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Conservation Assessment for the Northern Leopard Frog in the Black Hills National Forest South Dakota and Wyoming

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of the

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INTRODUCTION

The northern leopard frog, *Rana pipiens*, is a widespread and formerly abundant frog that had one of the largest ranges of any amphibian in North America (Stebbins, 1985; Conant and Collins, 1991). As early as the 1960s (Gibbs et al. 1971), the northern leopard frog began to decline in abundance throughout large portions of its range (see "Population trend", pp. 4-6). Various factors have been invoked to explain these declines including habitat destruction, diseases, chemical contamination, acidification, increased ultraviolet light due to loss of the ozone layer, introduced predators, overcollecting, climatic changes, and general environmental degradation. Any one of these factors or combinations thereof seem to have been important in different parts of the range but the specific causes of the declines remain poorly known in most cases (Corn, 1994; Blaustein and Wake, 1995; Alford and Richards, 1999). The northern leopard frog is not necessarily declining in all portions of its range, either. Recent surveys in the Black Hills and surrounding regions have found them to be common (Smith et al., 1996a, b; Smith et al., 1998). Since amphibians that breed in ponds, like the northern leopard frog, tend to be exposed to all sorts of environmental contaminants, they have sometimes been seen as "canaries in a coal mine" that warn of environmental disaster. Basically, anything put into the environment runs into these ponds and can eventually pass into an amphibian's body through their highly permeable skin.

The northern leopard frog is a more or less typical pond-breeding amphibian that overwinters underwater beneath the ice of streams and lakes or larger ponds, then comes out relatively early in the spring season to breed. It is usually one of the first frogs to be found breeding in the Black Hills, soon after the emergence of the chorus frog, *Pseudacris triseriata*, and probably breeds in May or June in the area depending on the elevation and weather (personal observations). Like most temperate zone anurans, eggs and sperm are shed into the water and egg masses can be found in clumps in smaller (ca. <5 ha) seasonal and semi-permanent ponds. Females immediately leave the ponds to spend the summer foraging in upland habitat around breeding ponds while males stay at ponds as long as possible calling in a breeding chorus to attract and breed with more females. Males also leave the ponds at some point to forage for the summer in upland habitats around the breeding ponds. Both sexes can be found far from water during the summer.

Tadpoles spend two to three months developing in natal ponds then metamorphose into young frogs. They may spend much of their time following metamorphosis foraging around natal ponds, but sometimes mass migration events have been observed in which these young frogs may move to other ponds. Young of the year and older frogs migrate to overwintering sites probably in October in the Black Hills, again depending on elevation and weather. The frogs are known use larger ponds, lakes, and streams in which to overwinter. There is apparently very high mortality in the tadpole and metamorph stages and also in the young subadults that are overwintering for their first time. In some parts of their range, and probably in the Black Hills as well, frogs take two to three years to mature. Sexually mature females may breed once each spring for two or three years. In the wild, northern leopard frogs probably do not live past five or six years. They are a typical r-selected animal, with few reproductive seasons, high potential growth rates, and high mortality rates as eggs and in the earlier life stages.

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CURRENT MANAGEMENT SITUATION

Management Status

The northern leopard frog has no special status in most states. However, several states near the periphery of the range accord the species special status. The species is considered of special concern in Idaho, Colorado, Indiana, and Connecticut. Montana considers the species endangered on the western side of the continental divide and of special concern to the east. Northern leopard frogs are protected in Oregon and endangered in Washington. Across Canada, the species is of special concern, which is a status that affords them protection in this country.

The United States Department of Agriculture Forest Service, Rocky Mountain Region (Region 2), considers the northern leopard frog a sensitive species. The Natural Heritage Network considers the species G5 (globally secure). The Natural Heritage Database of South Dakota ranks the species S5 (secure within the state of South Dakota, though it may be quite rare in parts of its range, especially at the periphery). The Wyoming Natural Diversity Database lists the species as S3 (rare or local throughout its range in the state, or found locally within a restricted range; from 21 – 100 occurrences within the state). It has no other special federal status or other special state status within the states of Wyoming or South Dakota.

Existing Management Plans, Assessments, Or Conservation Strategies

There is one management plan in existence for the northern leopard frog (Seburn, 1992; cited in Fisher, 1999), but I have not been able to locate a copy of this plan. Maxell (2000) covers some aspects of the management of the northern leopard frog as part of a more general publication on the management of the 14 species of amphibians found in the national forests of Montana.

REVIEW OF TECHNICAL KNOWLEDGE

Systematics

Pace (1974) includes a synonymy of names applied to the leopard frog complex, including *Rana pipiens*. The name *R. pipiens* was first applied by Schreber in 1782, based on a leopard frog sent to him from New York (Schreber 1782, cited in Pace, 1974). Using biochemical techniques, Hillis et al. (1983) resolved the phylogeny of the Alpha and Beta groups of the *R. pipiens* complex. *Rana pipiens*, along with *R. blairi*, *R. sphenocephala*, and *R. berlandieri*, falls within the Beta division. The Alpha division contains *R. palustris*, *R. capito*, and *R. areolata*. Hillis (1988) further reviewed the literature and provided range maps of all the North American leopard frogs referred to the *R. pipiens* complex, including the northern leopard frog. Dunlap and Platz (1981) discussed areas of hybridization deduced through calling variation in the upper midwest. Lynch (1978) discussed the distribution of the northern leopard frog and the Plains leopard frog (*R. blairi*) and zones of sympatry of the two species in Nebraska. Dunlap and Kruse (1976) discussed the distribution of the "northern" (*R. pipiens*) and "western" (*R. blairi*) "morphotypes" (now known as two distinct species) in the northern and central Plains states. From the discussion of Dunlap and Kruse (1976) it is clear that a zone of hybridization between *R. pipiens* and *R. blairi*, if a hybrid zone exists in South Dakota, is far to the east of the Black Hills near the Missouri River. All the leopard frogs studied by Dunlap and Kruse (1976) from the Black Hills are clearly assigned to *R. pipiens*. Although none of these authors have studied the leopard frogs of the Black Hills of Wyoming these can also unequivocally be assigned to the species *R. pipiens*.

Distribution And Abundance

The northern leopard frog is basically a species of cooler climates, with a range that encompasses most of the northern states of the United States and far north into Canada. The species ranges southwards only in the western United States, in the higher elevations of the Rocky Mountains. Figure 1 shows the extent of their historical range, as reported by Stebbins (1985), Hillis (1988), and Conant and Collins (1991). Table 1 lists the states and provinces in which the northern leopard frog is found, historical abundance (if known), present abundance (if known), and the population trend (where known). A few facts are worth noting. The distribution in Washington was historically spotty (Leonard et al., 1999), and this probably has made it difficult to determine population trends. Localized extinctions have occurred across the range. In Alberta the range of the northern leopard frog north of 55°N latitude is poorly known (Russell and Bauer, 1993). The northern extent of the range in Canada is poorly known in general (Russell and Bauer, 1993). Northern leopard frogs have been found up to 3355 m in southern Colorado (Hammerson, 1999) and up to 2700 m in the mountains of Wyoming (Baxter and Stone, 1985). Northern leopard frogs range throughout the Black Hills and are found at all elevations (Peterson, 1974; B. Smith, unpublished data).

Rana pipiens has been introduced to a variety of areas. Populations in Newfoundland and on Vancouver Island, British Columbia were introduced (Buckle, 1971; Green and Campbell, 1984). California populations may also be introduced (Bury and Luckenbach, 1976; Jennings, 1984).

Northern leopard frog distribution has been poorly studied in the Black Hills as well. Peterson (1974) conducted a wide-ranging reptile and amphibian survey throughout the Black Hills and I have surveyed reptiles and amphibians in the lower elevations of the Black Hills (Smith et al., 1996a) and plains and Badlands surrounding the Black Hills (Smith et al., 1996b). Only one recent survey has been completed in a small portion of the northern Black Hills (Smith et al., 1998). I keep an historical database that lists 207 specimens that have been collected in the Black Hills and surrounding plains (unpublished data). Peterson (1974) found them to be abundant in the Black Hills. He found them in shallow water in beaver ponds, stock ponds, streams, and marshy areas. A study at Wind Cave National Park found no northern leopard frogs on the park due to lack of suitable habitat, but some specimens were reported from Custer State

Park, immediately north of Wind Cave National Park (Smith et al., 1996a). Studies on the plains revealed that northern leopard frogs were common on the Fall River Ranger District immediately southeast of the Black Hills and on Badlands National Park (Smith et al., 1996b). Northern leopard frogs were found to be common at suitable sites in the northern Black Hills of South Dakota by Smith et al. (1998), but they also noted that northern leopard frogs appeared to be threatened by cattle grazing, introduced predaceous fish, and the general decline of wetland acreage across the Black Hills (Parrish et al., 1996).

I have found northern leopard frogs to be common in suitable habitats as reported by Peterson (1974) but they were missing from some sites collected by Peterson (1974) and others (unpublished historical database), where introduced predaceous fish are now abundant. Northern leopard frogs have not been systematically surveyed anywhere in the Black Hills since 1998. There has never been a complete survey of northern leopard frogs in the Black Hills, except for a localized area around Spearfish, South Dakota (Smith et al., 1998). The Bear Lodge Mountains of Wyoming were spottily surveyed by Peterson (1974). Although considered common in the Black Hills, Badlands, and surrounding plains (Peterson, 1974; Smith et al., 1996a, b; 1998), the species should be considered vulnerable since several risk factors including loss of beaver pond habitat (Parrish et al., 1996), introduced predaceous fish, general wetland loss, cattle grazing, and road construction (Nash et al., 1970), are all present in the Black Hills.

Population Trend

The northern leopard frog was formerly abundant across its range but has suffered wide-ranging population declines. In the western United States the species has undergone major declines or has become locally extinct. It is locally extinct west of the Continental Divide in Montana except for two population centers, one near Kalispell and one near Eureka (Maxell, 2000). It is largely absent from central Montana where northern leopard frogs were found at only nine of 47 historical sites in the mid-1990s (Maxell, 2000). It is declining in some parts of eastern Montana (Reichel, 1996). Northern leopard frogs have apparently gone extinct in the Targhee National Forest of western Wyoming and adjacent Idaho (Koch and Peterson, 1995). Northern leopard frogs are severely reduced in the Laramie Basin of Wyoming but may still be common in other parts of the state (Baxter and Stone, 1985; Stebbins and Cohen, 1995). Northern leopard frogs have become scarce at many sites in Colorado (Hammerson, 1999). Corn and Fogleman (1984) documented extinctions at nine high elevation sites in Colorado. Northern leopard frogs have also gone extinct or become severely reduced at low elevation sites in Colorado (Hammerson, 1982; Cousineau and Rogers, 1991). Clarkson and Rorabaugh (1989) surveyed 13 of the 28 historical localities known in Arizona. They found that the northern leopard frog was absent from all of these localities and present at only one previously unreported locality in the White Mountains. It is now absent from its historic range in California, except for a few small populations in northeastern California (Stebbins and Cohen, 1995). Leonard et al. (1999) visited 27 historical collecting localities in eastern Washington and found populations at only three of them. The species was formerly common throughout the central Plains states but has declined there as well (Stebbins and Cohen, 1995).

In the upper Midwest, northern leopard frogs are generally thought to be less abundant than in the past. Moriarty (1998) found them to be widespread across Minnesota but much less common than historical records indicated. Hine et al. (1975, 1981) documented a decline of northern leopard frogs in Wisconsin in the 1970s. Mossman et al. (1998) reported that northern leopard frogs underwent a further decline in Wisconsin from 1984 – 1995, although they were still common in the state. Casper (1998) reported that some investigators believed that they saw a partial rebound after 1985. Dhuey and Hay (2000) reported that they were rare in Wisconsin. To sum up Wisconsin data, they are probably far below historical population levels (Casper, 1998; Mossman et al., 1998). Collins and Wilbur (1979) noted that northern leopard frogs had become rare on their study site near Ann Arbor, Michigan, during the previous 20 years.

Recent estimates of the abundance of northern leopard frogs in the Midwestern United States are found in Lannoo (1998a). Orr et al. (1998) found them still abundant in northeastern Ohio. However, Davis et al. (1998) found northern leopard frogs to be rare or extinct (most populations) in Hamilton County, Ohio, the county in which Cincinnati is located. Mierzwa (1998) also found them to be common in northeastern Illinois. Brodman and Kilmurry (1998) reported that they were rare or uncommon at their study sites in northwestern Indiana. The state of Indiana lists them as a species of special concern. Minton (1998), writing from a perspective of 45 years of collecting in Indiana, stated that northern leopard frog populations have declined markedly since 1948. Lannoo et al. (1994) wrote that northern leopard frog populations had probably declined across Iowa by two to three orders of magnitude over historical levels. Hemesath (1998) was unable to determine whether there had been further declines in Indiana based on calling survey data.

Canadian populations are discussed in Green (1997) and Bishop and Pettit (1992). The distribution and abundance of the northern leopard frog is poorly known for many parts of Canada (Russell and Bauer, 1993; Fournier, 1997; Maunder, 1997; Mennell, 1997). They are rare in the Northwest Territories (Fournier, 1997). Northern leopard frogs are found in Saskatchewan but are insufficiently known there to assess abundance or population trends (Didiuk, 1997). The northern leopard frog has declined in abundance in British Columbia (Orchard, 1992). It is now extinct or rare throughout much of Alberta (Roberts, 1992; Russell and Bauer, 1993; Stebbins and Cohen, 1995). They are common in New Brunswick and probably have suffered no decline there (McAlpine, 1997).

It is important to realize that population declines may not have occurred everywhere and data showing that declines are not occurring may not be as "interesting" as data showing that declines are occurring. Therefore these data may not be published. Generally, it is thought that eastern populations of northern leopard frogs are probably in better condition than western populations. Orr et al. (1998) concluded that population declines were not occurring at study sites in northeastern Ohio. Also, northern leopard frogs were found to be "common", but probably less abundant than surveys conducted in 1855, in 1995 in Illinois (Mierzwa, 1998). McAlpine (1997) reported no evidence of population declines in New Brunswick, Canada. McAlpine (1997), Mierzwa (1998), and Orr et al. (1998) were the only three reports I was able to find in the peer-reviewed literature that did not claim declines in northern leopard frog populations.

Although recent studies in the Black Hills and surrounding regions have shown that northern leopard frogs appear to be reasonably common (Smith et al., 1996a, b; 1998), these studies provide only baseline information. They are also incomplete. There are no historical studies to which these data can be compared, although Peterson (1974) conducted basic museum work in the area and described northern leopard frogs as "abundant" in the Black Hills. I maintain an historical database, available on request, which includes all museum records examined by Peterson (1974) and other records from this source. The South Dakota State Natural Heritage database includes other records from the Black Hills region.

It is reasonable to assume that there has been a downward trend in the Black Hills due to the loss of wetlands (Parrish et al., 1996) and also to the introduction of predaceous fish by both state fish and game agencies and by private individuals. Both the grazing and timber industries probably have some effect as well in disrupting normal migratory routes through destruction of meadows. Road building and urbanization throughout the Black Hills has probably also adversely affected northern leopard frog populations in the area. Riparian areas may also be important as migration routes for dispersing northern leopard frogs, and road building, urbanization, cattle grazing, and logging may have seriously affected some of these areas. However, there are no substantive baseline surveys of leopard frogs throughout the Black Hills and no ongoing monitoring efforts. Without such surveys and ongoing monitoring, population trends and sizes for northern leopard frogs in the Black Hills will remain unknown and speculative.

Movement Patterns

Northern leopard frog movement patterns have been studied by Bovbjerg and Bovbjerg (1964), Bovbjerg (1965), Dole (1965a, b, 1967, 1968), Merrell (1970, 1977), and Seburn et al. (1997). Movement patterns consist of spring movement from overwintering sites to breeding ponds (Dole, 1967; Merrell, 1970, 1977), adult dispersal into upland foraging habitat during the summer and summer movement patterns (Dole, 1965a, b; Dole, 1968), natal dispersal from breeding ponds (Bovbjerg and Bovbjerg, 1964; Bovbjerg, 1965; Seburn et al., 1997), and fall migration to overwintering sites (Merrell, 1970, 1977).

In the spring frogs in Minnesota moved from overwintering sites in deep water of larger lakes to the shore but would not leave the lakeshore until temperatures were above $10^{o}C$ (Merrell, 1970). Sexually mature frogs migrated from overwintering sites to breeding ponds and did so sometimes under extremely dry conditions and during daylight, even becoming dusty while doing so (Merrell, 1970). In contrast, subadult frogs stayed near the larger lakes (Merrell, 1970). This seems unusual given the fact that many larger ponds have longer seasonal hydroperiods and may therefore have predaceous fish that prey on subadult frogs (Semlitsch, 2000a). Both larger lakes (i.e., lacustrine areas as described by Cowardin et al., 1979) and predaceous fish were not historically present in the Black Hills. Northern leopard frogs in the Black Hills may show a different pattern of movement or may use different types of habitats in which to overwinter.

Merrell (1970) found that northern leopard frogs tended to frequent grassy meadows where the grass was from "several inches to a foot" (i.e., up to 30 cm) in height during the summer. Dole (1965b) and Merrell (1977) both studied movements of northern leopard frogs and found that they used a home range. Dole (1965b) found that home range sizes varied from 68 – 503 m^2 and varied in size due to habitat type, sex, and life stage (i.e., subadult or adult). Merrell (1977) also concluded that *R. pipiens* utilized a home range but gave no other specifics. Fitch (1958) marked many frogs with no recaptures and concluded that *R. pipiens* did not use a home range in Kansas. Dole (1965b) measured long distance movements (>100 m in one night) in the species in response to nocturnal summer rains but the reasons for these movements remained unknown. As temperatures rose and vegetation dried out, frogs tended to move closer to water (Merrell, 1970). Dole (1965a) and Merrell (1970) agreed that small frogs were more closely tied to water.

Merrell (1970, 1977) found that tadpoles metamorphosed into subadult frogs in July in Minnesota. This is also likely in the Black Hills (personal observations). They then stayed close to the breeding ponds until their tails had been fully resorbed (Merrell, 1977). Mass migrations to larger lakes then occurred and sometimes would result in mass mortality events along roadways (Bovbjerg and Bovbjerg, 1964; Bovbjerg, 1965; Merrell, 1977).

Seburn et al. (1997) studied the dispersal of young frogs by marking 938 metamorphs at a source pond in southern Alberta. Of these, 104 were recaptured. They dispersed up and down streams, showing that streams were used for dispersal. They also dispersed across land, since they wound up at ponds that were not connected to the source pond by waterways. They were found at various ponds up to 4.0 km from the source pond. On average they dispersed twice as far up and down streams as across land. They reached dispersal ponds within 1 km of the source pond within three weeks, while the more distant ponds were reached within six weeks.

In fall, frogs migrated to overwintering sites in lakes, streams, and rivers (Merrell, 1970; Emery et al., 1972; Cunjak, 1986; Ultsch et al., 2000). Fall migration of northern leopard frogs In Minnesota usually occurred at night from mid-September through October, but seemed to end by late October (Merrell, 1970). At the overwintering area in the fall, disturbance of frogs caused them to swim directly into deep water, in contrast to their summer behavior in which they tended to return to shore (Merrell, 1970). They hibernated on lake bottoms, often under debris, and tended to congregate near areas of high O^2 concentration such as the bottom of spillways (Merrell, 1970). They may also excavate shallow pits on the bottom of sandy ponds as overwintering sites (Emery et al., 1972).

Anecdotal information is available on how far northern leopard frogs can move. Merrell (1970) marked 107 frogs (their age was not noted) and released them in “favorable” habitat, only to return a day later to find no frogs except one 0.40 km from the release point. Seburn et al. (1997) recorded subadult movements up to 2.1 km while Dole (1971) recorded maximum subadult movements of 5.2 km. These are estimated straight-line movements and undoubtedly the reported distances underestimate the full extent of distance traveled by these individuals.

Semlitsch (2000a) has pointed out that it is critical to understand the movement patterns of any species of amphibian if a successful management strategy is to be developed. Any such strategy will depend on the movement pattern of the species and on the spatial distribution and size of ponds and migration corridors (Semlitsch, 2000a). Semlitsch and Bodie (1998) and Semlitsch (2000b) convincingly showed that elimination of wetlands <5 ha in size could prevent some species from reaching and colonizing new ponds, depending on the movement patterns of species and the spatial distribution of wetlands suitable for reproduction by these species. Semlitsch (1998) measured the dispersal distances of several southeastern salamanders and determined that core habitat for salamanders consisted of the wetlands habitat in which they bred and a surrounding upland area to which they dispersed following breeding. The upland habitat was described by Semlitsch (1998) as “buffer” habitat but is more appropriately considered “core” habitat, as it is necessary for the survival of local populations (Semlitsch, personal communication, March 2001). Semlitsch (1998) found that an upland area that included up to 164 m of upland habitat around a pond would contain roughly 95% of salamanders of six species studied. Based on what is known of *Rana pipiens* movements, an area containing 95% of a population of these frogs would probably be much greater.

Northern leopard frogs are similar to the salamanders that were reviewed by Semlitsch (1998) in that the frogs also use wetland habitat for breeding and spend considerable amounts of time away from the pond after the breeding season feeding in upland habitat (personal observations). It is not known, however, how large an upland area should surround each breeding site to manage a population of northern leopard frogs nor what types of routes frogs use to migrate between breeding ponds or disperse from the natal area as subadults. Given the importance of identifying movement corridors to management strategies, the general lack of knowledge of movement patterns and home range use among northern leopard frogs is a serious impediment to managing the species.

Habitat Characteristics

Northern leopard frogs are likely to use a broad range of habitats due to their complicated life histories. Merrell and Rodell (1968) categorize three major habitat types: winter habitat (overwintering in lakes, streams, and ponds), summer habitat (feeding by adults in upland areas), and tadpole habitat (up to three months spent as tadpoles in shallow breeding ponds). However, to completely understand the types of habitats used by northern leopard frogs the habitat they use during various stages of their life history must be categorized and include habitat used by tadpoles, subadults, and adults, and any sexual differences in habitat usage. Their complicated movement patterns during the year must also be considered and include habitat used for reproduction, summer feeding ranges, fall migrations, and overwintering. Another consideration is that much of the relevant literature is on populations studied all over North America. There are likely to be differences in habitat usage by Black Hills populations as compared to other North American populations due to the unique nature of the Black Hills. Most notable among these differences is the historical lack of large bodies of water, which are used for overwintering in some parts of the range of the northern leopard frog (Merrell, 1977), and the historical lack of larger predaceous fish in the Black Hills. European settlers created all the large bodies of water in the Black Hills and all these water bodies contain introduced predaceous fish. Northern leopard frogs may also hibernate under water in ponds (Emery et al., 1972; Hammerson, 1999), streams (Cunjak, 1986; Hammerson, 1999), and rivers (Ultsch et al., 2000), but many streams in the Black Hills also contain introduced predaceous fish.

Tadpole Habitat

Tadpoles obviously start as eggs, and eggs are laid in breeding ponds. Therefore, discussion of tadpole habitat requires consideration of egg laying and breeding of the northern leopard frog. In an extensive study of the life history of the northern leopard frog in Minnesota, Merrell (1977) found that they bred in mid-sized ponds; i.e., ponds that were 30 – 60 m in diameter, were from 1.5 – 2.0 m in depth, and dried "periodically every few years". Merrell (1968) also characterized breeding ponds and noted that they did not support fish populations, were not connected with other bodies of water, and dried up during droughts. Werner and Glennemeier (1999) found that northern leopard frogs required breeding ponds with an open canopy. Collins and Wilbur (1979) found that northern leopard frogs bred only in ponds that were permanent, dried completely in exceptionally dry years, or dried only by the very end of the summer. They bred at sites that had fish or were without fish. Interestingly, subadults were only found at sites that were fishless, which coincidentally were either semi-permanent ponds or dried by the end of the summer. Hammerson (1999) noted that the northern leopard frog bred in shallow, quiet areas of permanent bodies of water, in beaver ponds, and in seasonally flooded areas adjacent to or contiguous with permanent pools or streams. Corn and Livo (1989) found that northern leopard frogs bred and successfully hatched in a gravel pit, stock ponds, and beaver ponds. Semlitsch

(2000a) discussed the importance of mid-sized ponds to reproductive success (i.e., egg laying, egg hatching, and successful metamorphosis) in many species of amphibians. According to Semlitsch (2000a), these ponds were semi-permanent to seasonal palustrine habitats that tended to last from 30 days to one year.

While I have not carefully measured the characteristics of breeding habitat of the northern leopard frog in the Black Hills region, my observations are in general concordance to those of Merrell (1968, 1977), Collins and Wilbur (1979), Corn and Livo (1989), and Hammerson (1999). I have found northern leopard frogs breeding in stock ponds, semi-permanent ponds, in the margin of larger lakes, and beaver ponds. While streams may be used for reproduction, breeding sites lack current. When streams are used for reproduction, eggs are deposited in backwaters out of the main flow of the stream. While I have found northern leopard frogs breeding in habitat with introduced predaceous fish, I have seldom found tadpoles or metamorphosing juveniles in such habitats. Neither have I found breeding adults, tadpoles, or metamorphs in springs in the Black Hills, which I believe stay too cold throughout the summer for normal development of the tadpoles. Applying the classification system of Cowardin et al. (1979) to what I would consider the "most typical" type of breeding site used by northern leopard frogs in the Black Hills, they are palustrine sites with an unconsolidated bottom, and usually have a pond margin with extensive growth of cattails (*Typha* species). Cowardin et al. (1979) consider the following four features to be characteristic of palustrine systems: 1) Size <8 ha; 2) No wave-formed or bedrock shoreline; 3) Water depth typically <2 m at the deepest part of the pond; and 4) Very low salinity. Palustrine systems with an unconsolidated bottom have a mud bottom (often composed of bentonite in the Black Hills) and vegetative cover <30%. The cattail margin is typical of these ponds in the Black Hills, and probably indicates some degree of permanency to the pond, although some of these sites may dry completely by late fall.

Tadpoles need bodies of water with no overhead canopy that are free of introduced predaceous fish (Kruse and Francis, 1977; Hecnar and M'Closkey, 1997a; Werner and Glennemeier, 1999). These bodies of water should be reasonably shallow so as to be heated by the sun to temperatures suitable for rapid development of the tadpoles, especially in the Black Hills, where the growing season may only last for five months. However, they should not be too shallow, because they would dry too rapidly, and tadpoles generally take from 58-105 days to complete their larval period (Hammerson, 1999). Although breeding ponds in the Black Hills have not been carefully characterized, they are of roughly the size determined by Semlitsch (2000b) to be highly productive for amphibian abundance and diversity in the southeastern United States, slightly smaller than 5.0 ha. These ponds should not be connected to larger bodies of water to preclude accidental introduction of predaceous fish. These types of ponds may be the most common ponds in the landscape but they may also be the most in danger of elimination and the least protected by law and management guidelines (Semlitsch and Bodie, 1998; Semlitsch, 2000b). The current Black Hills National Forest Land and Resource Management Plan (USDA Forest Service, 1997) makes no mention of the protection of these sorts of wetlands.

Subadult Habitat

In Minnesota subadult frogs, after completing their larval period, migrate across land to suitable feeding sites at larger lakes (Merrell, 1970). Bovbjerg and Bovbjerg (1964) and Bovbjerg (1965) also observed mass emigrations of young frogs in Iowa at one site for three consecutive summers. These movements occurred in early July in Iowa and in late July in Minnesota, a difference attributed by Merrell (1977) to the differing climatic regimes between the two study sites. Regardless of the goal of these movements, Seburn et al. (1997) showed that recently metamorphosed frogs had a complicated pattern of movement, moving up and down streams and also across land. Sometimes these movements result in mass mortality (Bovbjerg and Bovbjerg, 1964; Bovbjerg, 1965; Merrell, 1977). It is critical to understand more about these movements, including determining whether Black Hills populations demonstrate dispersal behaviors similar to those described elsewhere in the range of the northern leopard frog. Further, it is important to accommodate any such movement patterns in management plans to increase the opportunity of leopard frogs to establish metapopulations, which may increase the chance for long-term survival of the species, compared to single, isolated populations.

Nothing is known about the migration patterns of northern leopard frogs in the Black Hills. I have noticed that large numbers of subadults can be found basking in the shallows of semi-permanent ponds in which they presumably had metamorphosed beginning about August through September or October, depending on weather and elevation (personal observations). This suggests that their pattern of movement in the Black Hills is different from that in the rest of their range. Presumably, management for tadpole habitat would also conserve habitat for metamorphs and subadults in the Black Hills region. The work of Seburn et al. (1997) suggests that it would be important to conserve migration corridors that might connect with suitable but possibly uncolonized habitat to increase northern leopard frog populations in the Black Hills.

Adult Habitat

Elsewhere, adult northern leopard frogs show a complicated pattern of movement that needs to be accommodated in any management plan for the species. Merrell and Rodell (1968) categorized three major habitat types necessary for northern leopard frogs: lakes in which adult frogs overwinter, upland habitat in which adult frogs feed during summer, and tadpole habitat, in which tadpoles spend up to three months developing. Of course, tadpole habitat is the same as breeding habitat for adult frogs, so can be included as another habitat critical for adults. Northern leopard frogs are also known to overwinter in streams, ponds, and rivers (Emery et al., 1972; Cunjak, 1986; Hammerson, 1999; Ultsch et al. 2000).

The types of water bodies in which northern leopard frogs breed are described above under "Tadpole Habitat", and the reader should consult this section and the citations therein for further information. Following reproduction, perhaps in May in the Black Hills region (again depending on weather and elevation), adult leopard frogs move into upland habitat in which they may feed for the summer. Conant and Collins (1991) point out that the northern leopard frog is one of the more terrestrial of the ranid frogs and it can be assumed that the northern leopard frog may use a considerable amount of upland habitat around breeding ponds. However, this portion of the life histories of many amphibians has been frequently neglected (Semlitsch, 1998) and such is also the case for the northern leopard frog. Many citations mention movements of from 0.5 – 3.0 km from water in this species, and Dole (1971) notes that subadults move up to 5.2 km away from natal ponds. There is no reason to think that Black Hills populations of the northern leopard frog are different and some USDA Forest Service biologists working in the Black Hills have commented that they have found northern leopard frogs a considerable distance from water in wet meadows or grasslands (Oscar Martinez, 1998, personal communication).

The pattern of spacing of suitable breeding sites across the landscape and upland movements made by northern leopard frogs are probably both very important in colonization of new ponds or recolonization of ponds in which breeding populations have gone extinct, thus maintaining a healthy metapopulation of the species in any area. Frog movements and pond spacing are two of the most important factors to consider in management of northern leopard frogs. Both factors are likely to greatly affect population density in this species as Semlitsch (2000a) has noted for other amphibians. Movement has not been studied in the Black Hills, but they probably favor meadows, wetlands, or riparian areas due to their relatively humid microclimates compared to surrounding habitats (see Seburn et al., 1997, for data from other parts of their range). For example, Bartelt (1998) documented the deaths of thousands of western toad metamorphs (*Bufo boreas*) in Idaho following the trampling by sheep of tall grasses in which the metamorphs were living. He attributed many of the deaths to trampling, but deaths of survivors of the trampling event were caused by dessication from the loss of the relatively humid microclimate that was lost when the grasses were trampled underfoot by the sheep. In addition, Seburn et al. (1997) showed that juvenile northern leopard frogs disperse farther and more rapidly along streams than they do over land.

Overwintering Habitat

In the fall subadult and adult frogs migrate to overwinter underwater in streams, rivers, and ponds (Emery et al., 1972; Merrell, 1977; Cunjak, 1986; Ultsch, 2000). Bradford (1983) noted that anoxia was one source of mortality for overwintering frogs in California and Nevada for the mountain yellow-legged frog, *Rana muscosa*. Bradford (1983) observed that anoxia was more severe in shallow lakes or ponds (i.e., <4 m deep) and nearly all adult frogs died in these bodies of water in some winters. Repeated winterkill has been observed in ponds in northern Indiana (Manion and Cory, 1952). Ultsch et al. (2000) also observed winterkill in a river in Vermont. Avoidance of wintertime anoxia is one reason why northern leopard frogs have been reported in high numbers in areas of high oxygen saturation such as stream inflow areas in ponds (Oldfield and Moriarty, 1994). It may also be why they overwinter in streams, where oxygen saturation should be higher than in lakes or ponds. Northern leopard frogs remain capable of movement throughout the winter but are usually very sluggish, moving away from observers very slowly (Emery et al., 1972; Cunjak, 1986). At low temperatures, frogs move more slowly than at warm temperatures (Rome et al., 1992).

Since the Black Hills historically had no large bodies of water such as lakes (Froiland, 1990), northern leopard frogs probably used streams and possibly other types of habitats in which to overwinter in the Black Hills. Interestingly, Oscar Martinez of the USDA Forest Service found a northern leopard frog under snow in winter in a wet meadow that had flowing, unfrozen water (personal communication, 1997). However, little else is known of potential overwintering sites for northern leopard frogs in the Black Hills. I would suspect that they would use the bottoms of flowing streams, the bottoms of ponds that are large enough that they don't freeze solid in winter, and possibly springs that do not freeze solid in winter. It seems unlikely that they would use the bottoms of recently created lakes for overwintering, both because these lakes may not have been used historically for overwintering and because these lakes have introduced predaceous fish such as brown trout (*Salmo trutta*) and pike (*Esox lucius*).

It is probable that overwinter mortality associated with predation by introduced predaceous fish in streams and larger ponds is another modern source of mortality for the northern leopard frog. The most common introduced fish in the Black Hills are brown trout (*Salmo trutta*), which breed in the wild in the area, brook trout (*Salvelinus fontinalis*), which are less common but also breed in the wild, and rainbow trout (*Salmo gairdneri*), which are introduced but do not breed in the wild in the Black Hills except in a small stretch of Spearfish Creek. Northern pike (*Esox lucius*) are intentionally introduced by sport fishermen to some areas but are not introduced by any government agency. Brook trout are smaller, insectivorous trout that probably do not eat frogs the size of northern leopard frogs. Cunjak (1986) reported no leopard frogs in stomach contents of >100 brook trout he examined from his study site. However, splake (a non-fertile hybrid of lake trout, *Salvelinus namaycush*, and brook trout), have been reported to eat northern leopard frogs in the winter (Emery et al., 1972). Splake are not introduced into Black Hills aquatic systems. Brown trout are more piscivorous and may well eat adult northern leopard frogs. Ice fishermen in North Dakota have reported northern leopard frogs in the stomachs of northern pike caught during mid-winter (unpublished data).

In general, overwinter mortality may be an important cause of mortality for northern leopard frogs, as is known for other ranid frogs (Bradford, 1983). Especially important as a source of overwintering mortality may be oxygen depletion at overwintering sites (Merrell and Rodell, 1968; Bradford, 1983), which may account for the habit of overwintering at inflow areas where oxygen saturation of water is relatively high (Oldfield and Moriarty, 1994). This further underscores the potential importance of permanently flowing streams, springs, and wet meadows as overwintering sites in the Black Hills.

Food Habits

Most of what is known about the food habits of tadpoles, subadults, and adult northern leopard frogs is anecdotal. Merrell (1963) discussed raising tadpoles on boiled lettuce, corn meal, and tropical fish food. Merrell (1977) considered northern leopard frog tadpoles to be generalist herbivores but he also noted that they sometimes scavenged on dead animals including conspecifers. Hendricks (1973) examined gut contents in the Rio Grande leopard frog, *Rana berlandieri*, formerly known as *R. pipiens* and closely related to the northern leopard frog. He described this species as a filter feeder that primarily ate free-floating algae. Franz (1971) found that *R. pipiens* tadpoles mostly ate various species of free-floating green algae and blue-green algae. Alford (1999) pointed out that high densities of tadpoles of various species may be the primary consumers in some ecosystems and are known to reduce the standing crop and change the species composition of algae. For example, Lamberti et al. (1992) found that *Ascaphus truei* (tailed frog) tadpoles at a density of 5 tadpoles per square meter could reduce periphyton biomass by 98% and chlorophyll a by 82% in streams in Washington. Some ponds in the Black Hills can have northern leopard frog tadpoles in this density range and higher.

Subadult and adult northern leopard frogs are carnivorous and are usually described as generalist insectivores. Merrell (1977) noted that northern leopard frogs became carnivorous at metamorphosis and fed primarily on insects. However, they tended to feed on anything that moved and that was small enough to fit into their mouths, including smaller northern leopard frogs. Breckenridge (1944) reported such unusual items as a small garter snake, ruby-throated hummingbirds, and a yellow warbler in the stomachs of northern leopard frogs. Drake (1914) also noted the propensity of northern leopard frogs to snap at anything that moved and that was small enough to be swallowed. In dissecting 209 adult northern leopard frogs, Drake (1914) found that they primarily ate "insects" (this category was not further broken down), spiders, mollusks, crustaceans, and various other arthropods. Whitaker (1961) found that they primarily ate insects as well, mostly coleopterans (beetles) and orthopterans (grasshoppers), but also dipterans (flies and associated groups), hemipterans (the true bugs), and hymenopterans (wasps and their allies). Linzey (1967), in a study of 463 specimens, also concluded that subadult and adult northern leopard frogs ate primarily insects. Nearly one quarter of the food items were beetles. Linzey (1967) also split his data up by life stage (adults and subadults), identified all food items to family, and identified seasonal variation. He found that all life stages seemed to be opportunistic carnivores; they ate the largest things that fit into their mouths and the most common prey items available at the time. Collier et al. (1998) also identified an extensive list of invertebrate prey consumed by 13 adult and 19 juvenile leopard frogs, concluding that the species was a generalist insectivore after metamorphosis. Miller (1978) noted that northern leopard frogs were opportunistic predators, feeding on insects that were most abundant. He also noted that northern leopard frogs only preyed on moving prey. Merrell (1977) reared northern leopard frogs in the laboratory on mealworms and crickets.

Breeding Biology

The reproductive biology of northern leopard frogs has been studied in Michigan (Collins and Wilbur, 1979), Minnesota (Merrell, 1965, 1968, 1970, 1977), Colorado and Wyoming (Corn and Livo, 1989), and in the laboratory (Noble and Aronson, 1942; McClelland and Wilczynski, 1989). Hammerson (1999) gave an excellent summary of breeding phenology for populations at various elevations in Colorado.

As soon as males leave overwintering sites, they travel to breeding ponds and call in shallow water around suitable pond sites (Merrell, 1965, 1968, 1970, 1977; Oldfield and Moriarty, 1994; Hammerson, 1999). Ponds suitable for breeding are described earlier in this work (see “Habitat Characteristics; Tadpole Habitat”, pp. 8 – 9). Like many pond-breeding frogs, male northern leopard frogs attract females by giving breeding calls from specific locations within a breeding pond, with several males typically calling together to form a breeding chorus. Females come to males and breed at the calling sites. After breeding, females immediately leave the ponds, while males stay in the chorus continuing to call (Merrell, 1977). This results in a preponderance of males at breeding ponds (Merrell, 1977).

Noble and Aronson (1942) described the mating call as a quavering sound pronounced phonetically as “ir-a-a-a---a-a-h”, lasting about three seconds. Wright and Wright (1949) described the call as a long, low guttural note lasting three or more seconds followed by three to six short notes each a second or less in length. The call starts softly and grows louder as the vocal sacs inflate (Noble and Aronson, 1942). Pace (1974) pointed out that male northern leopard frogs do not have external vocal sacs, but have well-developed internal vocal sacs. Davidson (1996) provided a recording of northern leopard frogs calling in the Rocky Mountains.

Pace (1974) gave the most extensive description of the call of the northern leopard frog and provided sonograms of the various components of the call. She divided the call into three components, including a long many-pulsed trill, a series of short trills, and a series of pulses that usually terminated calls. Typically, male frogs gave calls that consisted of several of these sounds, usually commencing with the longer trills, unless they were in the middle of a larger chorus. They usually followed these longer trills with the shorter trills, ending the typical call with a series of a few pulses. To the typical observer, this call sounds like a kind of lower frequency trill that may descend in frequency and end with what seems to be a few short grunts (personal observations). Pace (1974) found that male frogs were stimulated to call by playbacks of the longer trills, and isolated males gave calls that consisted of a longer series of the longer trills. She concluded that the long, slow, trilled call functioned as a long-range call that attracted females, and the shorter, rapid trills were short-range calls that helped females to find the calling male at close distances. Finally, the calls typically were terminated by some short terminal sounds that were used to maintain separation amongst males in choruses (the third part of a typical call).

Northern leopard frogs give at least one other type of call. Male northern leopard frogs will clasp virtually anything with the general size and shape of a female frog and have been found clasping floating beer cans, females of other Rana species, a *Bufo americanus* (American toad) female, a dead female northern leopard frog, and a bowfin (*Amia calva*) fish (Merrell, 1977). It is therefore not surprising that the other vocalization males will give is a release call when clasped by other males (Merrell, 1977; McClelland and Wilczynski, 1989). Females also give the release call if not in mating readiness (McClelland and Wilczynski, 1989). McClelland and Wilczynski (1989) gave a sonogram of the release call.

As described by Wright and Wright (1949), choruses in the eastern United States (near Ithaca, New York) were conspicuous, although an individual call was very quiet. However, various workers have found choruses to vary in volume. Bishop et al. (1997) found that breeding choruses of northern leopard frogs were “low volume”. Peterson (1974) came across a “faintly vocalizing” chorus at Stockade Lake in the Black Hills. My co-workers and I have found it very difficult to hear breeding choruses in the Black Hills. Calling can be nearly indiscernible over other nighttime sounds and calls may be sporadically given. However, Dunlap and Platz (1981) found little variation in calls across a transect from Wisconsin to Idaho. Merrell (1977) stated that northern leopard frogs tended to call while floating in water, but Noble and Aronson (1942) noted that northern leopard frogs also called from land if particularly excited.

Male calling has been recorded following the onset of daytime air temperatures of 15 – 20^{o}C (Merrell, 1977; Corn and Livo, 1989). Specific sites used for calling and breeding within ponds were described by Merrell (1977) as being the warmest part of the pond, typically in water of 40 cm depth or less in an unshaded location with maximal exposure to sunlight. The water temperature during calling was usually 20^{o}C or more (Merrell, 1977). Merrell (1977) believed that differences in temperature within ponds typically resulted in the use of one spot one to two meters in diameter to lay eggs even when most breeding ponds in his study area were 30 – 60 m in diameter.

Northern leopard frogs show geographic variation in the timing of reproduction and egg laying that is probably determined by various environmental cues. Corn and Livo (1989) noted that two to three days of air temperatures of 15 – 20^{o}C were needed to initiate calling activity at their study sites. Elevation at these sites was 1555 – 2520 m. Corn and Livo (1989) also recorded precipitation but noted that calling and breeding at their sites in northern Colorado and southern Wyoming seemed to correspond more with temperature than with precipitation. Corn and Livo (1989) found that calling started anywhere from mid-March to early to late May, depending on elevation. At these sites, eggs were laid within two to three days following the onset of chorusing (Corn and Livo, 1989). In the San Luis Valley of Colorado at elevations of 2285 m, Hammerson (1999) has reported calling extending into late June. In Minnesota northern leopard frogs bred from mid-March to mid-May depending on the weather, but usually bred in April

(Merrell, 1977). At lower elevations in Colorado northern leopard frogs began breeding in March but they often did not start breeding until April or May in higher elevations (Hammerson, 1999). High elevation populations studied in northern Colorado began breeding in May (Corn and Livo, 1989). In the Black Hills the timing of reproduction is uncertain, but calling has been heard in April at mid-elevation (ca. 1500 m) ponds (personal observations) and also in May and June in the cooler northern Black Hills at higher elevations (Smith et al., 1998). The timing of courtship and breeding doubtless is sooner in southern populations and at lower elevations.

The number of eggs laid in a clutch appears to vary widely, even within a population. Linzey and Wright (1947) estimated a clutch size of 3500 - 6500 eggs for northern leopard frogs, Merrell (1965) reported from 2000 to more than 5000 eggs in some Minnesota clutches, and Hupf (1977) counted from 1000 – 7000 eggs in an unreported number of preserved females from Nebraska. Corn and Livo (1989) counted from 645 – 6272 eggs in clutches at their study ponds, with a mean of 3045 eggs per clutch. Corn and Livo (1989) also reported three distinct size classes of clutches. They suggested that this roughly corresponded to three different size classes of females at their study sites. Hatching success at six ponds was 70 – 99% (Corn and Livo, 1989).

Egg masses were attached to emergent vegetation such as sedges (*Carex* spp.) or rushes (*Scirpus* spp.) in Colorado and Wyoming (Corn and Livo, 1989). Wright and Wright (1949) reported that egg masses were flattened spheres that were 75 – 150 mm by 5 – 75 mm in dimension. Like all ranid frogs, there is no parental care in this species. Mean water depth of 39 oviposition sites was 12.9 cm (standard deviation = 3.3 cm). In Minnesota, egg masses were left in the area in which males had been calling and were placed in water less than 40 cm in depth that was exposed to the sun (Merrell, 1977). Hammerson (1999) stated that egg masses were attached to vegetation just below the surface in warm shallow water from 7 – 25 cm deep, while Merrell (1977) noted that egg masses were attached to vegetation “a few cm” below the water surface. The temperature of egg masses was typically 2 – 3^{o}C higher than the water temperature adjacent to the egg masses (Merrell, 1970). Merrell (1977) suggested that the dark pigmentation of the embryos caused them to act like black bodies, implying that it was adaptive for females to lay their eggs in locations in ponds that would receive a substantial amount of solar radiation. It may also help embryos to avoid freezing during short periods of cold springtime weather (Merrell, 1977). Warm temperatures also speed development in amphibian eggs and larvae (Duellman and Trueb, 1986).

Hatching time and time to metamorphosis also varies geographically, probably dependent on environmental variables, especially temperature. Hine et al. (1981) reported that hatching occurred in 5 – 9 days when temperatures were at or above 10^{o}C. Wright (1914) reported that eggs hatched in 13 – 20 days in the vicinity of Ithaca, New York. Wright and Wright (1949) reported that tadpoles usually transformed in 60 – 80 days. Corn (1981) observed egg laying in late May and early June at elevations of 2035 – 2365 m in Larimer County, Colorado (northern Colorado) with metamorphosis from mid-July through mid-September. He reported that the larval period ranged from 58 – 105 days, but his study ended before individuals were fully transformed. The 105-day larval period was reported at the highest elevation sites (Corn, 1981). Ryan (1953) noted that northern leopard frogs metamorphosed in the Ithaca area from June 30 to August 15, with most individuals metamorphosing in the first half of July. Wright and Wright (1949) also reported that most individuals metamorphosed in July in the Ithaca area. In various high elevation sites in Colorado, Hammerson (1999) reported metamorphosis throughout August.

Mosimann and Rabb (1952) collected newly metamorphosed tadpoles July 26, 1950, in Liberty Co., north-central Montana. I have observed large numbers of tadpoles in some ponds in the Black Hills in July, but have not taken detailed notes on development in this species in the Black Hills.

Demography

Data on age to maturity, age at first reproduction, and age at death are incomplete for the northern leopard frog. In a population Ryan (1953) studied in the vicinity of Ithaca, New York, female northern leopard frogs did not become sexually mature until at least their first year following metamorphosis, and he felt that most frogs were not sexually mature until their second year following metamorphosis. Force (1933) estimated that northern leopard frogs attained reproductive maturity at three years of age in northern Michigan. Baxter (1952) reported that sexual maturity in females was not achieved until late in the second year in frogs from the vicinity of Laramie, Wyoming (2200 m), and these females laid eggs in the third year following metamorphosis. At elevations of 2600 m female frogs did not attain sexual maturity until late in the third year with these eggs being laid in the fourth year following metamorphosis (Baxter, 1952). Leclair and Castanet (1987) reported that males in Quebec populations reached sexual maturity at an age of two years, with few frogs older than four to five years. Since Baxter (1952) studied populations near Laramie, Wyoming, at elevations only slightly higher than those typical of Black Hills populations (but further south) and found that these frogs matured in two years, laying eggs at the start of their third year, it might be reasonable to assume that females in the Black Hills also may first lay eggs in their third year. A leopard frog in captivity lived for five years and 11 months (Flower, 1936). It is probably reasonable to assume that most northern leopard frogs living in the wild seldom reach their sixth year. It also seems reasonable to conclude that female northern leopard frogs may breed two or three, but certainly no more than four times in the Black Hills. This agrees in general with the conclusions of Corn and Livo (1989) in southern Wyoming and northern Colorado, who wrote that the three classes of clutch sizes occurring at their study site corresponded to three age classes of frogs. Their sites may well have been similar to the Black Hills in general climatological conditions.

There is no other information on growth rates, age at sexual maturity, or age at death in any natural populations of the northern leopard frog. Corn and Livo (1989) recorded an average of 3045 eggs per clutch (range 645 – 6272 eggs), which may mean that females produce some 9000 eggs during their lifetime, assuming three reproductive bouts during three consecutive years. There are no studies of survival of northern leopard frogs to sexual maturity, but it is likely that mortality is significant after hatching, since hatching success seems high, from 70 – 99% at the sites studied by Corn and Livo (1989), and around 95% at sites studied by Hine et al. (1981). There are also no studies of survivorship at any other life stage in northern leopard frogs, however, Merrell (1977) has provided some interesting insights from work done in Minnesota.

Merrell (1977) counted a total of 173 egg masses at eight adjacent breeding ponds at an area near Minneapolis/St. Paul, Minnesota. At 2000 – 5000 eggs per egg mass (determined from studies of Merrell, 1965), Merrell (1977) calculated that the number of eggs at his study sites ranged from 346,000 – 865,000. Capture/mark/release data obtained in July prior to dispersal of the young metamorphs indicated that approximately 20,000 metamorphs existed in the area. The study of Merrell (1977) would then indicate a mortality rate of at least 94% and possibly as high as 97% in the tadpole stage. Hine et al. (1981) estimated that mortality for about 1.5 months following metamorphosis, and before the first overwintering, was from 94 – 99%. Another study found a ratio of newly metamorphosed frogs to sexually mature adult frogs somewhere between 15:1 and 20:1 (Merrell, 1969). This would further indicate a 93 – 95% mortality rate between metamorphs and sexually mature frogs. These numbers should all be considered approximate due to the techniques used, but they would still indicate a mortality rate that is very high, probably over 90%, for the young age classes (i.e., from tadpole to metamorph and from metamorph to the adult stage).

The issue of faithfulness to natal areas and breeding sites has not been studied in northern leopard frogs. Merrell (1970) noted that genetic drift seemed low in northern leopard frog populations, possibly suggesting that this species might not show a high degree of philopatry to natal sites (genetic drift is greater in small and highly philopatric populations). Although many researchers assume that amphibians return to their natal ponds to breed (Semlitsch and Bodie, 1998), these types of movements have not been studied in *Rana pipiens*. Eighteen percent of over 5000 wood frogs (*Rana sylvatica*) dispersed to new ponds to breed in one study (Berven and Grudzien, 1990), while 27% of Fowler's toads (*Bufo fowleri*) dispersed to new ponds to breed in another study (Breden, 1987). At a study site in Germany where several ponds were spaced very closely, from 80 – 98% of three species of ranids and one bufonid returned to their natal ponds to breed (Kneitz, 1998; cited in Pough et al., 2001). In a study of the natterjack toad (*Bufo calamita*) in Germany, all adult males returned to their natal ponds to call, but the sample (nine toads) was small (Sinsch, 1997). Genetic studies could infer the amount of isolation and migration amongst northern leopard frog populations.

Various estimates of the population density of northern leopard frogs exist. Merrell (1968) found populations of 124 – 1568 individuals at six breeding ponds in Minnesota. Exact sizes of these ponds were not given, although Merrell (1968) stated that they were "about 50 to 100 feet in diameter" (15.4 – 30.8 m). Hine et al. (1981) found 2 – 76 frogs at six ponds in Wisconsin that were from 0.02 – 32 ha in size. Hine et al. (1981) compared these data to those of Merrell (1968) to argue that there had been serious declines in northern leopard frog populations in the upper Midwest. Merrell (1977) provided an estimate of about 20,000 newly metamorphosed frogs in an area of about 15 ha in Minnesota and he sampled about 25,000 frogs of all ages in this area. Estimates of mortality rates derived from the data of Merrell (1977) show rather clearly that northern leopard frogs are probably rather typical r-selected species with a type III survivorship curve and probably show large fluctuations in population dynamics from year to year (Begon et al., 1996). This is typical of many amphibians, and it can be difficult to determine whether population density is trending upward or downward due to these large natural fluctuations in population density (Pechmann et al., 1991; Pechmann and Wilbur, 1994). Species that are r-selected can recover from low population densities due to high potential growth rates, but they can also go locally extinct if affected by severe mortality pressures at times when population densities are low (Begon et al., 1996).

Community Ecology

There are a variety of studies of the community ecology of the northern leopard frog. Various studies of the predators of the northern leopard frog are anecdotal and consist mainly of lists of potential predators, but several are experimental. There are several studies on competition and predation of northern leopard frog tadpoles in company with other tadpoles or in combination with a variety of predators. A few studies on the competitors of adult northern leopard frogs exist. There is a growing literature on the parasites and diseases of ranid frogs in general, and there are a variety of studies on other aspects of ecology.

Basic Community Ecology

Several studies have been done on *Rana pipiens* and their role in amphibian communities (DeBenedictis, 1974; Smith-Gill and Gill, 1978; Woodward, 1982, 1983; McAlpine and Dilworth, 1989; Hecnar and M'Closkey, 1998; Relyea and Werner, 2000; Relyea, 2001a, 2001b). These studies can be divided into studies of *R. pipiens* tadpoles (DeBenedictis, 1974; Smith-Gill and Gill, 1978; Woodward, 1982, 1983; Relyea and Werner, 2000; Relyea 2001a, 2001b) and adults (McAlpine and Dilworth, 1989; Hecnar and M'Closkey, 1998). They can be further divided into studies on competition (DeBenedictis, 1974; Smith-Gill and Gill, 1978; Woodward, 1982; McAlpine and Dilworth, 1989), predation (Woodward, 1983; Relyea and Werner, 2000; Relyea 2001a, 2001b), and general ecology (McAlpine and Dilworth, 1989; Hecnar and M'Closkey, 1998).

Although no studies examining tadpole densities or their role in structuring the community have been completed in the Black Hills, *Rana pipiens* tadpoles can clearly be dominant species in some semi-permanent ponds in the area during the spring and early summer (personal observations). Woodward (1982, 1983) studied the reasons why some anurans were temporary pond breeders and some bred in permanent ponds. He found that temporary pond breeders were often superior competitors to permanent pond breeders, and that some temporary pond breeders ate tadpoles of permanent pond breeders (Woodward, 1982). For example, *Spea multiplicata* ate the tadpoles of *R. pipiens* (Woodward, 1982). *Spea bombifrons* occurs in the Black Hills area and breeds in temporary ponds, but it is seldom found above 1400 m (unpublished data). Since *R. pipiens* do not breed in the temporary ponds in which *S. bombifrons* breed (unpublished data), they probably do not interact in the wild in the Black Hills or surrounding plains. Although they are at a competitive disadvantage to temporary pond breeders, Woodward (1983) found that *R. pipiens* tadpoles are better able to avoid predation because they tend not to move very much, as compared to tadpoles of temporary pond breeders. He also found that there are more tadpole predators in permanent ponds, thus explaining why *R. pipiens* might have evolved this important behavioral trait.

Two papers examine various biotic and abiotic parameters and how they affected the distribution of adult frogs in Canada. McAlpine and Dilworth (1989) investigated competition and microhabitat of various anurans in New Brunswick and Hecnar and M'Closkey (1998) examined species richness patterns of various frogs in Ontario. McAlpine and Dilworth (1989) found that green frogs (*Rana clamitans*) and *R. pipiens* overlapped significantly in diet (the two frogs are similar in size), and seemed to divide the niche by microhabitat. In terrestrial habitats, *R. pipiens* tended to be found in areas of denser vegetation. They were found farther from shore than *R. clamitans* when in ponds. Both tended to be found in the diet of bullfrogs, *R. catesbeiana*. Whether these patterns of microhabitat use by *R. pipiens* are similar in the Black Hills, where no other ranids are found (except bullfrogs in some isolated localities), is unknown. Hecnar and M'Closkey (1998) underscore the effect of predatory fish on amphibian presence; it was one of the most significant factors structuring the amphibian community across much of southwestern Ontario. They also found that various vegetation factors accounted for the patterns of species richness that they observed, with increased richness in areas richer in woodlands. The species accounting for this result were various species of amphibians associated with woodlands. Their list of such species did not include *R. pipiens*.

Predators

Northern leopard frogs are eaten by a variety of predators at all life stages. Merrell (1977) reported that most mortality occurred in the tadpole stage, and most of this appeared to be from predators, although overwintering mortality seemed to be important in subadults. Merrell (1977) noted that various early authors recorded the following as predators of tadpoles: Mallards (*Anas platyrhynchos*), blue-winged teal (*Anas discors*), newts (unknown species), waterfowl, fishes, aquatic insects, leeches, diving beetle larvae (Dytiscidae) and adult diving beetles (*Dytiscus* species), dragonfly larvae (Libellulidae and probably other families), caddisfly larvae (Phryganeidae), backswimmers (genus *Notonecta*), and giant water bugs (*Belostoma* species). Spiders (Lycosidae and Pisauridae) may also eat tadpoles (Merrell, 1977). Various species of garter snakes (*Thamnophis* species) have been recorded to feed on tadpoles, as have water snakes (genus *Nerodia*). Tiger salamander (*Ambystoma tigrinum*) adults and tadpoles are known to feed on frog tadpoles (Petranka, 1998). In fact, populations of tiger salamander tadpoles have completely eliminated frog tadpoles in experimental interactions (Morin, 1983). In the Black Hills the breeding period of the tiger salamander overlaps with that of the northern leopard frog and they may breed in similar ponds (unpublished observations). Paedomorphic tiger salamanders (Petranka, 1998) also occur in the Black Hills (unpublished observations) and I suspect that they would readily eat northern leopard frog eggs and tadpoles. Hammerson (1999) noted that pied-billed grebes (*Podilymbus podiceps*) and tiger salamanders (*Ambystoma tigrinum*) preyed on northern leopard frog tadpoles in Colorado. Important tadpole predators that Woodward (1983) identified in his predation experiments were Belostomatids (diving beetles), Notonectids (backswimmers), Aeshnid (dragonfly) larvae, tiger salamander larvae, *Gambusia affinis* (mosquitofish), Corydalid (dobsonfly) larvae, and garter snakes (*Thamnophis marcianus*). Northern leopard frogs have not evolved with introduced predaceous fish and *R. pipiens* probably have no natural defense against them. All of these predators, except mosquitofish, are also found in the Black Hills, although the garter snake species differ (*T. elegans*, *T. radix*, and *T. sirtalis* are found in the Black Hills and vicinity).

In a series of studies, Relyea and Werner (2000) and Relyea (2001a, b) examined morphological and behavioral plasticity in response to predation threats in tadpoles of a number of amphibian species, including the tadpoles of *Rana pipiens*. Increases in tail depth should result in better swimming speed of tadpoles (Wassersug and Hoff, 1985; McCollum and Leimberger, 1997). Relyea and Werner (2000) found that *R. pipiens* tadpoles were marginally smaller with deeper tailfins and more robust tail musculature when reared in the presence of the larvae of *Anax* species (dragonflies), a known predator on frog larvae, but the difference was not significant. Relyea (2001a, b) found that responses to predators were complex and varied according to predator and anuran species. In the presence of *Anax* larvae and mudminnows (*Umbra* species), *R. pipiens* larvae became less active, while their activity levels did not change in the presence of *Notophthalmus viridiscens* (eastern newts) or *Dytiscus* species (giant water beetles) (Relyea 2001a). Relyea (2001b) explained why these behavioral differences probably occurred; *Notophthalmus viridiscens* and *Dytiscus* were relatively inefficient predators on *R. pipiens* tadpoles, while *Umbra* and *Anax* had high capture efficiencies. Relyea (2001a) also found that *R. pipiens* tadpoles changed morphology in the presence of *Umbra* species, developing smaller bodies with deeper tail fins, a result that was not found to be significant when they were reared with *Anax* larvae (Relyea and Werner, 2000). This result was not obtained when *R. pipiens* tadpoles were reared with any of the other predators. When taken together, Relyea and Werner (2000) and Relyea (2001a, b) showed that the responses of various species of anurans to various species of predators were complex, with changes in morphology and behavior depending on the predators to which they were exposed. Probably most importantly as regards the natural history of *R. pipiens*, these studies showed that predation is a significant factor structuring various aspects of the natural history of anuran tadpoles, including *R. pipiens*.

Most authors have combined discussions of predation on subadults with that on adults. Dole (1965b, 1968) asserted (without evidence) that snakes were major predators of subadult and adult northern leopard frogs. Hammerson (1999) reported that recently metamorphosed frogs were preyed upon by great blue herons (*Ardea herodias*), burrowing owls (*Athene cunicularia*), northern water snakes (*Nerodia sipedon*), and western terrestrial garter snakes (*Thamnophis elegans*). According to Merrell (1977), the most common predators on adult and subadult northern leopard frogs were garter snakes (genus *Thamnophis*). He claimed that northern leopard frogs supported large populations of garter snakes. Leeches also fed on northern leopard frogs, leaving them debilitated and presumably more likely to die (Merrell, 1977). Merrell (1977) also reported that various predators such as fishes, snakes, turtles, amphibians, birds, and mammals all fed on adult northern leopard frogs. I have observed garter snakes feeding on northern leopard frogs in the Black Hills (unpublished observations).

Introduced Predators

Introduced predators have the capacity to overwhelm northern leopard frog populations since the frogs have not evolved along with such predators, and these predators deserve special mention. Bullfrogs (*Rana catesbeiana*) are well known to cause the elimination of populations of ranid frogs, especially in the western United States, where bullfrogs have been widely introduced (Stebbins and Cohen, 1995). Although northern leopard frogs and bullfrogs co-occur in part of the range of the northern leopard frog, in areas where bullfrogs are extralimital but to which they have been introduced northern leopard frogs have declined (Hammerson, 1982, 1999). Southwestern South Dakota appears to be the northwesternmost extension of the natural range of the bullfrog (Ballinger et al., 2000). While the bullfrog occurs in water around warm springs in the Hot Springs, South Dakota, area, and occasionally on the plains near Oelrichs, South Dakota (Smith et al., 1996a, b), widespread introductions in the Oelrichs area in 1968 appear to have mostly been unsuccessful (USDA Forest Service, Buffalo Gap National Grasslands, unpublished records). The bullfrog is a species that needs warm water ponds in which to breed and the climate in southwestern South Dakota is probably too cold to support such ponds. It is almost certainly too cold in the higher elevations of the Black Hills to support bullfrog populations. Since it is well known that bullfrogs can cause serious declines when introduced to areas where they are not native (Stebbins and Cohen, 1995), introductions of bullfrogs should be treated as a major management problem should they occur.

Introduced predaceous fish are another serious issue that probably has caused declines of northern leopard frogs in the Black Hills. The native fish fauna of the Black Hills included mountain suckers (*Catostomus platyrhyncus*) and possibly white suckers (*C. commersoni*) and longnose suckers (*C. catostomus*), and probably none of these fish prey on frogs, their eggs, or tadpoles. Other dace and chubs may have occurred in the Black Hills, but these are also not predators on frogs, their eggs, or tadpoles. Introduced predaceous fish known to occur in the

Black Hills are the rainbow trout (*Oncorhynchus gairdneri*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), and rock bass (*Ambloplites rupestris*). The various trout species (except brook trout) will all eat tadpoles (Smith et al., 1998) and probably also eat frog eggs, the northern pike eats hibernating adult frogs (unpublished data), and the bass and sunfish will probably eat eggs and tadpoles. Kruse and Francis (1977) found that largemouth bass, green sunfish, and black bullhead (*Ictalurus melas*) all ate northern leopard frogs. Bluegill sunfish (*Lepomis macrochirus*) will also eat northern leopard frogs (Relyea, 2001b). Brönmark and Edenhamn (1994) showed that introduced predaceous fish reduced the abundance of tree frogs (*Hyla arborea*) and Hecnar and M'Closkey (1997b) showed that introduced predaceous fish reduced the abundance and diversity of frog communities in Canada, including those in ponds that contained northern leopard frogs. Bovbjerg (1965) reported that the introduction of truckloads of young fish by the Iowa Conservation Commission completely exterminated a population of northern leopard frog tadpoles at his study site following stocking of the slough under study. Introduced fish also eat overwintering northern leopard frogs, which are extremely vulnerable to predation (Emery et al., 1972). In the Black Hills I have observed that ponds with breeding colonies of chorus frogs (*Pseudacris triseriata*) and northern leopard frogs that also contained predaceous fish had no successful metamorphs later in the active season. However, I have made no systematic study of this phenomenon.

Overcollection

Finally, human collectors capture northern leopard frogs and their tadpoles, typically for use in biology teaching laboratories or as fish bait. Overcollecting of northern leopard frogs by humans has accounted for the removal of large numbers of frogs from the wild (Gibbs et al., 1971; Moriarty, 1998; Dan Fogell, personal communication[1]). However, there is no evidence that large-scale collecting is occurring in the Black Hills (personal observations).

Competitors

Larval amphibians have provided an excellent system in which to study competition amongst a closely related group of competitors (Wilbur, 1997). DeBenedictis (1974) and Smith-Gill and Gill (1978) studied competition between *Rana pipiens* and the wood frog, *R. sylvatica*, a frog that breeds slightly earlier in the spring than northern leopard frogs but frequently in the same types of ponds. DeBenedictis (1974) conducted a field study; the study of Smith-Gill and Gill (1978) was a laboratory study designed to examine some of the predictions of competition as determined by the Lotka-Volterra competition equations. The tadpoles of these two species have a high degree of temporal overlap in most parts of the range of the northern leopard frog but the wood frog does not occur in the Black Hills. DeBenedictis (1974) found that the intensity of competition depended on the amount of food, predation, and density of the two species and in some situations did not occur at all. Smith-Gill and Gill (1978) also found complex density effects and discussed these with relation to the Lotka-Volterra competition equations.

In most elevations of the Black Hills encompassed by the Black Hills National Forest the only anurans that occur are the chorus frog and the northern leopard frog. The chorus frog is much

[1] From 1995 – 1999, 174,772 northern leopard frogs were collected in Nebraska for export to two biological supply houses; approximately 120,000 were collected in 1996 alone. Of these, 161,296 were exported by a single individual.

smaller than the northern leopard frog and tends to breed in temporary ponds or in pond margins dominated by rushes rather than the cattail dominated margins that seem to be preferred as breeding habitat by northern leopard frogs. Although they both breed at about the same time it would appear that there is little opportunity for competition amongst tadpoles of these two species due to spatial separation. Even at lower elevations (<1400 m), northern leopard frogs are seldom found in breeding ponds with other anurans. Northern leopard frogs may also breed in ponds with the tiger salamander, but no studies exist that show whether these two species compete.

In amphibian assemblages the most obvious stage at which competition could occur is during the larval period. This is the life stage that has been emphasized in studies of amphibian competition. It is not known whether adult northern leopard frogs could have competitors in the Black Hills, although generalist insectivores of similar sizes to adult northern leopard frogs could compete with them.

Parasites And Diseases

Three basic types of diseases have been identified in amphibians: Viruses, fungal infections, and bacterial infections (Carey et al., 1999). Of these three Carey et al. (1999) and Daszak et al. (1999) wrote that only viruses and fungal infections have been implicated in mass mortality events. However, the bacterial diseases collectively called "red leg" have been reported to cause mass mortality events by Faeh et al. (1998). The term "red leg" may refer to the symptomology of a variety of different bacteria (Faeh et al., 1998) but is frequently associated with *Aeromonas hydrophila*, a bacterium blamed for the disappearance of boreal toads (*Bufo boreas*) at several sites in Colorado (Carey, 1993). However, Carey et al. (1999) stated that they believed that bacterial infections were largely secondary to fungal and viral infections.

Specific types of iridoviruses known as ranaviruses are known to infect ranid frogs (Cunningham et al., 1996; Daszak et al., 1999) and some amphibian declines are blamed on this virus (Jancovich et al., 1997; Daszak et al., 1999). Daszak et al. (1999) reported that ranavirus was extremely lethal, with 100% mortality in tadpoles exposed to the virus. Tadpoles are most susceptible to the virus but all life stages can acquire the disease (Daszak et al., 1999). Infected metamorphs die without signs of infection and infected adults show no overt signs or may display a general weakness (Daszak et al., 1999). Secondary bacterial infections are common in cases of ranavirus. Introductions of amphibians like bullfrogs have probably moved ranaviruses around the country (Daszak et al., 1999). In South Dakota, tiger salamanders are often introduced around the countryside as fish bait and this species has an iridovirus of its own (Daszak et al., 1999). The linkage between ranaviral infections and amphibian declines is less clear than the link between chytridiomycosis and amphibian declines (Daszak et al., 1999).

Chytridiomycosis, a disease of frogs caused by a chytrid fungus, has recently been blamed for frog declines around the world (Berger et al., 1998; Morell, 1999; Daszak et al., 1999, 2000), and has been found in northern leopard frogs (Carey et al., 1999). The disease was first blamed for amphibian declines in Australia in 1998, but it probably emerged separately on two continents at around the same time (Berger et al., 1998) and has been found in frogs collected as far back as 1978 (Milius, 2000). Of concern to persons involved with field surveys, chytrids may also frequently be spread by introduced amphibians or by boots or survey gear contaminated by the fungus. The signs of chytridiomycosis are loss of the righting reflex, lethargy, and abnormal posture (Daszak et al., 1999).

Carey et al. (1999) discussed hypotheses that could explain the apparent recent increases in the susceptibility of amphibians to infectious disease. Among several hypotheses they suggested that these pathogens can be introduced to frog habitats by fish stocking, introduction of non-native amphibians such as bullfrogs or extralimital populations of tiger salamanders, wind-blown insects, the activity of birds or other animals, by workers monitoring amphibian ponds, or by anglers or other tourists. As a standard protocol for amphibian survey and monitoring, investigators should sterilize boots and other gear with a solution of 10% standard household bleach (1:10 by volume), leave this solution on gear for at least 10 seconds, and then rinse the gear with fresh water. This methodology is commonly used in veterinary clinics to prevent the transmission of disease.

Like many amphibians, northern leopard frogs collected in the wild probably have a high parasite load. There have been various field investigations of the parasites of *Rana pipiens*, including Prudhoe and Bray (1982), Baker (1987), and McAlpine and Burt (1998). Goldberg et al. (2001) have discussed the helminths of northern leopard frogs from North and South Dakota. In addition, Dyer (1991) has reviewed records of parasites found in northern leopard frogs. Fried et al. (1997) found that some parasites are particularly lethal to northern leopard frog tadpoles. Of particular interest are trematode parasites in the genus *Ribeiroia*, which have emerged as a potential cause of limb abnormalities in Pacific treefrogs, *Pseudacris regilla* (Sessions and Ruth, 1990; Johnson et al., 1999) and western toads, *Bufo boreas* (Johnson et al., 2001). Limb abnormalities are discussed further on p. 28.

WATER QUALITY

The complex life cycle of amphibians and the permeability of their skin make them especially susceptible to ecotoxicological agents (Cooke, 1981; Bishop, 1992; Hall and Henry, 1992), so there has generally been great interest in their response to such agents. Harfenist et al. (1989), Pauli et al. (2000), and Sparling et al. (2000a) have all summarized the voluminous literature on the ecotoxicology of amphibians. The database of Pauli et al. (2000) is particularly useful, since it is searchable using a variety of parameters including species, contaminant, author, and study type (i.e., field study, lab study, and other types). There has been extensive work on the effect of water quality on *Rana pipiens* as well. A literature search of Pauli et al. (2000) for studies on *Rana pipiens* returned 412 citations, and a comprehensive summary of this literature is beyond the scope of my work. However, review articles by Harfenist et al. (1989), Diana and Beasley (1998), and Sparling et al. (2000a) provide a useful summary of existing ecotoxicological data on amphibians.

Diana and Beasley (1998) offered a concise review of toxicant studies in amphibians, including brief summaries of studies on polychlorinated biphenyls, benzene, phenol, crankcase oil, mercury, cadmium, lead, hydrogen ions (acidification), aluminum, nitrate fertilizers, trichlopyr, triazine herbicides, phenoxy herbicides, dipyridyl herbicides, glyphosate (found and tested in Roundup®), pyrethroids, cholinesterase-inhibiting insecticides, carbamate insecticides, organophosphorus insecticides, organochlorine insecticides, and rotenone. Diana and Beasley (1998) pointed out that, collectively, the amount of toxicants dumped into the environment constituted an enormous amount of chemical pollution and likely contributed to amphibian declines across the world. Breeding ponds used by northern leopard frogs tend to collect all manner of toxicants from runoff water.

It is difficult to meaningfully discuss water quality issues and *Rana pipiens* in the Black Hills without relevant background data. All data on water quality in the Black Hills are from underground aquifers, streams, or lakes, and not from the ponds in which frogs breed, so these data may be unrepresentative of the ecotoxicological environment encountered by frogs. Williamson and Hayes (2000) studied water quality in Lawrence County, South Dakota, partially to determine if mining had caused long-term decline in water quality in the area. Williamson and Carter (2001) studied water quality in various aquifers and streams throughout the Black Hills. Various unpublished data sets exist on water quality at Sylvan Lake, Center Lake, and Legion Lake (Aaron Larson, South Dakota Department of Environment and Natural Resources, personal communication). Steve Anderson (Black Hills State University Department of Science) has taken water samples from Spearfish Creek (unpublished data). None of these studies indicate any major problems with water quality in the Black Hills.

In general, these various sources indicate that water in the Black Hills tends to be slightly alkaline to very alkaline (the pH tends towards about 8.0). Mining residues, although they can be considerable in some soils, are generally light in the water. However, very low pH readings have occasionally been reported from the immediate vicinity of abandoned mines (Williamson and Carter, 2001). Although the USDA Forest Service has an active program of spraying to reduce noxious weeds, most of the pesticides used in this and other applications in the Black Hills seem to be relatively benign. For example, the half-life of most of the commonly used pesticides is less than one month. At higher elevations, the effect of such agents is probably less, since agricultural use at these elevations is minimal, although spraying for noxious weeds by the USDA Forest Service is conducted throughout the Black Hills National Forest. There are also applications of pesticides and fertilizers by private landowners that are not routinely tracked. Cattle may be treated with various agents to reduce ectoparasites, and it is not known if this poses an ecotoxicological threat. Due to the light industrialization of the area, agents used in industrial processes, such as PCBs, are probably of little consequence in the Black Hills. Arsenic levels, a natural contaminant, are high on occasion in some parts of the Black Hills (Williamson and Carter, 2001). These and other potential concerns are discussed below.

Pesticides

As noted by Sparling et al. (2000b), this was one of the most studied classes of ecotoxicological agents. In the Black Hills various pesticides are used, the most common being 2, 4-D Amine, Escort®, Plateau®, and Roundup®. Atrazine has been used, but its use is being phased out by the U. S. Environmental Protection Agency. However, its effects can be alarming, even at low and ecologically relevant doses (Hayes et al., 2002), and it has a long half-life, approximately five to six years. Hayes et al. (2002) found that it created hermaphroditic *Xenopus laevis* (African clawed frogs, a common experimental frog) and emasculated male frogs. It was commonly used in the northern Great Plains and was found in 80 – 90% of the row-crop acreage in the region in the 1980s (Grue et al., 1986). The effects of most of the pesticides used in the Black Hills area are probably highest at lower elevations, since few crops are grown at higher elevations. In addition, pesticides are probably less important in western South Dakota, since much of the area is not suitable cropland. Most of the commonly used pesticides in the Black Hills have short half-lives; from one week to 30 days.

Studies conducted in other areas may have some general relevance to northern leopard frog populations in the Black Hills. Berrill and co-workers (Berrill et al., 1993, 1994, 1997) studied various pesticides that are commonly used in agriculture and silviculture in Canada. Berrill et al. (1993) found that the pyrethroid insecticides permethrin and fenvalerate did not kill eggs or tadpoles when exposed to low levels of these insecticides. However, they caused delayed growth of tadpoles and abnormal behavior, such as twisting rather than darting away after being prodded by investigators. Both of these results indicated that higher mortality could occur in the wild to tadpoles exposed to these chemicals or hatched from eggs exposed to these chemicals than in non-exposed eggs and tadpoles. The effects of the insecticides were different at different temperatures and were lessened at lower dosages. However, Berrill et al. (1993) pointed out that the concentrations used in their study were considered to be low concentrations. Both of these insecticides are commonly used in the United States as well as Canada.

Berrill et al. (1994) studied herbicides used to manage coniferous forests in Canada. They exposed northern leopard frog embryos and tadpoles to low levels of the insecticide fenitrothion and the herbicides triclopyr and hexazinone. None of these pesticides affected hatching success or subsequent behavior in tadpoles exposed to them as eggs in the levels used in these experiments. However, newly hatched tadpoles were very sensitive to the concentrations used in this study, 2.4 – 4.8 ppm triclopyr and to 4.0 – 8.0 ppm fenitrothion, becoming paralyzed or dying. Berrill et al. (1997) exposed northern leopard frogs to low levels of the insecticides permethrin, fenvalerate, and fenitrothion and the herbicides hexazinone, triclopyr, glyphosate, bromoxynil, triallate, and trifluralin, which are used in the management of coniferous forests and croplands in Canada. Embryos were again unaffected by the exposures but newly hatched tadpoles were paralyzed or killed.

Other studies have looked at the exposure of northern leopard frogs to pesticides in the field. Ouellet et al. (1997) sampled northern leopard frogs in farm ponds and non-farm ponds in the St. Lawrence River Valley of Québec, Canada, and found substantial amounts of a variety of hindlimb deformities in frogs from farmland habitats. They blamed pesticides for the hindlimb deformities but established no causal link. Leonard et al. (1999) blamed the loss of leopard frog populations in Washington partially on water quality issues stemming from the use of DDT. They noted that a large amount of pesticides had been found in waters throughout their Columbia River Plateau study area and pointed out the recent results of Berrill et al. (1997) on the effects of low levels of pesticides on larval stages of amphibians. However, the conclusions of Leonard et al. (1999) were largely conjectural.

Fertilizers

Only one study has looked at the effects of fertilizers on northern leopard frogs (Hecnar, 1995). In this study northern leopard frog tadpoles were exposed to chronic and acute doses of ammonium nitrate fertilizer. In acute tests northern leopard frog tadpoles suffered severe weight loss and an LC50 of 22.6 mg/l was calculated. In chronic tests, northern leopard frog tadpoles lost weight and also died, even at fairly low dosages of 10 mg/l. The northern leopard frog was the most severely affected of the three species tested. Hecnar (1995) pointed out that the differential mortality of the species tested would likely cause shifts in species composition in free-living communities of amphibians. The chorus frog, *Pseudacris triseriata*, was much less affected than the northern leopard frog. The chorus frog is a common resident of the Black Hills National Forest (Smith et al., 1998), so shifts in community composition might occur in the area.

Fertilizer effects may not be as important in the higher elevations of the Black Hills, where few crops are grown, but runoff of fertilizer from various sources besides cropland (lawns and golf courses, for example) can be significant.

Mining/Metals

Mining has been practiced in the Black Hills for at least 100 years. Although mining impact has lessened in the Black Hills in recent years, residue from mining still remains and many parts of the region have not been carefully studied. Mining causes acidification and also precipitates metals from mining residue. Some authors have found devastating effects of mining on local herpetofauna, even decades after mines have closed (Porter and Hakanson, 1976). Williamson and Hayes (2000) specifically addressed mining in the Lawrence County area but found that water quality was relatively little affected by mining within the 1988 to 1992 time frame of their study. Linder and Grillitsch (2000) reviewed the effects of metals on amphibians. Acidification is another potential effect of mining on amphibians, which is discussed below.

pH/Acidification

Acidification has been studied intensively in frogs due to the potential for acid rain to cause amphibian declines (see symposium reprinted in the Journal of Herpetology, volume 26, number 4, December 1992). Mining also causes acidification (Diana and Beasley, 1998). Schlichter (1981), Freda and Dunson (1985), Corn and Vertucci (1992), Freda and Taylor (1992), and Long et al. (1995) have all studied the effects of low pH or acid rain in northern leopard frogs. Northern leopard frog eggs cannot develop normally at pH 5.8 or lower (Schlichter, 1981). Northern leopard frog tadpoles were amongst the most sensitive to low pH of all species tested so far, with an LC50 pH of 4.06 (Freda and Taylor, 1992). Northern leopard frog sperm also shows decreased motility at lower pH, with 50% of normal motility at pH 5.5 and maximum motility at pH above 6.5 (Schlichter, 1981). Northern leopard frogs also show chronic effects of decreased pH, with increasing mortality over time when exposed to low pH (Freda and Dunson, 1985). Low pH also acts synergistically with higher levels of UV-B that might result from loss of the ozone layer (Long et al., 1995). However, Corn and Vertucci (1992) found that declines of *Rana pipiens* in the Colorado and Wyoming Rocky Mountains were probably not due to acidification of ponds, since the ponds were simply not acidic enough to affect northern leopard frogs.

Acidification of water in the Black Hills is probably most likely to occur as a result of mining activities. Williamson and Carter (2001) found very low pH in the vicinity of abandoned mines in the Black Hills. They were not concerned about pH in this study because water near these mines was diluted downstream, but it is important to realize that theirs was a study of streams and aquifers. If runoff from abandoned mines enters the small ponds used by frogs for breeding, pH could be too low for reproduction of northern leopard frogs at times in some localities in the Black Hills. As I have pointed out elsewhere (p. 24), more study of amphibian breeding ponds is needed. Because pH tends towards 8.0 in many parts of the Black Hills (Aaron Larson, South Dakota Department of Environment and Natural Resources, personal communication), the area may be naturally buffered against the deleterious effects of lower pH.

Roadways

Roads create a number of problems for amphibians besides deaths on roads by automobiles, as has been reported by Bovbjerg and Bovbjerg (1964), Bovbjerg (1965), Merrell (1977), and Ashley and Robinson (1996). Motor oil can kill some amphibians (Sparling, 2000), and motor oil washes off of roads during rain and snowmelt. Sedimentation and toxic runoff from roads can also affect amphibians (Welsh and Ollivier, 1998; Trombulak and Frissell, 2000). There are a large number of roads in the Black Hills, both paved and unpaved.

Lumberyards

The production of treated lumber uses various chemicals and lumberyards are common throughout the Black Hills. Coal tar creosote, used in treating lumber, is a well-known carcinogen, for example (Holme et al., 1999). Some of these agents are polycyclic aromatic hydrocarbons (PAHs), and Sparling (2000) reviewed their effects in amphibians, but there are few studies of this class of pollutants on amphibians in the field or laboratory.

Cattle grazing

Cattle produce considerable amounts of waste products that run into waterways. Cattle feedlots, especially, produce inordinate amounts of waste that may run off into amphibian breeding ponds. Grazing by cattle has also been reported to affect water quality (Buckhouse and Gifford, 1976), water chemistry (Jefferies and Klopatek, 1987), and water temperature (Van Velson, 1979). The changes are subtle over time (Elmore and Beschta, 1987), but tend to have a profound effect on aquatic ecosystems (Kauffman and Krueger, 1984). Two tadpoles collected in a heavily polluted pond used by cattle in Lawrence County, South Dakota, had deformed mouthparts and irritated skin (unpublished data). High levels of cattle grazing and cattle drinking out of or standing in frog breeding ponds should increase the levels of nitrates and fecal coliform bacteria in these ponds. Reaser (2000) found that cattle grazing influenced the decline of the Columbia spotted frog, *Rana luteiventris*, at a study site in Nevada. Ross et al. (1999) recommended that cattle be fenced out of sensitive wetlands in this area to conserve *R. luteiventris*. I would recommend studies of the effects of cattle on northern leopard frog tadpoles in breeding ponds in the Black Hills National Forest.

Sedimentation From Other Sources

Sedimentation can also run into waterways due to erosion caused by a variety of sources. Although road cuts are probably a primary source of sedimentation in the Black Hills, cattle are also known to cause erosion by trampling streamside vegetation and slopes, and logging can increase erosion. Recent large fires in the Black Hills should also increase the sediment load in nearby waterways.

Rotenone

This chemical is commonly used in fisheries management and can have negative effects on northern leopard frogs (Hamilton, 1941). Northern leopard frog tadpoles could not survive levels of rotenone typically used to sample fish. Metamorphs survived for 24 hours, but Hamilton (1941) gave no further details about morbidity or mortality in metamorphs following the initial 24 hours of exposure. However, he concluded that rotenone had substantially the same effect on tadpoles (or other organisms that use gills to breathe) as on fish; the chemical was lethal to most of these organisms. Rotenone should not be used in waterways used by northern leopard frogs during the active season.

Limb Malformations

This section would not be complete without a discussion of limb malformations, known from forty states and four provinces (Northern Prairie Wildlife Research Center, 1997). The most famous recent reports were those in Minnesota, which were virtually all from metamorphic northern leopard frogs (Helgen et al., 1998). These frogs usually do not survive long because locomotion and basic behavior is seriously compromised by these gross malformations (Merrell, 1969). Helgen et al. (1998) featured several photographs of the affected frogs, most of which had multiple hind limbs or missing hind limbs, although some front limbs were also affected. Helgen et al. (1998) assumed that the cause must be a teratogen or possibly a chemical that disrupts normal endocrine function. The Minnesota Pollution Control Agency sampled the water in which these frogs were found to search for possible causes including pesticides, heavy metals, or polychlorinated biphenyls, but Helgen et al. (1998) did not report these results. Encysted parasites have also been implicated as a possible cause of some limb malformations (incidents of multiple legs) in amphibians (Sessions and Ruth, 1990; Johnson et al., 1999; Sessions et al., 1999). However, a study by Meteyer et al. (2000) showed that limb malformations in frogs probably have several causes. Limb malformations are not a new phenomenon, and Merrell (1969) reported a high frequency of malformations in metamorphic northern leopard frogs collected at a site in Minnesota in 1965. Hoppe (2000) also discussed various historical reports of limb malformations. Northern leopard frogs with limb malformations found in the Black Hills should be reported to the Northern Prairie Wildlife Research Center, which collects such reports from around North America (http://www.npwrc.usgs.gov/narcam).

Ozone/Ultraviolet Penetration

Recent concern over the loss of the ozone layer has prompted investigations of the effects of increasing levels of ultraviolet light on limb deformities in northern leopard frogs (Ankley et al., 1998, 2000). Elevated levels of ultraviolet light can cause hind limb malformations in the laboratory (Ankley et al., 1998) and in the field (Ankley et al., 2000), but it is unclear what the significance of these results is for populations of northern leopard frogs in natural situations. Crump et al. (1999) found that incident light levels had no significant effect on *Rana pipiens* in the field.

Polychlorinated Biphenyls (PCBs)

These are probably of little consequence in the Black Hills, due to the lack of large manufacturing processes that would produce PCBs in large quantities. There is a large literature on PCBs, summarized by Sparling (2000). Phaneuf et al. (1995) studied PCB contamination in northern leopard frogs in Canada.

Arsenic

Williamson and Carter (2001) reported that arsenic levels could occasionally be very high in some streams in the Black Hills. Birge and Just (1973, cited in Linder and Grillitsch, 2000) found that high levels of sodium arsenite were lethal to *Rana pipiens* tadpoles. However, it is not known how arsenic affects frog breeding ponds in the Black Hills. Since arsenic is found naturally in the Black Hills, it is not possible to manage for levels of this chemical. However, it could act synergistically with other noxious agents.

In summary, the various agents discussed in this section have the potential to seriously affect amphibians. As Sparling et al. (2000b) noted, overall input of these agents into aquatic systems is considerable and is probably partially responsible for the decline of amphibians worldwide. At the moment there seems to be little evidence of serious problems in the Black Hills. The most important local considerations would be pollution from cattle, input of pesticides into streams and breeding ponds, mining, and runoff from roadways (including sedimentation). Almost none of these have been extensively investigated in the Black Hills, and most importantly, they have not been investigated in small ponds of standing water where frogs breed. Further studies in the Black Hills would be useful, but these studies should concentrate on breeding ponds rather than on streams and other waterways, as has been the case in the past. Finally, I would recommend consulting the database of Pauli et al. (2000) on specific pesticides that are being used by applicators in the Black Hills or when new treatments are planned. Pauli et al. (2000) provided literature for all chemicals that had been investigated in amphibians as of the publication date of this database.

RESPONSE TO HABITAT CHANGES

Management Activities

The literature reviewed above indicates the potential for negative impacts on northern leopard frog populations from the majority of management activities planned by the USDA Forest Service in the Black Hills National Forest. However, it is hard to predict the extent of negative impact. Some planned management practices probably have little to no effect on northern leopard frog populations in the Black Hills.

Timber Harvest

The best review of timber management practices and their effects on amphibians in North America is deMaynadier and Hunter (1995). They report a variety of negative effects on amphibian populations caused by timber harvest, primarily from clear-cutting (deMaynadier and Hunter, 1995). However, they did not examine ranid frogs in this review. Other types of harvesting activities seem to be less well studied. Certainly timber harvest activities should be directed away from northern leopard frog breeding habitat and core upland habitat and should be undertaken at least 150 – 200 m away from breeding ponds (Semlitsch, 1998). However, this estimate of upland habitat used by northern leopard frogs is tentative at this time. Detailed studies are needed of northern leopard frog movements following the breeding season to establish a core use area. Timber harvest could also disrupt normal migratory pathways if meadows or other grassy areas are destroyed during harvesting activities or, especially, if riparian corridors are damaged (Seburn et al., 1997). Northern leopard frogs probably use such habitats during migrations to avoid dessication.

Recreation

The main recreational activity on the Black Hills National Forest that could cause population declines of northern leopard frogs is management for introduced predaceous fish (i.e., sport fishing). Sport fishing is an important industry that is likely to continue in the Black Hills and efforts will need to be made to reduce the damaging effects of predaceous fish on northern leopard frogs. This will require innovative management techniques. Also, I am not aware of any efforts that have been made elsewhere to ameliorate the damage caused to northern leopard frog populations by sport fishing. Therefore, there may be no precedent on which to draw to design management techniques to reduce the damage that sport fishing causes to the northern leopard frog. Minimizing the amount and extent of predaceous fish introduced into smaller ponds may be simpler but will require monitoring and considerable public education efforts. Northern leopard frogs may also experience predation if they commonly select overwintering sites occupied by predaceous fish. It would be possible to manage for sport fishing and northern leopard frogs by selecting certain watersheds as pristine areas, where predaceous fish are to be removed and not reintroduced, while other watersheds would continue to be managed to provide predaceous fish for sport fishing (D. Backlund, South Dakota Department of Game, Fish, and Parks, personal communication 2001).

Livestock Grazing

Substantial portions of the Black Hills National Forest are grazed under the Forest Service Management Plan (USDA Forest Service, 1997). As reported on p. 27, various problems have been associated with cattle grazing. Livestock trampling also causes mortality in various frogs and toads (Bartelt, 1998; Ross et al., 1999). Northern leopard frog tadpoles with irritated skin and deformed mouthparts have been collected in the Black Hills in ponds with heavy cattle exposure (unpublished data). Redirecting livestock away from northern leopard frog breeding ponds is essential but could be managed by simply fencing off breeding ponds, as was done to conserve populations of *Rana luteiventris* in Nevada (Ross et al., 1999). However, the fencing required could prove to be extensive, especially if runoff from cattle waste is determined to be a problem. Fencing placed around some breeding ponds in the Black Hills seems to be very effective in increasing population sizes of tadpoles in some ponds (Oscar Martinez, USDA Forest Service, personal communication and personal observations). Providing stock tanks for cattle gives them drinking water while keeping them out of breeding habitat.

Harder to assess is the impact of cattle on upland habitat used by northern leopard frogs during the summer feeding period and also the impact of cattle grazing on migratory pathways that may be used by northern leopard frogs. It is important to minimize cattle grazing in core upland habitat around breeding ponds, but again it is not certain exactly how much core area should be provided. A core size of 150 – 200 m in all directions from breeding ponds might be recommended based on the work of Semlitsch (1998), but it might be necessary to expand this core size to about 300 m in all directions since northern leopard frogs are more terrestrial than the amphibians studied by Semlitsch (1998). It is also very hard to determine if there are migration corridors that should be kept free of cattle grazing during periods of leopard frog migrations (i.e., to/from overwintering sites or during natal dispersal). Seburn et al. (1997) showed that riparian corridors were used for migration and showed that migration also occurred over land. However, they did not show how frogs moved over land so there are no guidelines as to which sorts of migration routes other than riparian corridors should be protected. Water quality and trampling issues, as discussed above, are a concern for all habitat used by northern leopard frogs as well

Mining

Porter and Hakanson (1976) showed that water contaminated by runoff from mining was lethal to boreal toad embryos and larvae. Most other amphibians and other aquatic organisms should also poorly tolerate such runoff. Diana and Beasley (1998) also showed that a diverse array of mining byproducts, such as mercury, cadmium, lead, acidification, and aluminum (often a byproduct of acidification), are deleterious to various amphibians as well. To this can be added zinc, iron, and copper studied by Porter and Hakanson (1976). These chemicals can cause increased mortality as well as malformations in a variety of amphibians. Mining activities in the Black Hills should be carefully controlled and monitored to avoid harming populations of northern leopard frogs. Old mining sites should be investigated for extant northern leopard frog populations and to gauge their potential for recovery as suitable northern leopard frog habitat, if extant populations do not exist at these sites.

Prescribed Fire

There are no studies of how populations of northern leopard frogs react to prescribed fire, and studies of ranid frogs at various sites have shown equivocal results. Mushinsky (1985) found that prescribed fire had no clear effect on ranids at fire-adapted study sites in Florida. McLeod and Gates (1998) showed that there were fewer ranid frogs in burned pine areas than in hardwood or cut hardwood habitats, while fire has also been found to maintain open wetlands used by frogs for breeding (Russell et al., 1999). Since many habitats, including those in the Black Hills (Parrish et al., 1996), are adapted to frequent cooler fires, it would logically follow that the animals living in these habitats would respond favorably to the maintenance of a "normal" fire regime. For the Black Hills, the frequency and intensity of historical fires is outlined by Parrish et al. (1996) and this schedule should probably be maintained. Since the effects of prescribed fire have seldom been studied in amphibians it would be an excellent idea to study the response of northern leopard frogs to prescribed fire in the Black Hills. Limiting prescribed fire to times of the year when northern leopard frogs are not active in the Black Hills (probably October or November to April) may be a good strategy. Perhaps prescribed fires should be kept away from the upland core areas used by frogs during the summer feeding period to avoid harming populations of adult frogs. However, I would suspect that a natural fire regime would not unduly harm populations since northern leopard frogs presumably evolved to tolerate the natural low-intensity fires common in the Black Hills prior to the arrival of Europeans (Parrish et al., 1996). Since deMaynadier and Hunter (1995) have also concluded that, in several studies, amphibians in a fire-adapted landscape have responded favorably to prescribed fire, I see no reason that prescribed fire should harm northern leopard frogs in the Black Hills. However, this statement is a deduction that is not based on objective studies of northern leopard frogs in the Black Hills.

Fire Suppression

The effects of fire suppression on northern leopard frog populations have also not been studied. Mushinsky (1985) showed that, on his fire-adapted study site in Florida, areas where fire was suppressed neither had more nor less ranid frogs than those under a prescribed fire regime. The studies of McLeod and Gates (1998) and Russell et al. (1999) have also showed equivocal responses of ranid frogs to fire suppression. Fire suppression allows fuel to build up, which may actually benefit northern leopard frogs to the extent it provides moist microhabitats in which to move or find shelter. However, as is well known, buildup of fuel also increases the likelihood of high intensity fires that are harder to control and can burn at unpredictable times. I would recommend prescribed fires to avoid out of control fires at inappropriate times of the year. Fires that are high intensity and out of control have the potential to harm northern leopard frogs if they burn at the wrong times of the year, such as during migrations, the summer feeding period, or right after metamorphosis, when large numbers of young northern leopard frogs may be moving across the landscape. Opportunistic studies following large fires at localities with northern leopard frogs in the Black Hills would help to understand how these frogs respond to unintentional large burns.

Use Of Pesticides

It is clear that the control of non-native plants using herbicides and the control of insects using insecticides has the potential to severely affect northern leopard frogs. It is imperative that control procedures be put in place to guard against the introduction of pesticides into water sources in the Black Hills. The USDA Forest Service is aware of this for many reasons, not the least of which is human health concerns. It is important to realize that amphibians are similar to fish in their reactions to most of the water-borne chemicals that have been tested on both groups of animals. Therefore, chemicals that negatively affect fish populations have the capacity to seriously affect populations of northern leopard frogs. However, it seems that adequate safeguards are in place to guard against accidental introduction of unsafe levels of pesticides into the water supply. It should be kept in mind, though, that recent studies have shown that extremely low levels of pesticides of various types can cause sublethal effects on northern leopard frogs that would probably prove lethal in the wild (Berrill et al., 1993, 1994, 1997). In short, extreme caution is needed in any pesticide application. Of possibly greatest concern is the control of the mountain pine beetle (*Dendroctonus ponderosae*) in the Black Hills, which periodically builds to extremely high population levels. The large amount of insecticides potentially needed to control this insect could be the worst chemical problem faced by northern leopard frogs in the Black Hills. Managers also need to remember that any chemical introduced into the environment has a high likelihood of draining into a pond that is suitable for reproduction by northern leopard frogs.

Fuelwood Harvest

Fuelwood harvest would seem to be a relatively low-impact activity on the Black Hills National Forest. As long as harvesting activities are kept away from breeding ponds and upland core habitat around these ponds during the active season for northern leopard frogs I foresee little impact on the frogs from this activity. The sound of chainsaws could have some effect on the normal activities of the frogs through the immobility reaction discussed earlier (Nash et al., 1970). Of most importance could be temporary failure of appropriate anti-predator behaviors or difficulties in foraging normally. Again, it is hard to predict impacts on migration routes. Protection against damage of certain microhabitats like grassy meadows that may be adjacent to breeding ponds or that may lie between two likely or known breeding ponds could be important.

Natural Disturbances

It would seem that species should have evolved to tolerate natural disturbances and that natural disturbance should not be a factor that needs to be managed by a management agency. However, when stressed by external factors, especially by factors caused by human agency, it is possible that natural disturbances can overwhelm species. For example, disease epidemics such as chytridiomycosis or ranaviruses may kill more frogs because they act in concert with environmental stressors introduced by humans (Carey et al., 1999). Ultraviolet light interacts with acidification to significantly increase embryonic mortality, whereas neither has much effect singly (Long et al., 1995).

Insect Epidemics

The Black Hills have historically been subject to epidemics of the mountain pine beetle on a regular schedule (Parish et al., 1996). The epidemic itself should not necessarily have an effect on populations of the northern leopard frog unless a large amount of trees are killed by beetles causing a concomitant loss of canopy cover, which could jeopardize shade that might provide higher humidity in some habitats used by northern leopard frogs. However, insecticides are often used in modern management schemes designed to save timber during a beetle outbreak and the negative effects of their use on northern leopard frogs have been discussed above. Also, increased logging activities designed to salvage trees following an epidemic could adversely affect northern leopard frogs. There are no other known insect epidemics that might affect northern leopard frogs in the Black Hills.

Disease Outbreaks

These have been implicated in the decline of northern leopard frogs and other amphibians in various areas (Faeh et al., 1998; Carey et al., 1999; Daszak et al., 1999). However, a direct causal link is hard to prove in most cases, and some authors believe that disease outbreaks could be secondary to another stressor or stressors in the environment (Crashaw, 1997; Carey et al., 1999). Usually the stressors are implied to be some sort of anthropogenic agent (Carey et al., 1999). Disease outbreaks could possibly be mitigated (or, at least, not spread further) by following procedures outlined above designed to sterilize boots and survey gear used by frog surveyors (see p. 23) and by discouraging accidental or intentional introduction of wildlife, especially fish and other amphibians, to northern leopard frog habitat. Probably most important in this regard is protection of breeding habitat from introductions of fish or amphibians.

Wildfire

As noted above (see “Management Activities; Prescribed Fire”, p. 31), low intensity wildfire is thought to have been common in the Black Hills prior to European colonization of the area (Parrish et al., 1996). Wildfire probably can have negative effects on northern leopard frogs, such as reducing cover (thereby reducing humidity in various habitats) and killing frogs outright. However, since northern leopard frogs in the Black Hills most likely evolved in concert with wildfire it seems unlikely that frequent low intensity wildfire is deleterious to northern leopard frog populations in the Black Hills, although it might be disastrous for certain populations or individuals. Higher intensity wildfires of the type that have occurred since European occupation of the Black Hills (Parrish et al., 1996) are probably much more deleterious to populations of northern leopard frogs in the Black Hills, as described above under “Management Activities; Fire Suppression”, pp. 31-32.

Weather

Long-term droughts have been blamed for amphibian declines in some areas and have even been cited as one of the causes of the extinction of the golden toad, *Bufo periglenes* (Crump et al., 1992; Pounds and Crump, 1994; Stebbins and Cohen, 1995). Some of these droughts may be associated with global warming (Stebbins and Cohen, 1995), but once again, a definite causal link is difficult to establish. At any rate, drought is common across western South Dakota and drought could put stress on amphibian populations that are already under stress from various other factors (Crump et al., 1992; Pounds and Crump, 1994). If drought occurs managers should probably be more observant of other potential stresses on populations of northern leopard frogs in the Black Hills.

As far as other weather events, frogs are typical r-selected animals with high potential reproductive rates, high mortality during some life stages, and short lives, and as such they are probably more subject to the vagaries of the abiotic environment than many other animals (Pechmann et al., 1991; Pechmann and Wilbur, 1994). The only other weather event reported to cause high mortality are severe and long winters, which can cause winterkill (Bradford, 1983). Breeding frogs caught unaware during a late spring snowstorm could perhaps be killed outright by such a storm. I have found various cold-blooded vertebrates in the southern United States (Louisiana and Texas, for example) dead after hard freezes in early spring, as if they had been frozen in their tracks. Such a fate could befall a northern leopard frog caught in a late spring snowstorm in the Black Hills as well.

Succession

Succession is a natural process affecting any habitat that is not in a climax state of vegetation. Historically, succession occurred in the Black Hills because of fires, conversion of beaver ponds to upland habitat by sedimentation, and conversion of aspen to coniferous forest in the absence of fire. Very little is known about how ranid frogs would react to these changes. Beaver ponds can be important habitat for northern leopard frogs in the Black Hills (personal observations), but it is likely that, for every beaver pond that becomes filled in by sedimentation and proceeds to a climax state, other ponds would be created. This would probably create a shifting mosaic of suitable habitat for northern leopard frogs and would require that normal patterns of migration be maintained so that the frogs could occupy new habitat as old ponds become unsuitable for reproduction. Managers should consider monitoring beaver ponds to be certain that frogs have a chance to migrate to new beaver ponds as older sites become filled in by sedimentation. In addition, since beaver are now less common in the Black Hills than they were prior to European colonization (Parrish et al., 1996), it is probable that fewer beaver ponds exist in the Black Hills in which frogs can breed, and this has probably caused a decrease in frog abundance. However, this issue is somewhat separate from that of succession.

The interruption of the fire regime in the Black Hills (Parrish et al., 1996) has probably caused the expansion of ponderosa pine at the expense of grassland and aspen habitat, but little data exist to shed light on this process since European colonization. Other than Russell et al. (1999), who pointed out that fire could maintain open wetlands that may be important frog habitat, there are no studies of fire as it pertains to succession and the maintenance of populations of frogs. In the Black Hills, I have found northern leopard frogs at ponds in grassland and aspen (unpublished data). I have also observed that herpetofauna are more rare in ponderosa pine habitat, but have made no detailed studies of this phenomenon.

RISK FACTORS

Prioritizing risk factors to northern leopard frogs in the Black Hills is an uncertain enterprise since risk factors will vary from site to site and are incompletely known in any case. The following should be taken as a tentative prioritization. In some ways these risks are presented as much in order of ease of avoidance of risk as they are in order of clear and present danger to northern leopard frog populations in the Black Hills. Beyond the first two items (of nearly equal importance), the order of the list is speculative. What is not speculative, however, is the fact that all these factors have affected northern leopard frogs at certain study sites throughout North America.

Protection Of Known And Potential Breeding Sites

Semlitsch and Bodie (1998) and Semlitsch (2000b) noted that breeding ponds that produced the highest density and biodiversity of amphibians are not protected by current federal law. Such is also the case in the Black Hills; the current Forest Plan does not provide for the protection of waters appropriate for the reproduction of large numbers of northern leopard frogs (USDA Forest Service, 1997). Streams, springs, and large lakes are protected; what is needed by northern leopard frogs are the smaller seasonal and semi-permanent ponds of <5 ha often left unprotected by law and ignored by management plans (Semlitsch and Bodie, 1998; Semlitsch, 2000b). It should also be noted that upland areas surrounding these ponds are used throughout the summer as foraging habitat and should also be protected (Semlitsch, 1998, 2000a).

Degradation of wetland and upland habitat is inimical to the protection of northern leopard frog populations (for use of upland habitat by northern leopard frogs see publications by Dole and Merrell cited in this report). Although Semlitsch (1998) refers to upland habitat as a "buffer zone", it is more appropriately referred to as "core habitat area" (Semlitsch, personal communication, March 2001) and should be protected as such. Dole (1965 a and b) showed that northern leopard frogs typically used a home range of about 68 – 503 m^2. However, this doesn't indicate how much upland core area should be protected to conserve an entire population because some of the population will have home ranges farther from the breeding pond than other members of the population.

Studies of Semlitsch (1998) on pond-breeding salamanders could be used as a start to protect upland core area for northern leopard frogs. Semlitsch (1998) reported that a "buffer zone" (i.e., core upland habitat) extending 164 m in all directions from each breeding pond is needed to conserve 95% of the adult breeding population of various pond-breeding salamanders foraging in the upland habitat following the breeding season. This core area is highly species specific, however. The larger salamanders Semlitsch (1998) studied are similar in mass to northern leopard frogs and use upland core areas of 150 – 200 m surrounding breeding ponds. This might be taken as a general indication of the amount of upland core area needed by northern leopard frogs, but this species might be more dry-tolerant than the salamanders studied by Semlitsch (1998). Thorough studies are needed specific to northern leopard frogs for more definitive management recommendations.

Introduced Predaceous Fish

These have been clearly implicated in the decline of some frogs (Bovbjerg, 1965; Brönmark and

Edenhamn, 1994; Hecnar and M'Closkey, 1997b) and are found throughout the Black Hills. Ongoing management by various agencies to maintain introduced predaceous fish in the Black Hills makes it difficult to resolve the conflict between this priority and the need to protect populations of northern leopard frogs in the Black Hills. Some of the ponds discussed in this report are found in drainages that are not connected to waterways suitable for introduced predaceous fish and are therefore excellent sites in which to promote the growth of vigorous populations of northern leopard frogs. However, many ponds are connected to waterways with introduced predaceous fish and many ponds that are not connected to such waterways have introduced predaceous fish. Only with communication and cooperation amongst agencies involved in management of introduced predaceous fish might it be possible to resolve conflicts between management for the production of introduced predaceous fish and northern leopard frogs.

Because introduced predaceous fish often do well in habitats not extensively used by northern leopard frogs, such as streams and lakes (but see "Risk Factors; Protection of Overwintering Sites", pp. 36-37), it might be possible to separate areas for fish propagation from habitats used by northern leopard frogs. However, a major impediment to management of ponds for northern leopard frogs in the Black Hills is the predilection of the public to introduce predaceous fish to any body of water that may be suitable for their propagation (and also to ponds that are not suitable). My co-workers and I have found predaceous fish in all sorts of ponds on USDA Forest Service lands in the Black Hills. It must be made clear to the public that this is not permitted and is contrary to attempts to conserve native species in the Black Hills, and the USDA Forest Service will probably have to monitor ponds managed for northern leopard frogs for the presence of introduced predatory fish. If fish are found, they might be safely removed using electroshock or rotenone, but only when northern leopard frogs are not in the pond at the same time. Also, ponds could be used by frogs for breeding and overwintering, making it difficult or impossible to use either of these techniques at any time without damaging the frog population. In addition, ponds without frogs but with fish may become good frog habitat if fish were to be removed. All agencies involved in managing fish and wildlife must realize that management for the maintenance of introduced predaceous fish for sport fishermen and management for the conservation of the northern leopard frog are contradictory management objectives. Collaborative and innovative solutions must be found and researched. The idea that some drainages might be managed for sport fishing and some for wildlife (D. Backlund, South Dakota Department of Game, Fish, and Parks, personal communication 2001) is an interesting one that should be pursued.

Protection Of Overwintering Sites

Northern leopard frogs use lakes, larger ponds, and streams in which to overwinter (Merrell, 1977; Cunjak, 1986). Since lakes did not historically exist in the Black Hills (Froiland, 1990) northern leopard frogs may not use them for overwintering sites in this area. Even if they do, introduced predaceous fish are likely to exert predation pressure on frogs in lakes during the winter. Other sites suitable for overwintering in the Black Hills are also subject to predation pressure by introduced predaceous fish, such as streams and larger ponds. A frog observed by Oscar Martinez (USDA Forest Service personal communication) apparently overwintering in a wet meadow under snow cover is interesting, but it is hard to know what to make of this observation. Since overwintering mortality can be high at times in ranid frogs (Bradford, 1983) it is important that overwintering sites in the Black Hills be identified and protected. Many of these sites are probably also stocked with introduced predaceous fish, which could easily decimate populations of northern leopard frogs in the winter.

Water Quality

It is well known that pesticides can negatively affect northern leopard frogs in the laboratory and in the field (Kaplan and Overpeck, 1964; Kaplan and Glaczenski, 1965; Dial and Dial, 1987; Berrill et al., 1993, 1994, 1997; Ouellet et al., 1997; Leonard et al., 1999). It is also obvious that northern leopard frog breeding ponds can receive significant inputs of environmental contaminants in runoff water. Current USDA Forest Service precautions seem adequate to inhibit degradation of water quality by pesticides. The pesticides used on the Black Hills National Forest are not known to cause significant problems although their health effects have not been investigated in amphibians. However, pesticides should always be carefully used near northern leopard frog breeding ponds and pesticides used by the USDA Forest Service need to be investigated for their health effects in amphibians. Possibly more significant is the impact of pesticides and fertilizers used by private landowners on lands near those under management by the USDA Forest Service. Efforts should be taken to ameliorate these negative impacts to the extent possible, including perhaps public education.

Of possibly more interest is the effect of mining on northern leopard frog breeding habitat. Although there appears to be a single study on mining and its potential effect on amphibians, it is highly significant. The site investigated by Porter and Hakanson (1976), though shut down for about 75 years, was particularly lethal to amphibians and probably also lethal to many other aquatic, and even terrestrial, organisms. Old mining sites in the Black Hills should probably be investigated particularly if they are associated with ponds that could potentially be used by northern leopard frogs. At least a few sites of this nature exist in the Black Hills (unpublished data) but the water quality of these sites and their use by northern leopard frogs is unknown. The USDA Forest Service should tightly regulate mining activities as they clearly have the potential to cause significant declines in northern leopard frog populations. Studies on acidification and metals are relevant to the negative impacts of mining in the Black Hills as well (Schlichter, 1981; Freda and Dunson, 1985; Corn and Vertucci, 1992; Freda and Taylor, 1992; Long et al., 1995).

Protection Of Migratory Pathways

Northern leopard frogs frequently migrate across the landscape for several reasons including dispersal of metamorphs (Dole, 1971; Merrell, 1977), summer movements associated with feeding (Dole, 1965b; Dole, 1967; Merrell, 1977), and migrations to and from overwintering sites (Dole, 1967; Merrell, 1977). The routes they take on these migrations probably include wet meadows, tall grass, and riparian corridors. It is likely that grazing and timber removal can jeopardize such habitat. However, deMaynadier and Hunter (1998) found that aquatic ranids were less affected by clearcutting than were the more terrestrial ranids, such as wood frogs (*Rana sylvatica*), and some salamanders. Without detailed studies it is hard to know what areas to protect and protection is already afforded to wet meadows and riparian corridors in the Forest Service Plan (USDA Forest Service, 1997). It is necessary to know the placement of suitable breeding ponds and overwintering sites on the Black Hills National Forest before it will be possible to infer potential migration routes and protect these routes.

Introduced Infectious Diseases

This potential cause of amphibian declines is well known, but the exact transmission vector is poorly known (Carey et al., 1999). Carey et al. (1999) noted that introduction of exotics might spread disease. Since introductions of bullfrogs are common across the United States, it is possible that such an introduction, although unlikely to establish a permanent population of bullfrogs in the Black Hills, could still cause damage by introducing chytridiomycosis, ranavirus, or a bacterial infection. More commonly introduced in South Dakota are tiger salamanders, which are used as bait by fishermen. Tiger salamanders are known to harbor iridoviruses (Daszak et al., 1999). Diseases could be introduced to Black Hills ponds through several other means as well, as noted in "Community Ecology; Parasites and Diseases", pp. 22-23, such as by fishermen or other tourists and investigators surveying and monitoring northern leopard frogs.

Road-Related Mortality

It has been known for some time that roads cause extensive mortality of juvenile *Rana pipiens* (Bovbjerg and Bovbjerg, 1964; Bovbjerg, 1965; Merrell, 1977). Recently, Ashley and Robinson (1996) showed that young-of-the-year *R. pipiens* were disproportionately represented amongst dead herpetofauna at their study site in Ontario. Carr and Fahrig (2001) found that traffic density within a 1.5 km radius of frog breeding ponds was negatively associated with the abundance of northern leopard frogs, suggesting that the viability of populations can also be affected by road mortality. Road associated factors such as sedimentation and runoff of toxic compounds can also affect aquatic communities nearby roads (Welsh and Ollivier, 1998; Trombulak and Frissell, 2000). If roads affect populations of frogs, it is likely that other types of habitat disturbance, especially logging in the Black Hills, would negatively affect populations of northern leopard frogs. The placement of new roads should be considered in relation to their effects on frog populations. In addition, frogs and their habitat should be considered when decisions are made to close or manage old roads.

Other Habitat Disturbances

Other activities can have unexpected effects on northern leopard frogs as shown by Nash et al. (1970) in their study of the immobility reaction in leopard frogs in response to generalized noise. This reaction would be of importance in any area of human activity, particularly in areas nearby construction or timbering operations. This reaction increases road mortality and probably interrupts feeding behavior. In addition, the loss of beaver in the Black Hills and concomitant reduction in wetlands across the area (Parrish et al., 1996) has reduced the habitat available for breeding by the northern leopard frog. Redoubled efforts to reintroduce beaver and protect beaver habitat would no doubt also benefit the northern leopard frog.

SUMMARY

Northern leopard frogs can be used as a unique indicator species in the Black Hills National Forest. As an amphibian, they have a permeable skin that offers little barrier against most types of chemicals, and they evaporate water essentially as if they were a free water surface (Pough et al., 2001). Also, the types of water bodies typically used as breeding habitat by northern leopard frogs are also used by many different vertebrates in the Black Hills (Rumble et al., in press).

Presence of healthy populations of northern leopard frogs at these ponds can be used as an indicator that the ponds are suitable for many of the wildlife of the Black Hills National Forest, both game and non-game species. Monitoring northern leopard frogs may tell us a great deal about forest health in general.

However, there are many reasons to be concerned about the status of northern leopard frogs. Declines in many parts of the range of the species are well known and northern leopard frogs are known to be subject to mortality by many agents, including destruction of breeding ponds, interruption of migratory pathways, habitat destruction, diseases, pollution, introduced species, and others. The species has been extirpated from many areas in the Rocky Mountain states. Fortunately, the most recent surveys of northern leopard frogs in the Black Hills have shown that they are still common in this area. However, these surveys are incomplete, monitoring is non-existent, and their habitat in the region is poorly described and not mapped.

The Black Hills National Forest is in a unique position to contribute to the science of this species, which in some ways is so well understood, yet in others is so poorly known. The nearest populations of northern leopard frogs that have been studied were in Larimer County, Colorado, some 300 miles southwest of the Black Hills, and in the Minneapolis/St. Paul region, 500 miles east. As is well known, the Black Hills also has a unique patchwork of habitat from eastern and western North America, grasslands, and upland forest, with other unique features found only in the Black Hills. It is likely that study of northern leopard frogs in the Black Hills would be rewarding not only because it is a declining species still common in the area, but also because the Black Hills offer an opportunity to examine how this versatile amphibian exploits a unique mix of habitats.

REVIEW OF CONSERVATION PRACTICES

Management Practices And Models

Few papers have addressed management concerns for amphibians, fewer still have looked at ranid frog management, and none have done so specifically for northern leopard frogs. Semlitsch (2000a) is the most extensive review of the amphibian management literature available and deMaynadier and Hunter (1995) have reviewed forest management practices and their affect on amphibians in North America. However, Lannoo (1998b) has provided perhaps the most succinct summation of a potentially successful strategy for conservation of frog populations in North America. Modified for northern leopard frogs in the Black Hills, his advice might be to provide a series of seasonal or semi-permanent ponds that are connected by upland migration corridors plus habitat for terrestrial life history stages (the upland core areas advocated by Semlitsch, 1998, 2000a).

To briefly summarize the findings of deMaynadier and Hunter (1995), we can conclude that several standard forestry practices can adversely affect populations of amphibians in general, and probably have some effect on northern leopard frogs. First, most amphibians do not use habitat in recently clear-cut areas, and there is a general association of stand age and abundance. However, the most important variables appear to be microhabitat variables such as herbaceous cover, downed wood, litter depth, and other variables. Amphibians better tolerate habitats that provide cover because these habitats allow them to avoid dessication. Therefore, timbering operations that strive to minimize understory disturbance are probably better for conserving amphibian populations than other types of forestry practices. Also, scattering this type of disturbance around the landscape is probably beneficial; i.e., smaller clear-cut areas interspersed amongst areas that have not been cut or have been cut using less intrusive treatments is better than large areas of clear-cutting. Secondly, riparian corridors are used as migration pathways by several amphibians, and we can expect that the wider they are and the more connected northern leopard frog breeding ponds are to these riparian zones, the better off populations of northern leopard frogs will be. Third, roadways can isolate populations or reduce their size, sometimes even if these roadways are low or no-use roadways. This might be less of a problem for the northern leopard frog, a species known to migrate long distances under less than ideal conditions. Finally, the little data that we currently have on prescribed burning has shown that amphibians sometimes tolerate prescribed burning rather well. However, all these conclusions are largely based on types of amphibians other than ranid frogs and remain to be tested in this group.

Semlitsch (2000a) provided a wider-ranging review of various management practices that is less focused on specific types of forestry practices. He identified several threats to local and regional amphibian populations including habitat destruction and alteration, global climate change, chemical contamination, diseases, invasive species, and commercial exploitation. Among this group I have already discussed the threats that pertain to Black Hills populations of northern leopard frogs, namely habitat destruction, chemical contamination, diseases, and particularly invasive species (introduced predaceous fish). Yet to be discussed in this report is the importance of local population dynamics and metapopulation dynamics as emphasized by Semlitsch (2000a).

Like many species, pond-breeding amphibian populations are connected across the landscape, with each pond serving as a population and all the populations of all the ponds existing as one, or several, metapopulations. Each pond may be more or less isolated, depending on how far it is from other ponds, the predilection of northern leopard frogs to migrate from pond to pond, the tendency of young to disperse from natal ponds, and the philopatry of subadult and adult frogs. Without detailed studies of the genetics and movement patterns of the frogs it is difficult to know whether there is a high degree of within-population genetic variability (i.e., most genetic variability is found within a population or pond), or a high degree of among-population genetic variability (i.e., most genetic variability is found among ponds). In the former case, conservation of one or a few breeding ponds and surrounding upland habitat conserves most of the genetic variability within the metapopulation. In the latter case, several ponds must be conserved to maintain a high degree of genetic diversity within the metapopulation. Of course, the safest way to manage to conserve high genetic diversity is to always maintain as many ponds and their surrounding upland core area as possible with as many migration corridors amongst these as possible, regardless of how genetic variation is apportioned among and within populations.

To manage the landscape for northern leopard frogs requires extensive knowledge of the management area. It is critical to identify breeding habitat and potential breeding habitat and any potential migration corridors amongst these habitats. This requires fine-grained mapping data that can be obtained from maintenance of an extensive GIS database. This is potentially a tremendously time-saving procedure. If we can identify or actually predict ponds suitable for northern leopard frog reproduction, we can map these ponds more easily than they can be surveyed for frogs and we are not restrained by the active season of the frogs to complete these surveys. If we can also identify potential migration corridors used by frogs, these can also be mapped, in this case considerably more easily than we can actually survey them for frogs. By connecting breeding habitat across the landscape in this manner, we have a reasonable chance of increasing the abundance of northern leopard frogs across the Black Hills National Forest.

However, it is critical that data be collected to develop a GIS model of habitat used by northern leopard frogs. This can be done by examining and characterizing known breeding ponds and by surveying upland habitat and migration corridors used by leopard frogs and characterizing these critical habitat features. Simultaneously, genetic data can be non-destructively obtained from the frogs surveyed during this process to determine the genetic connectedness of these ponds, upland areas, and migration corridors. Both habitat and genetic data can be entered into a fine-grained GIS database. The genetic data can be used to tell us something about the pattern of genetic diversity within or among sites. The habitat data gathered at each site can be used to query the existing GIS database to find other suitable northern leopard frog habitat. Once the model is developed, it can be used to predict other sites where frogs should occur, to reconnect formerly connected habitat, or to restore breeding ponds and upland habitats. Favorable sites without northern leopard frogs could even be targeted for reintroductions of northern leopard frogs, an approach which has proven to be successful for spotted salamanders (*Ambystoma maculatum*) and wood frogs in Missouri (Sexton et al., 1998). Sexton et al. (1998) showed that reintroduced populations of wood frogs began expanding into formerly occupied habitat. Using a habitat model derived through sampling known northern leopard frog habitat and the use of a GIS database, judiciously picked reintroduction sites would increase the possibility of the expansion of northern leopard frogs into formerly occupied habitat in the Black Hills, should such areas be identified.

Survey And Inventory Approaches

As usually done by biologists, a survey is a study in which investigators attempt to delineate the boundaries of a species' range or its occurrence within a specified portion of a range. An attempt to determine the abundance of the species within the area of interest is also usually made, but not always. An inventory, on the other hand, is usually a study in which biologists attempt to ascertain the current status of a species within its range or within a portion of its range. This implies that the investigators will attempt to determine the abundance of the species within the study area. In the Black Hills, it is especially important to determine the specific localities where northern leopard frogs are found and effective population sizes of populations of frogs at these sites. An overall survey of the northern leopard frog within the Black Hills has never been undertaken. Of course, an inventory of the species cannot start without such a survey. Any ongoing monitoring of the status of northern leopard frogs (i.e., an ongoing inventory) within the Black Hills would necessarily start with a comprehensive survey of the species within the Black Hills National Forest, preferably with concomitant determination of effective population sizes at sites where frogs are found. These data should be entered into a GIS database.

Heyer et al. (1994) compiled existing techniques for surveying and monitoring amphibians. They and their contributors also discussed associated issues such as standardization and quantification, research design, data and planning of studies, estimation of population size, and data analysis. Of the survey and monitoring techniques discussed in Heyer et al. (1994), the following techniques could be useful in surveying and monitoring northern leopard frogs in the Black Hills: 1) Acoustic monitoring, i.e., call surveys (Berrill et al., 1992; Peterson and Dorcas, 1994; Zimmerman, 1994; Bishop et al., 1997; Bonin et al., 1997; Lepage et al., 1997; Johnson, 1998; Mossman et al., 1998); 2) Drift fences and pitfall traps (Corn, 1994; Dodd and Scott, 1994; Smith et al., 1996a, b); 3) Various quadrat sampling techniques (Jaeger 1994a, b; Jaeger and Inger, 1994); 4) Cover boards (Fellers and Drost, 1994; Bonin and Bachand, 1997; Davis, 1997); and 5) Visual encounter surveys (Crump and Scott, 1994; Smith et al., 1996a, b; 1998). Various marking techniques can be used in conjunction with these survey methods to mark and track amphibians in the field (Dole, 1972; Green, 1992; Ashton, 1994; Heyer, 1994; Richards et al., 1994; Madison, 1997; Madison and Farrand, 1997; Semlitsch, 1998).

Probably the simplest, least expensive, and most commonly used practice to survey amphibian populations are call surveys (Berrill et al., 1992; Peterson and Dorcas, 1994; Zimmerman, 1994; Bishop et al., 1997; Bonin et al., 1997; Lepage et al., 1997; Johnson, 1998; Mossman et al., 1998). Call surveys may be set up a number of ways, including traveling along transects randomized by habitat, at locations specified along a roadway (itself a kind of transect), and other methods. In the Black Hills, I have typically carried out call surveys by first surveying during daytime hours for ponds in which northern leopard frogs may occur. Then, co-workers and I have traveled at night from potential breeding pond to potential breeding pond to listen for breeding choruses of frogs, recording whether we heard choruses and sometimes estimating the size of the chorus. Usually, ponds are visited at least three times during the breeding season to verify whether the pond is being used as a chorusing site. Depending on the species, call surveys can be an excellent way to survey and monitor frogs.

The longest lasting and most successful of yearly call surveys has been the volunteer call survey ongoing in Wisconsin since 1981 (Mossman et al., 1998). Although some call surveys have been quite successful as survey and monitoring efforts, not all anurans are easily surveyed and the calls of some frog species vary in volume geographically. For example, Bishop et al. (1997) noted that northern leopard frogs have low volume calls that may be hard to hear. Smith et al. (1996b) have pointed out that northern leopard frogs call sporadically and at very low volume in the Black Hills region. They have cautioned against the use of call surveys to survey or inventory the species in the Black Hills. Bonin et al. (1997) have also advised against the use of the technique to quantitatively assess the extent of frog declines over several years. I would advise against using any auditory-based survey techniques such as audio strip transects (Zimmerman, 1994), breeding site surveys (Scott and Woodward, 1994), or basic acoustic monitoring (Rand and Drewry, 1994) because northern leopard frogs chorus sporadically and can be difficult to hear in the Black Hills. Automated data loggers (Peterson and Dorcas, 1994) might be of use if they can discern the calls of northern leopard frogs in the Black Hills. Areas identified by the data loggers could be visited by observers to determine the extent of calling at these sites.

Drift fences and pitfall traps can be installed and periodically monitored to assess the abundance of amphibians at a study site (Corn, 1994). Drift fences can also be installed at breeding sites, completely encircling the site and trapping every individual entering or leaving the site (Dodd and Scott, 1994). Drift fences are long fences made of sheet metal and placed flush to the ground such that amphibians cannot climb over or burrow under the fence. Pitfall or funnel traps are placed along the fence to trap amphibians moving along the fence. In my experience it can be difficult to train non-herpetologists to properly install drift fences and I recommend that a herpetologist be consulted and survey teams be properly trained if drift fences are to be used at any ponds in the Black Hills to survey northern leopard frogs. I believe that the primary use of drift fences in the Black Hills would be for studies of northern leopard frog breeding ponds or studies of movement in the species. Drift fences can be costly, both in terms of materials and construction effort. However, once installed drift fences can be cheaply and easily operated.

Upland habitats can be quantitatively sampled using quadrat sampling (Jaeger and Inger, 1994), transect sampling (Jaeger, 1994a), and patch sampling (Jaeger, 1994b). Each of these techniques relies on sampling various sizes and shapes of plots to determine how many amphibians occur per unit area of sampled habitat. Of all the techniques discussed, these are the only techniques that can provide information on the number of animals per unit of habitat.

Patch sampling (Jaeger, 1994b) refers to the sampling of patches where frogs are more likely to occur, which obviously in the case of northern leopard frogs should be habitat near breeding ponds, along streams, or in riparian corridors. One general drawback to patch sampling is that the habitat is not randomly sampled; e.g., habitats that investigators think lack frogs are not sampled. However, as long as the data are properly reported, i.e., the data are not presented as being a random sample of all possible habitats, patch sampling is an appropriate tool that can be used to survey amphibians.

Patch sampling can be combined with quadrat or transect sampling. During the breeding season, northern leopard frogs are concentrated at ponds, but following breeding they are dispersed in upland habitat and may be difficult to locate. Of course, it might be expected that frogs will be found closer to ponds, streams, or riparian areas. Therefore, the areas nearby ponds, streams, and in riparian strips can be selected as patches in which to search for northern leopard frogs following the breeding season. To systematically sample these areas, researchers might restrict searches to areas immediately adjacent to ponds (for example, the 200 – 300 m core area discussed throughout this work), along streams, and in riparian corridors. They can then conduct quadrat or transect samples (quadrats are square plots while transects are basically long strip-like plots; some researchers make little distinction between the two) in these patches to assess the numbers of adult frogs using these habitats. These combined techniques could result in an assessment of frog density around breeding ponds, along streams, and in riparian corridors following the breeding season.

Cover boards are cover objects such as plywood boards that are placed in the environment (Fellers and Drost, 1994). They are probably best used for salamanders and snakes and have not been validated for use with northern leopard frogs. Most herpetologists have long known that many amphibians take refuge under various objects and trash piles are frequently coveted areas in which to search for specimens. Cover boards can be made of plywood or other material and cut to specific sizes. They can be placed in various arrays as a method of quantitatively surveying amphibians. The technique has proven useful to monitor salamander populations (Bonin and Bachand, 1997; Davis, 1997) but there are differences in how species use cover boards and the types of cover boards favored by different species (Bonin and Bachand, 1997; Davis, 1997). Construction techniques and suggested arrays can be found in Bonin and Bachand (1997) and Davis (1997). Cost would be minimal following initial testing and construction of cover boards, but testing the technique for northern leopard frogs could be costly and time consuming and should be conducted by a professional herpetologist. Unlike drift fences, cover boards could be left in place unmonitored for long periods of time since specimens can leave or use cover boards at will and are not trapped in pitfalls or funnel traps that cause rapid dessication and must be checked frequently.

Any technique that allows the hand capture of specimens can be used in conjunction with marking techniques as part of a larger study on breeding or movement patterns. Amphibians can be marked and tracked using a variety of devices including thread bobbins (Heyer, 1994), radiotransmitters (Richards et al., 1994), radioactive tags (Ashton, 1994), toe clipping (Green, 1992), and passive integrated transponder (PIT) tags. Thread bobbins have been used to track northern leopard frogs (Dole, 1972). The device is a spool of thread attached to a harness that is tied around the body of the frog just ahead of the hind legs. It can be used to track frogs over short distances of up to 50 m (Heyer, 1994). The technique is somewhat time-consuming but is inexpensive and can provide basic information on the movements of northern leopard frogs in the field (Dole, 1972). There are occasional harmful effects of the harness as the frogs can become entangled in the string or the harness can irritate the frog (Dole, 1972).

Radiotracking has been used on larger animals for a number of years but with miniaturization of transmitters it has recently (within the last ten years) been successfully used on amphibians in the field. It has been used extensively with ranid frogs as well (Rathbun and Murphey, 1996; Lamoureux and Madison, 1999; Mathews and Pope, 1999; Bull, 2000; Bull and Hayes, 2001), including *Rana pipiens* (Waye, 2001). The technique is time-consuming, expensive, requires detailed training of investigators, and also may require invasive surgery to install transmitters. However, it is the best way available to obtain detailed information on the movement of animals in the field.

Radioactive tags have also been used to monitor amphibian movements in the field (Ashton, 1994) and have been used in salamanders for several years (Semlitsch, 1998). Radioactive tags are particularly useful for small organisms that cannot be tracked using radiotransmitters. The tags can be detected by scintillation counters up to 5 m (Semlitsch, 1998). The technique is available for use to monitor amphibian movements in the Black Hills but concerns over handling of the tags, health effects on frogs with implanted tags, and environmental effects may argue against studies using radioactive tags.

Toe clipping has long been used to mark various animals in the field and can be used to track northern leopard frogs in the Black Hills over time. A basic pattern for numbering frogs using toe clipping is outlined by Green (1992). In conjunction with other sampling techniques, toe clipping can be used to monitor the movements of individuals and can be used to derive a mark-recapture estimate of population density using a number of open population estimators given in Krebs (1999). Deriving a mark-recapture estimate of population size at most ponds would probably require marking and recapturing large numbers of northern leopard frogs. Since toe clipping is invasive it should not be used unless it is part of a determined effort to monitor frog movements or derive population estimates. Toe clipping, when done in conjunction with basic sampling, is simple and inexpensive to implement.

Individual northern leopard frogs may be identifiable through unique markings. Robert Newman, of the University of North Dakota, has identified a number of wood frogs through computer analysis of photographs of unique patterns on their back (personal communication, 1997). The spotted pattern across the back of northern leopard frogs might serve to uniquely identify individuals should an intensive study of population sizes or movements be undertaken at certain sites. The technique is time consuming and management of the individual records could be difficult. Attempting to discern one frog from another using specific markings could be difficult or impossible. I am not aware of anyone that has attempted such a study in northern leopard frogs.

Finally, passive integrated transponder (PIT) tags can be used to mark individuals as well. These are small glass rods, usually no more than 10 mm in length, that are inserted under the skin of individuals. A reading device reads uniquely coded numbers from the tags when waved over the marked individuals. Such tags have been used for several years to mark a variety of amphibians, such as the Jemez Mountain salamander, *Plethodon neomexicanus*, a slim and small salamander found in the United States, with a snout-vent length of only 4.7 – 6.5 cm (Charles Painter, New Mexico Department of Game and Fish, personal communication 2000). They would probably work to mark northern leopard frogs as well, again as part of a detailed movement or population study. They and the reader are somewhat expensive to purchase, but are much less expensive than radiotransmitters without the safety issues associated with radioactive tags. However, PIT tags are invasive to install since they must be inserted under the skin or into the abdomen of animals.

Herpetologists for many years have simply walked around and looked in suitable habitat for amphibians. This is frequently the most productive way to search for amphibians, and if properly quantified (for instance, by keeping track of the amount of time spent searching), this is a suitable technique to survey and monitor many species (Crump and Scott, 1994). Crump and Scott (1994) called the technique a visual encounter search. Investigators simply approach a survey area and walk around the area searching for the species of interest, possibly flipping suitable cover objects all the while. After a pre-determined period of time, the search is halted and results (number of specimens encountered) recorded. I have used this technique in all of the survey work I have conducted in the Black Hills region and it has worked well to find all species (Smith et al., 1996a, b; 1998). Typically I have used a three or four person crew and have conducted a two person-hour search at each survey site. The time is derived by using a three person crew for 40 minutes (3 persons by 40 minutes = 2 person-hours) or a four person crew for 30 minutes (4 persons by 30 minutes = 2 person-hours).

For northern leopard frogs I have searched for subadults, adults, and metamorphs later in the season using this technique. I have also used this method to search for developing tadpoles using a dipnet that is swept through shoreline vegetation. Sometimes tadpoles are obvious using this technique but sometimes I have not found tadpoles at sites at which I have found metamorphs later in the season. During the breeding season I have found that northern leopard frogs are cryptic and hard to locate either by sight or by sound. The tadpoles are sometimes hard to find as well, perhaps because they are hiding in dense cover. I have also found it difficult to provide accurate counts of northern leopard frogs because they can be present in large numbers (e.g., hundreds of tadpoles or metamorphs are present) or are otherwise hard to count (e.g., several individuals jump and escape simultaneously). I usually record northern leopard frogs as "present" or "absent" at study sites. If frogs are found at a site I have not re-visited the pond whereas I visit ponds at least three times before recording northern leopard frog absence at a site. Crump and Scott (1994) covered the assumptions and limitations of the technique and provided a sample data sheet.

Another survey method useful in monitoring northern leopard frogs is egg mass surveys (Corn and Livo, 1989; Werner et al., 1999; Crouch and Paton, 2000). In this type of survey, investigators visit ponds that are suspected to have breeding populations of northern leopard frogs to search for their egg masses. As described on p. 16, these are laid in clumps on submerged vegetation slightly below the water surface and may be found by trained investigators. Since each clump is laid by a single female, simply counting all egg masses found in a pond gives an estimate of the number of females using the pond for reproduction. If a 1:1 sex ratio is assumed, the total breeding population size could be determined, but it is important to recognize that not all females may breed during a given year, the sex ratio may not be 1:1, and there would be an undetermined number of sexually immature individuals in the population. It might be difficult for non-specialists to identify northern leopard frog eggs, but clumps of the eggs of this species look substantially different than those of the other anurans that are predominantly found in higher elevations in the Black Hills such as chorus frogs and Woodhouse's toads (*Bufo woodhousei*).

Aquatic funnel trapping is a presence/absence technique that can be used to detect northern leopard frog tadpoles in breeding ponds. Various types of funnel traps are described in Adams et al. (1997). These traps are placed in ponds, where tadpoles swim into them and are captured. The traps are checked on a frequent basis and tadpoles are identified and released. The materials used are not expensive (minnow traps and even used two-liter plastic soda bottles can be used for the purpose), but they need to be checked daily or every few days during the tadpole growing season. Non-specialists may find it difficult to differentiate the various tadpoles found in the Black Hills.

A General Survey And Monitoring Technique For The Black Hills

During our work in the Black Hills my co-workers and I have found that it is extremely difficult to hear northern leopard frog choruses or to otherwise find breeding northern leopard frogs during the breeding season. We have also sometimes found it difficult to find developing tadpoles in ponds at which we have later found metamorphosing northern leopard frogs. We have found that the best approach to survey northern leopard frogs with limited time and money has been the use of visual encounter surveys following the metamorphosis of tadpoles into subadult frogs (Smith et al., 1996b, 1998).

We have generally looked for metamorphic or subadult northern leopard frogs in August through September depending on the elevation. We have often found that, if the ponds are suitable for northern leopard frogs and frogs exist at the site, we can find frogs in numbers too large to reliably count in just a few minutes. However, sometimes they are harder to find and turn up during a visual encounter search. Regardless, I always spend two person hours searching at a site and then move on to another site. To be certain that they don't exist at ponds that appear suitable we have frequently gone back to re-survey each site until at least three searches have been conducted at each pond. If frogs are found at a pond we note that the frogs are "present" at the site and do not return during the season. In my opinion an accurate count of northern leopard frogs at a site is very difficult to obtain without resorting to more detailed mark-recapture estimates as outlined in Krebs (1999). If detailed estimates are needed, then a detailed study is needed. Otherwise, presence/absence information is the best estimate obtainable, and simple frog counts should not be considered reliable.

Of course, this kind of survey work provides very coarse presence and absence data that is difficult to analyze and also may not be very responsive to population density fluctuations. For this reason a large number of sites must be visited to identify trends through years. I recommend that as many sites as possible be identified and mapped using Global Positioning Systems and tracked over many years. The surveys are quick and simple to conduct and northern leopard frogs are easy to survey so time and expense spent surveying should be minimal. Approximately

100 or more known and potential breeding ponds might be picked across the Black Hills National Forest, with perhaps 25 – 50 ponds in each forest district. Over time trends might be detected with this sampling regime if frog presence begins to increase or decline.

I would recommend consultation with a professional herpetologist in the initial stages of this survey and monitoring effort to pick appropriate ponds for monitoring, and ongoing consultation to guide the work and data analysis over the years. If 100 or more ponds are picked and surveyed during the first year of the survey these ponds can provide baseline information. In following years monitoring efforts can continue at these same ponds and rotate from district to district such that each district performs a complete survey every four years. With four districts on the Black Hills National Forest, these data can be collated and reported every four years or more frequently to search for trends in northern leopard frog populations throughout the Black Hills National Forest. I would also suggest that a professional statistician be consulted before this plan is implemented to comment on the statistical design of the plan and its ability to detect population changes.

ADDITIONAL INFORMATION NEEDS

Mapping Of Habitat

To date, the Black Hills National Forest has not adequately mapped the habitat of the northern leopard frog in the Black Hills. Northern leopard frogs need seasonal and semi-permanent ponds that are probably <5 ha in size, about the size discussed by Semlitsch and Bodie (1998) and Semlitsch (1998, 2000a, b) for other pond-breeding amphibians. I have used National Wetlands Inventory maps on parts of the Black Hills National Forest to locate potential northern leopard frog breeding habitat but have found these maps to be frequently inaccurate, perhaps because of the dense forests found throughout the Black Hills. There appears to be no substitute for ground surveys of appropriate northern leopard frog breeding habitat. When found, these ponds need to be located using GPS and then downloaded into an appropriate GIS system to find these ponds in the future and track presence and absence of northern leopard frogs at these sites over time. Mapping of northern leopard frog sites should be relatively quick and inexpensive with the appropriate equipment and software. As Oscar Martinez has demonstrated on parts of the Spearfish-Nemo District in the Black Hills National Forest, when these ponds are located and protected, the result is large and growing populations of the northern leopard frog over time (personal observations).

Characterization Of Habitat

Unfortunately, although we have good studies of the natural history of the northern leopard frog to guide mapping efforts (Merrell, 1977), the habitat of the species has not been carefully characterized in a quantitative sense (but see Beauregard and Leclair, 1988) and has not been studied in the Black Hills. A good herpetologist can guide a mapping team to “good” northern leopard frog habitat but the mapping team may not easily find such habitats without special training. Quantitative characterization of ponds used by northern leopard frogs should be relatively easy and some work has already been done (Smith et al., 1998). Upland habitat and migration corridors that are used extensively by northern leopard frogs will probably be more difficult to find than breeding habitat but should also be easy to characterize once found.

Unfortunately, mapping needs to be completed and habitat models need to be developed concurrently to guide conservation efforts. These types of data are needed to develop any habitat management plan (as envisioned by Semlitsch, 2000a) for the northern leopard frog in the Black Hills.

Survey And Monitoring

Unfortunately as well, except for the studies of Peterson (1974) and Smith et al. (1998), there have been no systematic surveys of northern leopard frogs in the Black Hills. It is critical that baseline data are obtained to assess the abundance of northern leopard frogs in the Black Hills and begin tracking population trends. Also unfortunate is the fact that all three information needs identified so far, including mapping, habitat characterization, and survey work, need to be completed concurrently to guide efforts to conserve northern leopard frogs in the Black Hills. The historical database compiled by Peterson (1974), state Natural Heritage Surveys, and by myself should also be consulted to drive initial steps to determine whether northern leopard frogs are still extant at historical collecting localities. Historical data is always the best place to start to determine the status of a species and it is rare when such detailed historical data is available (Resetar, 1998).

Effect Of Introduced Predaceous Fish

Sport fishing is a large industry in the Black Hills and it is unlikely to diminish in importance. It can be assumed that management agencies will continue to manage for the presence of sport fish that are predators on all life stages of the northern leopard frog. The industry depends on predaceous fish that have been introduced to the Black Hills. Therefore, it can be assumed that northern leopard frogs have not evolved a natural defense against these predators and that some of their life history strategies put them into the same habitats occupied by these predators. All life stages are probably vulnerable, but there may be certain life stages that are more subject to predation than others. Some unanswered questions are: Are eggs and tadpoles more vulnerable than subadult and adult frogs to predation by introduced predaceous fish? What types of introduced fish are most likely to eat which life history stages? Are frogs likely to suffer predation during the overwintering period? Do frogs overwinter in habitats that are also used by introduced predaceous fish? Is predation by introduced predaceous fish ameliorated in certain types of habitats, and can introduced fish be kept out of these habitats? Given the likelihood that management objectives for northern leopard frogs will continue to clash with management objectives for sport fishing it is imperative that management agencies come up with innovative and collaborative means of managing for these two conflicting objectives.

Some of these studies could be rather simple; for example, breeding ponds can be sampled for predaceous fish and monitored to determine the likelihood of successful frog metamorphosis at these ponds. One would expect decreased or no metamorphosis at breeding ponds with predaceous fish. Another simple study would be to examine the stomach contents of predaceous fish captured in winter by ice fishermen. Anecdotal evidence from North Dakota showed that stomachs of pike caught in winter contained many northern leopard frogs (unpublished data). Other studies could be much more difficult. Determining effective means to isolate frogs from introduced fishes could be one of the biggest challenges in deriving a management plan for the northern leopard frog.

Grazing Effects

Cattle can easily affect eggs, tadpoles, metamorphic, subadult, and adult frogs. Cattle can affect breeding ponds through erosion of pond margins, by direct effects such as trampling, or by water quality issues such as alteration of temperature, water chemistry, increased nitrate load, or by causing fecal coliform contamination. Siltation can affect the eggs by covering them with silt. Like fish eggs, frog eggs respire through their surface and anything that covers the surface impedes oxygen flow. Cattle can affect tadpoles in breeding ponds through the toxic effects of nitrogen buildup in ponds to which cattle have access. One simple and inexpensive study that is needed is to examine series of tadpoles from fenced and unfenced ponds in the Black Hills. Post-mortem of two diseased tadpoles collected at one pond open to cattle in 1998 showed that the tadpoles had deformed mouthparts and skin irritation consistent with exposure to an aquatic irritant (unpublished data).

The effects of cattle on upland frog habitat would be more difficult to study, but I could envision a controlled study of ponds with fences set at different circumferences from the pond. Mark-recapture techniques can be used to determine if the protection of a core upland habitat area results in a higher density of northern leopard frogs at a site. Such a study would serve several purposes, as it should tell us something about the size of core upland areas needed to foster large and healthy northern leopard frog populations. These core sizes can be applied broadly across the forest to manage timber harvest and other practices that could adversely affect frog populations.

Grazing effects on migration corridors on Black Hills National Forest land would be more difficult to study. It would seem that streamside vegetation and riparian corridors should be protected as northern leopard frog migration routes. However, the only controlled studies possible would be to allow cattle to invade such corridors between ponds to try to determine the result on northern leopard frog populations. The results of such a study might be difficult to interpret. A more direct study of streamsides and riparian corridors would be to simply mark and follow frogs in these corridors or to survey for frogs in these corridors during appropriate times of the year.

Genetic Studies

It would be relatively easy to collect frogs from several sites across the forest, sample small pieces of tissue (this should not increase mortality or morbidity of the frogs as very small amounts of tissue are needed), and subject these samples to genetic analysis. However, the genetic data needed are very fine-grained and require considerable expertise and funding to obtain. Development of primers to extract the genetic information needed can be difficult and time consuming. However, such data would be invaluable and could tell us the extent of philopatry at specific ponds, the extent of genetic connectedness of each pond, and whether there is high within- or among – site genetic variation in northern leopard frogs in the Black Hills. These data can be used to guide management strategies by telling us something about which ponds need conservation attention (for example, which ponds serve as sources for colonization) and the extent and direction of movement of frogs from pond to pond.

Studies Of Movements

Movement studies are probably the most time-intensive and difficult field studies to conduct on amphibians. They would, however, give us detailed information on how the habitat is used by subadult and adult northern leopard frogs that may be difficult to obtain any other way. They would also address two critical questions: How much upland habitat is needed to conserve 95% of the northern leopard frog population at a particular breeding pond (i.e., how much core upland habitat needs to be protected around each pond), and what habitat features are used for migration by subadult and adult northern leopard frogs (i.e., how migration corridors used by frogs could be protected).

The marking technology is probably limiting in studies of this nature. High technology marking techniques, such as radiotracking, are expensive but reveal detailed movement patterns relatively quickly, unlike any other technique. Radiotracking is time and technology intensive and requires advanced training. I favor passive integrated transponders since they are easily inserted, simple to use in the field, and are being used extensively in herpetological studies with few health effects noted. Radioactive tagging can be used but can be problematic for the researcher, the environment, and the frogs. Toe clipping is a time-tested inexpensive technique that can also be used, but may cause adverse health effects for the frogs. Individual markings of the frogs themselves could be used but the computer technology needed for this technique may be difficult to use and time-consuming. Regardless of the marking technique, time and effort is required to mark and recapture large numbers of northern leopard frogs. However, it is critical to the management of northern leopard frogs that core upland habitats and migration corridors used by the frogs be delineated and conserved.

As a side benefit, movement studies conducted over numerous years would give information on the basic demography of populations. Another benefit to movement studies is that they could be combined with studies of other issues in northern leopard frog conservation, including timber practices, burning, the effects of roads, mining, and overwintering, and are critical in studies of most of these potential conservation issues.

Timber Removal

As discussed by deMaynadier and Hunter (1995), timber removal practices have significant effects on amphibian populations. As part of studies on other aspects of northern leopard frog biology in the Black Hills, study sites could be picked such that some sites are located in or nearby areas under different types of forest removal practices so as to investigate the effects of these practices on northern leopard frogs. Such a study would be long-term and therefore somewhat costly but would represent value added to any ongoing studies while costing relatively little additional funding to implement.

Prescribed Fire And Fire Suppression

It would be of a great deal of interest to investigate the effects of fire on northern leopard frog populations. This could be done either opportunistically, for example by tracking frog populations in recently burned areas, or through studies that specifically address the effects of a prescribed fire regime on northern leopard frog populations. In the latter case, studies on some other aspect of northern leopard frog biology, such as the movements of northern leopard frogs, could be modified by placing study sites within areas under prescribed burn regimes and in areas in which fire is suppressed. The study sites in both study areas could then be compared. Again, such a study would represent value added to an ongoing study while costing relatively little additional funding to implement.

Effect Of Roadways

The results of Wyman (1991) demonstrated that roadways can cause heavy mortality in some amphibian populations. However, the results of deMaynadier and Hunter (1995) showed that this is not necessarily the case depending on the road type. The Black Hills have a considerable amount of both paved and unpaved roads and a current management objective of the USDA Forest Service in the Black Hills is to reduce the number of roads open to the public (Rob Hoelscher, USDA Forest Service, Black Hills National Forest, personal communication, 2001). It would seem logical to combine movement studies with a study of the effect of roadways by picking a few breeding ponds near different types of roads as study sites. If done in combination with a broader study on the movement of northern leopard frogs a study on road effects would simply represent value added to a current study and would not cost anything beyond funds spent on the broader movement study.

Mining

The effects of mine residue could be very important to amphibian populations. Also, amphibians are particularly sensitive to the effects of chemicals given their extremely permeable skin and may serve as indicators of general environmental conditions. Parts of the Black Hills have historically been under intense mining pressure and some areas are still being mined. Former mine sites should be investigated for the presence of northern leopard frogs and appropriate studies undertaken if frogs are not present at sites that otherwise appear suitable for frogs. No surveys of former (or current) mine sites have been undertaken in the Black Hills to investigate the presence or absence of amphibians.

Overwintering Habitat

Studies of overwintering sites can be difficult to undertake. Cunjak (1986) relied on SCUBA techniques to study frogs overwintering in streams in Ontario while Merrell (1977) relied on simple but careful visual observations early in spring and late in the fall to report on frogs entering and leaving overwintering sites. Currently we know very little about where northern leopard frogs may overwinter in the Black Hills.

Radio tracking in late fall could show where frogs go to overwinter and the migratory pathways taken to reach these sites. Such a study would be expensive but the data obtained would be invaluable and difficult to obtain in any other manner. Otherwise I would recommend observation of frogs at appropriate times of the year or checking potential overwintering sites, such as springs, wet meadows, lakes, and streams, in the winter. Investigating potential overwintering sites in winter would obviously present numerous logistical difficulties. Northern leopard frogs are also difficult to observe in mid-winter as they become covered in debris on the bottom of lakes and streams (Cunjak, 1986; J. Grier, North Dakota State University, personal communication, 1998). This aspect of northern leopard frog natural history may well be the most challenging to investigate.

Disease And Limb Malformations

Any potential disease outbreaks should be carefully noted and investigated. Red leg presents itself as a reddish rash on the inside of the thighs and can result in death. The symptoms of several other diseases are drooping posture or a moribund state, difficulty of righting or movement or complete lack of a righting response, or mortality. Determination of the presence of disease would have to be made by a qualified wildlife disease specialist. Investigators whose works are cited in the "Community Ecology; Parasites and Diseases" section (pp. 22-23) should be alerted and consulted. Any large kills of northern leopard frogs should be reported (these could represent death by disease or by chemicals). Pesticides should be investigated if they become more heavily used in the Black Hills or if their usage is contemplated to combat disease or insect outbreaks. Kills of northern leopard frogs could result from overuse of pesticides or accidental (or intentional) pesticide spills. Any limb malformations observed in the Black Hills should be reported to an appropriate biologist in charge of the affected district, to myself, to the various state game departments, and especially to the limb malformations website maintained by the Northern Prairie Wildlife Research Center and cited in the Literature Cited section (Northern Prairie Wildlife Research Center, 1997).

LITERATURE CITED

Adams, M. J., K. O. Richter, and W. P. Leonard. 1997. Surveying and monitoring amphibians using aquatic funnel traps. Pp. 47-54 in Olson, D. H., W. P. Leonard, and R. B. Bury, eds. Sampling Amphibians in Lentic Habitats: Methods and Approaches for the Pacific Northwest. Northwest Fauna No. 4. 134 pp.

Alford, R. A. 1999. Resource use, competition, and predation. Pp. 240-278 in McDiarmid, R. W. and R. Altig, eds. Tadpoles: The Biology of Anuran Larvae. The University of Chicago Press, Chicago, Illinois. 444 pp.

Alford, R. A. , and S. J. Richards. 1999. Global amphibian declines: A problem in applied ecology. Annual Review of Ecology and Systematics 30:133-165.

Ankley, G. T., J. E. Tietge, D. L. DeFoe, K. M. Jensen, G. W. Holcombe, E. J. Durham, and S. A. Diamond. 1998. Effects of ultraviolet light and methoprene on survival and development of *Rana pipiens*. Environmental Toxicology and Chemistry 17:2530-2542.

Ankley, G. T., J. E. Tietge, G. W. Holcombe, D. L. DeFoe, S. A. Diamond, K. M. Jensen, and S. J. Degitz. 2000. Effects of laboratory ultraviolet radiation and natural sunlight on survival and development of *Rana pipiens*. Canadian Journal of Zoology 78:1092-1100.

Ashley, E. P., and J. T. Robinson. 1996. Road mortality of amphibians, reptiles, and other wildlife on the Long Point Causeway, Lake Erie, Ontario. Canadian Field-Naturalist 110:403-412.

Ashton, R. E., Jr. 1994. Tracking with radioactive tags. Pp. 158-166 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D.C. 364 pp.

Aubry, K. B., and Hall, P. A. 1991. Terrestrial amphibian communities in the southern Washington Cascade Range. Pp. 327-338 in Ruggiero, L. F., K. B. Aubry, A. B. Carey, and M. H. Huff, eds. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S.D.A. Forest Service General Technical Report. PNW-GTR-285.

Aubry, K. B., L. L. C. Jones, and P. A Hall. 1988. Use of woody debris by plethodontid salamanders in Douglas-fir forests in Washington. Pp. 32-37 in Szaro, R.C., K. E. Severson, and D. R. Patton, eds. Management of Amphibians, Reptiles, and Mammals in North America. U.S.D.A. Forest Service General Technical Report. RM-166. 458 pp.

Baker, M. R. 1987. Synopsis of the Nematoda parasitic in amphibians and reptiles. Memorial University of Newfoundland, Miscellaneous Publications in Biology 11:1-325.

Ballinger, R. E., J. W. Meeker, and M. Thies. 2000. A checklist and distribution maps of the amphibians and reptiles of South Dakota. Transactions of the Nebraska Academy of Sciences 26:29-46.

Bartelt, P. E. 1998. *Bufo boreas* mortality. Herpetological Review 29:96.

Baxter, G. T. 1952. Notes on growth and the reproductive cycle of the leopard frog, *Rana pipiens* Schreber, in southern Wyoming. Journal of the Colorado-Wyoming Academy of

Science 4:91.

Baxter, G. T., and M. D. Stone. 1985. Amphibians and Reptiles of Wyoming, 2nd ed. Wyoming Game and Fish Department. 137 pp.

Beauregard, N., and R. Leclair, Jr. 1988. Multivariate analysis of the summer habitat structure of *Rana pipiens* Schreber, in Lac Saint Pierre (Québec, Canada). Pp. 129-143 in Szaro, R. C., K. E. Severson, and D. R. Patton, eds. Management of Amphibians, Reptiles and Small Mammals in North America. U.S.D.A Forest Service General Technical Report RM-166. 458 pp.

Begon, M., J. L. Harper, and C. R. Townsend. 1996. Ecology: Individuals, Populations, and Communities, 3rd ed. Blackwell Science Ltd., Editorial Offices: Osney Mead, Oxford, London. 1068 pp.

Berger, L., R. Speare, P. Daszak, D. E. Green, A. A. Cunningham, C. L. Gogging, R. Slocombe, M. A. Ragan, A. D. Hyatt, K. R. McDonald, H. B. Hines, K. R. Lips, G. Marantelli, and H. Parkes. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. Proceedings of the National Academy of Sciences 95:9031-9036.

Berrill, M., S. Bertram, D. Brigham, and V. Campbell. 1992. A comparison of three methods of monitoring frog populations. Pp. 87-93 in Bishop, C. A., and K. E. Pettit, eds. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Occasional Paper Number 76, Canadian Wildlife Service, Ottawa, Ontario. 120 pp.

Berrill, M., S. Bertram, A. Wilson, S. Louis, D. Brigham, and C. Stromberg. 1993. Lethal and sublethal impacts of pyrethroid insecticides on amphibian embryos and tadpoles. Environmental Toxicology and Chemistry 12:525-539.

Berrill, M., S. Bertram, L. McGillivray, M. Kolohon, and B. Pauli. 1994. Effects of low concentrations of forest-use pesticides on frog embryos and tadpoles. Environmental Toxicology and Chemistry 13:657-664.

Berrill, M., S. Bertram, and B. Pauli. 1997. Effects of pesticides on amphibian embryos and larvae. Pp. 233-245 in Green, D. M, ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Bertram, S., and M. S. Berrill. 1997. Fluctuations in a northern population of gray treefrog, *Hyla versicolor*. Pp. 57-63. in Green, D. M, ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Berven, K. A., and T. A. Grudzien. 1990. Dispersal in the wood frog (*Rana sylvatica*): implications for genetic structure. Evolution 44:2047-2056.

Bishop, C. A. 1992. The effects of pesticides on amphibians and the implications for determining the causes of declines in amphibian populations. In C. A. Bishop and K. E. Pettit, eds. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Ottawa, Ontario, Canadian Wildlife Service. Occasional Paper Number 76.

Bishop, C. A., and K. E. Pettit. 1992. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Canadian Wildlife Service, Occasional Paper No. 76.

Bishop, C. A., K. E. Pettit, M. E. Gartshore, and D. A. MacLeod. 1997. Extensive monitoring of anuran populations using call counts and road transects in Ontario (1992 to 1993). Pp. 149-160 in Green, D. M, ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Blaustein, A. R., and D. B. Wake. 1995. The puzzle of declining amphibian populations. Scientific American 272(4):56-61.

Bonin, J., and Y. Bachand. 1997. The use of artificial covers to survey terrestrial salamanders in Québec. Pp. 175-179 in Green, D. M, ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Bonin, J., M. Ouellet, J. Rodrigue, J. L. DesGranges, F. Gagné, T. F. Sharbel, and L. A. Lowcock. 1997. Measuring the health of frogs in agricultural habitats subjected to pesticides. Pp. 246-257 in Green, D. M, ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Bovbjerg, R. V. 1965. Experimental studies on the dispersal of the frog, *Rana pipiens*. Proceedings of the Iowa Academy of Science 72:412-418.

Bovbjerg, R. V., and A. M. Bovbjerg. 1964. Summer emigrations of the frog *Rana pipiens* in northwestern Iowa. Proceedings of the Iowa Academy of Science 71:511-518.

Bradford, D. F. 1983. Winterkill, oxygen relations, and energy metabolism of a submerged dormant amphibian, *Rana muscosa*. Ecology 64:1171-1183.

Breckenridge, W. J. 1944. Reptiles and Amphibians of Minnesota. University of Minnesota Press, Minneapolis, Minnesota. xiii + 202 p.

Breden, F. 1987. The effect of post-metamorphic dispersal on the population genetic structure of Fowler's toad, *Bufo woodhousei fowleri*. Copeia 1987:386-395.

Brodman, R., and M. Kilmurry. 1998. Status of amphibians in northwestern Indiana. Pp. 125-136 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Brönmark, C., and P. Edenhamn. 1994. Does the presence of fish affect the distribution of tree frogs (*Hyla arborea*)? Conservation Biology 8:841-845.

Buckhouse, J. C., and G. F. Gifford. 1976. Water quality implications of cattle grazing on a semi-arid watershed in southeastern Utah. Journal of Range Management 29:109-113.

Buckle, J. 1971. A recent introduction of frogs to Newfoundland. Canadian Field-Naturalist 85:72-74.

Bull, E. L. 2000. Comparison of two radio transmitter attachments on Columbia spotted frogs (*Rana luteiventris*). Herpetological Review 31:26-28.

Bull, E. L., and M. P. Hayes. 2001. Post-breeding season movements of Columbia spotted frogs (*Rana luteiventris*) in northeastern Oregon. Western North American Naturalist 61:119-123.

Bury, R. B., and P. S. Corn. 1988. Douglas-fir forests in the Oregon and Washington Cascades: Relation of the herpetofauna to stand age and moisture. Pp. 11-22 in Szaro, R. C., K. E. Severson, and D. R. Patton. Management of Amphibians, Reptiles, and Small Mammals in North America. U.S.D.A. Forest Service General Technical Report. RM-166. 458 pp.

Bury, R. B., and R. A. Luckenbach. 1976. Introduced amphibians and reptiles in California. Biological Conservation 10:1-14.

Cameron, J. A. 1940. Effects of fluorine on hatching time and hatching stage in *Rana pipiens*. Ecology 21:288-292.

Carey, C. 1993. Hypothesis concerning the causes of the disappearance of boreal toads from the mountains of Colorado. Conservation Biology 7:355-362.

Carey, C., N. Cohen, and L. Rollins-Smith. 1999. Amphibian declines: An immunological perspective. Developmental and Comparative Immunology 23:459-472.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Biological Conservation 15:1071-1078.

Casper, G. S. 1998. Review of the status of Wisconsin amphibians. Pp. 199-205 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Clarkson, R. W., and J. C. Rorabaugh. 1989. Status of leopard frogs (*Rana pipiens* complex: Ranidae) in Arizona and southeastern California. Southwestern Naturalist 34:531-538.

Collier, A., J. B. Keiper, and L. P. Orr. 1998. The invertebrate prey of the northern leopard frog, *Rana pipiens*, in a northeastern Ohio population. Ohio Journal of Science 98:39-41.

Collins, J. P., and H. M. Wilbur. 1979. Breeding habits and habitats of the amphibians of the Edwin S. George Reserve, Michigan, with notes on the local distribution of fishes. Occasional Papers of the Museum of Zoology, University of Michigan. No. 686:1-34.

Conant, R., and J. T. Collins. 1991 A Field Guide to Reptiles and Amphibians: Eastern and Central North America, 3rd ed. Houghton Mifflin Company, Boston, Massachusetts. 450 pp.

Cooke, A. S. 1981. Tadpoles as indicators of harmful levels of pollution in the field. Environmental Pollution Series A 25:123-133.

Corn, P. S. 1981. Field evidence for a relationship between color and developmental rate in the northern leopard frog (*Rana pipiens*). Herpetologica 37:155-160.

Corn, P. S. 1994. What we know and don't know about amphibians declines in the west. Pp. 59-67 in W. W. Covington and L. F. DeBano, eds. Sustainable Ecological Systems: Implementing an Ecological Approach to Land Management. U. S. D. A. Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. General Technical Report RM-247.

Corn, P. S., and J. C. Fogleman. 1984. Extinction of montane populations of the northern leopard frog (*Rana pipiens*) in Colorado. Journal of Herpetology 18:147-152.

Corn, P. S., and L. J. Livo. 1989. Leopard frog and wood frog reproduction in Colorado and Wyoming. Northwestern Naturalist 70:1-9.

Corn, P. S., and F. A. Vertucci. 1992. Descriptive risk assessment of the effects of acidic deposition on Rocky Mountain amphibians. Journal of Herpetology 26:361-369.

Cousineau, M., and K. Rogers. 1991. Observations on sympatric *Rana pipiens*, *R. blairi*, and their hybrids in eastern Colorado. Journal of Herpetology 25:114-116.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Government Printing Office, Washington, D. C. 103 pp.

Crashaw, G. J. 1997. Diseases in Canadian amphibian populations. Pp. 258-270 in Green, D. M. J., ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Crouch, W. B., and P. W. C. Paton. 2000. Using egg-mass counts to monitor wood frog populations. Wildlife Society Bulletin 28:895-901.

Crump, D., M. Berrill, D. Coulson, D. Lean, L. McGillivray, and A. Smith. 1999. Sensitivity of amphibian embryos, tadpoles, and larvae to enhanced UV-B radiation in natural pond conditions. Canadian Journal of Zoology 77:1956-1966.

Crump, M. L., F. R. Hensley, and K. L. Clark. 1992. Apparent decline of the golden toad: Underground or extinct? Copeia 1992:413-420.

Crump, M. L., and N. J. Scott, Jr. 1994. Visual encounter surveys. Pp. 84-92 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayak, and M. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D.C. 364 pp.

Cunjak, R. A. 1986. Winter habitat of northern leopard frogs, *Rana pipiens,* in a southern Ontario stream. Canadian Journal of Zoology 64:255-257.

Cunningham A. A., T. E. S. Langton, P. M. Bennett, J. F. Lewin, S. E. N. Drury, R. E. Gough, and S. K. MacGregor. 1996. Pathological and microbiological findings from incidents of unusual mortality of the common frog (*Rana temporaria*). Philosophical Transactions of the Royal Society of London 351:1539-57.

Daszak, P., L. Berger, A. A. Cunningham, A. D. Hyatt, D. E. Green, and R. Speare. 1999. Emerging infectious diseases and amphibian population declines. Emerging Infectious Diseases 5:735-748.

Daszak, P., A. A. Cunningham, and A. D. Hyatt. 2000. Emerging infectious diseases of wildlife: Threats to biodiversity and human health. Science 287:443-449.

Davidson, C. 1996. Frog and toad calls of the Rocky Mountains: Vanishing voices. Library of Natural Sounds, Cornell Laboratory of Ornithology, Ithaca, New York.

Davis, J. G., P. J. Krusling, and J. W. Ferner. 1998. Status of Amphibians in Minnesota. Status and Conservation of Midwestern Amphibians. Pp. 166-168 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Davis, T. M. 1997. Non-disruptive monitoring of terrestrial salamanders with artificial cover objects on southern Vancouver Island, British Columbia. Pp. 161-174 in Green, D. M., ed.

Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, Number One. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

DeBenedictis, P. A. 1974. Interspecific competition between tadpoles of *Rana pipiens* and *Rana sylvatica*: An experimental field study. Ecological Monographs 44:129-151.

deMaynadier, P. G., and M. L. Hunter, Jr. 1995. The relationship between forest management and amphibian ecology: A review of the North American literature. Environmental Review 3:230:261.

deMaynadier, P. G., and M. L. Hunter, Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology 12:340-352.

Dhuey, B., and R. Hay. 2000. Frog and toad survey. Pp. 140-147 in 1999 Wildlife Survey Summary Report. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Dial, N. A., and C. A. B. Dial. 1987. Lethal effects of diquat and paraquat on developing frog embryos and 15-day-old tadpoles, *Rana pipiens*. Bulletin of Environmental Contamination and Toxicology 38:1006-1011.

Diana, S. G., and V. R. Beasley. 1998. Amphibian toxicology. Pp. 266-277 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Didiuk, A. 1997. Status of amphibians in Saskatchewan. Pp. 110-116 in D. M. Green, ed., Amphibians in Decline: Canadian Studies of a Global Problem. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

Diller, L. V., and R. L. Wallace. 1994. Distribution and habitat of *Plethodon elongatus* on managed young growth forests in north coastal California. Journal of Herpetology 28:310-318.

Dodd, C. K., Jr., and D. E. Scott. 1994. Drift fences encircling breeding sites. Pp. 125-141 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Dodd, C. K., Jr., and R. A. Seigel. 1991. Relocation, repatriation, and transolocation of amphibians and reptiles: Are they conservation strategies that work? Herpetologica 47:336-350.

Dole, J. W. 1965a. Spatial relations in natural populations of the leopard frog, *Rana pipiens* Schreber, in northern Michigan. American Midland Naturalist 74:464-478.

Dole, J. W. 1965b. Summer movement of adult leopard frogs, *Rana pipiens* Schreber, in northern Michigan. Ecology 46:236-255.

Dole, J. W. 1967. Spring movements of leopard frogs, *Rana pipiens* Schreber, in northern Michigan. American Midland Naturalist 78:167-181.

Dole, J. W. 1968. Homing in leopard frogs, *Rana pipiens*. Ecology 49:386-399.

Dole, J. W. 1971. Dispersal of recently metamorphosed leopard frogs, *Rana pipiens*. Copeia 1971:221-228.

Dole, J. W. 1972. The role of olfaction and audition in the orientation of leopard frogs, *Rana pipiens*. Herpetologica 28:258-260.

Drake, C. J. 1914. The food of Rana *pipiens*. The Ohio Naturalist 14:257-269.

Duellman, W. E., and L. Trueb. 1986. Biology of Amphibians. McGraw-Hill, Inc. New York, New York. 670 pp.

Dunlap, D. G., and K. C. Kruse. 1976. Frogs of the *Rana pipiens* complex in the northern and central plains states. Southwestern Naturalist 20:559-571.

Dunlap, D. G., and J. E. Platz. 1981. Geographic variation of protein and call in *Rana pipiens* from the northcentral United States. Copeia 1981:876-879.

Dupuis, L. A., J. N. M. Smith, and F. Bunnell. 1995. Relation of terrestrial-breeding amphibian abundance to tree-stand age. Conservation Biology 9:645-653.

Dyer, W. G. 1991. Helminth parasites of amphibians from Illinois and adjacent Midwestern states. Transactions of the Illinois State Academy of Science 84:125-143.

Elmore, W., and R. L. Beschta. 1987. Riparian areas: Perceptions in management. Rangelands 9:260-265.

Emery, A. R., A. H. Berst, and K. Kodaira. 1972. Under-ice observations of wintering sites of leopard frogs. Copeia 1972:123-126.

Faeh, S. A., D. K. Nichols, and V. R. Beasley. 1998. Infectious diseases of amphibians. Pp.259-265 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Fellers, G. M., and C. A. Drost. 1994. Sampling with artificial cover. Pp. 146-150 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Fisher, C. 1999. Feasibility of northern leopard frog translocations in Alberta: A review of physiological, ecological, methodological requirements for successful repatriations and results from field investigations. Alberta Environment, Fisheries, and Wildlife Management Division, Edmonton, AB. Unpublished report. 30 pp.

Fitch, H. S. 1958. Home ranges, territories, and seasonal movements of vertebrates of the Natural History Reservation. University of Kansas Publications, Museum of Natural History 11:63-326.

Flower, S. S. 1936. Further notes on the duration of life in animals II: Amphibia. Procedings of Zoological Society of London: 369-394.

Force, E. R. 1933. The age of the attainment of sexual maturity of the leopard frog *Rana pipiens* (Schreber) in northern Michigan. Copeia 1933:128-131.

Fournier, M. A. 1997. Amphibians in the Northwest Territories. Pp. 100-106 in D. M. Green, ed., Amphibians in Decline: Canadian Studies of a Global Problem. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

Franz, R. 1971. Notes on the distribution and ecology of the herpetofauna of northwestern Montana. Bulletin of the Maryland Herpetological Society 7:1-10.

Freda, J., and W. A. Dunson. 1985. Field and laboratory studies of ion balance and growth rates of ranid tadpoles chronically exposed to low pH. Copeia 1985:415-423.

Freda, J., and D. H. Taylor. 1992. Behavioral response of amphibian larvae to acidic water. Journal of Herpetology 26:429-433.

Fried, B., P. L. Pane, and A. Reddy. 1997. Experimental infection of *Rana pipiens* tadpoles with Echinostoma *trivolvis* cercariae. Parasitology Research 83:666-669.

Froiland, S. G. 1990. Natural History of the Black Hills and Badlands. The Center for Western Studies, Augustana College, Sioux Falls, South Dakota. 225 pp.

Gibbs, E. L., G. W. Nace, and M. B. Emmons. 1971. The live frog is almost dead. Bioscience 21:1027-1034.

Goldberg, S. R., C. R. Bursey, R. G. McKinnell, and I. S. Tan. 2001. Helminths of northern leopard frogs, *Rana pipiens* (Ranidae), from North Dakota and South Dakota. Western North American Naturalist 61:248-251.

Grant, B. W., K. L. Brown, G. W. Ferguson, and J. W. Gibbons. 1994. Changes in amphibian biodiversity associated with 25 years of pine forest regeneration: Implications for biodiversity management. Pp. 355-367 in Majumdar, S. K., F. J. Brenner, J. E. Lovich, J. F. Schalles, and E. W. Miller, eds. Biological Diversity: Problems and Challenges. Pennsylvania Academy of Science, Philadelphia, Pennsylvania.

Green, D. M. 1992. Fowler's toads (*Bufo woodhousei fowleri*) at Long Point, Ontario: Changing abundance and implications for conservation. Pp. 37-43 in Bishop, C. A., and K. E. Pettit, eds. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Occasional Paper Number 76, Canadian Wildlife Service. 120 pp.

Green, D. M. 1997. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation, No. 1, Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri. 338 pp.

Green, D. M., and R. W. Campbell. 1984. The Amphibians of British Columbia. Royal British Columbia Museum, Handbook 45.

Grue, C. E., L. R. DeWeese, P. Mineau, G. A. Swanson, J. R. Foster, P. M. Arnold, J. N. Huckins, P. J. Sheehan, W. K. Marshall, and A. P. Ludden. 1986. Potential impacts of agricultural chemicals on waterfowl and other wildlife inhabiting prairie wetlands: An evaluation of research needs and approaches. Transactions of the Northern American Wildlife Natural Resources Conference 51:357-383.

Hall, R. J., and P. F. P. Henry. 1992. Review. Assessing effects of pesticides on amphibians and reptiles: Status and needs. Herpetology Journal 2:65-71.

Halliday, T. R., and M. Tejedo. 1995. Intrasexual selection and alternative mating behaviour. Pp. 419-468 in Heatwole, H., and B. K. Sullivan, eds. Amphibian Biology, Vol. 2. Social Behaviour. Surrey Beatty and Sons, Chipping Norton, New South Wales, Australia.

Hamilton, H. L. 1941. The biological action of rotenone of fresh water animals. Proceedings of the Iowa Academy of Science 48:467-479.

Hammerson, G. A. 1982. Bullfrog eliminating leopard frogs in Colorado? Herpetological

Review 13:115-116.

Hammerson, G. A. 1999. Amphibians and Reptiles in Colorado, 2nd ed. University Press of Colorado and Colorado Division of Wildlife, Niwot, Colorado. 484 pp.

Harfenist, A., T. Power, K. L. Clark, and D. B. Peakall. 1989. A review and evaluation of the amphibian toxicological literature. Canadian Wildlife Service Technical Report Series No. 61:1-222.

Hayes, T. B., A. Collins, M. Lee, M. Mendoza, N. Noriega, A. A. Stuart, and A. Vonk. 2002. Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proceedings of the National Academy of Sciences 99:5476-5480.

Hecnar, S. J. 1995. Acute and chronic toxicity of ammonium nitrate fertilizer to amphibians from southern Ontario. Environmental Toxicology and Chemistry 14:2131-2137.

Hecnar, S. J., and R. T. M'Closkey. 1997a. The effects of predatory fish on amphibian species richness and distribution. Biological Conservation 79:123-131.

Hecnar, S. J., and R. T. M'Closkey. 1997b. Changes in the composition of a ranid frog community following bullfrog extinction. American Midland Naturalist 137:145-150.

Hecnar, S. J., and R. T. M'Closkey. 1998. Species richness patterns of amphibians in southwestern Ontario ponds. Journal of Biogeography 25:763-772.

Helgen, J., R. G. McKinnell, and M. C. Gernes. 1998. Investigation of malformed northern leopard frogs in Minnesota. Pp. 288-297 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Hemesath, L. M. 1998. Iowa's Frog and Toad Survey, 1991-1994. Pp. 206-216 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Hendricks, F. S. 1973. Intestinal contents of *Rana pipiens* Schreber (Ranidae) larvae. Southwestern Naturalist 18:99-101.

Heyer, W. R. 1994. Thread bobbins. Pp. 153-155 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster. 1994. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Hine, R. L., B. L. Les, and B. F. Hellmich. 1981. Leopard frog populations and mortality in Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin No. 122:1-139.

Hine, R. L., B. L. Les, B. F. Hellmich, and R. C. Vogt. 1975. Preliminary report on leopard frog (*Rana pipiens*) populations in Wisconsin. Wisconsin Department of Natural Resources Research Report No. 81:1-31.

Hillis, D. M. 1988. Systematics of the *Rana pipiens* complex: Puzzle and paradigm. Annual Review of Ecology and Systematics 19:39-63.

Hillis, D. M., J. S. Frost, and D. A. Wright. 1983. Phylogeny and biogeography of the *Rana* *pipiens* complex: A biochemical evaluation. Systematic Zoology 32:132-143.

Holme, J. A., M. Refsnes, and E. Dybing. 1999. Possible carcinogenic risk associated with the production and use of creosote-treated wood. Tidsskrift for den Norske Laegeforening 119:2664-2666.

Hoppe, D. M. 2000. History of Minnesota frog abnormalities: Do recent findings represent a new phenomenon? Journal of the Iowa Academy of Science 107:86-89.

Howard, R. D. 1978. The evolution of mating strategies in bullfrogs, *Rana catesbeiana*. Evolution 32:850-871.

Hupf, T. H. 1977. Natural histories of two species of leopard frogs, *Rana blairi* and *Rana pipiens,* in a zone of sympatry in northeastern Nebraska. Unpublished M. S. thesis, University of Nebraska, Lincoln. 125 pp.

Jaeger, R. G. 1980. Microhabitats of a terrestrial forest salamander. Copeia 1980:265-268.

Jaeger, R. G. 1994a. Transect sampling. Pp. 103-107 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Jaeger, R. G. 1994b. Patch sampling. Pp. 107-109 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Jaeger, R. G., and R. F. Inger. 1994. Quadrat sampling. Pp. 97-102 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Jancovich, J. K., E. W. Davidson, J. F. Morado, B. L. Jacobs, and J. P. Collins. 1997. Isolation of a lethal virus from the endangered tiger salamander *Ambystoma tigrinum stebbinsi*. Diseases of Aquatic Organisms 31:161-167.

Jefferies, D. L., and J. M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. Journal of Range Management 40:390-392.

Jennings, M. R. 1984. Geographic distribution: *Rana muscosa*. Herpetological Review 15:52.

Johnson, T. R. 1998. Missouri toad and frog calling survey: The first year. Pp. 357-359 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Johnson, P. T. J., K. B. Lunde, E. G. Ritchie, and A. E. Launer. 1999. The effect of trematode infection on amphibian limb development and survivorship. Science 284:802-804.

Johnson, P. T. J., K. B. Lunde, and A. R. Blaustein. 2001. *Ribeiroia ondatrae* (Trematoda: Digenea) infection induces severe limb malformations in western toads (*Bufo boreas*). Canadian Journal of Zoology 79:370

Kaplan, H. M., and J. G. Overpeck. 1964. Toxicity of halogenated hydrocarbon insecticides for the frog *Rana pipiens*. Herpetologica 20:163-169.

Kaplan, H. M., and S. S. Glaczenski. 1965. Hematological effects of organophosphate insecticides in the frog (*Rana pipiens*). Life Sciences 4:1213-1219.

Kauffman, J., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: A review. Journal of Range Management 37:430-437.

Koch, E. D., and C. R. Peterson. 1995. Amphibians and Reptiles of Yellowstone and Grand Teton National Parks. University of Utah Press, Salt Lake City, Utah. 188 pp.

Krebs, C. J. 1999. Ecological Methodology, 2nd ed. Benjamin Cummings, Menlo Park California. 620 pp.

Kruse, K. C., and M. G. Francis. 1977. A predation deterrent in larvae of the bullfrog, *Rana catesbeiana*. American Fisheries Society Transactions 106:248-252.

Lamberti, G. A., S. V. Gregory, C. P. Hawkins, R. C. Wildman, L. R. Ashkenas, and D. M. Denicola. 1992. Plant-herbivore interactions in streams near Mt. St. Helens. Freshwater Biology 27:237-247.

Lamoureux, V. S., and D. M. Madison. 1999. Overwintering habitats of radio-implanted green frogs, *Rana clamitans*. Journal of Herpetology 33:430-435.

Landé, S. P., and S. I. Guttman. 1973. The effects of copper sulfate on the growth and mortality rate of *Rana pipiens* tadpoles. Herpetologica 29:22-27.

Lannoo, M. J. 1998a. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Lannoo, M. J. 1998b. Amphibian conservation and wetland management in the upper midwest: A catch-22 for the cricket frog? Pp. 330-339 in M. J. Lannoo, ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Lannoo, M. J., K. Lang, T. Waltz, and G. S. Phillips. 1994. An altered amphibian assemblage: Dickinson County, Iowa, 70 years after Frank Blanchard's survey. American Midland Naturalist 131:311-319.

Leclair, R., Jr., and J. Castanet. 1987. A skeletochronological assessment of age and growth in the frog *Rana pipiens* Schreber (Amphibia, Anura) from southwestern Quebec. Copeia 1987:361-369.

Leonard, W. P., K. R. McAllister, and R.C. Friesz. 1999. Survey and assessment of northern leopard frog (*Rana pipiens*) populations in Washington State. Northwestern Naturalist 80:51-60.

Lepage, M., R. Courtois, C. Daigle, and S. Matte. 1997. Surveying calling anurans in Québec using volunteers. Pp. 128-140 in Green, D. M., ed. Amphibians in Decline: Canadian Studies of a Global Problem. Herpetological Conservation Number One. Society for the Study of Amphibians and Reptiles, St. Louis, Missouri. 338 pp.

Linder, G., and B. Grillitsch. 2000. Ecotoxicology of metals. Pp. 325-459 in D. W. Sparling, G. Linder, and C. A. Bishop, eds. Ecotoxicology of Amphibians and Reptiles. SETAC Press, Pensacola, Florida. 877 pp.

Linzey, D. W. 1967. Food of the leopard frog, *Rana p. pipiens*, in central New York. Herpetologica 23:11-17.

Linzey, D. W., and A. H. Wright. 1947. A synoptic key to the salientian eggs of the United States. American Midland Naturalist 37:179-222.

Long, L. E., L. S. Saylor, and M. E. Soule. 1995. A pH/UV-B synergism in amphibians. Conservation Biology 9:1301-1303.

Lynch, J. D. 1978. The distribution of leopard frogs (*Rana blairi* and *Rana pipiens*) (Amphibia, Anura, Ranidae) in Nebraska. Journal of Herpetology 12:157-162.

Madison, D. M. 1997. The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. Journal of Herpetology 31:542-552.

Madison, D. M., and L. Farrand. 1997. Habitat use during breeding and emigration in radio-implanted tiger salamanders, *Ambystoma tigrinum*. Copeia 1998:402-410.

Manion, J. J., and L. Cory. 1952. Winter kill of *Rana pipiens* in shallow ponds. Herpetologica 8:32.

Martof, B. 1953. Home range movements of the green frog, *Rana clamitans*. Ecology 34:529-543.

Mathews, K. R., and K. L. Pope. 1999. A telemetric study of the movement patterns and habitat use of *Rana muscosa*, the mountain yellow-legged frog, in a high-elevation basin in Kings Canyon National Park, California. Journal of Herpetology 33:615-624.

Maunder, J. E. 1997. Amphibians of Newfoundland and Labrador: Status changes since 1983. Pp. 93-99 in D. M. Green, ed. Amphibians in Decline: Canadian Studies of a Global Problem, Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

Maxell, B. A. 2000. Management of Montana's amphibians: A review of factors that may present a risk to population viability and accounts on the identification, distribution, taxonomy, habitat use, natural history, and the status and conservation of individual species. Report to USFS Region 1, Order Number 43-0343-0-0224. University of Montana, Wildlife Biology Program. Missoula, Montana. 161 pp.

McAlpine, D. F. 1997. Historical evidence does not suggest New Brunswick amphibians have declined. Pp. 117-127 in D. M. Green, ed., Amphibians in Decline: Canadian Studies of a Global Problem. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

McAlpine, D. F., and M. D. B. Burt. 1998. Helminths of bullfrogs, *Rana catesbeiana*, green frogs, *R.* clamitans, and leopard frogs, *R. pipiens*, in New Brunswick. Canadian Field Naturalist 112:50-68.

McAlpine, D. F., and T. G. Dilworth. 1989. Microhabitat and prey size among three species of *Rana* (Anura: Ranidae) sympatric in eastern Canada. Canadian Journal of Zoology 67:2244-2252.

McClelland, B. E., and W. Wilczynski. 1989. Release call characteristics of male and female *Rana pipiens*. Copeia 1989:1045-1049.

McCollum, S. A., and J. D. Leimberger. 1997. Predator-induced morphological changes in an amphibian: Predation by dragonflies affects tadpole shape and color. Oecologia 109:615-621.

McLeod, R., and J. E. Gates. 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. American Midland Naturalist 139:164-177.

Mennell, L. 1997. Amphibians in southwestern Yukon and northwestern British Columbia. Pp. 107-109 in D. M. Green, ed., Amphibians in Decline: Canadian Studies of a Global Problem. Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

Merrell, D. J. 1963. Rearing tadpoles of the leopard frog, *Rana pipiens*. Turtox News 41:263-265.

Merrell, D. J. 1965. The distribution of the dominant Burnsi gene in the leopard frog, *Rana pipiens*. Evolution 19:69-85.

Merrell, D. J. 1968. A comparison of the estimated size and the "effective size" of breeding populations of the leopard frog, *Rana pipiens*. Evolution 22:274-283.

Merrell, D. J. 1969. Natural selection in a leopard frog population. Journal of the Minnesota Academy of Science 35:86-89.

Merrell, D. J. 1970. Migration and gene dispersal in *Rana pipiens*. American Zoologist 10:47-52.

Merrell, D. J. 1977. Life history of the leopard frog, *Rana pipiens*, in Minnesota. Bell Museum of Natural History Occasional Papers No. 15:1-23.

Merrell, D. J., and C. F. Rodell. 1968. Seasonal selection in the leopard frog, *Rana pipiens*. Evolution 22:284-288.

Meteyer, C. U., I. K. Loeffler, J. F. Fallon, K. A. Converse, E. Green, J. C. Helgen, S. Kersten, R. Levey, L. Eaton-Poole, and J. G. Burkhart. 2000. Hind limb malformations in free-living northern leopard frogs (*Rana pipiens*) from Maine, Minnesota, and Vermont suggest multiple etiologies. Teratology 62:151-171.

Mierzwa, K. S. 1998. Biogeography of Midwestern Amphibians. Pp. 24-30 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Milius, S. 2000. New frog-killing disease may not be so new. Science News 157:133.

Miller, J. D. 1978. Observations on the diets of *Rana pretiosa*, *Rana pipiens*, and *Bufo boreas* from western Montana. Northwest Science 52:243-249.

Minton, S. A. 1998. Observations on Indiana amphibian populations: A Forty-five-year overview. Pp. 217-220 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Morell, V. 1999. Are pathogens felling frogs? Science 284:728-731.

Mosimann, J. E., and G. B. Rabb. 1952. The herpetology of Tiber Reservoir Area, Montana. Copeia 1952:23-27.

Mossman, M. J., L. M. Hartman, R. Hay, J. R. Sauer, and B. J. Dhuey. 1998. Monitoring long-term trends in Wisconsin frog and toad populations. Pp. 169-198 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Moriarty, J. J. 1998. Status of Amphibians in Minnesota. Pp. 166-168 in Lannoo, M. J., ed.

Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Morin, P. J. 1983. Predation, competition, and the composition of larval anuran guilds. Ecological Monographs 53:119-138.

Mushinsky, H. R. 1985. Fire and the Florida sandhill herpetofaunal community: With special attention to responses of *Cnemidophorus sexlineatus*. Herpetologica 41:333-342.

Muths, E., T. L. Johnson, and P. S. Corn. 2001. Experimental repatriation of boreal toad (*Bufo boreas*) eggs, metamorphs, and adults in Rocky Mountain National Park. Southwestern Naturalist 46:106-113.

Nash, R. F., G. G. Gallup, Jr., and M. K. McClure. 1970. The immobility reaction in leopard frogs (*Rana pipiens*) as a function of noise-induced fear. Psychonometric Science 21:155-156.

Noble, G. K., and L. R. Aronson. 1942. The sexual behavior of Anura: The normal mating pattern of *Rana pipiens*. Bulletin of the American Museum of Natural History 80:127-142.

Northern Prairie Wildlife Research Center. 1997. North American Reporting Center for Amphibian Malformations. Jamestown, North Dakota: North Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/narcam (Version 12, April 2001).

Oldfield, B., and J. J. Moriarty. 1994. Amphibians and Reptiles Native to Minnesota. University of Minnesota Press, Minneapolis, Minnesota. 237 pp.

Olson, D. H., W. P. Leonard, and R. B. Bury, eds. 1997. Sampling Amphibians in Lentic Habitats. Northwest Fauna No. 4, Olympia, Washington.

Orchard, S. A. 1992. Amphibian population declines in British Columbia. Pp. 10-13 in Bishop, C. A., K. E. Pettit, eds. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Occasional Papers of the Canadian Wildlife Service No. 76. 120 pp.

Orr, L., J. Neumann, E. Vogt, and A. Collier. 1998. Status of northern leopard frogs, pickerel frogs and wood frogs, in Illinois. Pp. 83-90 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Ouellet, M., J. Bonin, J. Rodrigue, J.-L. DesGranges, and S. Lair. 1997. Hindlimb deformities (ectromelia, ectrodactyly) in free-living anurans from agricultural habitats. Journal of Wildlife Diseases 33:95-104.

Pace, A. E. 1974. Systematic and biological studies of the leopard frogs (*Rana pipiens* Complex) of the United States. Miscellaneous Publications of the Museum of Zoology, University of Michigan, No. 148:1-140.

Parrish, J. B., D. J. Herman, and D. J. Reyher. 1996. A Century of Change in Black Hills Forest and Riparian Ecosystems. U.S. Forest Service Agricultural Experiment Station, U.S. Department of Agriculture. South Dakota State University. No. B722. 20 pp.

Pauli, B. D., J. A. Perrault, and S. L. Money. 2000. RATL: A database of reptile and amphibian toxicology literature. Canadian Wildlife Service, Technical Report Series 357:1-495. (On the web at www.cws-scf.ec.gc.ca/pub/tr/tech357/index_e.htm.)

Pechmann, J. H. K., D. E. Scott, R. D. Semlitsch, J. P. Caldwell, L. J. Vitt, and J. W. Gibbons. 1991. Declining amphibian populations: The problem of separating human impacts from natural fluctuations. Science 253:892-895.

Pechmann, J. H. K., and H. M. Wilbur. 1994. Putting declining amphibian populations in perspective: Natural fluctuations and human impacts. Herpetologica 50:65-84.

Peterson, C. R. 1974. A Preliminary Report on the Amphibians and Reptiles of the Black Hills of South Dakota and Wyoming. Unpublished M. S. Thesis, University of Illinois at Urbana-Champaign, Illinois. 59 pp.

Peterson, C. R., and M. E. Dorcas. 1994. Automated data acquisition. Pp. 47-57 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Petranka, J. W. 1994. Response to impact of timber harvesting on salamanders. Conservation Biology 8:302-304.

Petranka, J. W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington, D. C. 587 pp.

Petranka, J. W., M. P. Brannon, M. E. Hopey, and C. K. Smith. 1994. Effects of timber harvesting on low elevation populations of southern Appalachian salamanders. Forest Ecology and Management 67:135-147.

Petranka, J. W., M. E. Eldridge, and K. E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7:363-370.

Phaneuf, D., J. L. DesGranges, N. Plante, and J. Rodrigue. 1995. Contamination of local wildlife following a fire at a polychlorinated biphenyls warehouse in St. Basile le Grand, Quebec, Canada. Archives of Environmental Contamination and Toxicology 28:145-153.

Porter, K. R., and D. E. Hakanson. 1976. Toxicity of mine drainage to embryonic and larval boreal toads (Bufonidae: *Bufo boreas*). Copeia 1976:327-331.

Pough, F. H., R. M. Andrews, J. E. Cadle, M. L. Crump, A. H. Savitzky, and K. D. Wells. 2001. Herpetology, 2nd ed. Prentice Hall, Upper Saddle River, New Jersey. 612 pp.

Pounds, J. A., and M. L. Crump. 1994. Amphibian declines and climate disturbance: The case of the golden toad and the harlequin frog. Conservation Biology 8:72-75.

Prudhoe, S., and R. A. Bray. 1982. Platyhelminth Parasites of the Amphibia. Oxford University Press, Oxford, United Kingdom. 217 pp.

Ramotnik, C. A., and N. J. Scott, Jr. 1988. Habitat requirements of New Mexico's endangered salamanders. Pp. 54-63 in Szaro, R. C., K. E. Severson, and D. R. Patton, eds. Management of Amphibians, Reptiles, and Mammals in North America. U. S. D. A. Forest Service General Technical Report RM-166. 458 pp.

Rand, A. S., and G. E. Drewry. 1994. Acoustic monitoring at fixed sites. Pp. 150-153 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Raphael, M. G. 1988. Long-term trends in abundance of amphibians, reptiles, and mammals in douglas-fir forests of northwestern California. Pp. 23-31 in Szaro, R. C., K. E. Severson, and D. R. Patton, eds. Management of Amphibians, Reptiles, and Mammals in North America. U. S. D. A. Forest Service General Technical Report RM-166. 458 pp.

Rathbun, G. B., and T. G. Murphey. 1996. Evaluation of a radio-belt for ranid frogs. Herpetological Review 27:187-189.

Raymond, L. R., and L. M. Hardy. 1991. Effects of a clearcut on a population of the mole salamander, *Ambystoma talpoideum*, in an adjacent unaltered forest. Journal of Herpetology 25:509-512.

Reaser, J. K. 2000. Demographic analysis of the Columbia spotted frog (*Rana luteiventris*): Case study in spatiotemporal variation. Canadian Journal of Zoology 78:1158-1167.

Reichel, J. D. 1996. Status of amphibians and reptiles in eastern Montana. Intermountain Journal of Sciences 2:57.

Relyea, R. A. 2001a. Morphological and behavioral plasticity of larval anurans in response to different predators. Ecology 82:523-540.

Relyea, R. A. 2001b. The relationship between predation risk and antipredator responses in larval anurans. Ecology 82:541-554.

Relyea, R. A., and E. E. Werner. 2000. Morphological plasticity in four larval anurans distributed along an environmental gradient. Copeia 2000:178-190.

Resetar, A. R. 1998. Locating historical information on amphibian populations. Pp. 379-384 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City, Iowa. 507 pp.

Richards, C. M. 1958. The inhibition of growth in crowded *Rana pipiens* tadpoles. Physiological Zoology 31:138-151.

Richards, S. J., U. Sinsch, and R. A. Alford. 1994. Radio tracking. Pp. 155-158 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Roberts, W. E. 1992. Declines in amphibian populations in Alberta. Pp.14-16 in Bishop, C. A., and K. E. Pettit, eds. Declines in Canadian Amphibian Populations: Designing a National Monitoring Strategy. Occasional Papers of the Canadian Wildlife Service No. 76. 120 pp.

Rome, L. C., E. D. Stevens, and H. B. John-Alder. 1992. The influence of temperature and thermal acclimation on physiological function. Pp. 183-205 in M. E. Feder and W. W. Burggren, eds. Environmental Physiology of the Amphibians. University of Chicago Press, Chicago.

Ross, D. A., J. K. Reaser, P. Kleeman, and D. L. Drake. 1999. *Rana luteiventris* mortality and site fidelity. Herpetological Review 30:163.

Rudolph, D. C., and J. G. Dickson. 1990. Streamside zone width and amphibian and reptile abundance. Southwestern Naturalist 35:472-476.

Rumble, M. A., D. Willis, and B. E. Smith. In press. Wildlife, fish, and herpetofauna of created impoundments in the intermountain west. In Anderson, S., M. McKinstry, and W. Hubert, eds. Palustrine Habitats of the Intermountain West.

Russell, A. P., and A. M. Bauer. 1993. The Amphibians and Reptiles of Alberta. University of Alberta Press, Edmonton, Alberta. 264 pp.

Russell, K. R., D. H. Van Lear, and D. C. Guynn, Jr. 1999. Prescribed fire effects on herpetofauna: Review and Management implications. Wildlife Society Bulletin 27:374-384.

Ryan, R. A. 1953. Growth rates of some ranids under natural conditions. Copeia 1953:73-80.

Schlichter, L. C. 1981. Low pH affects the fertilization and development of *Rana pipiens* eggs. Canadian Journal of Zoology 59:1693-1699.

Scott, N. J., Jr., and B. D. Woodward. 1994. Surveys at breeding sites. Pp. 118-125 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

Seburn, C. N. L., D. C. Seburn, and C. A. Paszkowski. 1997. Northern leopard frog (*Rana pipiens*) dispersal in relation to habitat. Pp. 64-72 in Green, D. M., ed. Amphibians in Decline: Canadian Studies of a Global Problem. Society for the Study of Amphibians and Reptiles, Herpetological Conservation Number One. St. Louis, Missouri. 338 pp.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12:1113-1119.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetlands expendable? Conservation Biology 12:1129-1133.

Semlitsch, R. D. 2000a. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64:615-631.

Semlitsch, R. D. 2000b. Size does matter: The value of small isolated wetlands. National Wetlands Newsletter, January-February 2000:5-13.

Sessions, S. K., R. A. Franssen, and V. L. Horner. 1999. Morphological clues from multilegged frogs: Are retinoids to blame? Science 284:800-802.

Sessions, S. K., and S. B. Ruth. 1990. Explanation for naturally occurring supernumerary limbs in amphibians. Journal of Experimental Zoology 254:38-457.

Sexton, O. J., C. A. Phillips, T. J. Bergman, E. B. Wattenberg, and R. E. Preston. 1998. Abandon not hope: Status of repatriated populations of spotted salamanders and wood frogs at the Tyson Research Center, St. Louis County, Missouri. Pp. 340-344 in Lannoo, M. J., ed. Status and Conservation of Midwestern Amphibians. University of Iowa Press, Iowa City. 507 pp.

Sinsch, U. 1997. Postmetamorphic dispersal and recruitment of first breeders in a *Bufo calamita* metapopulation. Oecologia 112:42-47.

Smith, B. E., J. J. Kolbe, and R. S. Ferguson. 1996a. A herpetological survey of Wind Cave National Park, South Dakota. U. S. G. S./Biological Resources Division. Northern Prairie Science Center. 66 pp.

Smith, B. E., D. M. Browning, E. Taylor, R. S. Ferguson, and K. Yturralde. 1996b.

Herpetofaunal surveys of the Fall River Ranger District, U. S. Forest Service, southwestern South Dakota and Badlands National Park. U. S. G. S./Biological Resources Division. Northern Prairie Science Center. 27 pp.

Smith, B. E., S. K. Ashton, and R. E. Baum. 1998. Herpetofaunal surveys on the Spearfish-Nemo District, Black Hills National Forest: Preliminary report and recommendations, 1998. Unpublished report submitted to the U. S. D. A. Forest Service, Black Hills National Forest, Spearfish-Nemo District. 27 pp.

Smith-Gill, S. J., and D. E. Gill. 1978. Curvilinearities in the competition equations: An experiment with ranid tadpoles. American Naturalist 112:557-570.

Sparling, D. W. 2000. Ecotoxicology of organic contaminants to amphibians. Pp. 461-494 in D. W. Sparling, G. Linder, and C. A. Bishop, eds. Ecotoxicology of Amphibians and Reptiles. SETAC Press, Pensacola, Florida. 877 pp.

Sparling, D. W., G. Linder, and C. A. Bishop, eds. 2000a. Ecotoxicology of Amphibians and Reptiles. SETAC Press, Pensacola, Florida. 877 pp.

Sparling, D. W., G. Linder, and C. A. Bishop. 2000b. The current status of amphibian and reptile ecotoxicological research. Pp. 1-13 in D. W. Sparling, G. Linder, and C. A. Bishop, eds. Ecotoxicology of Amphibians and Reptiles. SETAC Press, Pensacola, Florida. 877 pp.

Stebbins, R. C. 1985. A Field Guide To Western Reptiles and Amphibians, 2nd ed. Houghton Mifflin Company, Boston, Massachusetts. 337 pp.

Stebbins, R. C., and N. W. Cohen. 1995. A Natural History of Amphibians. Princeton University Press. Princeton, New Jersey. 316 pp.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

U. S. D. A. Forest Service. 1997. Black Hills National Forest Land and Resource Management Plan. Custer, South Dakota.

U.S. Environmental Protection Agency. 2001. Office of Pesticide Programs Homepage. http://www.epa.gov/pesticides/. (Updated May 18, 2001).

Ultsch, G. R., T. E. Graham, and C. E. Crocker. 2000. An aggregation of overwintering leopard frogs, *Rana pipiens*, and common map turtles, *Graptemys geographica*, in northern Vermont. Canadian Field-Naturalist 114:314-315.

Van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. Pp. 53-55 in Proceedings of the Forum – Grazing and Riparian/Stream Ecosystems. O. B. Cope., ed. Trout Unlimited, Denver, Colorado.

Wassersug, R. J., and K. Hoff. 1985. Kinematics of swimming in anuran larvae. Journal of Experimental Biology 119:1-30.

Waye, H. L. 2001. Teflon tubing as radio transmitter belt material for northern leopard frogs (*Rana pipiens*). Herpetological Review 32:88-89.

Wells, K. D. 1977. The social behaviour of anuran amphibians. Animal Behaviour 25:666-693.

Wells, K. D. 1978. Territoriality in the green frog (*Rana clamitans*): Vocalizations and agonistic behaviour. Animal Behaviour 26:1051-1063.

Welsh, H. H., Jr., and A. J. Lind. 1995. Habitat correlates of the Del Norte salamander, *Plethodon* elongatus, in northwestern California. Journal of Herpetology 29:198-210.

Welsh, H. H., Jr., and L. M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: A case study from California's redwoods. Ecological Applications 8:1118-1132.

Werner, E. E., and K. S. Glennemeier. 1999. Influence of forest canopy cover on breeding pond distributions of several amphibian species. Copeia 1999:1-12.

Werner, J. K., J. Weaselhead, and T. Plummer. 1999. The accuracy of estimating eggs in anuran egg masses using weight or volume measurements. Herpetological Review 30:30-31.

Whitaker, J. O., Jr. 1961. Habitat and food of mousetrapped young *Rana pipiens* and *Rana clamitans*. Herpetologica 17:174-179.

Wilbur, H. M. 1997. Experimental ecology of food webs: Complex systems in temporary ponds. Ecology 78:2279-2302.

Williamson, J. E., and J. M. Carter. 2001. Water-quality characteristics in the Black Hills area, South Dakota. Water-Resources Investigations Report 01-4194. 196 pp.

Williamson, J. E., and T. S. Hayes. 2000. Water-quality characteristics for selected streams in Lawrence County, South Dakota, 1988-92. Water-Resources Investigations Report 00-4220. 137 pp.

Woodward, B. D. 1982. Tadpole competition in a desert anuran community. Oecologia 54:96-100.

Woodward, B. D. 1983. Predator-prey interactions and breeding-pond use of temporary-pond species in a desert anuran community. Ecology 64:1549-1555.

Wright, A. H. 1914. North American Anura: Life-histories of the Anura of Ithaca, New York. Carnegie Institution, Washington, Publication 197:1-98.

Wright, A. H., and A. A. Wright. 1949. Handbook of Frogs and Toads. Comstock Publishing. Ithaca, New York. 640 pp.

Wyman, R. L., ed. 1991. Global Climate Change and Life on Earth. Chapman and Hall, New York.

Zimmerman, B. 1994. Audio strip transects. Pp. 92-97 in Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, eds. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, D. C. 364 pp.

DEFINITIONS

Abiotic: Non-biological. Used in this report to refer to non-biological factors that influence growth rates of frog populations, such as fluctuations in weather during the year and from year to year.

Adult: A sexually mature frog.

Anoxia: Lack of oxygen. In this report, it may refer to lack of oxygen in a pond during the overwintering season or to lack of oxygen in the bodies of frogs that die in ponds that are anoxic.

Autecology: The ecology of a specific organism. Often used to refer to studies that have focused specifically on a single species, rather than a group of species.

Buffer zone: A zone of habitat that is created around a conserved area and is used to ameliorate the effects of human influence.

Call stations: Points from which male frogs call when in a chorus.

Calling: Generally refers to the male advertisement call. This call is given in the spring to attract females to mate with the male giving the call.

Carnivore, carnivorous: Any animal that eats other animals. Refers in this report to northern leopard frog dietary habits after metamorphosis. I have sometimes used this interchangeably with insectivorous to more specifically describe the food habits of post-metamorphic northern leopard frogs.

Chlorophyll a: A pigment found in algae and plants that converts sunlight energy to chemical energy used for plant growth. Chlorophyll a is easily assayed and is often measured in the water to determine the amount of periphyton found in aquatic systems.

Chorus, chorusing: A group of male frogs giving advertisement calls attempting to attract females to mating ponds.

Conspecifers, conspecific: Refers to other individuals of the same species.

Core habitat: Habitat that is critical to the conservation of populations of species.

Effective population size: The size of a population that is actually breeding, as opposed to the overall size of the population. For example, many organisms may not breed because they are immature. Although they make up the overall population, they are not part of the breeding population. Similarly, many male frogs are not successful at acquiring mates during a particular breeding season. Likewise, these males are not part of the breeding population. It is important to realize that the effective population size could be considerably smaller than the population size. Biologically, the effective population size may be more important than the population size, since effective population size gives important information about the reproductive success of the population.

Emergent vegetation: Shoreline vegetation in which part of the body of the plant emerges above the surface of the water.

Extralimital: Populations found outside the normal range of an organism.

Herbivore, herbivorous: Any animal that primarily eats plant matter. Used here to refer to northern leopard frog tadpoles. Although the single-celled algae they eat are sometimes not regarded as true plants, I see no reason to become involved in this controversy as part of this report.

Hydroperiod: The period of time that a pond holds water. Seasonal ponds have shorter hydroperiods than semi-permanent ponds.

Insectivore, insectivorous: Any animal that primarily eats insects.

Iridovirus: A genus of viruses comprised mostly of iridescent insect viruses but which also infect various vertebrates. Ranaviruses are iridoviruses.

Lacustrine: A lake or larger pond. In this report, lacustrine usually refers to the larger lakes in the Black Hills.

Larvae: Refers to the form in which an amphibian spends its larval period. In this report, I have used tadpole to refer to larval frogs. Salamander larval forms are always called larvae. The term tadpole is reserved for use with frogs.

Larval period: In an amphibian, the period of time spent as a larval form (tadpole, in the case of frogs).

Metamorph, metamorphic: A frog undergoing metamorphosis from a tadpole to a subadult frog, or a frog that has very recently metamorphosed. Throughout this document, I have used metamorph to refer only to a frog that is recently metamorphosed or is metamorphosing. I have used subadult to refer to a frog that is at least a week past metamorphosis.

Metamorphosis: The complex physiological and anatomical process undergone by northern leopard frogs as they change from an herbivorous, swimming larval life form to a carnivorous, saltatory (jumping locomotion), terrestrial/aquatic form of life.

Microclimate: A specific climate available in a subsection of a habitat, such as the elevated humidity and lowered temperatures found in a mammal burrow, under a rock, or in tall grasses.

Metapopulation: A group of interconnected populations (in northern leopard frogs, ponds and associated upland habitats) through which there is some gene flow. Gene flow probably occurs as occasional immigration and emigration to and from populations, probably most commonly during specific life stages. It would appear that most gene flow in northern leopard frog metapopulations occurs as a result of dispersal of subadults.

Natal pond: Pond in which an amphibian was born.

Overwinter: The period of relative inactivity in which frogs spend the colder season. I use overwinter instead of hibernation to distinguish between the distinctive physiological state that mammals undergo during the cold season and the period of relative inactivity that seems to be a result of cold temperatures in amphibians, although some amphibians may also undergo distinctive physiological processes during this period.

Oviposition: The laying of eggs.

Paedomorphs, paedomorphic: The ability to become sexually mature as a larval form. In the Black Hills some populations of tiger salamanders are paedomorphic and reproduce as animals that look like large aquatic larval forms. Called neotenic by some authors.

Palustrine: A pond. Usually used in this report to refer to habitat that is <10 ha in size.

Periphyton: A term used by aquatic ecologists to describe a community composed mostly of microorganisms that may include algae, bacteria, fungi, some macrophytes (larger plants), invertebrate grazing organisms, and detritus. Periphyton often grows in thick mats that may float on the water surface. Periphyton mats produce much of the vegetative biomass in some aquatic habitats.

Phenology: A timeline of specific events. Refers in this report to the fact that northern leopard frogs leave overwintering sites at particular times of the year, call for a specific period of time, forage for part of the year, and then return to overwintering sites. It also refers to the fact that eggs are laid at a specific time, hatch within a certain period, tadpoles develop for a time and metamorphose, then subadults migrate and overwinter at certain sites.

Philopatry, philopatric: Refers to the fact that some amphibians are "faithful" to certain sites, returning to them over and over to breed. Some amphibians are highly philopatric and return to their natal pond to breed or return to the same pond repeatedly to breed (not necessarily their natal pond).

Population: A group of individuals that could potentially interbreed with each other. In practice probably a high degree of non-randomness is operating in any natural population because individuals (usually females) chose to mate with specific individuals. In northern leopard frogs, populations probably usually all use the same breeding pond or could be considered the group of individuals centered on specific breeding ponds.

Primary consumers: Herbivores. Refers to the fact that herbivores eat primary producers, the plants that create biomass from sunlight. Carnivores are secondary consumers, because they eat primary consumers (and other secondary consumers). Northern leopard frog tadpoles are primary consumers while adults are secondary consumers.

r-selected: An organism tending to have high growth rates with type III survivorship curves and often extreme population fluctuations. It is often said that r-selected species are particularly subject to mortality from abiotic sources.

Ranavirus: A type of iridovirus that infects frogs in the genus Rana.

Reproductive success: In this report, successful hatching of eggs and rearing of tadpoles to metamorphosis. Some authors may also define this term as meaning successful rearing through the subadult stage to the adult stage and to the laying of eggs by this adult, or success in reaching any step in between this sequence, but that is not the meaning intended here.

Righting reflex: When placed upside down, amphibians will try to right themselves. The righting reflex is typically used to determine the state of health of an amphibian. If it has lost the ability to right itself, the animal is thought to be seriously ill or disoriented.

Riparian: A habitat strip along a river or larger stream. Undisturbed riparian corridors usually contain considerable growth of willows in the Black Hills.

Seasonal pond: A pond with a relatively short hydroperiod, usually drying out every year. In the Black Hills, northern leopard frogs occasionally use seasonal ponds in which to breed, but they seem to favor semi-permanent ponds as breeding habitat.

Semi-permanent pond: A pond with a hydroperiod longer than a seasonal pond but shorter than a permanent pond. Semi-permanent ponds tend to dry completely every few years, but hold water throughout most years. In the Black Hills, northern leopard frogs are predominantly found breeding in semi-permanent ponds.

Subadult: A frog that is post-metamorphic but not a sexually mature adult.

Tadpole: The larval form of a frog. The tadpole period lasts from hatching of the egg for a period of 58 – 105 days, at the conclusion of which a tadpole metamorphoses into a subadult frog.

Teratogen: A cancer-causing agent.

Trematode parasites: Flatworm parasites commonly referred to as flukes. Many of these parasites have suckers to attach to the internal organs of the host organism. Many flukes have complicated life histories.

Type III survivorship curve: A survivorship curve showing high mortality in early life stages of an organism. Often, these organisms show relatively high survivorship after an early period of very high mortality.

Upland habitat: Any completely terrestrial habitat used by northern leopard frogs.

Figure 1. Range of the northern leopard frog, Rana pipiens. (Prepared by Jason Bennett, of the Wyoming Natural Diversity Database, University of Wyoming.)

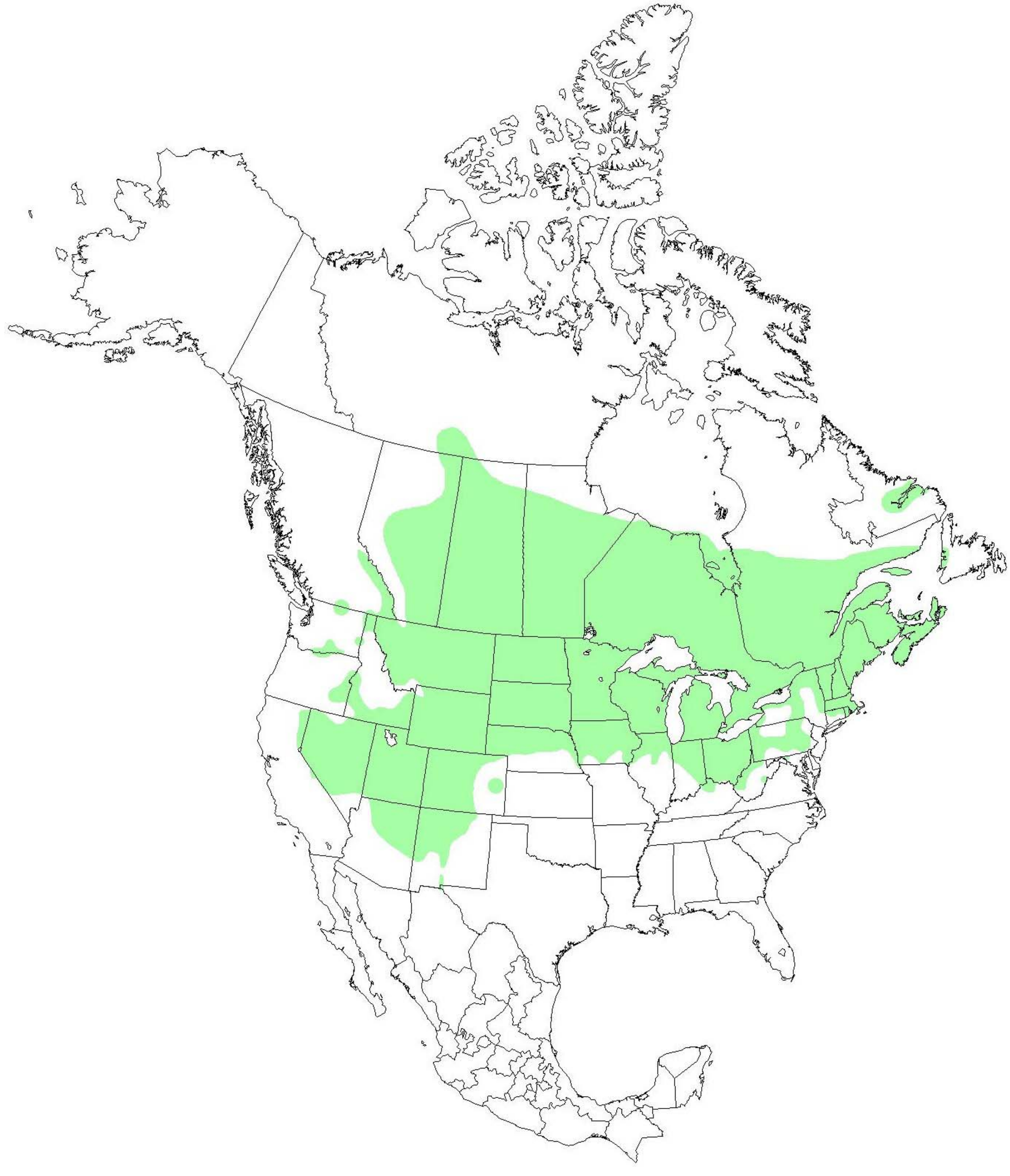

Table 1. Historic and current levels of abundance and population trends for northern leopard frogs across their range in North America. If no reference is given, the data are unknown for the various provinces and states that are listed. (List of references follows table).

State or Province	Historical Abundance	Present Abundance	Population Trend
Alberta	Unknown[1]	Uncommon[1,2,3]	Declining[1,2,3]
Arizona	Uncommon[4]	Uncommon[4]	Declining[4]
British Columbia	Unknown	Unknown	Unknown
California	Extralimital?[5,6]	Uncommon[3]	Declining[3]
Colorado	Unknown	Uncommon[7,8,9]	Declining[7,8,9,10]
Connecticut	Unknown	Unknown	Unknown
Idaho	Unknown	Uncommon[11]	Declining[11]
Illinois	Unknown	Common[12]	Stable[12]
Indiana	Common[13]	Uncommon[13,14]	Declining[13,14]
Iowa	Common[15]	Uncommon[15]	Declining[15]
Kentucky	Unknown	Unknown	Unknown
Maine	Unknown	Unknown	Unknown
Manitoba	Unknown	Unknown	Unknown
Massachusetts	Unknown	Unknown	Unknown
Michigan	Uncommon[16]	Unknown	Declining[16]
Minnesota	Common[17]	Common[17]	Declining[17]
Montana	Unknown	Uncommon[18,19]	Declining[18,19]
Nebraska	Unknown	Unknown	Unknown
Nevada	Unknown	Unknown	Unknown
New Brunswick	Unknown	Common[20]	Stable[20]
New Hampshire	Unknown	Unknown	Unknown
New Mexico	Unknown	Unknown	Unknown
New York	Unknown	Unknown	Unknown
Newfoundland	Extralimital[21,22]	Unknown	Unknown
North Dakota	Unknown	Unknown	Unknown
Northwest Territories	Unknown	Uncommon[23]	Unknown
Nova Scotia	Unknown	Unknown	Unknown
Ohio	Unknown	Common[24]	Stable[24]
Ontario	Unknown	Unknown	Unknown
Pennsylvania	Unknown	Unknown	Unknown
Quebec	Unknown	Unknown	Unknown
Saskatchewan	Unknown	Unknown[25]	Unknown[25]
South Dakota	Unknown[26]	Common[26,27,28,29,30]	Unknown[26]
Utah	Unknown	Unknown	Unknown
Vermont	Unknown	Unknown	Unknown
Washington	Uncommon[31]	Uncommon[31]	Declining[31]
West Virginia	Unknown	Unknown	Unknown
Wisconsin	Common[32]	Common[32]	Declining[32,33,34,35]
Wyoming	Unknown	Unknown	Declining[3,11,36]

References: 1 = Russell and Bauer (1993); 2 = Roberts (1992); 3 = Stebbins and Cohen (1995); 4 = Clarkson and Rorabaugh (1989); 5 = Bury and Luckenbach (1976); 6 = Jennings (1984); 7 = Hammerson (1999); 8 = Hammerson (1982); 9 = Cousineau and Rogers (1991); 10 = Corn and Fogleman (1984); 11 = Koch and Peterson (1995); 12 = Mierzwa (1998); 13 = Minton (1998); 14 = Brodman and Kilmurry (1998); 15 = Lannoo (1994); 16 = Collins and Wilbur (1979); 17 = Moriarty (1998); 18 = Maxell (2000); 19 = Reichel (1996); 20 = McAlpine (1997); 21 = Buckle (1971); 22 = Green and Campbell (1984); 23 = Fournier (1997); 24 = Orr et al. (1998); 25 = Didiuk (1997); 26 = B. Smith, personal observation; 27 = Peterson (1974); 28, 29, 30 = Smith et al. (1996a, b; 1998); 31 = Leonard et al. (1999); 32 = Mossman (1998); 33, 34 = Hine et al. (1975, 1981); 35 = Dhuey and Hay (2000); 36 = Baxter and Stone (1985).