Thomas C. Grubb Jr. "Effects of winter weather on horizontal and vertical use of isolated forest fragments by bark-foraging birds." *Condor* (1999): 408-412.

Donald, David B., et al. "Winter snowfall determines the occupancy of northern prairie wetlands by tadpoles of the Wood Frog (*Lithobates sylvaticus*)." *Canadian Journal of Zoology* 89.11 (2011): 1063-1073.

Donnelly, M.A.; Crump, M.L. Potential effects of climate change on two Neotropical amphibian assemblages. *Clim. Change* 1998, 39, 541-561.

Dougherty, Christopher K., and Geoffrey R. Smith. "Acute effects of road de-icers on the tadpoles of three anurans." *Applied Herpetology* 3.2 (2006): 87-93.

Dowling, Herndon G. "Geographic relations of Ozarkian amphibians and reptiles." *The Southwestern Naturalist* (1956): 174-189.

Duellman, W.E.; Trueb, L. *Biology of Amphibians*; Johns Hopkins University Press: Baltimore, MD, USA, 1986.

Duellman, William E., and Linda Trueb. *Biology of amphibians*. Johns Hopkins University Press, 1994.

Duellman, William E., and SAMUEL S. Sweet. "Distribution patterns of amphibians in the Nearctic region of North America." *Patterns of distribution of amphibians. Johns Hopkins Univ. Press, Baltimore, MD* (1999): 31-109.

Duffy, W. G. "Population dynamics, production, and prey consumption of fathead minnows (*Pimephales promelas*) in prairie wetlands: a bioenergetics approach." *Canadian Journal of Fisheries and Aquatic Sciences* 55.1 (1998): 15-27.

Duffy, David Cameron, et al. "Landscape assessment of the degree of protection of Alaska's terrestrial biodiversity." *Conservation Biology* 13.6 (1999): 1332-1343.

Dunson W, Wyman R, Corbett E. 1992. A symposium on amphibian declines and habitat acidification. *Journal of Herpetology* 26: 349-352.

Durand, J. R., et al. "Environmental heterogeneity and community structure of the Kobuk River, Alaska, in response to climate change." *Ecosphere* 2.4 (2011): 44.

DuRant, Sarah E., and William A. Hopkins. "Amphibian predation on larval mosquitoes." *Canadian Journal of Zoology* 86.10 (2008): 1159-1164.

Dwyer, G.; Elkinton, J.S. Using simple models to predict virus epizootics in gypsy moth populations. *J. Anim. Ecol.* 1993, 62, 1-11.

Dynesius, Mats, and Roland Jansson. "Evolutionary consequences of changes in species' geographical distributions driven by Milankovitch climate oscillations." *Proceedings of the National Academy of Sciences* 97.16 (2000): 9115-9120.

Eagleson, Gerald W. "A comparison of the life histories and growth patterns of populations of the salamander *Ambystoma gracile* (Baird) from permanent low-altitude and montane lakes." *Canadian Journal of Zoology* 54.12 (1976): 2098-2111.

Easterling, David R., et al. "Climate extremes: observations, modeling, and impacts." *Science* 289.5487 (2000): 2068-2074.

Eaton, Brian R., et al. "Deformity levels in wild populations of the wood frog (*Rana sylvatica*) in three ecoregions of western Canada." *Journal of Herpetology* 38.2 (2004): 283-287.

Edgehouse, Michael J. *Garter snake (Thamnophis) natural history: food habits and interspecific aggression*. ProQuest, 2008.

Efford, Ian E., and Jack A. Mathias. "A comparison of two salamander populations in Marion Lake, British Columbia." *Copeia* (1969): 723-736.

Egan, Robert S., and Peter WC Paton. "Within-pond parameters affecting oviposition by wood frogs and spotted salamanders." *Wetlands* 24.1 (2004): 1-13.

Eigenbrod, Felix, Stephen J. Hecnar, and Lenore Fahrig. "The relative effects of road traffic and forest cover on anuran populations." *Biological conservation* 141.1 (2008): 35-46.

Eklöv, Peter, and Stellan F. Hamrin. "Predatory efficiency and prey selection: interactions between pike *Esox lucius*, perch *Perca fluviatilis* and rudd *Scardinius erythrophthalmus*." *Oikos* (1989): 149-156.

Elzinga, Caryl L., et al. *Monitoring plant and animal populations: a handbook for field biologists*. Wiley-Blackwell, 2009.

Environment Canada, 2001. Canadian Environmental Protection Act, 1999: Priority Substance List Assessment Report on Road Salts. Environment Canada, Hull, Quebec.

Executive Order 13112. 1999. Federal Register / Vol. 64, No. 25 / Monday, February 8, 1999. Fahrig, Lenore, et al. "Effect of road traffic on amphibian density." *Biological Conservation* 73.3 (1995): 177-182.

Eschscholtz, F. 1833. Zoologischer Atlas, enthaltend Abbildungen und Beschreibungen neuer Thierarten während des Flottcapitains von Kotzebue zweiter Reise um die Welt: auf-der-Russisch-Kaiserlichen Kriegsschlupp *Predpriaetie* in den Jahren 1823-1826. Berlin, part V. vii + 28 pp. plates XXI-XXII.

Fay, Virginia. *Alaska aquatic nuisance species management plan*. Alaska Department of Fish and Game, 2002.

Feldman, Chris R., Edmund D. Brodie, and Michael E. Pfrender. "The evolutionary origins of beneficial alleles during the repeated adaptation of garter snakes to deadly prey." *Proceedings of the National Academy of Sciences* 106.32 (2009): 13415-13420.

Fellers, G.M. and Kleeman, P.M. 2006. Diurnal versus Nocturnal Surveys for California Red-Legged Frogs. *Journal of Wildlife Management* 70(6):1805–1808; 2006.

Ferguson, Denzel E. "The geographic variation of *Ambystoma macrodactylum* Baird, with the description of two new subspecies." *American Midland Naturalist* (1961): 311-338.

Fisher R, Shaffer H (1996) The decline of amphibians in California's great central valley. *Conservation Biology* 10: 1387-1397

Foley, R. 1976. Garter snakes found on mainland SE [Alaska](sic). *Southeastern Log*, August 1976:27-28.

Forman, Richard TT, and Lauren E. Alexander. "Roads and their major ecological effects." *Annual Review of ecology and systematics* (1998): 207-C2.

Field, Scott A., et al. "Making monitoring meaningful." *Austral Ecology* 32.5 (2007): 485-491.

Fretwell, Stephen Dewitt. "On territorial behavior and other factors influencing habitat distribution in birds." *Acta biotheoretica* 19.1 (1969): 45-52.

Fukumoto J, Herrero S (1998) Observations of the long-toed salamander, *Ambystoma macrodactylum*, in Waterton Lakes National Park, Alberta. *The Canadian Field-Naturalist* 112: 579-585

Funk, W. Chris, and William W. Dunlap. "Colonization of high-elevation lakes by long-toed salamanders (*Ambystoma macrodactylum*) after the extinction of introduced trout populations." *Canadian Journal of Zoology* 77.11 (1999): 1759-1767.

Funk, W. Chris, et al. "Population structure of Columbia spotted frogs (*Rana luteiventris*) is strongly affected by the landscape." *Molecular Ecology* 14.2 (2005): 483-496.

Funk, W. Chris, et al. "Range-wide phylogeographic analysis of the spotted frog complex, *Rana luteiventris* and *Rana pretiosa* in northwestern North America." *Molecular Phylogenetics and Evolution* 49.1 (2008): 198-210.

Gamradt, Seth C., and Lee B. Kats. "Effect of introduced crayfish and mosquitofish on California newts." *Conservation Biology* 10.4 (1996): 1155-1162.

Garner, Trenton WJ, et al. "The emerging amphibian pathogen *Batrachochytrium dendrobatidis* globally infects introduced populations of the North American bullfrog, *Rana catesbeiana*." *Biology Letters* 2.3 (2006): 455-459.

Gascon, Claude, and Dolors Planas. "Spring pond water chemistry and the reproduction of the wood frog, *Rana sylvatica*." *Canadian Journal of Zoology* 64.2 (1986): 543-550.

Gascon, C. 1992 The effects of reproductive phenology on larval performance traits in a three-species assemblage of central Amazonian tadpoles. *Oikos* 65, 307–313.

Gascon, Claude, Stephen C. Loughheed, and James P. Bogart. "Genetic and morphological variation in *Vanzolinius discodactylus*: a test of the river hypothesis of speciation." *Biotropica* (1996): 376-387.

Gascon, Claude, Stephen C. Loughheed, and James P. Bogart. "Patterns of Genetic Population Differentiation in Four Species of Amazonian Frogs: A Test of the Riverine Barrier Hypothesis1." *Biotropica* 30.1 (1998): 104-119.

Geffeney, Shana, Edmund D. Brodie, and Peter C. Ruben. "Mechanisms of adaptation in a predator-prey arms race: TTX-resistant sodium channels." *Science* 297.5585 (2002): 1336-1339.

Geffeney, Shana L., et al. "Evolutionary diversification of TTX-resistant sodium channels in a predator-prey interaction." *Nature* 434.7034 (2005): 759-763.

Gervasi, S.S.; Foufopoulos, J. Costs of plasticity: responses to desiccation decrease post-metamorphic immune function in a pond-breeding amphibian. *Funct. Ecol.* 2008, 22, 100-108.

Gibbons, J. Whitfield. "Terrestrial habitat: a vital component for herpetofauna of isolated wetlands." *Wetlands* 23.3 (2003): 630-635.

Gibbs, James P. "Amphibian movements in response to forest edges, roads, and streambeds in southern New England." *The Journal of Wildlife Management* (1998): 584-589.

Gibbs, James P. "Distribution of woodland amphibians along a forest fragmentation gradient." *Landscape Ecology* 13.4 (1998): 263-268.

Gibbs, James P., Sam Droege, and Paige Eagle. "Monitoring populations of plants and animals." *BioScience* 48.11 (2000): 935-940.

Gibbs, J. P. & Breisch, A. R. 2001 Climate warming and calling phenology of frogs near Ithaca, New York, 1900–1999. *Conserv. Biol.* 15, 1175–1178.

Gill, Douglas E. "The metapopulation ecology of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque)." *Ecological Monographs* 48.2 (1978): 145-166.

Gilpin, Michael E., and Michael E. Soule. "Minimum viable populations: processes of species extinction." (1986).

GIORDANO, ANDREW R., BENJAMIN J. RIDENHOUR, and Andrew Storfer. "The influence of altitude and topography on genetic structure in the long-toed salamander (*Ambystoma macrodactylum*)." *Molecular Ecology* 16.8 (2007): 1625-1637.

Goates, Michael C., Kent A. Hatch, and Dennis L. Eggett. "The need to ground truth 30.5 m buffers: A case study of the boreal toad (*Bufo boreas*)." *Biological Conservation* 138.3 (2007): 474-483.

Goodsell, Jeff A., and Lee B. Kats. "Effect of introduced mosquitofish on Pacific treefrogs and the role of alternative prey." *Conservation Biology* 13.4 (1999): 921-924.

Govindarajulu, P.P.; Anholt, B.R. Interaction between biotic and abiotic factors determines tadpole survival rate under natural conditions. *Ecoscience* 2006, 13, 413-421.

Graham, Alan. *Late Cretaceous and Cenozoic history of North American vegetation: north of Mexico*. New York: Oxford University Press, 1999.

Grant, J. B., and J. Evans. "TECHNIQUES: A Technique to Collect and Assay Adhesive-free Skin Secretions from Ambystomatid Salamanders." *Herpetological Review* 38.3 (2007): 301-304.

Gray, Matthew J., Debra L. Miller, and Jason T. Hoverman. "Ecology and pathology of amphibian ranaviruses." *Diseases of aquatic organisms* 87.3 (2009): 243-266.

Greene, Allison E., and W. Chris Funk. "Sexual selection on morphology in an explosive breeding amphibian, the Columbia spotted frog (*Rana luteiventris*)." *Journal of Herpetology* 43.2 (2009): 244-251.

Green, David M., et al. "Postglacial range fluctuation, genetic subdivision and speciation in the western North American spotted frog complex, *Rana pretiosa*." *Evolution* (1996): 374-390.

Green, David M., et al. "Cryptic species of spotted frogs, *Rana pretiosa* complex, in western North America." *Copeia* (1997): 1-8.

Green, D.M. 1999. The amphibians of British Columbia: a taxonomic catalogue. B.C. Ministry of Environment, Lands and Parks, Wildlife Bulletin No. B-87. 22 pages.

Green, D., KATHrYN A. CoNVerSe, and AUDrA K. SCHrADER. "Epizootiology of Sixty-Four Amphibian Morbidity and Mortality Events in the USA, 1996-2001." *Annals of the New York Academy of Sciences* 969.1 (2002): 323-339.

Green, David M. "The ecology of extinction: population fluctuation and decline in amphibians." *Biological conservation* 111.3 (2003): 331-343.

Greer, Amy L., Michael Berrill, and Paul J. Wilson. "Five amphibian mortality events associated with ranavirus infection in south central Ontario, Canada." *Diseases of aquatic organisms* 67.1/2 (2005): 9.

Gregory, PATRICK T. "Reptilian hibernation." *Biology of the Reptilia* 13 (1982): 53-154.

Gregory, Patrick T., and Kari J. Nelson. "Predation on fish and intersite variation in the diet of common garter snakes, *Thamnophis sirtalis*, on Vancouver Island." *Canadian Journal of Zoology* 69.4 (1991): 988-994.

Griffiths, Jennifer R., and Daniel E. Schindler. "Consequences of changing climate and geomorphology for bioenergetics of juvenile sockeye salmon in a shallow Alaskan lake." *Ecology of Freshwater Fish* 21.3 (2012): 349-362.

Guerry, Anne D., and Malcolm L. Hunter. "Amphibian distributions in a landscape of forests and agriculture: an examination of landscape composition and configuration." *Conservation Biology* 16.3 (2002): 745-754.

Gulve, Per Sjogren. "Distribution and extinction patterns within a northern metapopulation of the pool frog, *Rana lessonae*." *Ecology* 75.5 (1994): 1357-1367.

Gurushankara, H. P., S. V. Krishnamurthy, and V. Vasudev. "Morphological abnormalities in natural populations of common frogs inhabiting agroecosystems of central Western Ghats." *Applied Herpetology* 4.1 (2007): 39-45.

Guthrie, R. Dale. *Frozen fauna of the mammoth steppe: the story of Blue Babe*. University of Chicago Press, 1990.

Guyton, Bill. *Glaciers of California: Modern Glaciers, Ice Age Glaciers, Origin of Yosemite Valley, and a Glacier Tour in the Sierra Nevada*. Vol. 59. Univ of California Press, 2001.

Hammerson, G., Santos-Barrera, G., and Muths, E. 2004. *Anaxyrus boreas*. In IUCN 2011. IUCN red list of threatened species. Version 2011.2. Available from <http://www.iucnredlist.org/apps/redlist/details/3179/0> [accessed 17 May 2013].

Hamning, Valerie K., Heather L. Yanites, and Nancy L. Peterson. "Characterization of adhesive and neurotoxic components in skin granular gland secretions of *Ambystoma tigrinum*." *Copeia* 2000.3 (2000): 856-859.

Hanifin, Charles T., et al. "Toxicity of dangerous prey: variation of tetrodotoxin levels within and among populations of the newt *Taricha granulosa*." *Journal of Chemical Ecology* 25.9 (1999): 2161-2175.

Hanifin, Charles T., Edmund D. Brodie Jr, and Edmund D. Brodie III. "Phenotypic mismatches reveal escape from arms-race coevolution." *PLoS biology* 6.3 (2008): e60.

Hanifin, Charles T. "The chemical and evolutionary ecology of tetrodotoxin (TTX) toxicity in terrestrial vertebrates." *Marine drugs* 8.3 (2010): 577-593.

Harding, James H. *Amphibians and reptiles of the Great Lakes region*. University of Michigan Press, 1997.

Harrington, C. R. "The eastern limit of Beringia: mammoth remains from Banks and Melville Islands, Northwest Territories." *Arctic* (2005): 361-369.

Harington, C. R. "Legend to reality – the story of the Whitestone Mammoth." *Beringian Research Notes* (2008). No. 20: 11-12.

Harington, C. R. "Pleistocene vertebrates of the Yukon Territory." *Quaternary Science Reviews* 30.17 (2011): 2341-2354.

Harp, Elizabeth M., and James W. Petranka. "Ranavirus in wood frogs (*Rana sylvatica*): potential sources of transmission within and between ponds." *Journal of Wildlife Diseases* 42.2 (2006): 307-318.

Harvell, C.D.; Mitchell, C.; Ward, J.; Altizer, S.; Dobson, A.; Ostfeld, R.; Samuel, M. Climate warming and disease risks for terrestrial and marine biota. *Science* 2002, 296, 2158-2162.

Haufler, J. B. *Climate change: anticipated effects on ecosystem services and potential actions by the Alaska Region, US Forest Service*. DIANE Publishing, 2010.

Haught, Stormy, and Frank A. von Hippel. "Invasive pike establishment in Cook Inlet Basin lakes, Alaska: diet, native fish abundance and lake environment." *Biological Invasions* 13.9 (2011): 2103-2114.

Heaton, Timothy H., Sandra L. Talbot, and Gerald F. Shields. "An ice age refugium for large mammals in the Alexander Archipelago, southeastern Alaska." *Quaternary Research* 46.2 (1996): 186-192.

Heaton TH, Grady F (2003) The late Wisconsin vertebrate history of Prince of Wales Island, Southeast Alaska. In: Ice age cave faunas of North America (eds Schubert BW, Mead JI, Graham RW), pp. 17–53. Indiana University Press, Indianapolis.

Hecnar, Stephen J., and Robert T. M'Closkey. "Regional dynamics and the status of amphibians." *Ecology* (1996): 2091-2097.

Hecnar, Stephen J., and Robert T. M'Closkey. "The effects of predatory fish on amphibian species richness and distribution." *Biological Conservation* 79.2 (1997): 123-131.

Henderson, B. 1973. The specialized feeding behavior of *Ambystoma gracile* in Marion Lake, British Columbia. *Canadian Field-Naturalist* 87:151-154.

Hensel Jr, John Leroy, and Edmund D. Brodie Jr. "An experimental study of aposematic coloration in the salamander *Plethodon jordani*." *Copeia* (1976): 59-65.

Herreid, Clyde F., and Stephen Kinney. "Survival of Alaskan woodfrog (*Rana sylvatica*) larvae." *Ecology* (1966): 1039-1041.

Herreid, Clyde F., and Stephen Kinney. "Temperature and development of the wood frog, *Rana sylvatica*, in Alaska." *Ecology* (1967): 579-590.

Hetherington, Renée, et al. "Late Pleistocene coastal paleogeography of the Queen Charlotte Islands, British Columbia, Canada, and its implications for terrestrial biogeography and early postglacial human occupation." *Canadian Journal of Earth Sciences* 40.12 (2003): 1755-1766.

Hetherington, Renée, et al. "Paleogeography, glacially induced crustal displacement, and Late Quaternary coastlines on the continental shelf of British Columbia, Canada." *Quaternary Science Reviews* 23.3 (2004): 295-318.

Heusser, C. J. "North Pacific coastal refugia-the Queen Charlotte Islands in perspective." *The outer shores* (1989): 91-106.

Hewitt, Godfrey M. "Some genetic consequences of ice ages, and their role in divergence and speciation." *Biological Journal of the Linnean Society* 58.3 (1996): 247-276.

Hewitt, G. M., and K. M. Ibrahim. "Inferring glacial refugia and historical migrations with molecular phylogenies." *SPECIAL SYMPOSIA-BRITISH ECOLOGICAL SOCIETY*. Vol. 14. British Ecological Society, 1997.

Hewitt, Godfrey M. "Post-glacial re-colonization of European biota." *Biological Journal of the Linnean Society* 68.1-2 (1999): 87-112.

Hewitt G, Ibrahim K (2001) Inferring glacial refugia and historical immigrations with molecular phylogenies. In Silvertown J, Antonovics J (eds), Integrating Ecology and Evolution in a Spatial Context. Fourteenth Special Symposium of the British Ecological Society. British Ecological Society, Blackwell Science Ltd. 271-294

Hewitt, Godfrey. "The genetic legacy of the Quaternary ice ages." *Nature* 405.6789 (2000): 907-913.

Heyer WR. 1994. Measuring and monitoring biological diversity. Standard methods for amphibians. Washington: Smithsonian Institution Press.

Hille, Bertil. "Ion channels of excitable membranes (Sinauer, Sunderland, MA)." (2001): 545-547.

Hillyard, S.D. Behavioral, molecular and integrative mechanisms of amphibian osmoregulation. *J. Exper. Zool.* 1999, 283, 662-674.

Hitchings, Susan P., and Trevor JC Beebee. "Genetic substructuring as a result of barriers to gene flow in urban *Rana temporaria* (common frog) populations: implications for biodiversity conservation." *Heredity* 79.2 (1997): 117-127.

Hock, R. J. "Alaskan zoogeography and Alaskan amphibia." *Proc. Fourth Alaskan Science Conference*. 1953.

Hodge, R.P. 1973. *Ambystoma macrodactylum* discovered in Alaska. *Hiss News Journal* 1:623.

Hodge, Robert Parker. *Amphibians and reptiles in Alaska, the Yukon, and Northwest Territories*. Anchorage, Alaska: Alaska Northwest Publishing Company, 1976.

Hodge, R. P., and B. L. Wing. "Occurrence of marine turtles in Alaska Waters: 1960-1998." *Herpetological Review* 31.3 (2000): 148-150.

HODGE, R. P. 2004. Geographic distribution. *Rana aurora*. *Herpetological Review* 35:79.

Hoffman, Robert L., Gary L. Larson, and Brendan J. Brookes. "Habitat segregation of *Ambystoma gracile* and *Ambystoma macrodactylum* in mountain ponds and lakes, Mount Rainier National Park, Washington, USA." *Journal of Herpetology* 37.1 (2003): 24-34.

Hoffmann, Robert S. "Different voles for different holes: environmental restrictions on refugial survival of mammals." *Evolution Today. Pittsburgh: Proceedings of the Second International Congress of Systematic and Evolutionary Biology, Hunt Institute for Botanical Documentation*. 1981.

Hokit, D. Grant, and Andrew Brown. "Distribution patterns of wood frogs (*Rana sylvatica*) in Denali National Park." *Northwestern Naturalist* 87.2 (2006): 128-137.

Holman, J. A. "Patterns of herpetological re-occupation of post-glacial Michigan. Reptiles and amphibians come home." *Michigan Academic* 24 (1992): 453-466.

Holzworth, James, and Kent D. Hall. "The absence of glycerol in the hibernating American Toad (*Bufo americanus*)."
Bios (1984): 31-36.

Homan, Rebecca Newcomb, Bryan S. Windmiller, and J. Michael Reed. "Critical thresholds associated with habitat loss for two vernal pool-breeding amphibians." *Ecological Applications* 14.5 (2004): 1547-1553.

Homan, REBECCA N., et al. "Movement orientation by adult and juvenile wood frogs (*Rana sylvatica*) and American toads (*Bufo americanus*) over multiple years." *Herpetological Conservation and Biology* 5.1 (2010): 64-72.

Hoogland, R., D. Morris, and N. Tinbergen. "The spines of sticklebacks (*Gasterosteus* and *Pygosteus*) as means of defence against predators (*Perca* and *Esox*)." *Behaviour* (1956): 205-236.

Hopkins, David Moody. *The Bering land bridge*. Vol. 3. Stanford, Calif: Stanford University Press, 1967.

Hopkins, David Moody, ed. *Paleoecology of Beringia*. Academic Press, 1982.

Hopkins, Gareth R., and Saphida W. Migabo. "Antipredator Skin Secretions of the Long-toed Salamander (*Ambystoma macrodactylum*) in Its Northern Range." *Journal of Herpetology* 44.4 (2010): 627-633.

Houlahan J, Findlay C, Schmidt B, Meyer A, Kuzmin S (2000) Quantitative evidence for global amphibian population declines. *Nature* 404: 752-755

Howard, James H., and Richard L. Wallace. "Life history characteristics of populations of the long-toed salamander (*Ambystoma macrodactylum*) from different altitudes." *American Midland Naturalist* (1985): 361-373.

Howard J, Wallace R (1981) Microgeographical variation of electrophoretic loci in populations of *Ambystoma macrodactylum columbianum* (Caudata: Ambystomatidae). *Copeia* 1981: 466-471

Howard J. Wallace R (1983) Critical thermal maxima in populations of *Ambystoma macrodactylum* from different elevations. *Journal of Herpetology* 173: 400-402

Howard J, Wallace R (1984) Life history characteristics of populations of the long-toed salamander (*Ambystoma macrodactylum*) from different altitudes. *The American Midland Naturalist* 113: 361-373

Hultén, Eric. *Outline of the history of arctic and boreal biota during the Quaternary period: their evolution during and after the glacial period as indicated by the equiformal progressive areas of present plant species*. Vol. 1. Bokförlags Aktiebolaget Thule, 1937.

Hutchison, Kristan. "Straying Turtles End Up Dead in the Water." *The Juneau Empire*. N.p., 17 Jan. 2000. Web. 1 Aug. 2013. <http://juneauempire.com/stories/011700/Loc_turtle.html>.

Ibrahim, Kamal M., Richard A. Nichols, and Godfrey M. Hewitt. "Spatial patterns of genetic variation generated by different forms of dispersal." *Heredity* 77 (1996): 282-291.

Imbrie, John. "A theoretical framework for the Pleistocene ice ages William Smith Lecture." *Journal of the Geological Society* 142.3 (1985): 417-432.

Inger, Robert F., and Harold K. Voris. "The biogeographical relations of the frogs and snakes of Sundaland." *Journal of Biogeography* 28.7 (2001): 863-891.

IPCC. 2001. The regional impacts of climate change. (31 October 2009 2009;
http://www.grida.no/publications/other/ipcc_sr/?src=/Climate/ipcc/regional/173.htm)

IPCC. 2007 Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press.

IPCC. Climate change and water. In *Technical Paper of the Intergovernmental Panel on Climate Change*; Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P., Eds.; Secretariat: Geneva, Switzerland, 2008.

Ivey, Frederick M., et al. "Effects of age, gender, and myostatin genotype on the hypertrophic response to heavy resistance strength training." *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 55.11 (2000): M641-M648.

Jackson T. Report on the status and conservation of the boreal toad (*Bufo boreas boreas*) in the southern Rocky Mountains 2006-2007, Colorado Division of Wildlife, 2008.

Jameson, David L. "Population structure and homing responses in the Pacific tree frog." *Copeia* 1957.3 (1957): 221-228.

Janzen, Fredric J., et al. "Molecular phylogeography of common garter snakes (*Thamnophis sirtalis*) in western North America: implications for regional historical forces." *Molecular Ecology* 11.9 (2002): 1739-1751.

Jaussi, R., and P. A. Kunz. "Isolation of the major toxic protein from the skin venom of the crested newt, *Triturus cristatus*." *Experientia* 34.4 (1978): 503-504.

Johansen, Kjell. "Observations on the wood frog *Rana sylvatica* in Alaska." *Ecology* 43.1 (1962): 146-147.

Johnson, Bob. "Recovery of the Puerto Rican crested toad." *ENDANGERED SPECIES* 24.3 (1999): 9.

Johnson, Oliver William. "Early development, embryonic temperature tolerance and rate of development in *Rana pretiosa luteiventris* Thompson." (1964).

Johnson, Pieter TJ, et al. "Parasite (*Ribeiroia ondatrae*) infection linked to amphibian malformations in the western United States." *Ecological Monographs* 72.2 (2002): 151-168.

Johnson, M.L.; Berger, L.; Philips, L.; Speare, R. Fungicidal effects of chemical disinfectants, UV light, desiccation and heat on the amphibian chytrid *Batrachochytrium dendrobatidis*. *Dis. Aquat. Organ.* 2003, 57, 255-260.

Johnson, P.T.J.; Chase, J.M.; Dosch, K.L.; Hartson, R.B.; Gross, J.A.; Larson, D.J.; Sutherland, D.R.; Carpenter, S.R. Aquatic eutrophication promotes pathogenic infection in amphibians. *Proc. Natl. Acad. Sci.* 2007, 104, 15781-15786.

Johnston, Barbara, and Leonardo Frid. "Clearcut logging restricts the movements of terrestrial Pacific giant salamanders (*Dicamptodon tenebrosus* Good)." *Canadian journal of zoology* 80.12 (2002): 2170-2177.

Josenhans, Heiner W., et al. "Post glacial sea levels on the Western Canadian continental shelf: evidence for rapid change, extensive subaerial exposure, and early human habitation." *Marine Geology* 125.1 (1995): 73-94.

Julius, S. H., and J. M. West, editors. 2008. Preliminary review of adaptation options for climate sensitive ecosystems and resources. U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Final Report Synthesis and Assessment Document 4.4.

Kao, C. Y. "Tetrodotoxin, saxitoxin and their significance in the study of excitation phenomena." *Pharm. Rev.* 18.2 (1966): 997-1049.

Karl, Stephen A., and Brian W. Bowen. "Evolutionary significant units versus geopolitical taxonomy: molecular systematics of an endangered sea turtle (genus *Chelonia*)." *Conservation Biology* 13.5 (1999): 990-999.

Kats, Lee B., James W. Petranksa, and Andrew Sih. "Antipredator defenses and the persistence of amphibian larvae with fishes." *Ecology* (1988): 1865-1870.

Kats, Lee B., and Andrew Sih. "Oviposition site selection and avoidance of fish by streamside salamanders (*Ambystoma barbouri*)." *Copeia* (1992): 468-473.

Kats, Lee B., and Ryan P. Ferrer. "Alien predators and amphibian declines: review of two decades of science and the transition to conservation." *Diversity and Distributions* 9.2 (2003): 99-110.

Kelleher, Kevin E., and John R. Tester. "Homing and Survival in the Manitoba Toad, *Bufo hemiophrys*, in Minnesota." *Ecology* (1969): 1040-1048.

Kelly, B. P., T. Ainsworth, D. A. Boyce, Jr., E. Hood, P. Murphy, and J. Powell. 2007. Climate change: Predicted impacts on Juneau. Report to Mayor Bruce Botelho and the City and Borough of Juneau Assembly. City and Borough of Juneau, AK.

Kezer, James, and Donald S. Farner. "Life history patterns of the salamander *Ambystoma macrodactylum* in the high Cascade Mountains of southern Oregon." *Copeia* 1955.2 (1955): 127-131.

Kessel, Brina. "Breeding dates of *Rana sylvatica* at College, Alaska." *Ecology* (1965): 206-208.

Kiesecker, Joseph M., and David K. Skelly. "Effects of disease and pond drying on gray tree frog growth, development, and survival." *Ecology* 82.7 (2001): 1956-1963.

(b) Kiesecker, J.M.; Blaustein, A.R.; Belden, L.K. Complex causes of amphibian population declines. *Nature* 2001, 410, 681-684.

Kilpatrick, A. Marm, Cheryl J. Briggs, and Peter Daszak. "The ecology and impact of chytridiomycosis: an emerging disease of amphibians." *Trends in Ecology & Evolution* 25.2 (2010): 109-118.

Kirshtein, Julie D., et al. "Quantitative PCR detection of *Batrachochytrium dendrobatidis* DNA from sediments and water." *Diseases of aquatic organisms* 77.1 (2007): 11.

Klein, E., E. E. Berg, and R. Dial. 2005. Wetland drying and succession across the Kenai Peninsula lowlands, south-central Alaska. *Canadian Journal of Forest Research* 35: 1931-1941.

Knapp, Roland A., and Kathleen R. Matthews. "Non-Native Fish Introductions and the Decline of the Mountain Yellow-Legged Frog from within Protected Areas." *Conservation Biology* 14.2 (2000): 428-438.

Knapp, Roland A. "Effects of nonnative fish and habitat characteristics on lentic herpetofauna in Yosemite National Park, USA." *Biological Conservation* 121.2 (2005): 265-279.

Knapp, Shannon M., et al. "Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance." *Conservation Biology* 17.3 (2003): 752-762.

Knowles L (2001) Did the Pleistocene glaciations promote divergence? Tests of explicit refugial models in montane grasshoppers. *Molecular Ecology* 10: 691-701

Knudsen, Jens W. "The courtship and egg mass of *Ambystoma gracile* and *Ambystoma macrodactylum*." *Copeia* 1960.1 (1960): 44-46.

KRAAIJEVELD-SMIT, F. J. L., et al. "Low gene flow but high genetic diversity in the threatened Mallorcan midwife toad *Alytes muletensis*." *Molecular Ecology* 14.11 (2005): 3307-3315.

Kusrini, M. D., et al. "Chytridiomycosis in frogs of Mount Gede-Pangrango, Indonesia." *Diseases of aquatic organisms* 82 (2008): 187-194.

Kuchta, Shawn R., and AN-MING TAN. "Isolation by distance and post-glacial range expansion in the rough-skinned newt, *Taricha granulosa*." *Molecular Ecology* 14.1 (2005): 225-244.

Kusano, T.; Inoue, M. Long-term trends toward earlier breeding of Japanese amphibians. *J. Herp.* 2008, 42, 608-614.

Kuyt, E. "A communal overwintering site for the Canadian toad, *Bufo americanus hemiophrys*, in the Northwest Territories." *Canadian field-naturalist. Ottawa ON* 105.1 (1991): 119-121.

Lacourse, Terri, Rolf W. Mathewes, and Daryl W. Fedje. "Paleoecology of late-glacial terrestrial deposits with in situ conifers from the submerged continental shelf of western Canada." *Quaternary Research* 60.2 (2003): 180-188.

Lacourse, T., and R. W. Mathewes. "Terrestrial paleoecology of Haida Gwaii and the continental shelf: Vegetation, climate, and plant resources of the coastal migration route." *Haida Gwaii: Human History and Environment from the Time of Loon to the Time of the Iron People* (2005): 38-58.

Lannoo MJ. 2005. Amphibian declines: the conservation status of United States species. Berkeley: University of California Press.

Larson, Gary L. "A limnological study of a high mountain lake in Mount Rainier National Park, Washington State; USA." *Arch. Hydrobiol* 72 (1973): 10-48.

Larson, Allan, David B. Wake, and Kay P. Yanev. "Measuring gene flow among populations having high levels of genetic fragmentation." *Genetics* 106.2 (1984): 293-308.

Lauck, Bonnie. "Can life history studies contribute to understanding the impacts of clearfell logging on pond breeding anurans? A review." *Applied Herpetology* 2.2 (2005): 125-137.

Lawler, S.P.; Morin, P.J. Temporal overlap, competition, and priority effects in larval anurans. *Ecology* 1993, 74, 174-182.

Lawler, Sharon P., et al. "Effects of Introduced Mosquitofish and Bullfrogs on the Threatened California Red-Legged Frog." *Conservation Biology* 13.3 (1999): 613-622.

LEE-YAW, JULIE A., JASON T. IRWIN, and DAVID M. GREEN. "Postglacial range expansion from northern refugia by the wood frog, *Rana sylvatica*." *Molecular Ecology* 17.3 (2008): 867-884.

Lee-Yaw, J. A., and D. E. Irwin. "Large geographic range size reflects a patchwork of divergent lineages in the long-toed salamander (*Ambystoma macrodactylum*)." *Journal of Evolutionary Biology* 25.11 (2012): 2276-2287.

Lehtinen, Richard M., and Susan M. Galatowitsch. "Colonization of restored wetlands by amphibians in Minnesota." *The American Midland Naturalist* 145.2 (2001): 388-396.

Leonard, William P. *Amphibians of Washington and Oregon*. Seattle Audubon Society, 1993.

Lerum, Lance, and Robbie Piehl. "Southeast Alaska, Chichagof Island Redlegged Frog Population Status." *Progress Report, Admiralty Island National Monument, USDA Forest Service* (2007).

Levey, Richard, et al. "Investigations into the Causes of Amphibian Malformations in the Lake Champlain Basin of New England." *Waterbury, VT: Vermont Department of Environmental Conservation* (2003).

Licht, Lawrence E., and Bobbi Low. "Cardiac response of snakes after ingestion of toad parotoid venom." *Copeia* (1968): 547-551.

Licht, Lawrence E. "Comparative breeding behavior of the red-legged frog (*Rana aurora aurora*) and the western spotted frog (*Rana pretiosa pretiosa*) in southwestern British Columbia." *Canadian Journal of Zoology* 47.6 (1969): 1287-1299.

Licht, Lawrence E. "Breeding habits and embryonic thermal requirements of the frogs, *Rana aurora aurora* and *Rana pretiosa pretiosa*, in the Pacific Northwest." *Ecology* (1971): 116-124.

Licht, Lawrence E. "Survival of embryos, tadpoles, and adults of the frogs *Rana aurora aurora* and *Rana pretiosa pretiosa* sympatric in southwestern British Columbia." *Canadian Journal of Zoology* 52.5 (1974): 613-627.

Licht, Lawrence E. "Growth and food of larval *Ambystoma gracile* from a lowland population in southwestern British Columbia." *Canadian Journal of Zoology* 53.11 (1975): 1716-1722.

Licht, Lawrence E. "Habitat selection of *Rana pipiens* and *Rana sylvatica* during exposure to warm and cold temperatures." *American Midland Naturalist* (1991): 259-268.

Lindsey, C. C. "TEMPERATURE-CONTROLLED MERISTIC VARIATION IN THE PARADISE FISH *MACROPODUS OPERCULARS* (L.)." *Canadian Journal of Zoology* 32.2 (1954): 87-98.

Linsdale, Jean M. "Amphibians and reptiles in Nevada." *Proceedings of the American Academy of Arts and Sciences*. Vol. 73. No. 8. American Academy of Arts & Sciences, 1940.

Lips, Karen R., et al. "Emerging infectious disease and the loss of biodiversity in a Neotropical amphibian community." *Proceedings of the National Academy of Sciences of the United States of America* 103.9 (2006): 3165-3170.

Lips, Karen R., et al. "Riding the wave: reconciling the roles of disease and climate change in amphibian declines." *PLoS biology* 6.3 (2008): e72.

Lochmiller, Robert L., and Charlotte Deerenberg. "Trade-offs in evolutionary immunology: just what is the cost of immunity?." *Oikos* 88.1 (2000): 87-98.

Logier, E. and G. Toner. 1961. Check list of the amphibians and reptiles of Canada and Alaska, a revision of Contribution No. 41. Life Sciences Division, Royal Ontario Museum, Toronto, Contrib. No.53., University of Toronto Press.

Long, Z. L., and E. E. Prepas. "Scale and landscape perception: the case of refuge use by Boreal Toads (*Anaxyrus boreas boreas*)." *Canadian Journal of Zoology* 90.8 (2012): 1015-1022.

Longcore, Jerry R., et al. "Chytridiomycosis widespread in anurans of northeastern United States." *The Journal of wildlife management* 71.2 (2007): 435-444.

Longson, C. G., and J. M. P. Joss. "Optimal toxicity in animals: predicting the optimal level of chemical defences." *Functional Ecology* 20.4 (2006): 731-735.

- Lougheed, S. C., et al. "Ridges and rivers: a test of competing hypotheses of Amazonian diversification using a dart-poison frog (*Epipedobates femoralis*).*" Proceedings of the Royal Society of London. Series B: Biological Sciences* 266.1431 (1999): 1829-1835.
- Lutterschmidt, Deborah I., Michael P. LeMaster, and Robert T. Mason. "Minimal overwintering temperatures of red-sided garter snakes (*Thamnophis sirtalis parietalis*): a possible cue for emergence?." *Canadian journal of zoology* 84.5 (2006): 771-777.
- Lynch, John D., and William E. Duellman. *Frogs of the genus Eleutherodactylus Leptodactylidae in western Ecuador: systematics, ecology, and biogeography*. Lawrence, Kan.: Natural History Museum, University of Kansas., 1997.
- MacCulloch, Ross. *The ROM field guide to amphibians and reptiles of Ontario*. McClelland & Stewart, 2002.
- MacDonald, SO. *The amphibians and reptiles of Alaska: a field handbook*. Alaska Natural Heritage Program, Environment and Natural Resources Institute, University of Alaska Anchorage, 2003.
- MacKenzie, Darryl I., et al. "Estimating site occupancy rates when detection probabilities are less than one." *Ecology* 83.8 (2002): 2248-2255.
- MacKenzie, Darryl I. *Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence*. Academic Press, 2006.
- Maltby E. 1986. *Waterlogged wealth : why waste the world's wet places?* Sterling, VA: Earthscan.
- Manier, Mollie K., and Stevan J. Arnold. "Ecological correlates of population genetic structure: a comparative approach using a vertebrate metacommunity." *Proceedings of the Royal Society B: Biological Sciences* 273.1604 (2006): 3001-3009.
- Mann, Daniel H., and Thomas D. Hamilton. "Late Pleistocene and Holocene paleoenvironments of the North Pacific coast." *Quaternary Science Reviews* 14.5 (1995): 449-471.
- Mann, R. H. K. "A pike management strategy for a trout fishery." *Journal of Fish Biology* 27.sA (1985): 227-234.
- Mantua, Nathan J., and Steven R. Hare. "The Pacific decadal oscillation." *Journal of Oceanography* 58.1 (2002): 35-44.
- Marsh, David M., and Peter C. Trenham. "Metapopulation dynamics and amphibian conservation." *Conservation Biology* 15.1 (2001): 40-49.
- Marsh, David M., et al. "Forest roads as partial barriers to terrestrial salamander movement." *Conservation Biology* 19.6 (2005): 2004-2008.
- Martin, Lynn B., Zachary M. Weil, and Randy J. Nelson. "Seasonal changes in vertebrate immune activity: mediation by physiological trade-offs." *Philosophical Transactions of the Royal Society B: Biological Sciences* 363.1490 (2008): 321-339.
- Martof, Bernard S., and Robert L. Humphries. "Geographic variation in the wood frog *Rana sylvatica*." *American Midland Naturalist* 61.2 (1959): 350-389.
- Matsuda, B.M., D.M. Green, and P.T. Gregory. 2006. *Amphibians and reptiles of British Columbia*. Royal BC Museum, Victoria. 266 pages.

- Maxwell, B. 1992 Arctic climate: potential for change under global warming. In Arctic ecosystems in a changing climate: an ecophysiological perspective (eds F. Chapin, R. Jefferies, J. Reynolds, G. Shaver & J. Svoboda), pp. 11–34. San Diego, CA: Academic Press.
- Maxwell, David, and Simon Jennings. "Power of monitoring programmes to detect decline and recovery of rare and vulnerable fish." *Journal of Applied Ecology* 42.1 (2005): 25-37.
- Mazerolle, Marc J. "Amphibian road mortality in response to nightly variations in traffic intensity." *Journal Information* 60.1 (2004).
- Mazerolle, M. J., and A. Desrochers. "Landscape resistance to frog movements." *Canadian Journal of Zoology* 83.3 (2005): 455-464.
- McAllister, K. R., et al. "Taricha granulosa (roughskin newt) toxicity." *Herpetol. Rev* 28 (1997): 82.
- McCallum, Hamish, and Andy Dobson. "Detecting disease and parasite threats to endangered species and ecosystems." *Trends in Ecology & Evolution* 10.5 (1995): 190-194.
- McCallum, Malcolm L., and Stanley E. Trauth. "A forty-three year museum study of northern cricket frog (*Acris crepitans*) abnormalities in Arkansas: upward trends and distributions." *Journal of wildlife diseases* 39.3 (2003): 522-528.
- McCallum M, McCallum J. 2006. Publication trends of natural history and field studies in herpetology. *Herpetological Conservation and Biology* 1: 63–68.
- McCallum M. 2007. Amphibian decline or extinction? Current declines dwarf background extinction rate. *Journal of Herpetology* 41: 483-491.
- McCallum M, McCallum J, Trauth S. 2009. Predicted climate change may spark box turtle declines. *Amphibia-Reptilia* 30: 259-264.
- McKeown, Sean. *A field guide to reptiles and amphibians in the Hawaiian Islands*. Diamond Head Publishing, 1996.
- McMenamin, S.K.; Hadley, E.A.; Wright, C.K. Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. *Proc. Natl. Acad. Sci. USA* 2008, 105, 16988-16993.
- Meier, P. T. "Fine spatial scale phenotypic divergence in wood frogs (*Lithobates sylvaticus*)." *Canadian Journal of Zoology* 85.8 (2007): 873-882.
- Meyer, J.L.; Sale, M.J.; Mulholland, P.K.; Hoff, N.L. Impacts of climate change on aquatic ecosystem functioning and health. *J. Am. Water Res. Assoc.* 1999, 35, 1373-1386.
- Mills, L. Scott, and Peter E. Smouse. "Demographic consequences of inbreeding in remnant populations." *American Naturalist* (1994): 412-431.
- Mills, N.E.; Barnhart, M.C. Effects of hypoxia on embryonic development in two *Ambystoma* and two *Rana* species. *Physiol. Biochem. Zool.* 1999, 72, 179-188.
- Milner, A. R. "The biogeography of salamanders in the Mesozoic and early Cenozoic: A cladistic vicariance model." *Evolution, Time, and Space. The Emergence of the Biosphere*. Academic Press, New York (1983): 431-468.
- Mobley, Jason A., and Thomas A. Stidham. "Great horned owl death from predation of a toxic California newt." *The Wilson Bulletin* 112.4 (2000): 563-564.

- Mokany, A., and R. Shine. "Competition between tadpoles and mosquito larvae." *Oecologia* 135.4 (2003): 615-620.
- Mokany, Allie. "Impact of tadpoles and mosquito larvae on ephemeral pond structure and processes." *Marine and freshwater research* 58.5 (2007): 436-444.
- Moritz, C. "Applications of mitochondrial DNA analysis in conservation: a critical review." *Molecular Ecology* 3.4 (1994): 401-411.
- Moritz, Craig. "Defining 'evolutionarily significant units' for conservation." *TRENDS in Ecology and Evolution* 9.10 (1994): 373-374.
- Moritz, Craig. "Uses of molecular phylogenies for conservation." *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 349.1327 (1995): 113-118.
- Morrow, James Edwin. *The freshwater fishes of Alaska*. Anchorage: Alaska Northwest Publishing Company, 1980.
- MOORE, JENNIFER A., et al. "Effects of the landscape on boreal toad gene flow: does the pattern–process relationship hold true across distinct landscapes at the northern range margin?." *Molecular Ecology* 20.23 (2011): 4858-4869.
- Moore, John A. "Temperature tolerance and rates of development in the eggs of Amphibia." *Ecology* 20.4 (1939): 459-478.
- Morand, A.; Joly, P.; Grolet, O. Phenotypic variation in metamorphosis in five anuran species along a gradient of stream influence. *C.R. Acad. Sci. Paris Life Sciences* 1997, 320, 645-652.
- Morin, P.J.; Lawler, S.P.; Johnson, E.A. Ecology and breeding phenology of larval *Hyla andersonii*: the disadvantages of breeding late. *Ecology* 1990, 71, 1590-1598.
- Moritz, Craig. "Defining 'evolutionarily significant units' for conservation." *TRENDS in Ecology and Evolution* 9.10 (1994): 373-374.
- Moulton, M. P., and S. L. Pimm. "Species introductions to Hawaii." *Ecology of biological invasions of North America and Hawaii*. Springer New York, 1986. 231-249.
- Mullally, Don P. "Habits and minimum temperatures of the toad *Bufo boreas halophilus*." *Copeia* 1952.4 (1952): 274-276.
- Muller, Richard A., and Gordon J. MacDonald. "Glacial cycles and astronomical forcing." *Science* 277.5323 (1997): 215-218.
- Murphy, K. A., and E. Witten. 2006. Fire regime condition class (FRCC) interagency guidebook reference conditions; Coastal forests. <http://frames.nbii.gov/documents/nifft/docs/bps/alaska/CSLF.pdf>.
- Murphy, Melanie A., Jeffrey S. Evans, and Andrew Storfer. "Quantifying *Bufo boreas* connectivity in Yellowstone National Park with landscape genetics." *Ecology* 91.1 (2010): 252-261.
- Muths, Erin. "Home range and movements of boreal toads in undisturbed habitat." *Copeia* 2003.1 (2003): 160-165.
- (b) Muths, Erin, et al. "Evidence for disease-related amphibian decline in Colorado." *Biological Conservation* 110.3 (2003): 357-365.

- Muths, Erin, David S. Pilliod, and Lauren J. Livo. "Distribution and environmental limitations of an amphibian pathogen in the Rocky Mountains, USA." *Biological Conservation* 141.6 (2008): 1484-1492.
- Muths, Erin, and Rick D. Scherer. "Portrait of a Small Population of Boreal Toads (*Anaxyrus boreas*).*" Herpetologica* 67.4 (2011): 369-377.
- Myneni, R. B., C. D. Keeling, C. J. Tucker, G. Asrar, and R. R. Nemani. 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature* 386:698-702.
- Nace, George W., Jean K. Waage, and Christina M. Richards. "Sources of amphibians for research." *BioScience* (1971): 768-773.
- NatureNorth. 2008. Manitoba Herp Atlas. (September 28, 2009 http://naturenorth.com/Herps/Herps_Atlas_Proposal.html)
- Neuman-Lee, Lorin A., et al. "Using Mitochondrial DNA to Determine the Identity and Origin of a Gartersnake Found in Alaska." *Journal of Herpetology* 45.1 (2011): 63-65.
- Newman, Dara, and Diana Pilson. "Increased probability of extinction due to decreased genetic effective population size: experimental populations of *Clarkia pulchella*." *Evolution* (1997): 354-362.
- Newman, Robert A., and Tina Squire. "Microsatellite variation and fine-scale population structure in the wood frog (*Rana sylvatica*).*" Molecular Ecology* 10.5 (2001): 1087-1100.
- Newton, A. C., et al. "Molecular phylogeography, intraspecific variation and the conservation of tree species." *Trends in Ecology & Evolution* 14.4 (1999): 140-145.
- Nielson, Marilyn, Kirk Lohman, and Jack Sullivan. "Phylogeography of the tailed frog (*Ascaphus truei*): implications for the biogeography of the Pacific Northwest." *Evolution* 55.1 (2001): 147-160.
- Niemelä, Jari, David Langor, and John R. Spence. "Effects of Clear-Cut Harvesting on Boreal Ground-Beetle Assemblages (Coleoptera: Carabidae) in Western Canada." *Conservation Biology* 7.3 (1993): 551-561.
- Noble, G. Kingsley. "The biology of the Amphibia." (1931).
- NOGUCHI, Tamao, et al. "Occurrence of tetrodotoxin and anhydrotetrodotoxin in *Vibrio* sp. isolated from the intestines of a xanthid crab, *Atergatis floridus*." *Journal of biochemistry* 99.1 (1986): 311-314.
- Norman, Bradford R., and T.J. Hassler. *Field investigations of the herpetological taxa in Southeast Alaska*. National Biological Service, California Cooperative Fishery Research Unit, Humboldt State University, 1995.
- Norman, Bradford R. "New Localities in Southeastern Alaska for the Long-toed Salamander, *Ambystoma macrodactylum* (Amphibia, Caudata, Ambystomatidae)." *Bulletin of the Chicago Herpetological Society* . 2004. 39 (4): 61-64. Print.
- Noon, Barry R. "Conceptual issues in monitoring ecological resources." *Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, DC, USA (2003): 27-71.
- Noon, Barry R., and Kevin S. McKelvey. "The process of indicator selection." *Notes* (2006).
- Norrström, Ann-Catrine, and G. Jacks. "Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts." *Science of the Total Environment* 218.2 (1998): 161-174.

NUSSBAUM RA, BRODIE ED JR, STORM RM. 1983. Amphibians and Reptiles of the Pacific Northwest. Moscow, ID: University Press of Idaho. 332 p.

Nussear, Kenneth E., et al. "Desert tortoise hibernation: temperatures, timing, and environment." *Copeia* 2007.2 (2007): 378-386.

Ohta T (1992) The nearly neutral theory of molecular evolution. *Annual Review of Ecology and Systematics* 23: 263–286

Oliver, M. G., and H. M. McCurdy. "Migration, overwintering, and reproductive patterns of *Taricha granulosa* on southern Vancouver Island." *Canadian Journal of Zoology* 52.4 (1974): 541-545.

(b) Oliver. (1974) "Habitat Selection and Its Relation to Reproductive Development of the Rough Skinned Newt. *Taricha Granulosa* (Skilton) on Southern Vancouver Island." PhD diss., Thesis (M. Sc.)--University of Victoria, 1974.

OLSON DH, RONNENBERG K. 2008. Batrachochytrium dendrobatidis mapping project. Available at: parcplace.org/bdmap2008update.html. Accessed 13 June 2013.

Olson, Deanna H. "Herpetological conservation in northwestern North America." *Northwestern Naturalist* 90.2 (2009): 61-96.

Ouellet, Martin, et al. "Hindlimb deformities (ectromelia, ectrodactyly) in free-living anurans from agricultural habitats." *Journal of wildlife diseases* 33.1 (1997): 95-104.

OVASKA, K., L. HYATr, AND L. SOPUCK. 2002. Geographic distribution. *Rana aurora*. *Herpetological Review* 33:318.

Parmesan, Camille, and Gary Yohe. "A globally coherent fingerprint of climate change impacts across natural systems." *Nature* 421.6918 (2003): 37-42.

Parson, Tiffany AS. *Kenai National Wildlife Refuge Contaminant Assessment*. Anchorage, Alaska, USA: US Fish and Wildlife Service, 2001.

Palis, J.G. Element stewardship abstract: flatwoods salamander (*Ambystoma cingulatum* Cope). *Nat. Areas J.* 1996, 16, 49-54.

Palis, J.G.; Aresco, M.J.; Kilpatrick, S. Breeding biology of a Florida population of *Ambystoma cingulatum* (Flatwoods salamander) during a drought. *Southeast. Nat.* 2006, 5, 1-8.

Parmesan, C. 2007 Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Glob. Change Biol.* 13, 1–13.

Patankar, R., F. A. Von Hippel, and M. A. Bell. "Extinction of a weakly armoured threespine stickleback (*Gasterosteus aculeatus*) population in Prator Lake, Alaska." *Ecology of Freshwater Fish* 15.4 (2006): 482-487.

Patrick, David A., Malcolm L. Hunter Jr, and Aram JK Calhoun. "Effects of experimental forestry treatments on a Maine amphibian community." *Forest Ecology and Management* 234.1 (2006): 323-332.

Pauly, Gregory B., Santiago R. Ron, and Lance Lerum. "Molecular and ecological characterization of extralimital populations of red-legged frogs from western North America." *Journal of herpetology* 42.4 (2008): 668-679.

Pawson, S. M., et al. "Clear-fell harvest impacts on biodiversity: past research and the search for harvest size thresholds." *Canadian Journal of Forest Research* 36.4 (2006): 1035-1046.

Pearl, C.A. and Hayes, M.P. 2001. Predation by Oregon Spotted Frogs (*Rana pretiosa*) on Western Toads (*Bufo boreas*) in Oregon. *American Midland Naturalist* 147:145–152.

Pearl, Christopher A., et al. "Occurrence of the amphibian pathogen *Batrachochytrium dendrobatidis* in the Pacific Northwest." *Journal of Herpetology* 41.1 (2007): 145-149.

Pearson, Kimberly J., and Cameron P. Goater. "Distribution of long-toed salamanders and introduced trout in high- and low-elevation wetlands in southwestern Alberta, Canada." *Ecoscience* 15.4 (2008): 453-459.

Pearson, K. J., and C. P. Goater. "Effects of predaceous and nonpredaceous introduced fish on the survival, growth, and antipredation behaviours of long-toed salamanders." *Canadian Journal of Zoology* 87.10 (2009): 948-955.

Pechmann, Joseph HK, et al. "Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians." *Wetlands Ecology and Management* 1.1 (1989): 3-11.

Pennock, David S., and Walter W. Dimmick. "Critique of the evolutionarily significant unit as a definition for "distinct population segments" under the US Endangered Species Act." *Conservation Biology* 11.3 (1997): 611-619.

Pessier, Allan P., et al. "Cutaneous chytridiomycosis in poison dart frogs (*Dendrobates* spp.) and White's tree frogs (*Litoria caerulea*)." *Journal of Veterinary Diagnostic Investigation* 11.2 (1999): 194-199.

Petranka, James W. "Geographic variation in the mode of reproduction and larval characteristics of the small-mouthed salamander (*Ambystoma texanum*) in the east-central United States." *Herpetologica* (1982): 475-485.

Petranka, James W. *Salamanders of the United States and Canada*. Washington: Smithsonian Institution Press., 1998.

Petranka, James W., and Caroline A. Kennedy. "Pond tadpoles with generalized morphology: is it time to reconsider their functional roles in aquatic communities?." *Oecologia* 120.4 (1999): 621-631

Pielou E (1991) *After the Ice Age: The Return of Life to Glaciated North America*. University of Chicago Press, Chicago

Pilliod, David S., and Charles R. Peterson. "Local and landscape effects of introduced trout on amphibians in historically fishless watersheds." *Ecosystems* 4.4 (2001): 322-333.

Pilliod, David S., Charles R. Peterson, and Peter I. Ritson. "Seasonal migration of Columbia spotted frogs (*Rana luteiventris*) among complementary resources in a high mountain basin." *Canadian Journal of Zoology* 80.11 (2002): 1849-1862.

Pilliod, David S., et al. "Effects of amphibian chytrid fungus on individual survival probability in wild boreal toads." *Conservation Biology* 24.5 (2010): 1259-1267.

Pimm, Stuart L., and Peter Raven. "Biodiversity: extinction by numbers." *Nature* 403.6772 (2000): 843-845.

Pope, Karen L. "Assessing changes in amphibian population dynamics following experimental manipulations of introduced fish." *Conservation Biology* 22.6 (2008): 1572-1581.

Porej, Deni, Mick Micacchion, and Thomas E. Hetherington. "Core terrestrial habitat for conservation of local populations of salamanders and wood frogs in agricultural landscapes." *Biological Conservation* 120.3 (2004): 399-409.

- Pounds J, Crump M. 1994. Amphibian declines and climate disturbance: the case of the golden toad and the harlequin frog. *Conservation Biology* 8: 72-85.
- Pounds, J.A.; Fogden, M.P.L.; Savage, J.M.; Gorman, G.C.; Test of null models for amphibian declines on a tropical mountain. *Conserv. Biol.* 1997, *11*, 1307-1322.
- Pounds, J.A.; Fogden, M.P.L.; Campbell, J.H. Biological responses to climate change on a tropical mountain. *Nature* 1999, *398*, 611-615.
- Pounds, J. Alan, et al. "Widespread amphibian extinctions from epidemic disease driven by global warming." *Nature* 439.7073 (2006): 161-167.
- Purvis, Andy, et al. "Predicting extinction risk in declining species." *Proceedings of the Royal Society of London. Series B: Biological Sciences* 267.1456 (2000): 1947-1952.
- Pyare, Sanjay, et al. 2004. "DRAFT Study Plan Inventory and monitoring for western toad in Southeast Alaska: Documenting regional distribution and habitat occupancy; baselines for detection of future change."
- (b)Pyare, Sanjay, Robert E. Christensen III, and Michael J. Adams. "Preliminary Assessment of Breeding-Site Occurrence, Microhabitat, and Sampling of Western Toads in Glacier Bay." *Proceedings of the Fourth Glacier Bay Science Symposium*. 2004.
- RABINOWE, J. H., J. T. SERRA, M. P. HAYES, AND T. QUINN. 2002. *Rana aurora aurora* (Northern Red-Legged Frog). Diet. *Herpetological Review* 33:128.
- Raverty, S., and T. Reynolds. "Cutaneous chytridiomycosis in dwarf aquatic frogs (*Hymenochirus boettgeri*) originating from southeast Asia and in a western toad (*Bufo boreas*) from northeastern British Columbia." *The Canadian Veterinary Journal* 42.5 (2001): 385.
- Reaser, Jamie Kristine. "Occurrence of the California red-legged frog (*Rana aurora draytonii*) in Nevada, USA." *Western North American Naturalist* 63.3 (2003): 400-401.
- Reeves MK, Green DE (2006) *Rana sylvatica* (wood frog) chytridiomycosis. *Herpetol Rev* 37:450
- Reeves, Mari K., et al. "Road proximity increases risk of skeletal abnormalities in wood frogs from National Wildlife Refuges in Alaska." *Environmental health perspectives* 116.8 (2008): 1009.
- (b) Reeves, M. K. "Batrachochytrium dendrobatidis in wood frogs (*Rana sylvatica*) from three national wildlife refuges in Alaska, USA." *Herpetological Review* 39.1 (2008): 68.
- Regosin, Jonathan V., Bryan S. Windmiller, and J. Michael Reed. "Terrestrial habitat use and winter densities of the wood frog (*Rana sylvatica*)." *Journal of Herpetology* 37.2 (2003): 390-394.
- Reh, W., and A. Seitz. "The influence of land use on the genetic structure of populations of the common frog (*Rana temporaria*)" *Biological Conservation* 54.3 (1990): 239-249.
- Relyea R, Schoeppner N, Hoverman J. 2005. Pesticides and amphibians: The importance of community context. *Ecological Applications* 15: 1125-1134.
- Resetarits Jr, William J., and Henry M. Wilbur. "Choice of oviposition site by *Hyla chrysoscelis*: role of predators and competitors." *Ecology* (1989): 220-228.
- Richter, S.C.; Young, J.E.; Johnson, G.N.; Seigel, R.A. Stochastic variation in reproductive success of a rare frog, *Rana*

sevoša: implications for conservation and for monitoring amphibian populations. *Biol. Conserv.* 2003, **111**, 171-177.

Ricketts, Taylor H. "The matrix matters: effective isolation in fragmented landscapes." *The American Naturalist* 158.1 (2001): 87-99.

Rittenhouse, Tracy AG, and Raymond D. Semlitsch. "Grasslands as movement barriers for a forest-associated salamander: migration behavior of adult and juvenile salamanders at a distinct habitat edge." *Biological Conservation* 131.1 (2006): 14-22.

Rittenhouse, Tracy AG, Raymond D. Semlitsch, and Frank R. Thompson III. "Survival costs associated with wood frog breeding migrations: effects of timber harvest and drought." *Ecology* 90.6 (2009): 1620-1630.

Riitters, Kurt H., and James D. Wickham. "How far to the nearest road?." *Frontiers in Ecology and the Environment* 1.3 (2003): 125-129.

Rocque, DA. *Tetlin National Wildlife Refuge Contaminant Assessment*. Anchorage, Alaska, USA: US Fish and Wildlife Service, 2007.

Rodda, Gordon H., Catherine S. Jarnevich, and Robert N. Reed. "What parts of the US mainland are climatically suitable for invasive alien pythons spreading from Everglades National Park?." *Biological Invasions* 11.2 (2009): 241-252.

Rödder, D.; Kielgast, J.; Bielby, J.; Schmidtlein, S.; Bosch, J.; Garner, T.W.K.; Veith, M.; Walker, S.; Fisher, M.C.; Lötters, S. Global amphibian extinction risk assessment for the panzootic chytrid fungus. *Diversity* 2009, **1**, 52-66.

Rohr, J.R., Raffel, T.R., Romansic, J.M., McCallum, H. & Hudson, P.J. (2008) Evaluating the links between climate, disease spread, and amphibian declines. *Proceedings of the National Academy of Science, USA*, **105**, 17436–17441.

Rome, L.C.; Stevens, E.D.; John-Alder, H.B. Temperature and thermal acclimation and physiological function. In *Environmental Physiology of the Amphibia*; Feder, M.E., Burggren, W.W., Eds.; University of Chicago Press: London, UK, 1992; pp. 183-205.

Rosenblum, Erica Bree, et al. "Global gene expression profiles for life stages of the deadly amphibian pathogen *Batrachochytrium dendrobatidis*." *Proceedings of the National Academy of Sciences* 105.44 (2008): 17034-17039.

Ross, B. A., J. R. Tester, and W. J. Breckenridge. "Ecology of mima-type mounds in northwestern Minnesota." *Ecology* (1968): 172-177.

Rossman, Douglas Athon, Neil B. Ford, and Richard A. Seigel. *The garter snakes: evolution and ecology*. University of Oklahoma Press, 1996.

Rothermel, Betsie B., and Raymond D. Semlitsch. "An Experimental Investigation of Landscape Resistance of Forest versus Old-Field Habitats to Emigrating Juvenile Amphibians." *Conservation Biology* 16.5 (2002): 1324-1332.

Rowe, Christopher L., and William A. Dunson. "Impacts of hydroperiod on growth and survival of larval amphibians in temporary ponds of central Pennsylvania, USA." *Oecologia* 102.4 (1995): 397-403.

Royle, J. Andrew, and William A. Link. "A general class of multinomial mixture models for anuran calling survey data." *Ecology* 86.9 (2005): 2505-2512.

Rubbo, Michael J., et al. "The Influence of Amphibians on Mosquitoes in Seasonal Pools: Can Wetlands Protection Help to Minimize Disease Risk?." *Wetlands* 31.4 (2011): 799-804.

Rudolf, Volker HW, and Mark-Oliver Rödel. "Phenotypic plasticity and optimal timing of metamorphosis under uncertain time constraints." *Evolutionary Ecology* 21.1 (2007): 121-142.

Russell A, Powell G, Hall D (1996) Growth and age of Alberta long-toed salamanders (*Ambystoma macrodactylum krausai*): A comparison of two methods of estimation. *Canadian Journal of Zoology* 74: 397-412.

Rutz, David S. *Seasonal movements, age and size statistics, and food habits of Upper Cook Inlet northern pike during 1994 and 1995*. Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, 1996.

Rutz, David S. "Movements, Food Availability and Stomach Contents of Northern Pike in Selected Susitna River Drainages." (1999).

Ryder, O. A. 1986. Species conservation and systematics: the dilemma of subspecies. *Trends in Ecology and Evolution* 1:9-10.

Saccheri, Ilik, et al. "Inbreeding and extinction in a butterfly metapopulation." *Nature* 392.6675 (1998): 491-494.

Sanderson, Eric W., et al. "The Human Footprint and the Last of the Wild: The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not." *BioScience* 52.10 (2002): 891-904.

Sanzo, Domenico, and Stephen J. Hecnar. "Effects of road de-icing salt (NaCl) on larval wood frogs (*Rana sylvatica*)." *Environmental Pollution* 140.2 (2006): 247-256.

Sargent, J.C., A. Hutton, and J. Waatti. 2003. Discovery of the red-legged frog (*Rana aurora*) in northwest Chichagof Island: An introduced species. Tongass National Forest, Hoonah Ranger District, Hoonah, Alaska. unpublished report.

Scenarios Network for Alaska Planning (SNAP). 2008. Preliminary report to the Governor's subcabinet on climate change. SNRAS Pub. No. MP 2008-06, University of Alaska, Fairbanks.

Schadich, Ermin. "Skin peptide activities against opportunistic bacterial pathogens of the African clawed frog (*Xenopus laevis*) and three Litoria frogs." *Journal of Herpetology* 43.2 (2009): 173-183.

Schaub, David L., and John H. Larsen Jr. "The reproductive ecology of the Pacific treefrog (*Hyla regilla*)." *Herpetologica* (1978): 409-416.

Scherer, Rick D., et al. "An evaluation of weather and disease as causes of decline in two populations of boreal toads." *Ecological Applications* 15.6 (2005): 2150-2160.

Scherer, Rick D., Erin Muths, and Brad A. Lambert. "Effects of weather on survival in populations of boreal toads in Colorado." *Journal of Herpetology* 42.3 (2008): 508-517.

Scherer, RICK D., and JEFF A. Tracey. "A power analysis for the use of counts of egg masses to monitor wood frog (*Lithobates sylvaticus*) populations." *Herpetological Conservation and Biology* 6.1 (2011): 81-90.

Schindler, D.W. Widespread effects of climatic warming on freshwater ecosystems in North America. *Hydrol. Process.* 1997, 11, 1043-1067.

Schmetterling, David A., and Michael K. Young. "Summer movements of boreal toads (*Bufo boreas boreas*) in two western Montana basins." *Journal of herpetology* 42.1 (2008): 111-123.

Schmidt, K.B., 1953. A Checklist of North American Amphibians and Reptiles. Sixth Ed. American Society of Ichthyologists and Herpetologists, Chicago, viii-280 pp.

Schock, Danna M., et al. "Experimental evidence that amphibian ranaviruses are multi-host pathogens." *Journal Information* 2008.1 (2008).

Schock, Danna M., et al. "Amphibian chytrid fungus and ranaviruses in the Northwest Territories, Canada." *Diseases of aquatic organisms* 92.2-3 (2010): 231-240.

Schoff, Patrick K., et al. "Prevalence of skeletal and eye malformations in frogs from north-central United States: estimations based on collections from randomly selected sites." *Journal of wildlife diseases* 39.3 (2003): 510-521.

Schriever, T.A.; Ramspott, J.; Crother, B.I.; Fontenot, C.L., Jr. Effects of hurricanes Ivan, Katrina, and Rita on a southeastern Louisiana herpetofauna. *Wetlands* 2009, 29, 112-122.

Scott, William Beverley, and Edwin John Crossman. "Freshwater fishes of Canada." *Fisheries Research Board of Canada Bulletin* 184 (1973).

Scudder, Geoffrey GE, and Nicholas Gessler, eds. *The Outer Shores: Based on the Proceedings of the Queen Charlotte Islands First International Scientific Symposium, University of British Columbia, August 1984*. Queen Charlotte Islands Museum Press, 1989.

Seimon TA, Seimon A, Daszak P, Halloy SRP, Schloegel LM, AGUILAR CA, Sowell P, Hyatt AD, Konecky B, Simmons JE. 2007. Upward range extension of Andean anurans and chytridiomycosis to extreme elevations in response to tropical deglaciation. *Global Change Biology* 13: 288-299.

Semlitsch, R. D. 1985 Analysis of climatic factors influencing migrations of the salamander. *Ambystoma talpoideum*. *Copeia* 1985, 477-489.

Semlitsch, Raymond D. "Relationship of pond drying to the reproductive success of the salamander *Ambystoma talpoideum*." *Copeia* (1987): 61-69.

Semlitsch, Raymond D., David E. Scott, and Joseph HK Pechmann. "Time and size at metamorphosis related to adult fitness in *Ambystoma talpoideum*." *Ecology* 69.1 (1988): 184-192.

Semlitsch, R. D. "Conservation of pond-breeding amphibians." *Amphibian conservation* (2003): 8-23.

Semlitsch, Raymond D., Reid N. Harris, and Henry M. Wilbur. "Paedomorphosis in *Ambystoma talpoideum*: maintenance of population variation and alternative life-history pathways." *Evolution* (1990): 1604-1613.

Semlitsch, Raymond D. "Effects of different predators on the survival and development of tadpoles from the hybridogenetic *Rana esculenta* complex." *Oikos* (1993): 40-46.

Semlitsch, Raymond D., et al. "Salamander abundance along road edges and within abandoned logging roads in Appalachian forests." *Conservation Biology* 21.1 (2007): 159-167.

Semlitsch, Raymond D., et al. "Effects of timber harvest on amphibian populations: understanding mechanisms from forest experiments." *Bioscience* 59.10 (2009): 853-862.

Sexton, Owen J., and Sue R. Hunt. "Temperature relationships and movements of snakes (*Elaphe obsoleta*, *Coluber constrictor*) in a cave hibernaculum." *Herpetologica* (1980): 20-26. (Browne and Paszkowski 2010)

- SHAFER, AARON, et al. "Of glaciers and refugia: a decade of study sheds new light on the phylogeography of northwestern North America." *Molecular Ecology* 19.21 (2010): 4589-4621.
- Shaffer, M. L. "Minimum viable populations: coping with uncertainty." *Viable populations for conservation* 69 (1987): 86.
- Shoo, Luke P., et al. "Engineering a future for amphibians under climate change." *Journal of Applied Ecology* 48.2 (2011): 487-492.
- Sinsch, Ulrich. "Migration and orientation in anuran amphibians." *Ethology Ecology & Evolution* 2.1 (1990): 65-79.
- Sites, Jack W., and Keith A. Crandall. "Testing species boundaries in biodiversity studies." *Conservation Biology* 11.6 (1997): 1289-1297.
- SitNews. "Rare Find: Green Sea Turtle Found in Alaska." *Stories in the News*. 6 Dec. 2007. Web. 1 Aug. 2013. <http://www.sitnews.us/1207news/120607/120607_greenseaturtle.html>.
- Sjögren, P. E. R. "Extinction and isolation gradients in metapopulations: the case of the pool frog (*Rana lessonae*)." *Biological Journal of the Linnean society* 42.1-2 (1991): 135-147.
- Skelhorn, John, and Candy Rowe. "Taste-rejection by predators and the evolution of unpalatability in prey." *Behavioral ecology and sociobiology* 60.4 (2006): 550-555.
- Skelly, David K. "Pond drying, predators, and the distribution of *Pseudacris* tadpoles." *Copeia* (1996): 599-605.
- Skerratt, L.F.; Berger, L.; Speare, R.; Cashins, S.; McDonald, K.R.; Phillott, A.D.; Hines, H.B.; Kenyon, N. Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth* 2007, 4, 125-134.
- Skids, Dennis E., et al. "Habitat correlates of reproductive effort in wood frogs and spotted salamanders in an urbanizing watershed." *Journal of Herpetology* 41.3 (2007): 439-450.
- Slater, James R. "Notes on *Ambystoma gracile* Baird and *Ambystoma macrodactylum* Baird." *Copeia* 1936.4 (1936): 234-236.
- Slatkin, Montgomery. "Gene flow in natural populations." *Annual review of ecology and systematics* 16 (1985): 393-430.
- Slough, Brian G., and R. Lee Mennell. "Diversity and range of amphibians of the Yukon Territory." *The Canadian Field-Naturalist* 120.1 (2006): 87-92.
- Smith, David C. "Factors controlling tadpole populations of the chorus frog (*Pseudacris triseriata*) on Isle Royale, Michigan." *Ecology* (1983): 501-510.
- Smith, C. K., and J. W. Petranks. "Prey size-distributions and size-specific foraging success of *Ambystoma* larvae." *Oecologia* 71.2 (1987): 239-244.
- Smith, Winston P., Scott M. Gende, and Jeffrey V. Nichols. "Ecological correlates of flying squirrel microhabitat use and density in temperate rainforests of southeastern Alaska." *Journal of Mammalogy* 85.4 (2004): 663-674.
- Smith, AM., and David M Green. "Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations?." *Ecography* 28.1 (2005): 110-128.

- Smith, K. F., K. Acevedo-Whitehouse, and A. B. Pedersen. "The role of infectious diseases in biological conservation." *Animal Conservation* 12.1 (2009): 1-12.
- Snyder, Richard C. "Comparative features of the life histories of *Ambystoma gracile* (Baird) from populations at low and high altitudes." *Copeia* 1956.1 (1956): 41-50.
- Soltis, Douglas E., et al. "Chloroplast DNA intraspecific phylogeography of plants from the Pacific Northwest of North America." *Plant Systematics and Evolution* 206.1-4 (1997): 353-373.
- Soltis, Douglas E., et al. "Comparative phylogeography of unglaciated eastern North America." *Molecular Ecology* 15.14 (2006): 4261-4293.
- Spear, Stephen F., et al. "Landscape genetics of the blotched tiger salamander (*Ambystoma tigrinum melanostictum*)." *Molecular Ecology* 14.8 (2005): 2553-2564.
- Spencer, Brint. "The Wyoming toad SSP." *ENDANGERED SPECIES* 24.3 (1999): 19.
- Spotila, J.R. Role of temperature and water in the ecology of lungless salamanders. *Ecol. Monogr.* 1972, 42, 95-124.
- Sprules, W. Gary. "The adaptive significance of paedogenesis in North American species of *Ambystoma* (Amphibia: Caudata): an hypothesis." *Canadian Journal of Zoology* 52.3 (1974): 393-400.
- (b) Sprules, W. Gary. "Environmental factors and the incidence of neoteny in *Ambystoma gracile* (Baird)(Amphibia: Caudata)." *Canadian Journal of Zoology* 52.12 (1974): 1545-1552.
- Stebbins, Robert Cyril. *Amphibians of Western North America*. Univ of California Press, 1951.
- Stebbins, Robert Cyril. A field guide to Western reptiles and amphibians, 2nd Edition. 1985. Houghton-Mifflin Co., Boston.
- Stebbins, Robert Cyril, and Nathan W. Cohen. *A natural history of amphibians*. Princeton University Press, 1997.
- Stebbins, Robert Cyril. *A field guide to western reptiles and amphibians*. Houghton Mifflin Harcourt, 2003.
- Steiner, Todd, and Reuven Walder. "Two Records of Live Olive Ridleys from Central California, USA." *Marine Turtle Newsletter* 107 (2005): 9-10. Turtle Island Restoration Network. Web. 1 Aug. 2013.
<<http://www.seaturtle.org/mtn/archives/mtn107/mtn107p9.shtml>>.
- Stevens, Virginie M., et al. "Quantifying functional connectivity: experimental evidence for patch-specific resistance in the Natterjack toad (*Bufo calamita*)." *Landscape Ecology* 19.8 (2005): 829-842.
- Stevens, Virginie M., et al. "Gene flow and functional connectivity in the natterjack toad." *Molecular Ecology* 15.9 (2006): 2333-2344.
- Storey, K. B. "Freeze tolerance in the frog, *Rana sylvatica*." *Experientia* 40.11 (1984): 1261-1262.
- Storey, Kenneth B., and Janet M. Storey. "Lifestyles of the Cold and Frozen: Whether supercooled or stiff as icicles, some animals can survive the harshest winters. Their tricks may one day benefit diabetics and organ-transplant recipients." *SCIENCES-NEW YORK*- 39 (1999): 32-37.
- Storfer, Andrew. "Quantitative genetics: a promising approach for the assessment of genetic variation in endangered species." *Trends in Ecology & Evolution* 11.8 (1996): 343-348.

- Storm, Robert M. "Notes on the breeding biology of the red-legged frog (*Rana aurora aurora*).*" Herpetologica* 16.4 (1960): 251-259.
- Stroh, C.L.; DeSteven, D.; Guntenspergen, G.R. Effect of climate fluctuations on long-term vegetation dynamics in Carolina Bay wetlands. *Wetlands* 2008, 28, 17-27.
- Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. & Waller, R.W. (2004) Status and trends of amphibian declines and extinctions worldwide. *Science*, 306, 1783–1786.
- Summers, Kyle, and Mark E. Clough. "The evolution of coloration and toxicity in the poison frog family (Dendrobatidae).*" Proceedings of the National Academy of Sciences* 98.11 (2001): 6227-6232.
- Tallmon, David A., et al. "Genetic differentiation among long-toed salamander (*Ambystoma macrodactylum*) populations." *Journal Information* 2000.1 (2000).
- Taylor, Brynn, et al. "Proximity to pollution sources and risk of amphibian limb malformation." *Environmental Health Perspectives* 113.11 (2005): 1497.
- Taylor, B.E.; Scott, D.E.; Gibbons, J.W. Catastrophic reproductive failure, terrestrial survival, and persistence of the marbled salamander. *Conserv. Biol.* 2006, 20, 792-801.
- Taylor, Tamra Faris, and United States. Forest Service. Alaska Region. Wildlife and Fisheries Management Division. "Species list of Alaskan birds, mammals, freshwater and anadromous fish, amphibians, reptiles, and commercially important invertebrates." (1979).
- Templeton A, Georgiadis N (1996) A landscape approach to conservation genetics: Conserving evolutionary processes in the African bovidae. In Avise J, Hamrick J (eds), *Conservation Genetics: Case Histories from Nature*. Chapman and Hall, New York, New York 398-430
- Tessler D. 2009. Alaska Herpetofaunal Regulations. Pages 6. Anchorage, Alaska: Alaska Department of Fish and Game.
- Thomas, C.D.; Cameron, A.; Green, R.E. Extinction risk from climate change. *Nature* 2004, 427, 145-148.
- Thompson, Mark D., and Anthony P. Russell. "Glacial retreat and its influence on migration of mitochondrial genes in the long-toed salamander (*Ambystoma macrodactylum*) in Western North America." *Migration of Organisms*. Springer Berlin Heidelberg, 2005. 205-246.
- Tilman, D.; Fargione, J.; Wolff, B. Forecasting agriculturally driven global environmental change. *Science* 2001, 292, 281-284.
- Trenham, Peter C., Walter D. Koenig, and H. Bradley Shaffer. "Spatially autocorrelated demography and interpond dispersal in the salamander *Ambystoma californiense*." *Ecology* 82.12 (2001): 3519-3530.
- Twitty, Victor Chandler. *Of scientists and salamanders*. San Francisco: WH Freeman, 1966.
- Todd, Brian D., and Betsie B. Rothermel. "Assessing quality of clearcut habitats for amphibians: Effects on abundances versus vital rates in the southern toad (*Bufo terrestris*).*" Biological Conservation* 133.2 (2006): 178-185.
- Todd, B. D. & Winne, C. T. 2006 Ontogenetic and interspecific variation in timing of movement and responses to climatic factors during migrations by pond-breeding amphibians. *Can. J. Zool.* 84, 715–722.

Todd, Brian D., et al. "Climate change correlates with rapid delays and advancements in reproductive timing in an amphibian community." *Proceedings of the Royal Society B: Biological Sciences* 278.1715 (2011): 2191-2197.

Trombulak, Stephen C., and Christopher A. Frissell. "Review of ecological effects of roads on terrestrial and aquatic communities." *Conservation biology* 14.1 (2000): 18-30.

Twitty, Victor C. "Experiments on the phenomenon of paralysis produced by a toxin occurring in *Triturus* embryos." *Journal of Experimental Zoology* 76.1 (1937): 67-104.

Tyler, Torrey J., et al. "Experimental analysis of trout effects on survival, growth, and habitat use of two species of ambystomatid salamanders." *Journal of Herpetology* (1998): 345-349.

(b) Tyler, Torrey, et al. "Interaction between introduced trout and larval salamanders (*Ambystoma macrodactylum*) in high-elevation lakes." *Conservation Biology* 12.1 (1998): 94-105.

Tzedakis P, Lawson I, Frogley M, Hewitt G, Preece R (2002) Buffered tree population changes in a quaternary refugium: evolutionary implications. *Science* 297: 2044-2047

Ultsch, Gordon R., Christine V. Herbert, and Donald C. Jackson. "The comparative physiology of diving in North American freshwater turtles. I. Submergence tolerance, gas exchange, and acid-base balance." *Physiological zoology* (1984): 620-631.

Urban, Mark C. "Road facilitation of trematode infections in snails of northern Alaska." *Conservation Biology* 20.4 (2006): 1143-1149.

Urban, Mark C., et al. "The cane toad's (*Chaunus* [Bufo] *marinus*) increasing ability to invade Australia is revealed by a dynamically updated range model." *Proceedings of the Royal Society B: Biological Sciences* 274.1616 (2007): 1413-1419.

U.S. Department of Agriculture (USDA). 2003b. Tongass National Forest facts. (September 4, 2003 http://www.fs.fed.us/r10/tongass/forest_facts/resources/wilderness/sawld.html#Stikine%20%20Leconte%20Wilderness)

U.S. Department of Commerce. 1991. Interim policy on applying the definition of species under the Endangered Species Act to Pacific salmon. *Federal Register* 56:10542-10544.

U.S. Department of the Interior and U.S. Department of Commerce. 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. *Federal Register* 61:4722-4725.

U.S. Forest Service (USFS) 2005. Assessment of Invasive Species in Alaska and its National Forests August 30, 2005. Compiled by Barbara Schrader and Paul Hennon.

U.S. Global Change Research Program. 2009. Global climate change impacts in the United States. Cambridge University Press, New York. <http://downloads.globalchange.gov/usimpacts/pdfs/alaska.pdf>

U.S. Fish and Wildlife Service. Wildlife and Sportfish Restoration Program. 2012 *Apportionment*. N.p., 25 Jan. 2012. Web. 17 Aug. 2013. <<http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG2012Apportionment.pdf>>.

U.S. Fish and Wildlife Service. Wildlife and Sportfish Restoration Program. 2013 *SWG Funded Projects*. N.p., 2013. Web. 17 Aug. 2013. <<http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG2013FundedProjects.pdf>>.

Vasconcelos, Daniel, and Aram JK Calhoun. "Movement patterns of adult and juvenile *Rana sylvatica* (LeConte) and *Ambystoma maculatum* (Shaw) in three restored seasonal pools in Maine." *Journal of Herpetology* 38.4 (2004): 551-561.

Velichko, A. A., Yu M. Kononov, and M. A. Faustova. "The last glaciation of Earth: size and volume of ice-sheets." *Quaternary International* 41 (1997): 43-51.

Vincent Balland, Jagtar Bhatti, , Ruth Errington Mark Castonguay, and Paul A. Arp. "Modeling snowpack and soil temperature and moisture conditions in a jack pine, black spruce and aspen forest stand in central Saskatchewan (BOREAS SSA)." *Canadian journal of soil science* 86.Special Issue (2006): 203-217.

Vitousek, Peter M., et al. "Human domination of Earth's ecosystems." *Science* 277.5325 (1997): 494-499.

Vitt, Laurie J., et al. "Amphibians as harbingers of decay." *BioScience* 40.6 (1990): 418-418.

Vitt LJ, and Caldwell JP. 2009. Herpetology. Burlington, MA: Elsevier.

Vogler, Alfried P., and Rob Desalle. "Diagnosing units of conservation management." *Conservation Biology* 8.2 (1994): 354-363.

Vonesh, James R., and Omar De la Cruz. "Complex life cycles and density dependence: assessing the contribution of egg mortality to amphibian declines." *Oecologia* 133.3 (2002): 325-333.

Voyles, Jamie, et al. "Pathogenesis of chytridiomycosis, a cause of catastrophic amphibian declines." *Science* 326.5952 (2009): 582-585.

Waitt Jr, Richard B., and Robert M. Thorson. "The Cordilleran ice sheet in Washington, Idaho, and Montana." *Late-quaternary environments of the United States* 1 (1983): 53-70.

Walker IR, Pellatt MG (2003) Climate change in coastal British Columbia – A paleoenvironmental perspective. *Canadian Water Resources Journal* 28: 531- 566

Wake, D.B., E.L. Jockusch, and T.J.Papenfuss. 1998. Does *Batrachoseps* occur in Alaska? *Herpetological Review* 29:12-14.

Wake, D.B.; Vredenburg, V.T. Are we in the midst of the sixth mass extinction? A review from the world of amphibians. *Proc. Natl. Acad. Sci. USA* 2008, 105, 11466-11473.

Walls, Susan C., David G. Taylor, and Charlena M. Wilson. "Interspecific differences in susceptibility to competition and predation in a species-pair of larval amphibians." *Journal Information* 58.1 (2002).

Waples, R. S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the endangered species act. *Marine Fisheries Review* 53:11-22.

Waples, R. S. 1995. Evolutionarily significant units and the conservation of biological diversity under the Endangered Species Act. Pages 8-27 in J. L. Nielsen, editor. *Evolution and the aquatic ecosystem: defining unique units in population conservation*. Symposium 17. American Fisheries Society, Bethesda, Maryland.

Warne, Robin W., Erica J. Crespi, and Jesse L. Brunner. "Escape from the pond: stress and developmental responses to ranavirus infection in wood frog tadpoles." *Functional Ecology* 25.1 (2011): 139-146.

Wassersug, R.J.; Seibert, E.A. Behavioral responses of amphibian larvae to variation in dissolved oxygen. *Copeia* 1975, 1975, 86-103.

Wassersug, Richard J., and David G. Sperry. "The relationships of locomotion to differential predation on *Pseudacris triseriata* (Anura: Hylidae)." *Ecology*(1977): 830-839.

Waters, D. L. 1991. Phenology and habitat associations of amphibians in the Stikine River Corridor, Stikine Area, Tongass National Forest, Southeast Alaska, with notes on herpetofauna biogeography in the Alexander Archipelago. California Cooperative Fishery Research unit, Humboldt State University, Arcata.

Waters, D., 1992. Habitat associations, phenology, and biogeography of amphibians in the Stikine River Basin and Southeast Alaska. Unpubl. rep. of the 1991 pilot project. US Dept. Interior, Fish and Wildlife Service, California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA.

(b) Waters, D. L. 1992. *Pseudacris regilla* (Pacific chorus frog). *Herpetological Review* 23(l):24.

Waters, Dana L., Thomas J. Hassler, and Bradford R. Norman. "On the Establishment of the Pacific Chorus Frog, *Pseudacris regilla* (Amphibia, Anura, Hylidae), at Ketchikan, Alaska." *Bull. Chicago Herp. Soc.* 33.6 (1998): 124-27.

Watney, Gertrude M. Smith. "Notes on the life history of *Ambystoma gracile* Baird." *Copeia* (1941): 14-17.

Webb, T. I. I., and P. J. Bartlein. "Global changes during the last 3 million years: climatic controls and biotic responses." *Annual review of Ecology and Systematics* 23 (1992): 141-173.

Weldon, Ché, et al. "Origin of the amphibian chytrid fungus." *Emerging infectious diseases* 10.12 (2004): 2100.

Weir, L. A., and M. J. Mossman. "North American amphibian monitoring program (NAAMP)." *Amphibian declines: conservation status of United States species* (2005): 307-313.

Welborn, Gary A., David K. Skelly, and Earl E. Werner. "Mechanisms creating community structure across a freshwater habitat gradient." *Annual review of ecology and systematics* (1996): 337-363.

Weller, W. F., and D. M. Green. "Checklist and current status of Canadian amphibians." *Herpetological Conservation* 1 (1997): 309-328.

Wells, Kentwood D., and Catherine Robb Bevier. "Contrasting patterns of energy substrate use in two species of frogs that breed in cold weather." *Herpetologica* (1997): 70-80.

Wells, K.D. *The Ecology and Behavior of Amphibians*; The University of Chicago Press: Chicago, IL, USA, 2007.

Welsh, Hartwell H., Karen L. Pope, and Daniel Boiano. "Sub-alpine amphibian distributions related to species palatability to non-native salmonids in the Klamath mountains of northern California." *Diversity and Distributions* 12.3 (2006): 298-309.

Werner, E.E. Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation. *Amer. Nat.* 1986, 128, 319-341.

Werner, Earl E., and Bradley R. Anholt. "Predator-induced behavioral indirect effects: consequences to competitive interactions in anuran larvae." *Ecology* 77.1 (1996): 157-169.

Werner, Earl E., et al. "Comparative landscape dynamics of two anuran species: climate-driven interaction of local and regional processes." *Ecological Monographs* 79.3 (2009): 503-521.

Wetzel, Robert G. *Limnology: lake and river ecosystems*. Academic press, 2001.

- White, Marshall, and James A. Kolb. "A preliminary study of *Thamnophis* near Sagehen Creek, California." *Copeia* (1974): 126-136.
- Whitlock, Cathy. "Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: implications for understanding present-day biodiversity." *Northwest Environmental Journal* 8 (1992): 5-5.
- Wilbur, H.M.; Collins J.P. Ecological aspects of amphibian metamorphosis. *Science* 1973, 182, 1305-1314.
- Wilbur, Henry M. "Complex life cycles." *Annual review of Ecology and Systematics* 11 (1980): 67-93.
- Wilbur, H.M.; Alford, R.A. Priority effects in experimental pond communities: responses of *Hyla* to *Bufo* and *Rana*. *Ecology* 1985, 66, 1106-1114.
- Wilbur, H. M. 1997 Experimental ecology of food webs: complex systems in temporary ponds. *Ecology* 78,2279–2303.
- Wilcove, David S., et al. "Quantifying threats to imperiled species in the United States." *BioScience* 48.8 (1998): 607-615.
- Williams, D. W., and A. M. Liebhold. 2002. Climate change and the outbreak ranges of two North American bark beetles. *Agriculture and Forest Entomology*. 4:87-99.
- Williams, Becky L., Edmund D. Brodie Jr, and Edmund D. Brodie III. "Coevolution of deadly toxins and predator resistance: self-assessment of resistance by garter snakes leads to behavioral rejection of toxic newt prey." *Herpetologica* 59.2 (2003): 155-163.
- Williams, Becky L., Edmund D. Brodie Jr, and Edmund D. Brodie Iii. "A resistant predator and its toxic prey: persistence of newt toxin leads to poisonous (not venomous) snakes." *Journal of chemical ecology* 30.10 (2004): 1901-1919.
- Williams, Becky L., et al. "Tetrodotoxin affects survival probability of rough-skinned newts (*Taricha granulosa*) faced with TTX-resistant garter snake predators (*Thamnophis sirtalis*)." *Chemoecology* 20.4 (2010): 285-290.
- Williams T, Larsen J (1986) New function for the granular skin glands of the eastern long-toed salamander, *Ambystoma macrodactylum columbianum*. *Journal of Experimental Zoology* 239: 329-333
- Wind, E. L., and L. A. Dupuis. "COSEWIC status report on the western toad *Bufo boreas* in Canada." *COSEWIC assessment and status report on the western toad Bufo boreas in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa* (2002): 1-31.
- Wiseman, K. D., and A. C. Pool. "*Thamnophis couchii* (Sierra garter snake): Predator-prey interaction." *Herpetol Rev* 38 (2007): 344.
- Wright, Albert H., and Anna Allen Wright. "Handbook of frogs and toads of the USA and Canada." (1949): 135-216.
- Wittwer, D. 2002. Forest health protection report. Forest insect and disease conditions in Alaska – 2002. USDA Forest Service, Alaska Region, State and Private Forestry, Forest Health Protection. GTR R10-TP-113.
- Wright, R.F.; Schindler, D.W. Interaction of acid rain and global changes: effects on terrestrial and aquatic ecosystems. *Water Air Soil Poll.* 1995, 85, 89-99.

Yasumoto, Takeshi, and Mari Yotsu-Yamashita. "Chemical and etiological studies on tetrodotoxin and its analogs." *Toxin Reviews* 15.2 (1996): 81-90.

Yotsu, Mari, et al. "Production of tetrodotoxin and its derivatives by *Pseudomonas* sp. isolated from the skin of a pufferfish." *Toxicon* 25.2 (1987): 225-228.

Youngman, Phillip M. *Mammals of the Yukon territory*. No. 10. National Museum of Natural Sciences, National Museums of Canada, 1975.

Zachos, James C., Benjamin P. Flower, and Hilary Paul. "Orbitally paced climate oscillations across the Oligocene/Miocene boundary." *Nature* 388.6642 (1997): 567-570.

Zedler, Joy B., and Suzanne Kercher. "Wetland resources: status, trends, ecosystem services, and restorability." *Annu. Rev. Environ. Resour.* 30 (2005): 39-74.

Zeiber, Rebecca A., Trent M. Sutton, and Brant E. Fisher. "Western mosquitofish predation on native amphibian eggs and larvae." *Journal of Freshwater Ecology* 23.4 (2008): 663-671.

Zimmer, Kyle D., Mark A. Hanson, and Malcolm G. Butler. "Factors influencing invertebrate communities in prairie wetlands: a multivariate approach." *Canadian Journal of Fisheries and Aquatic Sciences* 57.1 (2000): 76-85.

APPENDIX

Table. 1. "Native species richness of amphibians, turtles, and reptiles in 10 northwestern states and provinces, ordered by species richness. Sea turtles are included in parentheses and totals. Species with uncertain ranges are excluded." Original image and description borrowed from Olson (2009).

State or Province	Amphibians		Turtles	Reptiles		Total
	Frogs/Toads	Salamanders		Snakes	Lizards	
No. California	12	21	1 (4)	17	11	66
Oregon	13	19	2 (4)	15	11	64
Washington	11	14	2 (4)	12	7	52
Wyoming	11	1	4	13	8	37
British Columbia	11	9	1 (4)	9	2	36
Idaho	8	4	1	12	10	35
Montana	9	4	3	10	4	30
Alberta	8	2	1	7	1	19
Alaska	3	3	0 (4)	0	0	10
Yukon Territory	4	0	0	0	0	4
Regional Total:	22	31	9	25	18	105

Table 2. The herpetofauna of Alaska. Abundance classifications derived from ADF&G (2006).

Native Alaska Herpetofauna						
	Species	Class	Order	Common Name	Origin	Abundance
1	<i>Anaxyrus boreas</i>	Amphibia	Anura	Boreal Toad	Native	Unknown
2	<i>Lithobates sylvaticus</i>	Amphibia	Anura	Wood Frog	Native	Common
3	<i>Rana luteiventris</i>	Amphibia	Anura	Columbian Spotted Frog	Native	Unknown
4	<i>Rana aurora</i>	Amphibia	Anura	Red-legged Frog	Introduced	Frequent, Island Isolated
5	<i>Pseudacris regilla</i>	Amphibia	Anura	Pacific Chorus Frog	Introduced	Infrequent, Island Isolated
6	<i>Ambystoma macrodactyla</i>	Amphibia	Caudata	Long-toed Salamander	Native	Unknown, Considered Rare
7	<i>Ambystoma gracile</i>	Amphibia	Caudata	Northwestern Salamander	Native	Unknown, Considered Rare
8	<i>Taricha granulosa</i>	Amphibia	Caudata	Rough-skinned Newt	Native	Common
9	<i>Dermochelys coriacea</i>	Reptilia	Testudines	Leatherback Seaturtle	Native	Infrequent in AK Waters
10	<i>Chelonia mydas</i>	Reptilia	Testudines	Green Seaturtle	Native	Infrequent in AK Waters
11	<i>Lipidochelys olivacea</i>	Reptilia	Testudines	Olive-Ridley Seaturtle	Native	Infrequent in AK Waters
12	<i>Caretta caretta</i>	Reptilia	Testudines	Loggerhead Seaturtle	Native	Infrequent in AK Waters
13	<i>Batrachoseps caudatus</i>	Amphibia	Caudata	Alaska Worm Salamander	Enigmatic	Unknown
14	<i>Thamnophis sirtalis</i>	Reptilia	Squamata	Common Garter Snake	Enigmatic	Unknown

Table 3. Marine turtle occurrences in Alaska waters, 1960-1998. Table borrowed from Hodge and Wing (2000).

Date	Location	Lat. (N)	Long. (W)	Comments
<i>Lepidochelys olivacea</i>				
Jan-86	Cannon Beach	59.50	139.75	Carcass
Jun-91	S. of Ketchikan	55.33	131.63	Carcass
<i>Caretta caretta</i>				
Dec-91	Shuyak Island	58.52	152.50	Carcass
Jul-93	Cape Georgena	57.33	135.87	Sighting
<i>Chelonia mydas</i>				
Oct-76	Point Macartney	57.00	134.05	Sighting
Nov-76	Eliza Harbor	57.20	134.28	Carcass
Sep-81	Dundas Island, B.C.*	54.50	130.67	Repeated sightings
Oct-93	Seldovia	59.50	151.72	Sighting
Oct-93	Homer (Bishop Beach)	59.67	151.67	Carcass
Oct-96	Rocky Pass	56.65	133.72	Sighting
Oct-96	Copper River Flats	60.42	145.00	Live-sent to San Diego
May-98	Blacksand Spit	59.38	139.43	Carcass
Oct-98	Ocean Cape	59.53	139.85	Carcass
Unidentified Hard Shell				
Aug-74	Kachemak Bay	59.67	151.62	Sighting
Aug-79	Marmot Bay	58.00	152.10	Sighting
<i>Dermochelys coriacea</i>				
Aug-63	Stephens Passage	58.07	134.02	Sighting
Sep-63	Copper River Flats	60.42	145.00	Netted & killed
Jul-78	Eaton Point	55.93	132.07	Netted & released
Aug-78	Craig	55.47	133.05	Netted & killed
Aug-78	Craig	55.47	133.05	Netted & released
Aug-78	Gravina Island	55.45	131.85	Sighting
Aug-78	Myer's Chuck	55.72	132.27	Sighting
Aug-79	Union Bay	55.82	132.22	Netted & released
Aug-79	Metlakatla	55.13	131.58	Netted & killed
Mar-83	Perryville	55.97	159.47	Carcass
Jul-83	Yakutat	59.00	139.00	Sighting
Aug-83	Noyes Island vicinity	55.00	134.00	Sighting
Aug-83	Cape Cross	57.92	136.57	Sighting
Aug-83	Deer Hbr., Yakobi Is.	57.95	136.58	Sighting, 2 individuals
Aug-83	Glacier Bay entrance	58.33	136.00	Sighting
Aug-84	Cape Addington	56.43	133.83	Sighting
Jan-90	Yakutat	59.50	139.65	Carcass
Jul-93	Vitskari Strait	57.00	135.80	Sighting
Aug-93	Vitskari Rocks	57.00	135.55	Sighting

*Dundas Island, British Columbia is 11 km south of the international boundary.

Table 4. A selection of important herpetological sampling efforts in Alaska.

Principal Investigator(s)	Affiliation	Target Species	Research Topic	Primary Location	Strategy	Years
Robert Parker Hodge	Self Interest	All Herpetofuana	Species Diversity and Distribution	Statewide	Opportunistic	1970-1987
Dana Waters	Humboldt State University	All Herpetofuana	Species Diversity and Distribution	Stikine River Region	Systematic	1991
Bradford Norman	Humboldt State University	All Herpetofuana	Species Diversity and Distribution	Southeast, Alaska	Opportunistic & Systematic	1992
Mary Reeves and Margaret Perdue	U.S. Fish and Wildlife Service	Wood Frog	Distribution, Abundance, Habitat, Disease, Malformations	Arctic, Innoko, Kenai, Tetlin, Yukon Delta N.W.R.s	Systematic	2000-2006
Mary Reeves and Margaret Perdue	U.S. Fish and Wildlife Service	Wood Frog	Distribution, Abundance, Habitat, Disease, Malformations	Kenai N.W.R.	Systematic	2000-2012
Richard Carstensen et al.	Discovery Southeast	All Herpetofuana	Distribution, Abundance, Habitat	Juneau Area	Systematic	2002-2003
Blaine Anderson	U.S. Park Service	All Herpetofuana	Species Diversity and Distribution	National Parks in Alaska	Opportunistic	2001-2003
D. Grant Hokit and Andrew Brown	Carroll College, Montana	Wood Frog	Distribution Patterns	Denali National Park & Preserve	Systematic	2003-2004
Sanjay Pyare	University of Alaska Southeast	Boreal Toad	Distribution, Breeding Site Occupancy, Microhabitat	Glacier Bay, Alaska	Systematic	2004
Lance Lerum & Robbie Piehl	U.S. Forest Service	Red-legged Frogs	Distribution	Chichagof Island	Systematic	2006
David Tessler & Marian Snively	Alaska Dept. of Fish and Game	Wood Frog	Distribution, Breeding Phenology, Population Trends	Statewide	Opportunistic	2002-2013
Joshua Ream	University of Alaska Fairbanks	All Herpetofuana	Species Diversity and Distribution	Stikine River Region	Opportunistic & Systematic	2010-2013

Table 5. Phenological reconstruction for the amphibians of the Stikine Area of the Tongass National Forest in 1991. Incomplete data on the timing of metamorphosis should be noted. Figure borrowed from Waters (1992).

	Northwestern Salamander ¹	Long-Toed Salamander ²	Rough-Skinned Newt ³	Western Toad ⁴	Spotted Frog ⁵	Wood Frog ⁶
January			HIBERNATION			
February			HIBERNATION			
March			EMERGENCE			
April		BREEDING			BREEDING	BREEDING
May	BREEDING		BREEDING	BREEDING		
June			BREEDING	BREEDING		META-MORPHOSIS
July				META-MORPHOSIS	META-MORPHOSIS	META-MORPHOSIS
August				META-MORPHOSIS		
September						
October			HIBERNATION			
November			HIBERNATION			
December			HIBERNATION			

¹ Northwestern Salamander (*Ambystoma gracile*)
² Long-Toed Salamander (*Ambystoma macrodactylum*)
³ Rough-Skinned Newt (*Taricha granulosa*)
⁴ Western Toad (*Bufo boreas*)
⁵ Spotted Frog (*Rana pretiosa*)
⁶ Wood Frog (*Rana sylvatica*)

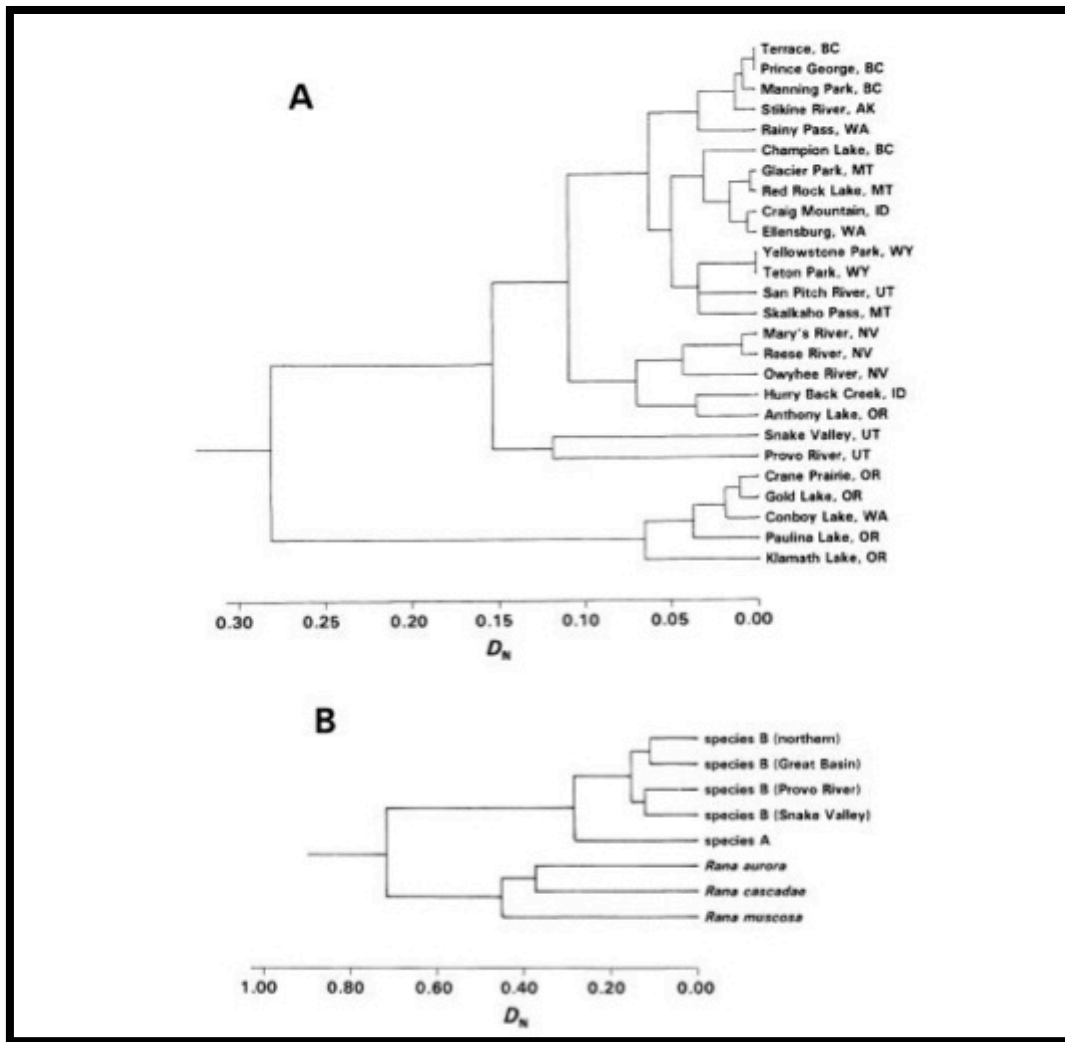


Fig 1. "UPGMA trees of D_N . (A) Relationships between populations of the *Rana pretiosa* [and *Rana luteiventris*] complex. (B) Relationships between the major taxa and subdivisions of the *R. pretiosa* complex to related outgroup species." Original image and description borrowed from Green et al. (1996).

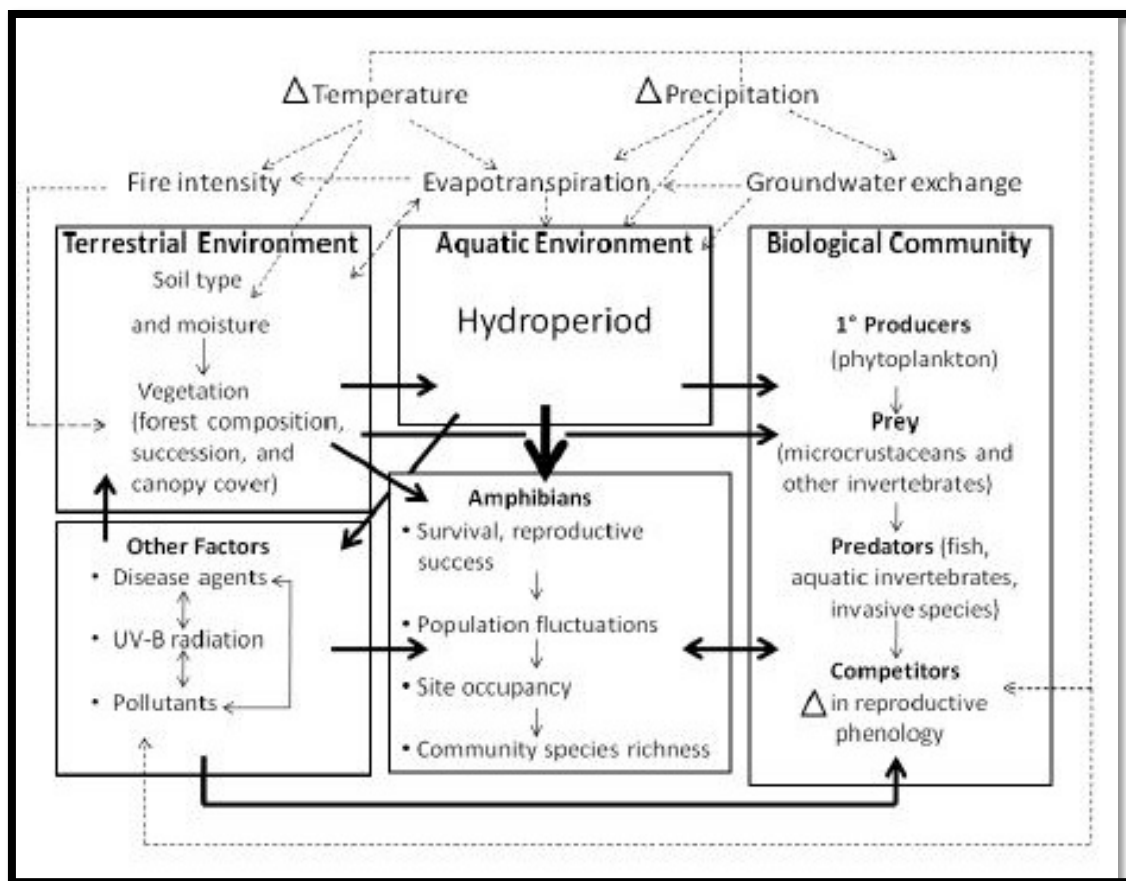


Fig. 2. “Conceptual model of pathways through which changes in temperature and precipitation may impact amphibian populations using a generalized freshwater ecosystem as an example. Changes in temperature and precipitation affect amphibians via the effects of climate on terrestrial and aquatic habitats, the biological community in which amphibians are embedded, and other factors such as disease agents, UV-B radiation and pollution. Factors that influence the availability of water, such as the hydroperiod of aquatic habitats, are likely the most important constraints on the reproductive success and persistence of amphibians (indicated by heavier arrow). Dashed arrows indicate interactions among meteorological variables, and their effects on biological communities and the environment in which they occur. Heavy solid arrows indicate relationships among compartments; light solid arrows indicate relationships within compartments.” Original image and description borrowed from Blaustein et al. (2010).



Fig. 3. Northwestern Salamander, *Ambystoma gracile* specimen collected on 12 September 1895 by the USS Albatross Expedition at Mary Island, Alaska. Now at the Smithsonian Institute's (SI) National Museum of Natural History, Department of Vertebrate Zoology, as record number USNM 36338. Photo courtesy of SI Collections Manager Jeremy F. Jacobs on 12 August 2013.



Fig. 4. Northwestern Salamander, *Ambystoma gracile* specimen collected on 12 September 1895 by the USS Albatross Expedition at Mary Island, Alaska. Now at the Smithsonian Institute's (SI) National Museum of Natural History, Department of Vertebrate Zoology, as record number USNM 36338. Photo courtesy of SI Collections Manager Jeremy F. Jacobs on 12 August 2013.



Fig. 5. Northwestern Salamander, *Ambystoma gracile*, collected by Matt and Adrianna Cahill, 28 September 2006 near Pelican, Alaska.

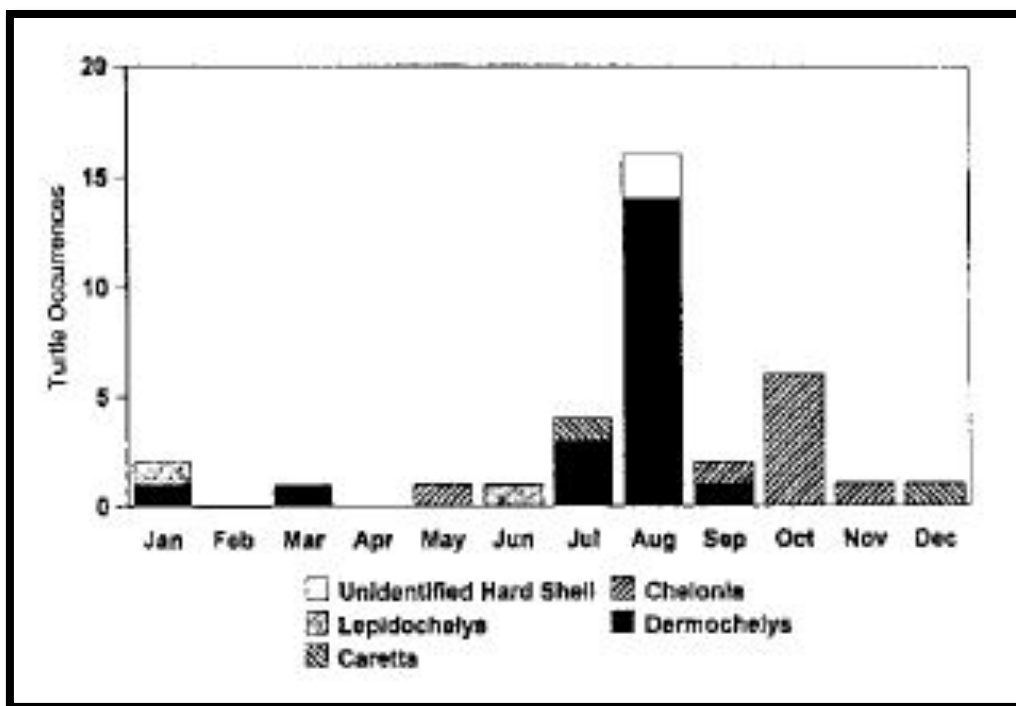


Figure 6. Seasonal distribution of marine turtle occurrences in Alaska waters, 1960-1998. Image borrowed from Hodge and Wing (2000).

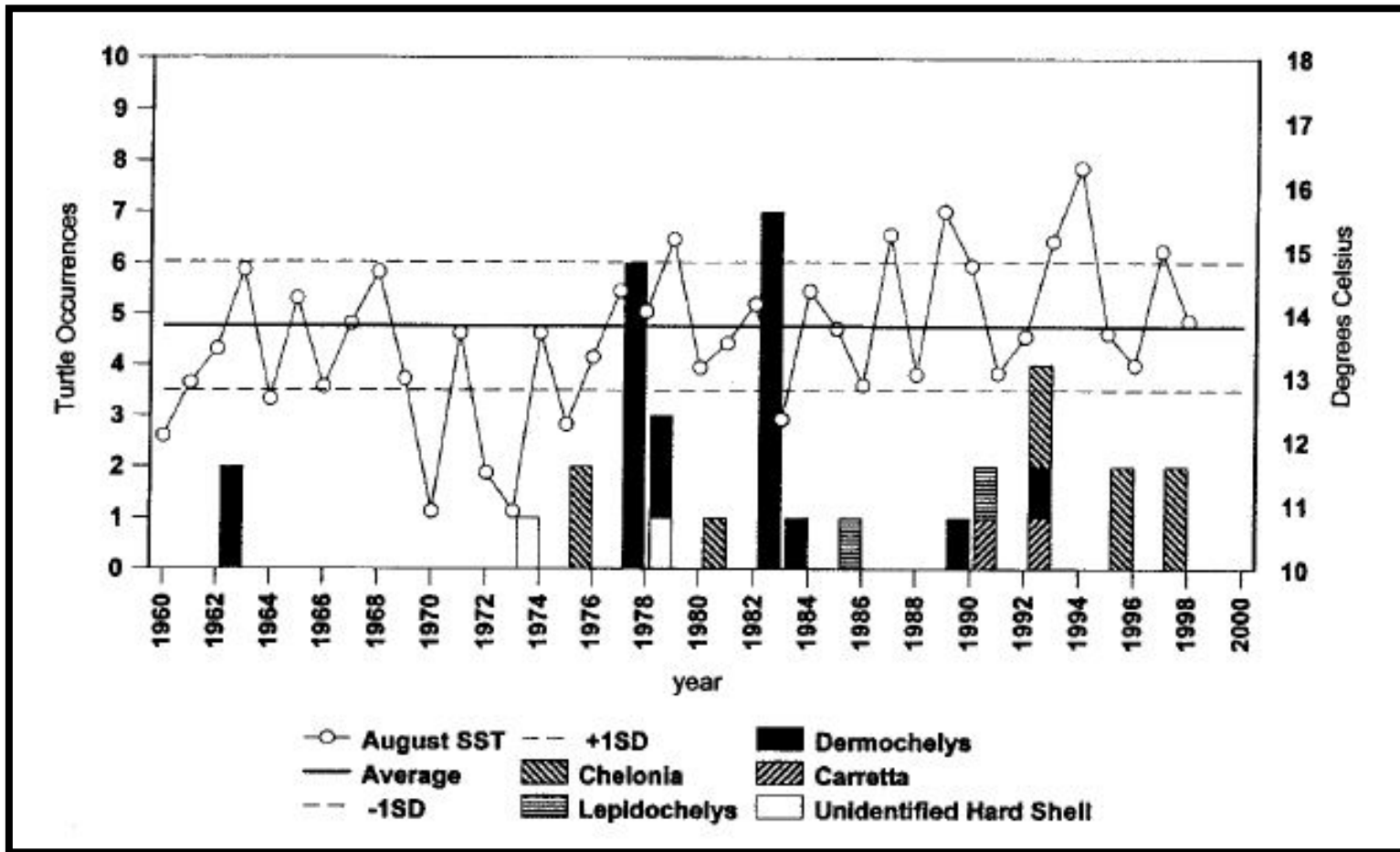


Figure 7. Annual distribution of marine turtle occurrences in Alaska waters and annual variation of August sea surface temperatures at Auke Bay, Alaska; 1960-1998. Image borrowed from Hodge and Wing (2000).

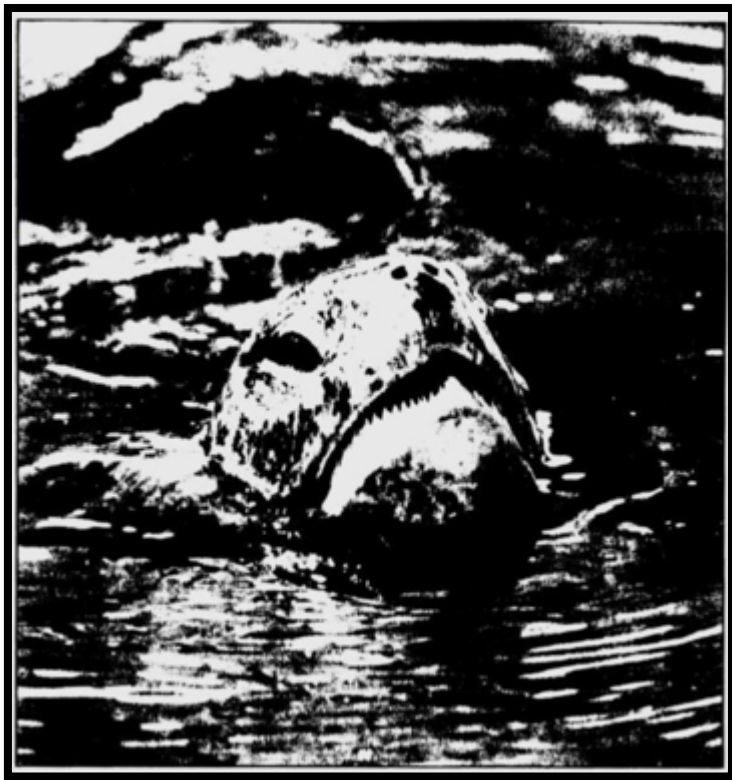


Fig. 8. Photograph of a Green Sea Turtle, *Chelonia mydas*, recovering at Hubbs' SeaWorld Research Institute in San Diego, California after being captured on Montague Island, Alaska by Jerry and Pat O'Brien on 9 October 1996 (Associated Press 1996).



Fig. 9. Remains of a Green sea turtle, *Chelonia mydas*, discovered on Gravina Island near Ketchikan by resident Mary Hert on 2 December 2007. (Photo taken by NOAA Enforcement)



Fig. 10. Remains of a Green Sea Turtle, *Chelonia mydas*, located by Dennis Diamond at Bond Bay, Alaska on 3 December 2010 (ADF&G 2011).



Fig. 11. Remains of a Green Sea Turtle, *Chelonia mydas*, located by Dennis Diamond at Bond Bay, Alaska on 3 December 2010 (ADF&G 2011). Photo taken after it was transported to Ketchikan.



Fig. 12. Remains of a Green Sea Turtle, *Chelonia mydas*, located by Dennis Diamond at Bond Bay, Alaska on 3 December 2010 (ADF&G 2011). Photo taken after it was transported to Ketchikan.



Figure 13. Northwestern Garter Snake, *Thamnophis ordinoides*, specimen collected in Haines, Alaska in 2005 (UAM, 21 August 2005).



Figure 14. Holotype of the Alaskan Worm Salamander, *Batrachoseps caudatus*, taken by Henry Nichols from Hassler Harbor, Annette Island, Alaska in December (or August) of 1881. Currently preserved in ethanol at the Smithsonian Institute's U.S. Museum of Natural History, Washington, D.C. (USNM 13561; Smithsonian 1881).

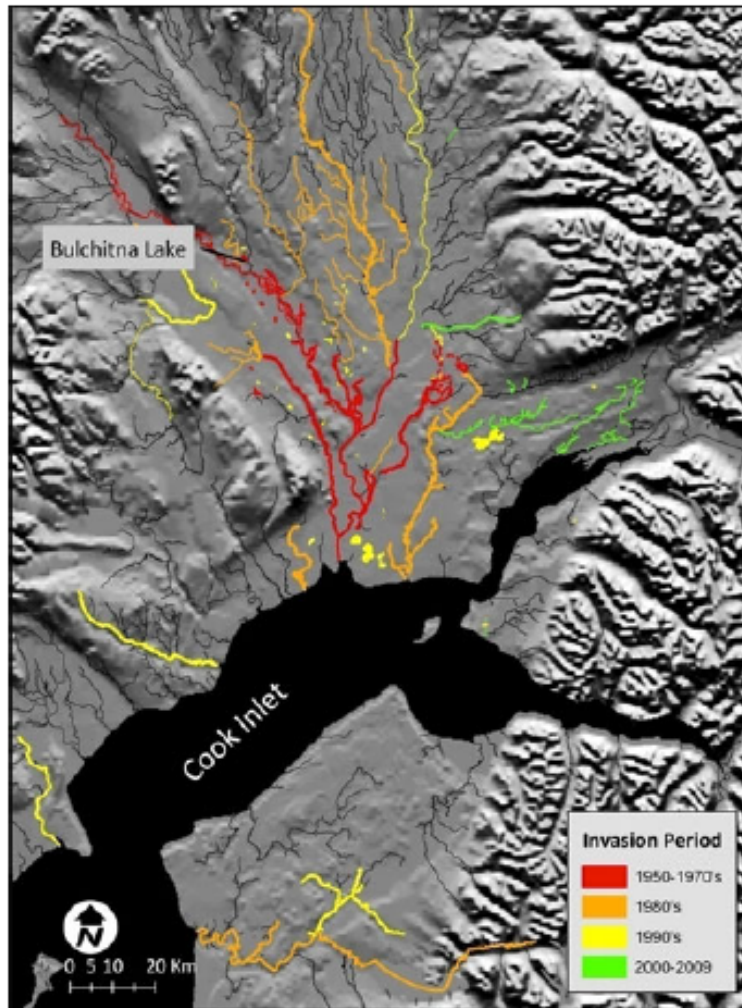


Fig. 15. Map depicting the approximated invasion of Northern Pike, *Esox lucius*, to southcenral Alaska following its suspected illegal introduction at Bulchitna Lake in the 1950s. Map borrowed from Haught and von Hippel (2011).



Fig. 16. A dissected invasive Northern Pike, *Esox lucius*, collected and photographed by Samuel Ivey, Northern & West Cook Inlet Area Management Biologist with ADF&G, at Alexander Creek, Alaska. Stomach contents contained five adult Wood Frogs, *Lithobates sylvaticus*, in various stages of decay following predation.

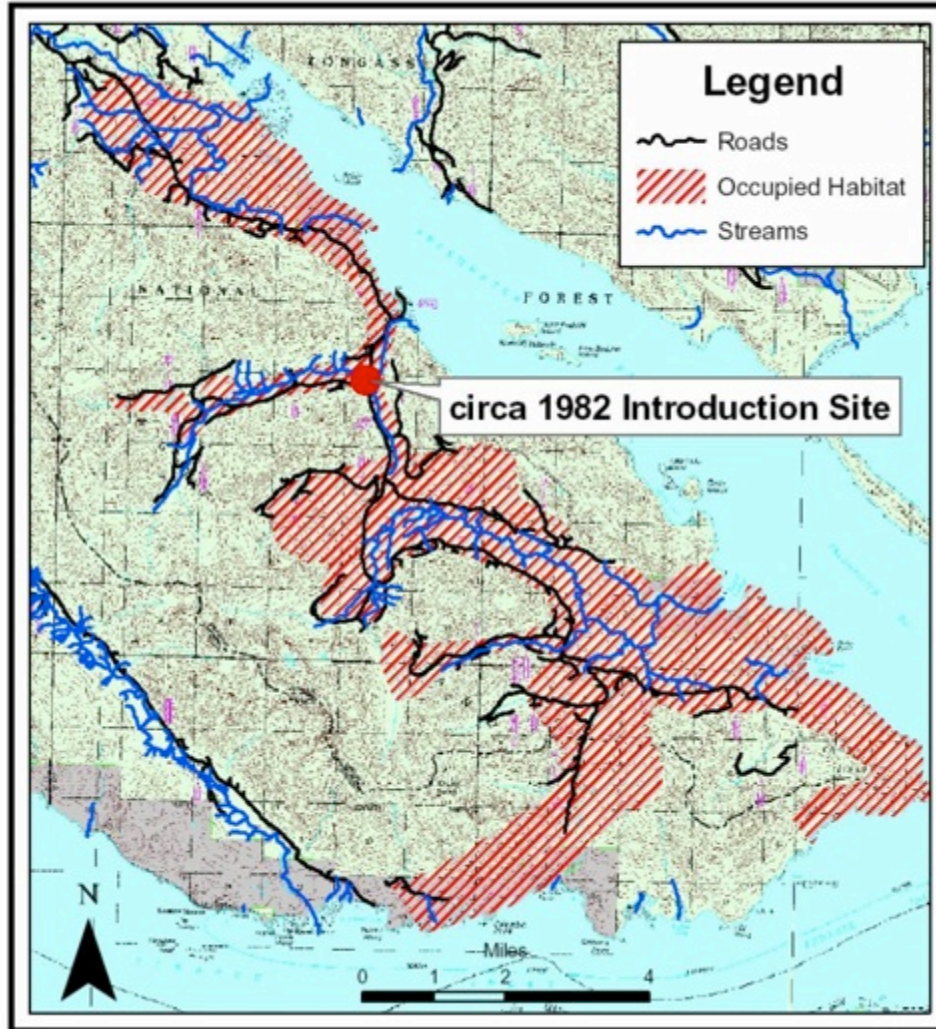


Fig. 17. Map depicting the 1982 introduction site of the Northern Red-legged Frog, *Rana aurora*, to Chichagof Island, Alaska, and its subsequent range expansion and distribution as of 2006. Image borrowed from Lerum and Piehl (2007).