SPECIES ASSESSMENT FOR COLUMBIA SPOTTED FROG (*RANA LUTEIVENTRIS*) IN WYOMING

prepared by

DEBRA A. PATLA[1] AND DOUGLAS A. KEINATH[2]
with support from Mathew McGee[2] and David S. Pilliod[3]

[1] *Herpetology Laboratory, Dept. of Biological Sciences, Idaho State University, Pocatello, ID*
[2] *Wyoming Natural Diversity Database, University of Wyoming, 1000 E. University Ave., Dept. 3381, Laramie, WY*
[3]*Dept. of Biological Sciences, College of Science and Math, California Polytechnic State University, San Luis Obispo, CA*

prepared for

United States Department of the Interior
Bureau of Land Management
Wyoming State Office
Cheyenne, Wyoming

January 2005

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Summary

Four populations of Columbia spotted frog (*Rana luteiventris*) are currently recognized, including three disjunct, southern populations and a main population extending from northwest Wyoming through western Canada. The main (or northern) population includes Wyoming. It has no federal status as endangered or threatened and is generally considered to be secure, although some local declines have been documented. Most occupied habitat for the Columbia spotted frog occurs on lands managed by the National Forest Service (Regions 2 and 4) and the National Park Service (Yellowstone and Grand Teton national parks). The Bureau of Land Management (BLM) may have potential habitat in the Green River Basin and higher elevation parcels near forest boundaries (Fig. 8 and 9), but the extent of this is largely unknown because most potentially suitable BLM land has not been surveyed for spotted frogs.

Historical data are too scarce to determine if declines have occurred in many areas where spotted frogs currently occur in Wyoming. Some populations in the state appear to be vulnerable. Habitat loss, degradation, and fragmentation are major threats to spotted frogs on multiple-use lands in Wyoming. Livestock grazing, water manipulation, road construction, and the introduction of sport fish are identified as the activities most likely to affect habitat. Spotted frog populations also may be directly affected, in terms of survival and reproduction, by elevated mortality rates from a variety of human and management activities (e.g., roadkill, trampling), predation by fish, and exposure to toxic chemicals. Drought is also a threat to frogs and their habitat, and its effects may be exacerbated by management activities and land uses. Two infectious diseases, chytridiomycosis and ranavirus, have been found in spotted frogs in northwest Wyoming and could threaten the persistence of local populations and the abundance of frogs. The main conservation concerns involve determining the distribution, abundance, and

status of populations on BLM lands. Identifying breeding, overwintering, and migration areas for local populations is necessary to determine if they are at risk from land uses and management activities. Table 2 summarizes threats to spotted frogs and their habitat in Wyoming. In general, management practices need to be evaluated for their site-specific impacts to ensure that viable populations are maintained on BLM lands.

Introduction

This report addresses the biology, ecology, and conservation status of the spotted frog in Wyoming. Information from spotted frog and other amphibian studies conducted outside Wyoming are used when applicable. Our goal is to provide a current summary of published information and expert interpretation of this information that can be used to develop management plans.

This assessment is based on the best information currently available, but it should be noted that new research on spotted frogs and the findings of on-going monitoring projects in the Greater Yellowstone Ecosystem (GYE; defined as the mountainous area surrounding Yellowstone National Park) are likely to provide additional insights and management tools in the future. We reviewed refereed scientific literature, research reports, unpublished documents, Natural Heritage data, and consulted with expert scientists. We emphasize information from peer-reviewed literature, whenever possible, over unpublished reports, but much of the relevant information on spotted frogs, particularly conservation management material, has not been published. Occurrence information from Natural Heritage Programs and survey-monitoring data in the GYE were used extensively to estimate distribution. These occurrence data were standardized to the methods and level of accuracy used in the Wyoming Natural Diversity Database.

Natural History

Morphological Description

Juveniles and Adults

The Columbia spotted frog has a slender body shape, with a rather pointed snout (Fig. 1). Body lengths of adult frogs range up to 100 mm in females, and 68 mm in males (Nussbaum et al. 1983). In Yellowstone and Grand Teton national parks (northwest WY), observed maximum snout-urostyle lengths approach 90 mm for females and 65 mm for males (Patla unpublished data). Size at metamorphosis is highly variable among breeding sites and ranges from 12 mm to 33 mm Nussbaum et al. 1983; Patla, unpublished data). The eyes are upturned, bright yellow or gold, sometimes dark in juveniles. Dorsal color is light to dark brown, tan, dull green, or olive. There are irregularly-shaped, large black spots on the back; often these spots have light-colored centers. The dorsal skin has a bumpy or warty texture. Dorsolateral folds are usually present. A white or yellowish jaw stripe (or lip line) extends from the tip of the snout, under the eye, to the front legs. Undersides of the hind legs and the lower abdomen of many but not all adults are brightly colored with yellow, orange, red, or salmon, resulting from a lipoid pigment (Fig. 2). On some individuals, the pigmentation extends into the chest or throat and front legs. Belly pigmentation is more extensive on large females and develops at an earlier age than in males (40 mm body length for females, 50 mm for males) (Turner 1959b). Ventral areas of adults are also variously mottled with melanin pigment (Turner 1959b). The hind feet are large relative to the hind leg length and have webbing that extends nearly the length of the hind toes. Male spotted frogs have dark, roughened nuptial pads at the base of the thumbs (Fig. 3), which do not become reliably apparent until frogs reach a snout-urostyle length (measured dorsally from tip of the snout to the terminus of the urostyle or coccyx bone) of about 45 mm (Turner 1960, Hollenbeck 1974; Patla 1997). Juveniles (post-metamorphic) are similar in appearance to adults except for the lack of reddish pigmentation on undersides (Fig. 4).

Similar species in or near the range of the Columbia spotted frog are the northern leopard frog (*Rana pipiens*) and the wood frog (*Rana sylvatica*). Leopard frogs can have dorsal coloration that is similar to spotted frogs, but leopard frogs are readily distinguished by their smooth skin and the light borders outlining oval-shaped spots. Wood frogs have a black mask, light upper jaw line, and dorsal coloration that can resemble spotted frogs; the smooth skin of wood frogs is probably the best field mark to distinguish them from spotted frogs. Juvenile spotted frogs may be confused with wood frogs, and records that consist only of juveniles should be considered with caution. Both leopard and wood frogs have white bellies. The lack of reddish or orange coloration on the underside does not reliably rule out identification as a spotted frog; many spotted frogs lack this feature.

Tadpoles

Tadpoles are dark in color after hatching; their color lightens as they grow to brown or greenish-brown, with gold or brassy flecks on the upper surface (Fig. 5). Bellies are light in color, often showing a metallic, copper sheen (Maxell 2000). Tadpole size varies from 7-8 mm total length at hatching (Nussbaum et al. 1983) to a maximum of 90 mm (Maxell 2000) reached prior to the onset of metamorphosis, when tails began to shrink. Spotted frog tadpoles have a tall, robust tail that is more than 1½ times the body length to twice as long (Maxell 2000). The tail fin is colorless or pale, flecked with black or gold. There are small differences among spotted frog, leopard frog, and wood frog tadpoles; a diagnostic key is provided by Corkran and Thoms (1996). In spotted frog tadpoles, the height of the dorsal fin is taller than the thickness of the tail trunk at its base (side view); in leopard frog tadpoles, the height of the dorsal fin is equal to or less than the thickness of the tail trunk at its base. Leopard and wood frog tadpoles have somewhat shorter tails (1 ½ times the body length or less viewed from above) (Corkran and Thoms 1996). However, spotted frogs tadpoles have variable tail size (D. Patla, pers. obs.), and in areas where these species have overlapping ranges, tadpoles may not safely be distinguished in the field except by experienced observers. However, given the rarity of co-occurrence of these species in Wyoming, it is probably fairly safe to assume that tadpoles matching the general description are indeed spotted frogs if adults and juveniles in the vicinity are positively identified as spotted frogs, and wood frogs or leopard frogs have not been found historically or recently during surveys in the area.

Eggs

Individual eggs are 10-12 mm in diameter, including ovum and two surrounding jelly layers. The ova are black in color, with a white spot. Eggs are deposited in a single, gelatinous mass (Fig. 6A) that is round and ca.12 to 20 cm in diameter (Nussbaum et al. 1983). Each egg mass contains from a few hundred to over 2,000 eggs (se section on Life History for details). Egg masses are deposited in shallow water where they initially rest on the bottom, but soon float and become partially submerged, increasingly covered with algae and debris as they age (Fig. 6B).

Taxonomy and Distribution

Taxonomy

Within the family of true frogs, Ranidae (order Anura), only the genus Rana occurs in North America, with approximately 26 species in North America (Duellman and Sweet 1999). Western North America hosts 29 endemic anuran species, including 8 endemic ranid frogs. The subject of this report, *Rana luteiventris*, is one of four anuran species (and the only ranid frog) that occurs in both the northern Rocky Mountains and the northern part of the Pacific-Cascade ranges. Recent phylogenetic analyses place *R. luteiventris* within the *Rana boylii* group, which is restricted mainly to the cool, montane regions of western North America, and includes the species *R. aurora*, *R. muscosa*, *R. boylii*, *R. cascadae*, and *R. pretiosa* (which is most closely related *to R. luteiventris*) (Duellman and Sweet 1999).

The species now known as *Rana luteiventris* was first described from Puget Sound in Washington as the Western Spotted Frog (*Rana pretiosa*) (Baird and Girard 1853). In 1913, two subspecies were recognized, *R. p. pretiosa* and *R. p. luteiventris* (Thompson 1913). The subspecies designations, which were based on differences in coloration and foot tubercles, were debated and contested for several decades, and they were eventually abandoned (Morris and Tanner 1969; Turner and Dumas 1972). Recent genetic analysis of spotted frogs, however, revealed the existence of two morphologically cryptic species, which had diverged into coastal and interior forms in the course of repeated glacial advances and retreats during the Quaternary (Green et al. 1996). The species occupying the type locality retained the name *R. pretiosa* (Oregon spotted frog), with a range comprised of Puget Sound, south-central Washington, the Oregon Cascades, and extreme southwestern British Columbia (Green et al. 1997). The name *R. luteiventris* (Columbia spotted frog) designates spotted frog populations in the remainder of spotted frog range (see Distribution and Abundance section) (Green et al. 1997). The subject of this species account is *R. luteiventris* Thompson, 1913, the Columbia spotted frog, with no subspecies formally recognized.

The designation of two spotted frog species (*R. luteiventris and R. pretiosa*) has been officially accepted by the scientific community, as evidenced by listing in Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico

(Crother 2003). This document is the official list of standard common and scientific names recognized by the Society for the Study of Amphibians and Reptiles, American Society of Ichthyologists and Herpetologists, and the Herpetologists' League.

The recent taxonomic change for spotted frogs occupying Wyoming (from *R. pretiosa* to *R. luteiventris)* may cause some confusion given that species lists, field guides, and most of the literature prior to 1998 use the name *R. pretiosa*. Adding to potential confusion in the future, there may be taxonomic re-designations resulting from continued genetic analysis of disjunct *R. luteiventris* populations, possibly resulting in three or more subspecies or "several weakly differentiated species" (Green et al. 1997).

There are no subspecies within the species *R. luteiventris*, but there are four recognized population segments: the Northern (or main) population and three smaller, disjunct populations in the Great Basin (eastern Oregon, southwest Idaho, and Nevada), Wasatch (Utah), and West Desert (Utah) (USFWS Region 6 2002). . -The spotted frog population of the Bighorn Mountains appears to have been overlooked in this delineation. This population, first identified in 1973, is geographically isolated and genetically distinct, occurring only on the northeast slope of the Bighorn Mountains (Dunlap 1977; Bos and Sites 2001). The USFWS listing decision (Worthing 1993) does not mention the Bighorn Mountain population. Lack of recognition of the Bighorn population as a disjunct population segment by USFWS probably is further hampered by the fact that Green et al.'s (1997) genetic analysis of spotted frog species and populations did not include specimens from the Bighorns.

Distribution and Abundance

The Columbia spotted frog has an extensive distribution in western North America, from southern Alaska through British Columbia and western Alberta and the states of Washington, Oregon, Idaho, Montana, Wyoming, Utah, and Nevada (Fig. 7). Disjunct populations exist south of the main range in southeast Oregon, Nevada, southwest Idaho, and Utah; and east of the main range, in the Bighorn Mountains of north central Wyoming. As explained above (Federal Endangered Species Act section), the disjunct populations south of the main range have been recognized as isolated, distinct population units.

In the southern part of the species range, the Great Basin and Wasatch Front populations have undergone significant decline, with wetland habitat loss and modification recognized as the primary causative factor (Worthing 1993). The West Desert population has suffered less habitat loss but is faced with limited habitat availability and potential habitat degradation from cattle grazing and agriculture (Worthing 1993). Spotted frogs in the southern disjunct populations are reported as locally abundant or occurring at high local densities in some areas, but uncommon and at low densities in others (Reaser and Pilliod 2005). In Nevada and Utah, spotted frogs were not found at many historically-occupied sites, but surveys also documented sites not previously recorded. Green et al. (1997) regard the two Utah populations (referred to as the "Bonneville spotted frog" and the "Provo River spotted frog") as the most threatened, based on their extremely limited distributions.

The main population of spotted frogs (western Alberta, British Columbia, eastern Washington and Oregon, northern and central Idaho, and western Montana and Wyoming) is regarded by USFWS as "common and abundant", although some declines have occurred (Worthing 1993). The Columbia spotted frog is reported to be the most common frog in western Montana's mountains and mountain valleys, but of uncertain status in the Big Snowy, Highwood, and Bighorn Mountains (Maxell 2000). In Glacier National Park, surveys of randomly selected watershed units found spotted frog breeding at 19% of 360 potential amphibian breeding sites surveyed in 2002 (USGS-ARMI 2002). In the mountains of central or north Idaho, spotted frogs are the most commonly encountered amphibians, with locally abundant populations (Reaser and Pilliod 2005).

Information from northwest Wyoming mostly verifies the USFWS assessment (Worthing 1993) that spotted frogs of the main population are still abundant. In Yellowstone and Grand Teton national parks, spotted frogs have been described as common to abundant (Koch and Peterson 1995); surveys of selected watersheds in the area indicate that the spotted frog is the second most abundant amphibian in the parks (Patla & Peterson 2003); and they were recently categorized as showing no indications of a widespread decline based on comparison of historical and recent records (Van Kirk et al. 2000). Assessment of amphibian species status on the Bridger-Teton National Forest (B-TNF) in northwest Wyoming found that spotted frogs were widespread and common on the northern districts of the B-TNF, but rare or absent on the southern districts with little evidence for range contraction (Patla 2000a).

Outside the national parks and the B-TNF, spotted frogs occur on and near the Shoshone and Bighorn National Forests (Fig. 8 and 9). Based on existing information, spotted frogs appear to be much less common on the Shoshone NF than on mountainous lands to the west. The apparent rarity of spotted frogs on much of the Shoshone NF may demonstrate actual scarcity on the southeastern edge of its range, but it could also be an artifact of "poor" information quality and low survey effort and/or lack of mechanisms for reliably recording incidental observations (Van Kirk et al. 2000). Distribution of spotted frogs in the Bighorns is extremely restricted. All occurrences on record are within a 5 by 11 km rectangle, on tributaries of the Tongue River. Only 3 breeding sites have been identified since 1992, and spotted frogs at these sites are not numerous when compared to some local populations in the

GYE (H. Golden, pers. comm., 2002; WYNDD database). Garber (1994) concluded that spotted frogs were restricted to a small area at the headwaters of the South Tongue River drainage and its tributaries; a much smaller range than depicted in Baxter and Stone (1985).

We must note that the above estimates of abundance are coarse and should be viewed with caution. A more precise measure of abundance within local populations may be determined through mark-recapture of individuals within a given area and the application of population estimation methods or through indices of population size from egg mass counts (e.g., Perkins and Lentsch 1998). Unfortunately no mark-recapture work or systematic egg-mass surveys (to our knowledge) have been conducted on spotted frogs in Wyoming outside the GYE.

Population Trends

Amphibian populations at the local scale may exhibit extreme fluctuations in size from year to year as well as over the course of many years (e.g., Pechmann et al. 1991; Pechmann and Wilbur 1994 and references therein). This is particularly true for anuran amphibians of the North Temperate zone, which respond to fluctuating environmental conditions with large variations in birth and survival rates (Green 1997). Researchers caution that determining the normal range of fluctuation for any single population and the deviation from that norm that would signify a decline, could take decades, or longer than a human lifetime (Pechmann and Wilbur 1994; Green 1997). Given this fact, coupled with the difficulty of obtaining demographic data, biologists often define amphibian population trend in terms of changes in the numbers of populations (per species) over time, rather than changes in the size of local populations (Green 1997). In areas where declines of an amphibian species are accepted as indisputable, such as *Bufo boreas* in Colorado, the evidence consists of range reductions, the disappearance of the species at sites where it was historically or recently documented, and the failure to find significant numbers of previously unknown "new" breeding populations despite adequate survey efforts (Loeffler 2001. To assess broad-scale trends in widespread populations, the USGS Amphibian Research and Monitoring Initiative (USGS-ARMI) is developing occupancy methodology, which assesses trends based on changes in the number of occupied breeding sites over time.

Where anuran species have declined to a few breeding populations, population trend in terms of the estimated number of individuals is of urgent interest. This is so because small and isolated populations are more vulnerable to extirpation, while larger ones are more robust; thus declines in some or all of the few remnant breeding populations could indicate that the species is in increasing peril.

The abundance of the Columbia spotted frog has been described as greatly reduced from its historic levels in portions of Utah, Oregon, Nevada (Worthing 1993). Assessment of population trends for the disjunct, southern populations is in progress by various researchers and agencies. Most extant populations of the Wasatch Front spotted frog population are said to have either increased or are of a larger population size (additional occupied sites or greater density of sites found within known population boundaries) than previously thought (USFWS Region 6 2002). Trends in the West Desert breeding populations are variable (Hogrefe 2001). Preliminary results (1997-2001) indicate that spotted frogs of southwest Idaho (within the Great Basin population) are declining; with apparently only small numbers of frogs at most sites were they occur (Engle 2002). Concerns about the status of this population segment were heightened by the discovery of chytrid disease in 2001 (Engle 2002; USFWS, Snake River Basin Office 2002). In eastern Oregon, USGSARMI surveys of historic sites found that 65% were occupied by spotted frogs, and no new populations were found at 87 sites surveyed on

BLM lands in southeast Oregon in 2002 (http://armi.usgs.gov/2002_report_PNW.asp). These findings suggest that declines may be occurring in the Great Basin spotted frog population.

Surveys and assessment of broad-scale trends using occupancy methodology are in progress through USGS in Glacier, Yellowstone and Grand Teton National Parks (e.g., http://www.mesc.usgs.gov/research/rarmi). While trends have not yet been quantitatively assessed and published for the GYE, initial assessments are that spotted frogs are probably not experiencing a widespread decline in these national parks (Patla and Peterson 2003; Patla and Peterson unpublished data). However, some local declines of spotted frogs have been observed in the GYE. Notably, at a long-term study site in central Yellowstone, a spotted frog population declined almost 80% between the 1950s and the 1990s (Patla 1997; Patla and Peterson 1999; Patla and Peterson *in prep*) and spotted frogs have completely disappeared from a few sites where they were previously observed (Patla, unpublished data).

Information is insufficient to determine population trend for spotted frogs across Wyoming, particularly in areas where monitoring has not been conducted and surveys have been few, and trends in the GYE cannot be assumed to describe the situation for the rest of Wyoming. Populations at the edge of the species range (like those on the Shoshone NF and Bighorn Mountains) may experience declines not occurring elsewhere (Green et al. 1996). Also, new amphibian diseases could be appearing in the Wyoming populations, thus dramatically altering their abundance trajectory (see *Parasites and Disease and Threat* sections of this report).

Habitat Requirements

General

Columbia spotted frogs inhabit a variety of vegetation communities, including coniferous or mixed forests, grasslands, and riparian areas of sage-juniper brushlands. Elevation range for the species is reported up to 3036 m, with frogs ranging up to 2890 m in the GYE (Reaser and Pilliod 2005). Dumas (1964) reported that relative humidity of 65% at 25°C is lethal to adult spotted frogs in approximately 2 hr, a factor which would restrict spotted frogs to higher elevations or moist riparian zones in arid western landscapes. Because both breeding and over-wintering occur at aquatic sites (see below) populations are located in the general vicinity of ponds, lakes, springs, and/or streams. The examination of movement distances above suggests that breeding and wintering sites are generally less than 600 m apart (although adults are capable of moving longer distances). Surveys for amphibians in Yellowstone National Park during 2000-2001 found a strong association of Columbia spotted frogs with National Wetland Inventory (NWI) classifications of Cowardin et al. (1979): 69% of 116 wetland sites occupied by spotted frogs had the classifications palustrine and emergent; 19% were classed palustrine and aquatic bottom. With regards to water regime, the majority (54%) was in seasonally flooded areas; 22% were in semi-permanently flooded areas, and 16% were in saturated areas (Patla and Peterson unpublished data). A study in arid southwestern Idaho (Munger et al. 1998) found adult spotted frogs were associated with palustrine, shrub-scrub, seasonally flooded sites, or with intermittent riverine, streambed, seasonally flooded sites. Frogs were also associated with vegetation indicating permanent water sources (i.e., willows and submerged aquatic plants rather than with emergent vegetation such as sedges) and vegetation providing hiding and thermal cover (e.g., willows). In investigating NWI classification as predictors of spotted frog (and Pacific Treefrog) occurrence, Munger et al. (1998) found only modest predictive power and suggested that habitat variables (e.g., slow-moving water) or fine-scale habitat models could provide better tools than NWI for locating frogs. Development of wetland habitat models as tools for predicting amphibian presence and habitat use is in progress for Yellowstone National Park (edc2.usgs.gov/armi/nmd/research.asp; P. Bartelt, A. Gallant, C. Peterson, and C. Wright, pers. comm.)

Breeding and larval habitat

Three main components must meet necessary criteria for adequate breeding and larval habitat: water bodies, vegetation, and temperature.

Water bodies should include stagnant or slow-moving water, with shallow areas. Breeding and egg deposition take place in ponds, marshes, stream oxbows, small springs, and along the margins of lakes and slow-flowing streams. Permanent, temporary (seasonal), and man-made water bodies (Monello and Wright 1999) all may serve as breeding sites (Fig. 10). Eggs are deposited in shallow water, reported as usually no more than 10-15 cm deep by Maxell (2000), and 10-20 cm deep by Reaser and Pilliod (2005).

Emergent and aquatic vegetation are usually present. Emergent vegetation (sedge) is usually present at breeding sites (Maxell 2000; Reaser and Pilliod 2005; Patla and Peterson unpublished data), but egg deposition occurs soon after snowmelt and thus prior to significant seasonal growth by most emergent and aquatic vegetation. Morris and Tanner (1969) report that eggs are never deposited among cattails, a generalization that appears to hold true for the GYE. Tadpoles, however, do use emergent cattail stands in the GYE following dispersal from the site of egg deposition (Patla, personal observation). Sources differ with regards to aquatic vegetation: Reaser and Pilliod (2005) report frequent associations of egg deposition with floating vegetation; Morris and Tanner (1969) describe an avoidance of floating *Spirogyra*. Bull and Hayes (2001) note that spotted frog breeding sites are dominated by submerged vegetation (pondweed and buttercup), while non-breeding sites to which frogs move had a predominance of emergent vegetation. However, amphibian surveys in the GYE in 2001 indicated a stronger association of breeding sites with emergent vegetation than with aquatic submerged or floating vegetation: 26 of 41 sites (63%) occupied by spotted frog eggs or larvae had no more than 10% aquatic vegetation cover, while 27 of the sites (66%) had >50% cover with emergent vegetation (mostly sedges) (Patla and Peterson unpublished data).

Spotted frogs show tolerance for a large temperature range but water should be exposed to sunlight to allow daily warming. Breeding activities and egg deposition usually occur in the portion of the water body with high exposure to morning sunlight (i.e., on the west side) (Morris and Tanner 1969), or on the north side, where snow melts most quickly in spring. However, oviposition locations are variable and depend on inlets, outlets, surrounding tree heights, and surrounding horizon. Eggs are normally deposited in water at temperatures of approximately 14°C (Morris and Tanner 1969). Water temperatures after egg deposition fluctuates, increasing on sunny afternoons, falling sharply at night, and generally increasing as the season advances toward the summer solstice, unless the site has a geo-thermal influence. Embryos at the upper surface of egg masses suffer high mortality due to freezing temperatures at night and/or during spring cold spells. Koch and Peterson (1995) report that spotted frog eggs at a geo-thermally influenced site in Yellowstone were found in water of 23°C, while the range of temperatures available nearby ranged from 15 to 35°C. Dumas (1964) found spotted frog tadpoles in ponds ranging from 8-28°C. Reaser and Pilliod (2005) concluded from their literature review that water temperature at breeding sites is often well below 18°C. Observations from the GYE suggest that water bodies fed continuously by cold-water springs, heavily shaded, or otherwise prevented from reaching warm temperatures during the day are unlikely to serve as spotted frog breeding sites (Patla, personal observation). Water temperatures measured at 67 sites with spotted frog larvae in Yellowstone during the years

2001 and 2002 averaged 17.8°C (se 0.59, range 5°C -29°C; Patla and Peterson, unpublished data).

Foraging habitat

Summer foraging may occur at the same water body used for breeding and overwintering, but in many cases frogs move to other areas. Spotted frogs move to other sites in summer for a variety of reasons including predator avoidance and the attractions of more abundant food and less competition (Bull and Hayes 2001). Pilliod (2001) found that female frogs migrating to adjacent wetlands for summer foraging were significantly larger than non-migratory females. Foraging sites include ephemeral pools in forests and meadows, streams (permanent and intermittent) and river edges, riparian zones, temporary and permanent ponds, lake margins, and marshes (Fig. 11).

Sites used for foraging only may be shallower, less vegetated, and more ephemeral than breeding sites. Sites used for summer foraging only (as opposed to breeding-and-summer or winter-only sites) in the Idaho mountains included all types of wetland habitats and were on average smaller and shallower than wetlands used for breeding and wintering , with less forest or shrub cover along shorelines (Pilliod et al. 2002). Patla (1997) found that "spotted frogs demonstrate considerable plasticity in summer foraging habitat, making use of small wet or damp areas in forest and meadows, including water-filled tire tracks, stream edges, and marshes", and surmised that the location of such sites, en route between breeding and wintering sites, was an essential aspect of their use by frogs. , , Water bodies that provide year-round habitat (breeding and hibernacula as well as foraging) have diverse habitat features. For example, one such site in the mountains of central Idaho was characterized by emergent vegetation, silt substrate, grassy shoreline, warm summer water temperature (21°C), perennial outlets and inlets or springs, and some deep-water habitat (up to 3 m) (Pilliod et al. 2002). A pond in northeast Oregon used for both breeding and summer foraging was relatively large (28,500 m^2) and deep (3 m), isolated from other permanent water bodies, and contained emergent vegetation (cattails and spike-rush) as well as aquatic vegetation (pondweed) (Bull and Hayes 2001).

Winter habitat

Wintering habitat may include ponds, streams, under stream banks, springs, beaver dams, and underground areas (associated with water bodies), but all such sites must have above freezing temperatures, be moist or wet, and be well oxygenated. Frogs of the genus *Rana* generally overwinter underwater in permanent water bodies, or terrestrially, depending on species physiological tolerances for chilling and hypoxia. Columbia spotted frogs winter in or immediately adjacent to aquatic sites, where they can avoid the threat of freezing or oxygen depletion (Bull and Hayes 2002).

The most detailed information on spotted frog wintering habitats was obtained by the radio-tagging of 66 frogs in northeast Oregon during the years 1997-1999, at elevations of 915-1800 m, where air temperatures remained below freezing from December through February and plunged to as low as -30°C (Bull and Hayes 2002). All wintered submerged in water bodies. This study found that 29 frogs of the 66 frogs overwintered in 7 ice-covered ponds. In the larger ponds, frogs moved under the ice, but most stayed within 1 m of shore and in water < 1 m deep. At other ponds, frogs remained hidden under logs in water < 30 cm deep and within 50 cm of the shore, or overwintered in hollow chambers under banks along the pond edges, with entrances at or below the water surface. Frogs (19 of 66) also overwintered in ponds with partially-frozen surfaces resulting from the up-welling of warmer water from springs; frogs remained in the ice-free sections. Frogs also overwintered under river banks (n=9), under logs in flowing creeks (n=3), in backwaters (n=2), and in a seep under the root wad of a fallen tree.

Spotted frogs are also known to winter in holes or pits filled with water from underground sources in springs, and beneath the undercut banks of streams (Turner 1958a; Reaser and Pilliod 2005). Two radio-tagged frogs in Yellowstone NP entered a small spring in early October (Fig. 12), where they apparently moved underground away from the spring mouth (Patla 1997). Another radio-tagged frog in the same study entered an under-bank cavity formed by tree roots, adjacent to a spring-fed, perennial stream. In southwest Idaho, spotted frogs winter in spring-fed ponds with willows (Engle 2001). Beaver dams also serve as spotted frog winter habitat (Reaser and Pilliod 2005), e.g., spotted frogs were observed in mid October (presumably at their winter site) in water immediately below a large wood-debris dam at an active beaver site on a tributary stream of the Snake River, Grand Teton National Park (Patla, personal observation).

Area Requirements

The preceding section on *Activity and Movement Patterns* discusses the nature and scale of movements among habitat components. This section describes what is known about the total size of the inhabited area. The concept of "activity range" is used to refer to the area containing breeding, foraging, and wintering areas, and including the seasonal or migratory movements among these areas. It differs from home range, which is more narrowly concerned with area occupied by an animal engaged in its daily activities and thus excludes migrations to breeding or winter habitat (Turner 1960). Turner (1960) assessed the size of the activity range for spotted frogs in Yellowstone, which he calculated by connecting the points of capture (5 or more captures, distributed throughout the active season) and then determining the area of the space so defined (minimum complex polygon). Activity ranges varied from 2,500 to 357,000 square feet (0.023 to 3.3 ha), with no significant differences among males, females, and juveniles (Turner 1960). In Idaho, female frogs (5 or more captures over 1 year) exhibited activity ranges of 0.14 to 26.3 ha, with a median of 2.5 ha (Pilliod 2001).

The size of activity ranges is correlated with geography and habitat components. For example, in Yellowstone, the smallest activity ranges occurred in an area where springs and wetlands provided wintering, breeding, and foraging habitat in close proximity; the largest ranges occurred where frogs used a meadow for breeding and summer foraging and then migrated to a permanent stream (Turner 1960; Patla 1997). A generalization about the size of the average area used by individual spotted frogs throughout their lifetime escapes definition due to the small number of studies examining this aspect of life history.

Because the size and configuration of activity ranges depends on local features, activity ranges change if the environment is altered. Replication of Turner's study in the 1990s, subsequent to modification of the study area by roads and residential development, indicated that activity ranges changed in configuration and size (Patla 1997; Patla and Peterson *in prep)*. Weather is also a factor, which complicates assessment of the size and configuration of activity ranges: drought or unusually wet conditions can cause some frogs to shift their movement patterns and the size of activity ranges (Patla 1997; Reaser and Pilliod 2005).

Landscape Context

Landscape context has important implications for population connectivity as discussed above, the type of terrain separating population segments may be a more important factor than distance. It is also relevant to an understanding of metapopulation dynamics (see *Spatial*

Characteristics section below), given that characteristics of landscapes determine the potential spatial structuring of breeding populations and their degree of isolation.

In general, landscapes providing suitable spotted frog habitat must include pooled water (in the form of ponds, lakes with shallow edges, ephemeral pools, oxbows, beaver ponds, etc.) for breeding habitat, and perennial streams, springs, or other permanent water bodies where frogs can overwinter. In selecting watersheds for spotted frog surveys in Oregon, Bull and Hayes (2000) used these landscape features as criteria: presence of a perennial stream with quiet water in the form of ponds, marshes, and backwaters nearby; and streams within a wide valley bottom (<10% gradient) and in open meadows adjacent to coniferous forests.

Predicting spotted frog occurrence can be difficult because of the fine scale of habitats used by frogs. Ephemeral ponds and springs may be too small to be included in National Wetland Inventory classifications, for example. Seasonal wetlands and intermittent streams that are important as stepping stones among habitat patches, foraging habitat, or migration routes may not be mapped. Beaver ponds may have been created (or disappeared) since the last topographic map or wetland inventory.

The influence of landscape structure on population dynamics was assessed by Pilliod (2001) in his study of Columbia spotted frogs in the mountains of central Idaho. This study found that breeding populations were smaller with increasing distance from overwintering sites, that breeding site size was not correlated with frog abundance, and that ponds >600 m from the nearest breeding site were unoccupied. The area of fishless habitat more strongly influenced frog abundance than did the total area of habitat. These results suggest the value of assessing both the spatial arrangement of habitat components and local habitat conditions as key aspects of understanding the landscape context for spotted frogs.

Movement and Activity Patterns

Similar to other amphibians of the north temperate zone, spotted frogs seasonally occupy habitats providing resources for their main annual activities: reproduction, nutritional acquisition, and hibernation (Sinsch 1990; Pilliod et al. 2002). Because suitable breeding, foraging, and overwintering sites are spatially separated in many areas occupied by spotted frog populations, frogs migrate among habitat patches in the course of a year (e.g., Turner 1960; Patla 1997; Pilliod et al. 2002). These seasonal movements are essential for the survival of individuals and for the persistence of populations. Three major movement patterns have been discerned by field studies: from hibernacula to breeding sites, from breeding sites to foraging areas, and from foraging areas back to hibernacula. The occupation of seasonal habitats and the timing and documented distance of movements to these habitats are described in the following sections, organized by season. Information relating to the size of the occupied area is provided in the *Area Requirements* section, below.

As a preface to this section, it is important to note that the scale of movements is tightly linked to the particular characteristics of the inhabited area. In some areas, all required habitat components occur in a spatially constricted zone or patch. Frogs in a population inhabiting such an area do not exhibit movements (Bull and Hayes 2001). It is unknown how common such non-migratory populations might be (i.e., what percent of local populations exhibit little or no migratory movements to other habitat patches). Further, field studies have revealed that individual frogs within a population exhibit very different movements; some frogs remain at a given habitat patch while others leave. For example, Bull and Hayes (2001) found that 11 of 22 radio-tagged spotted frogs remained at breeding sites, while the remaining 11 others moved to other sites. Pilliod et al. (2002) found that 6-11% of male spotted frogs and 16-51% of females in a high mountain basin moved from breeding ponds to summer habitats. Engle (2001) found that a large majority of the 2,094 spotted frogs she marked (with pit tags) over a 4-year time period in southwest Idaho moved less than 100 m. A summary of maximum reported distances for seasonal movements in various types of habitat is provided in Table 1.

Some spotted frogs have been documented moving long distances. The maximum straight-line distances for movements of individual spotted frogs are reported as 5 km for an adult female in Nevada in one year (Reaser 1996); and 6.5 km by a subadult in southwest Idaho in one year (Engle 2001). It is unknown if these long-distance movements signify a one-way dispersal resulting in occupation of a totally new area and a different set of breeding, foraging, and wintering sites, or if the frogs undertaking such long movements eventually return to their natal sites, which would suggest that the movements are part of a migration, perhaps extending over multiple years.

Emergence and early-season movements

Spotted frog breeding adults emerge from wintering sites when conditions allow and travel various distances to reach breeding sites. Little is known about the distance and speed of these movements. Juvenile frogs and non-breeding females also disperse away from overwintering sites after emergence, and tend to avoid breeding sites until after breeding activities have ceased (Turner 1960).

Emergence from over-wintering sites by spotted frogs occurs from late February to early July, depending on elevation, latitude, and local conditions (Reaser and Pilliod 2005). In Utah, spotted frogs appear in March, following several days of air temperatures reaching 13-16° C or after a rain storm (Morris and Tanner 1969). In Yellowstone National Park at an elevation of 2380 m (7800 feet), spotted frogs emerge “not before the first or second week in May” (Turner 1958a), or later (into early June) (Koch and Peterson 1995), depending on snowmelt and air temperatures. Turner (1958a) reports that activity in May and early June is sporadic, with frogs remaining underwater during periods of low temperatures. A critical water temperature threshold occurs at 10°C; below this temperature frogs are inactive and concealed at the bottom of ponds (Turner 1960; Morris and Tanner 1969).

Where breeding habitat is spatially separated from overwintering sites, adults that are prepared to breed migrate from the hibernacula to breeding sites, in advance of the movements of non-breeding frogs (Turner 1960; Patla 1997). The distance depends on the local configuration of habitat features (e.g., the location of springs or streams suitable for hibernation in relation to the location of pools suitable for breeding). Researchers have seldom succeeded in directly witnessing such movements due to the difficulty of accessing wintering sites in early spring and apprehending frogs prior to their breeding migration, but some information is available:

- Engle (2001) observed movements to breeding sites of 100 m or less, with one female traveling while the male was clasped to her back in amplexus.
- *Rana pretiosa* pairs have been observed to migrate in amplexus up to 0.7 km (J. Bowerman observation cited in Engle 2001).
- Turner (1960) ascertained that some spotted frogs at a study site in Yellowstone moved a maximum of 200-400 m from their overwintering site to the breeding site.
- In the mountains of central Idaho Pilliod et al. (2002) indicated that spotted frogs moved a maximum of about 600 m between overwintering and breeding habitat (Pilliod et al. 2002).

Summer

Outside of the breeding period, spotted frogs spend the warm months of the year meeting their nutritional needs. They may move large distances to reach summer foraging habitats (described in the *Habitat* section), but can remain at or near breeding and wintering areas if the habitat is adequate. They may be active day or night. Cold temperatures limit diurnal activity and greatly reduce nocturnal activity (Turner 1959a). Spotted frogs tend to be relatively sedentary at suitable summer foraging areas, defining small home ranges by their foraging activities. Spotted frogs often bask in sunshine along the edges of ponds, lakes, and stream edges, a habit causing them to be visually conspicuous to humans and leading to high observation rates relative to other amphibians.

Particularly in higher elevation areas, the season available for growth is shorter than the active season. In Yellowstone National Park, Turner (1960) found that nearly all annual change in frog body lengths occurred between mid-June and early August. Access to good foraging sites is an important component of the life history of spotted frogs, and several studies have provided examples of considerable summer movements:

- In Yellowstone, spotted frogs dispersed to seasonally moist meadows, ephemeral pools, and intermittent streams in May and June and returned to more permanent water sources as surface water evaporated, with maximum movement rates up to 620 m occurring the first three weeks in July (Turner 1960) ..
- In northeast Oregon, spotted frogs moved distances ranging from 22 to 560 m between breeding sites and summer habitat in ponds and streams (Bull and Hayes 2001). The only breeding pond where frogs remained through the summer was isolated from other permanent water and also considerably larger in size, leading Bull and Hayes (2001) to conclude that larger water bodies may provide adequate resources for year-round occupation.
- In the mountains of central Idaho, movements from breeding and wintering sites to summer habitats were found to be more common and longer among adult females than juveniles or males. (m the maximum straight-line distances of these movements in a 4-week period were 424 m for males and 1033 m for females) (Pilliod et al. 2002).

Although spotted frogs may move some distance to reach summer foraging habitats, movements within these habitats are restricted to rather small areas. In Jackson Hole

Wyoming, spotted frogs observed during July and August moved an average of 1.5 m per day (minimum, straight-line distance), and a maximum of 45 m between the first and last capture points, with frogs showing a tendency to return toward the original point of capture (Carpenter 1954). Similarly, Turner (1960) and Patla (1997) documented examples of spotted frogs in Yellowstone remaining at sites for extended periods in summer. Radio-tagging at a Yellowstone study area indicated that frogs tend to occupy small areas for variable amounts of time, followed by short periods of movement; only 16% of the locations of 46 frogs revealed movements greater than 30 m, and nearly all movements exceeding 30 m were categorized as post-breeding or late-summer migratory movements (Patla 1997).

Late summer and movements to winter habitats

For adult and sub-adult spotted frogs, drying conditions (i.e., desiccation of upland sites) and falling temperatures trigger movements away from widely dispersed summer foraging ranges to suitable winter habitat. Frogs congregate near their overwintering sites in August and September (Turner 1960; Pilliod et al. 2002), with some individuals seen into October during warm afternoons (D. Patla, pers. obs). When metamorphosed froglets emerge and disperse from the breeding sites; survival depends on their ability to reach over-wintering sites, without the benefit of previous experience. Adults are not known to migrate in large groups, likely because they are quite widely dispersed in summer, but mass migrations of young of the year frogs YOY (over 100 frogs) have been observed (Pilliod et al. 2002). Routes can be along drainages or overland, and distances can be substantial (>1000 m) and rapid (700 m per day). Reports from specific studies are as follows:

- Spotted frogs in Idaho were found crossing at least 500 m of dry forested land, taking the most direct, terrestrial route rather than following streams (Pilliod et al. 2002).

Young of the year in this study crossed 100 m of dry land and 350 m total distance to travel from a shallow breeding pool to overwintering sites in lakes(Pilliod et al. 2002).

- In Yellowstone, young of the year crossed about 300 m of dry meadow and forest to reach a seep leading to a stream flowing from a spring used as the winter site, a total distance of about 480 m between breeding and wintering sites (Patla 1997).
- Spotted frog adults that move far during the summer have the most arduous fall migration, as shown by Pilliod et al. (2002), who reported that 3 to 5 female frogs at a high-elevation study area in Idaho were making annual round-trip migrations of at least 2066 m.
- Radio-tagged frogs in Idaho completed migrations in 1-2 days, moving up to 700 m per day and 160 m per hour. The most rapid movements were accomplished at night, with air temperatures between 3 and 10 °C (Pilliod et al. 2002). Fall migrations were also observed during the day and following rainfall as well as during dry periods (Pilliod et al. 2002).
- As air temperatures drop and day-length shortens, spotted frogs lose weight, often become darker in dorsal coloration, and tend to remain concealed underwater when flushed from stream or pond edges (D. Patla, pers obs).

Winter

In winter spotted frogs cease growth (Reaser 2000) and experience greatly reduced activity levels and metabolic rates. They can maintain anaerobic metabolism for only brief periods and therefore must have access to adequate oxygen (or dissolved oxygen in water). Radio-tagging of overwintering spotted frogs (Bull and Hayes 2002) revealed that the frogs are not dormant; they exhibited considerable mobility in water below 3°C, and in winter habitat under the ice and banks of frozen ponds, in partially frozen ponds, and in a river. Movements between consecutive winter locations varied in distance from just a few meters at some sites, to an average of 30 m at one ice-covered pond, to 500 m downstream in the river. Such winter mobility allows frogs to avoid the risks of freezing, anoxic conditions, scouring, and predation (Bull and Hayes 2002).

Site Fidelity

Columbia spotted frogs exhibit strong site fidelity, although movement patterns vary and mobility may increase in years with abundant rainfall (Ross et al. 1999; Reaser and Pilliod 2005). Turner (1960, p. 274) reported "in many cases it was found that frogs occupied the same area year after year, their cyclic migration sometimes bringing them to the same spot they occupied exactly a year before". Fidelity to breeding and wintering sites is pronounced; a number of breeding and wintering sites used by spotted frogs at Turner's Lake Lodge study area in the 1950s are still being used (Turner 1960; Patla 1997; Patla 2002). Strong fidelity to particular winter sites was reported for spotted frogs in Idaho, with frogs returning to their winter sites even where winter sites used by other frogs in the vicinity were closer and more accessible (Pilliod et al. 2002). Pilliod et al. (2002) also found that both sexes show strong fidelity to breeding sites, but only females tended to return to the same summer habitats

Inferred Connectivity

If it is assumed that linkages among (or isolation of) spotted frog populations are governed by the capacity of spotted frogs for movement, some informed guesses can be made about the connectivity of populations. The spotted frog migration distances documented by field studies (Table 1 and sections above) suggest that suitable habitat patches separated by 1 km (or less) are likely to be linked. Pilliod (2001) stated that his study in central Idaho suggests that adult dispersal and migration is sufficient to colonize wetlands within at least 1 km of breeding sites.

Population segments separated by more than 1 km are not necessarily isolated, as substantiated by the occasional reports of frogs recaptured between 1 and 6.5 km from the initial capture point, measured as a straight-line distance and over one year or more (e.g., Reaser 1996; Engle 2001; Pilliod 2002). Engle (2001), for example, found that 15 of 631 recaptured spotted frogs in her 4-year study moved over 1 km along riparian corridors. However, as evidenced by Engle's (2001) finding that no spotted frogs crossed a 550 m stretch of sagebrush upland between two occupied drainages, the nature of the terrain separating population segments is more important than the distance. Pilliod (2001), citing Van Gelder et al. (1986), pointed out that reported movement distances merely reflect local landscape characteristics rather than the actual capabilities of the animals. Movement barriers and hazards (discussed in more detail later in this report) are vital to considerations of potential connectivity or isolation, which in turn are important for population persistence (see section on Spatial Characteristics).

Reproduction and Survivorship

Columbia spotted frogs in montane areas usually begin breeding activities while snow still remains on the ground in patches. Adult frogs gather at breeding sites early in the season, while non-breeding frogs may still be in or near the wintering site (Turner 1958a; Morris and Tanner 1969). Males arrive first, and may be present 3 or 4 days before females (Morris and Tanner 1969). Males outnumber females at breeding sites, and remain there longer (Turner 1958a). Males vocalize weakly and sporadically from ponds, mostly at night but occasionally by day (Turner 1958a), calling either above or below the water surface (Morris and Tanner 1969). Vocalization may be related to the density of frogs; e.g., Turner (1957) described much more persistent calling at his Lake Lodge study area than was observed at the same areas in the 1990s where the population has undergone an 80% decline since the 1950s (Patla and Peterson

1999 and unpublished data). Vocalization is too sporadic and faint (the sound carries only 25 m or less) to provide a useful or reliable tool for finding breeding sites (Turner 1959a).

Mating commences as soon as females arrive at the breeding site (Morris and Tanner 1969). Males use their front feet to grasp females behind their forelimbs (axcillary amplexus) in an embrace that may last for several days (Turner 1959a; Engle 2001) and until the female deposits eggs. Eggs are fertilized externally by the amplexed male during egg deposition. Females move about while in amplexus, apparently not greatly hindered by the usually smaller males clinging to their backs (Engle 2001). Males are very vulnerable during this time; they often remain visible at or near the water surface while the female is concealed in the pond substrate (Patla, pers. obs.)

In the GYE, egg masses are deposited between late April (elevation 1908 m, National Elk Refuge) and before the middle of June at upper elevation sites (Patla, unpublished data). The dates of egg deposition at any given site vary among years, depending on temperatures and snowmelt. In Yellowstone, at a pool in a forested area at 2380 m elevation, the earliest date of first egg deposition was May 4 and the latest was June 6, over 14 consecutive years of monitoring 1991-2004 (Patla, unpublished data).

As noted previously, this species shows a strong fidelity for breeding sites. Females deposit eggs in the same small area at a breeding site year after year, but will shift locations if necessary (e.g., if pool becomes too small due to drought, or the shallow-water section shifts [Patla, pers. obs.]).

Eggs are held by surrounding gelatin in a globular mass that initially sinks to the pond bottom, and then rises and floats on the surface. Wind may blow the clusters around in larger pools, moving them away from the deposition site (Turner 1958a). Females often deposit their clutches in close proximity to each other; Turner (1958a) surmised that after the first pair deposits eggs, other pairs are attracted to the same area for oviposition. This can result in large clusters of egg masses. Up to 45 eggs masses have been observed at a single site in the GYE (Koch and Peterson 1995). While counting egg masses provides a method of monitoring reproductive effort, sometimes egg masses are so coalesced that individual egg masses cannot be distinguished and precisely counted.

No parental care of egg masses or tadpoles is provided. Females depart breeding sites soon after depositing eggs. Males are often found lingering near egg masses, probably awaiting other potential mates.

Time to hatching is highly variable; Turner (1958a) reported 12 to 21 days in Yellowstone; Maxell (2000) reported 5 to 21 days in Montana. Hatching and developmental time depends on local conditions, including water temperature, fluctuations in air temperatures, and the amount of cloud cover that reduces solar radiation (Morris and Tanner 1969). Time to metamorphosis also varies among sites and has been reported as 80 to85 days in Yellowstone (Turner 1958a), 56 to 112 days in Montana (Maxell 2000), and 122 to 209 days in Utah (Morris and Tanner 1969).

The number of larvae and metamorphosing young is extremely variable, both among breeding sites and among different years at the same breeding site. Except at ponds or wetlands where breeding, rearing, and over-wintering sites occur within the same water body, successfully metamorphosed young must emerge from the breeding pools and travel to suitable over-wintering sites.

Population Demographics

Summary

Columbia spotted frogs of mountainous areas are slow-growing, requiring 4 to 6 years to reach sexual maturity. Although spotted frogs are capable of a large reproductive effort (e.g., several hundred eggs per clutch), reproduction is limited by the inability of females to breed every year, the occasional total loss of embryos due to freezing or desiccation, and by the high variability of larval survival due to the interaction of many factors at the breeding site, including rainfall, evaporation, food, predation, crowding, disease, and pollution (Turner 1962b). In many areas, successfully metamorphosed young must migrate across dry land to reach suitable wintering areas, possibly experiencing high mortality. The long lives of adults make it possible for populations to sustain several years of null or low recruitment rates. Successive years of reproductive failures can lead to local extirpation within less than a decade if no immigration from other populations takes place, with extirpation accelerated if adult mortality rates are high due to natural or anthropogenic factors (discussed below). Considering the large variation in local population sizes and year-to-year reproductive performance, in addition to uncertainties about the frequency of breeding in females, the use of demographic models from areas outside Wyoming may be of limited value as a tool for local conservation management.

Fecundity and Larval Survivorship

Probably most relevant for Wyoming are Turner's (1958a) findings from Yellowstone which suggested a mean of approximately 540 eggs per mass (N=16 egg masses, se = 42). More generally, egg masses are variously reported to contain about 200 to 800 eggs in Yellowstone (Turner 1958a), 300 to 2400 eggs for low elevation sites in northwest Montana (Maxell 2000), 150 to 1160 eggs in Utah (Morris and Tanner 1969), and 700 to 1500 eggs in the Pacific Northwest (Nussbaum et al. 1983). Morris and Tanner (1969) report that ova numbers in dissected gravid females vary widely in number and that female body size does not reliably correlate to egg numbers. Although the number of egg masses produced per female per reproductive season remains unverified for this species, it may be safe to assume that each egg mass generally represents a single female's effort (B. Maxell, pers. comm. Perkins and Lentsch 1998).

No precise information is available on survivorship of embryos for the Columbia spotted frog, but it probably is extremely variable among years. For *R. pretiosa* in southwest British Columbia, Licht (1974) reported 68-74% embryonic survival in one year, and a probable 0% survival the following year when water levels dropped at the breeding sites (eggs were moved by the author to safer locations). Turner (1958a) noted that the upper layer of egg masses is usually exposed to air in the floating egg mass; eggs at the surface often do not develop due to exposure and freezing (Turner 1958a). As Licht observed, stranding of egg masses and subsequent total mortality can occur at breeding sites with ephemeral water.

There is little specific information on *R. luteiventris* tadpole survival rates, but a review of tadpole mortality rates indicates that ranid frogs typically have a relatively constant mortality rate during this life stage (Alford 1999). Total mortality occurs at ponds that dry up prior to tadpole metamorphosis, which may be quite frequent given that spotted frogs often use ephemeral pools for breeding. Assuming ponds remain moist through hatching, ranid tadpole survival rates have been reported from 5% to 37.5% (Alford 1999). Turner (1960 and 1962b) reported 3.2% survival (varying from 0 to 8.5%) at 3 sites in Yellowstone. Licht (1974) reported less than 1% survival for *R. pretiosa* from hatching to metamorphosis in marshes in British Columbia.

Age at First Reproduction

Turner (1960) concluded on the basis of mark-recapture and growth rates in Yellowstone National Park that male spotted frogs breed for the first time in their 4th year of life (3 years and 9 months after hatching), at about 47 mm in length, while females first breed in their 5th or 6th year, at 50-60 mm in length. At lower elevations with longer growing seasons, much younger or smaller spotted frogs are capable of reproduction. Using skeletochronology to determine age, Reaser (2000; Reaser and Pillod 2005) found that male spotted frogs in central Nevada reach reproductive maturity after 1–2 winters (at 35 mm minimum length), and females after 2-4 winters.

The time required to reach adult size and sexual maturity is a function of growth rate, which is strongly influenced by local conditions and the length of the seasonal activity period (Duellman and Trueb 1986). Turner's study area in Yellowstone was located at nearly 2400 m in elevation, with a mean annual temperature of only 0.1°C, an environment he described as "marginal" for spotted frogs (Turner 1960). Growth rates may be greater and age at first reproduction earlier for more favorable sites (e.g., sites with warmer temperatures and a longer growing season).

Proportion of the Population Breeding

Adult males are probably capable of breeding every year (Turner 1958a; 1960), but females apparently breed less frequently. Based on his Yellowstone research, Turner (1958a; 1960) thought that spotted frog females produced eggs every two or three years, or even less often. This finding is not highly unusual; Duellman and Trueb (1986) report that although annual reproduction by female anurans is most common in temperate regions, females of populations in extremely cold environments may not produce eggs every year. Turner (1958a) points to other anuran species females that do not breed annually and attributes this to the considerable amount of energy necessary to develop eggs, a process that might require several seasons. However, recent work in a high elevation basin in Idaho suggests that at least some females of this species breed every year at elevations similar to those of Turner's study area in Yellowstone (Pilliod, unpublished data). A reasonable conclusion from available information is that some females in spotted frog populations of Wyoming may breed annually depending on conditions, but the majority probably do not.

Spotted frog populations typically have higher proportions of adult females than males. Turner reported that 65% of the adult population at his study area in Yellowstone was female (Turner 1960); Patla found a similar 66% of the adult population to be female at the same study area 40 years later (Patla 1997). Reaser (2000) found that 4 of 7 study sites in Nevada had more females than males: 57-67% of the adult frogs caught at these sites were female. Turner (1962b) reported as a generalization for spotted frog populations that older females consistently outnumber older males by about 3.5 to 1, while smaller frogs show an equal sex ratio.

Post-metamorphic Survivorship and Longevity

Survivorship data for amphibians in the wild are scarce, and existing data are highly variable (Duellman and Trueb 1986). Annual survivorship of *Rana pretiosa* (the Oregon spotted frog, closely related to *R. luteiventris*) was estimated at 45% for males and 67% for females (Licht 1974). Turner (1960; 1962b) estimated one-year survival at about 60% for spotted frogs in Yellowstone.

Maximal longevity of spotted frogs in Yellowstone National Park, based on growth rates, has been estimated at 12 to 13 years for females and 10 years for males, with the shorter lifespan of males possibly reflecting higher levels of metabolic activity associated with yearly breeding (Turner 1960). More recent investigations at Turner's study area (1993-2001) found that a few female spotted frogs lived at least 11 years (Patla, unpublished data). Aging of spotted frogs using skeletochronology produced results consistent with Turner's (1960) estimates of longevity for spotted frogs in the mountains of central Idaho, but in Nevada the technique revealed 7 years as the maximum age for females and 3 years as maximum age for males (Reaser 2000; Reaser and Pilliod 2005). Frogs dwelling in colder areas with short growing seasons are expected to have longer life spans, due to lower metabolic rates (Turner 1962b).

Spatial Characteristics and Metapopulations

Previous sections (*Movements and Activity Patterns*, *Habitat Requirements*) discussed the importance of spatial characteristics for spotted frog biology (e.g., migrations and movements) and habitat occupancy (connectivity and landscape context). Because the persistence of frog populations may be dependent on spatially governed linkages in many natural contexts, consideration of spatial factors is also an essential aspect of demography. Metapopulation theory seeks to describe the dynamics of collections of discrete, unstable, local populations, governed by local extinctions (parallel to 'deaths' in a single population) and establishment of new populations ('births'). While local population units are subject to extinction, they can be "rescued" by migrants from other populations, or eventually recolonized if extinction occurs. Metapopulations can expand, as previously uninhabited areas are colonized, or contract or even disappear as local populations "wink out" and are not recolonized. Continuing and more recent development of metapopulation concepts have elucidated the effects of patch area and isolation, and the dynamics of "sources" and "sinks" (see below) (Hanski and Gilpin 1991; Hanski 1998). Metapopulation dynamics explain how species living in patchy environments can persist in a region over time, or alternatively, why they vanish. Human or natural factors that decrease the size of populations (thus increasing the potential for extinction) and/or that increase the isolation of populations either by distance or by diminished potential for successful dispersal and colonization of habitat patches are thus of critical interest for the conservation of amphibians and the management of their habitat.

Metapopulation theory is thought to be highly relevant to amphibian populations of the north temperate zones. There have been a number of studies (e.g., Gill 1978; Berven and Grudzien 1990; Sjogren 1991; Sinsch 1992; Sjogren-Gulve 1994; Hecnar and M'Closkey 1996; Skelly et al. 1999), and the topic is frequently cited in literature about amphibian declines and conservation (e.g, Bradford et al. 1993; Blaustein et al. 1994; Alford and Richards 1999; Semlitsch 2000).

However, a recent critique of metapopulation dynamics in terms of amphibian conservation points out the risks of assuming that breeding aggregations of frogs signify populations within a metapopulation, as amphibian metapopulation studies commonly do (Marsh and Trenham 2001). These risks include mistakenly thinking that perceived absence at the breeding site signifies extinction (when it is in fact due to other factors such as sampling error), misunderstanding what constitutes isolation, and ignoring the importance of terrestrial habitats in population dynamics. Marsh and Trenham (2001) urge managers to balance metapopulation considerations with careful attention to habitat quality, and to see pond isolation as a concern primarily in disturbed environments that have movement barriers to amphibian dispersal such as roads and developed areas.

To rescue or colonize uninhabited areas, frogs must disperse away from their natal sites. In the context of the potential for dispersal and colonization of suitable habitats, Engle (2001) and Munger et al. (2002) discuss barriers to spotted frog dispersal in southwest Idaho: dry upland habitat, intermittent streams after they become dry, heavily grazed riparian corridors, canyons, ponds or reservoirs stocked with fish, and severely eroded gullies. In Engle's study, movements occurred exclusively along watercourses, in contrast to the findings of Pilliod et al. (2002) (see Late summer and movements to winter habitats section, above). Adult spotted frogs have strong breeding site fidelity (Engle 2001); recently-metamorphosed juveniles are thought to be the most likely dispersers (Munger et al. 2002). However, considerable uncertainty exists about the extent, timing, conditions, and success of such dispersal movements. Munger et al. (2002) point out that combined study of movements and genetics is necessary to depict metapopulation dynamics of spotted frogs.

A corollary of the metapopulation concept is the idea that population units can operate as "sinks" (mortality exceeds recruitment) or "sources" (frogs breed successfully and the reproductive surplus disperses to other areas, including sinks). This concept has been applied to Columbia spotted frogs. Pilliod (2001, p. 78) provides a working definition of source and sink habitat patches, used for his assessment of the influence of landscape structure: Source patches are breeding sites containing 1 year-old juvenile frogs or breeding sites where 1-year-old frogs were found in adjacent habitats within 300 m; sink patches are breeding sites without 1-year-old juvenile frogs within 300 m, and all non-breeding habitats. Pilliod and Peterson (2001) regard lakes stocked with fish as probable sinks, where frogs only persist because of immigration. Reaser (2000) suggests that trout and excessive cattle grazing may cause some spotted frog breeding sites to operate as sinks in Nevada. Reaser (2000) concludes that her study area in the Toiyabe Range, where drainages that formerly may have allowed for dispersal are either stocked with fish or partially dry, is "at best a contracting metapopulation".

Temporal and spatial variation in breeding success may be common, however, and multi-year mark-recapture studies are needed to better elucidate population dynamics (Reaser 2000).

Whether or not spotted frog populations of Wyoming are organized as some type of metapopulation, knowledge of the spatial structure of populations is an important tool for conservation. For example, the loss of a source population (one that consistently produces recruits) due to management actions may have an irrevocable effect, but managers may assume mistakenly that the presence of frogs at other sites in the locale signifies that the loss of any single site is inconsequential. Furthermore, currently unoccupied habitat patches may be critically important for long-term persistence (Hanski 1998). In order to understand such dynamics in Wyoming, we require more information at both coarse (between populations) and fine (within population) scales. At the coarse scale, knowledge is needed about the distribution, number, and relative isolation of populations. At finer scales, information is needed about dispersal capabilities and conditions, movement barriers, and the frequency and causes of local population declines or extinctions.

Genetic Concerns

Most Wyoming populations of spotted frogs are unlikely to be genetically divergent due to their proximity to the main body of the Rocky Mountain clade. However, spotted frogs of the Bighorn Mountains have no possibility of genetic exchange with other populations due to the 100 km of dry and lower-elevation land extending between the Bighorn Range and the eastern margin of the main population's range in the Absaroka Mountains. While identified as belonging to the Rocky Mountain clade, the Bighorn population is genetically distinct, separated by a few mutational steps from the nearest populations to the west (Bos and Sites 2001). This is thought to reflect a more recent separation from the main population than the separation among some of the Utah disjunct populations, which were likely fragmented from the main population during the Pleistocene (Bos and Sites 2001). Peripherally isolated populations may have retained or acquired types of variation not found elsewhere in the species, thus they can be important sources of evolutionary novelty or speciation potential (Bos and Sites 2001 and sources therein).

Concerns about inbreeding and reduced heterozygosity from genetic isolation are infrequently expressed in recent amphibian decline literature (but were stressed by the Conservation Strategy for spotted frogs in Utah, see paragraph below). This apparently reflects the view that demographic factors, habitat problems and various anthropogenic agents are much more likely to cause declines and extirpations than genetic factors, and/or the lack of data on the role of inbreeding depression in the extinction of natural populations in general (Sjogren 1991). Potentially, populations lose fitness and are more likely to go extinct when they are genetically isolated and become inbred. Reh and Seitz (1990) found that subpopulations of a ranid species (*Rana temporaria*) isolated by roads and railways had reduced heterozygosity and appeared to be highly inbred, noting that this genetic effect occurred within 30 years, or in about 10 to 12 frog generations. However, the investigators did not report any deleterious effects.

Maintaining genetic variability, such that populations can respond to changing environmental pressures while reducing the chance loss of genetic variability through drift, is considered central to the Conservation Strategy for spotted frogs in Utah (Perkins and Lentsch 1998). The Strategy thus has an emphasis on maintaining sufficient effective population size, or "the number of breeding individuals that contribute genes to the next generation" (Perkins and Lentsch 1998, p. 10). The Conservation Strategy adopts 1000 as an acceptable effective population size within geographical management units.

Food Habits

Food habits of the spotted frog were analyzed in detail by Turner (1959a), based on the gut contents of 178 frogs collected in the central portion of Yellowstone National Park, elevation 2380 m. Turner found that 79-90% of all food items are spiders and representatives of four order of insects: Hemiptera (bugs), Coleoptera (beetles), Diptera (flies), and Hymenoptera (ants, wasps, and bees). Six families of insects (Carabidae, Chrysomelidae, Curculionidae, Formicidae, Cordiluridae, and Gerridae) account for 55% of all food items (Turner 1959a). Mollusks and earthworms are also consumed by spotted frogs.

Like many other amphibians, Columbia spotted frogs are opportunistic and flexible predators. Variation in diet relates to prey availability and ecological conditions; thus snails and water striders are found in the diets of frogs inhabiting lakes and backwaters, while the strawberry crown-girdler (*Brachyrhinus ovatus*) is consumed by frogs in areas where strawberries grow (Turner 1959a). Spotted frogs have been observed exhibiting cannibalism; e.g., an adult frog was observed consuming a metamorphosing spotted frog tadpole (Pilliod 1999). Presumably, spotted frog adults would also consume other amphibian species of the right size. Captive spotted frogs will eat new-born mice, suggesting that even small mammals (e.g. young mice or voles) may serve as prey in the wild if encountered by foraging adult frogs.

Turner (1959a) found that feeding habits of male and female spotted frogs were similar. However, differences related to body size of frogs were apparent. . Small frogs (<31 mm in length) consumed small prey (2 - 9.5 mm, maximum dimension); large frogs (>50 mm) consumed both small and large prey (2 - 18+ mm). The vast majority of prey (66%) was within the size range of 4 to 9.5 mm. Time of year influenced species composition of the diet, with the most diversity in prey occurring from mid to late summer (July 15-Aug 31). Caddis fly larvae were consumed only in early summer, which Turner attributed to the frogs being more restricted to water at that time. Spiders and ants were available throughout the active season.

Spotted frogs feed mainly during the day, probably because low night temperatures in mountainous areas limit activity by both frogs and their prey (Turner 1959a). Frogs may travel away from water during foraging, such as Turner's observation (Turner 1959a) of a frog consuming a moth about 12 m from a stream edge. However, in a study of the diets of leopard frogs, spotted frogs, and toads in western Montana, Miller (1978) observed that spotted frogs were generally not more than 10 m from the edge of the water, with juveniles foraging further away from water than adults.

Little is known about the specific diets of spotted frog tadpoles. In general, anuran larvae are opportunistic omnivores or detritivores, obtaining green algae or planktonic material by filtering or scraping material from sediments and vegetation surfaces. Bacteria, viruses, and dissolved nutrients may also serve as food (Hoff et al. 1999). Spotted frog tadpoles have been observed grazing on water starwort (*Callitriche palustris*) and *Spirogyra* (Turner 1959a); and lodgepole pine pollen (Patla, pers. obs), and conspecific dead or dying tadpoles (Morris and Tanner 1969; Patla, pers. obs). Based on observations of spotted frog tadpoles in pools devoid of plant life, Turner (1959a) speculated that bacteria might serve as a food source when vegetation is depleted or absent.

Community Ecology

Predators

The most common predator of spotted frogs is probably the garter snake (*Thamnophis* sp.), which frequents areas in and near waters that are also inhabited by spotted frogs and tadpoles. Koch and Peterson (1995) report finding spotted frog tadpoles, juveniles, and adults in the stomachs of wandering garter snakes (*Thamnophis elegans vagrans*). Reaser (2000) asserts that garter snakes are a common cause of natural mortality in spotted frogs, with tadpoles and male frogs more likely to be consumed than adult females, due to their smaller size.

Some fish species prey on spotted frogs when available, particularly embryonic and larval life stages (Munger et al. 1997; Pilliod and Peterson 2000; Pilliod and Peterson 2001). Game fish populations (e.g., brook trout [*Salvelinus fontinalis*], cutthroat trout [*Oncorhynchus clarkii*], rainbow trout [*O. mykiss*], and carp [*Cyprinus carpio*]) introduced into naturally fishless waters can have negative effects on amphibian populations and are a recent topic of concern among amphibian researchers (see discussion in the Threats section of this report) (Pilliod and Peterson 2001; Reaser and Pilliod 2005). Amphibians, including spotted frogs, are less likely to exist or successfully breed in lakes with non-native predatory fish. In addition to the direct effects of predation, female amphibians avoid depositing eggs at sites with predatory fish (Pilliod and Peterson 2001). Introduced fish are capable of affecting the abundance and distribution of spotted frogs, as well as the long-term persistence of populations in montane basins where source populations are extirpated or key wintering habitat is occupied by fish (Pilliod and Peterson 2001).

A large variety of other animals also prey on spotted frogs. Tadpoles and metamorphosing young are preyed on by some aquatic insects, particularly dystiscid (diving) beetle larvae, and by adult amphibians including con-specifics (Pilliod 1999) and tiger salamanders. Many avian species prey on spotted frogs, including herons and cranes, gulls, waterfowl, hawks and owls, ravens and other corvids (Turner 1960; Koch and Peterson 1995; Pilliod 2002; Reaser and Pilliod 2005). Some smaller birds, such as blackbirds and robins, consume spotted frog tadpoles; Turner surmised that predation on tadpoles could only affect population levels if metamorphosis occurred coincident with dessication of breeding pools (Turner 1960). A number of mammals are known or thought to be predators of spotted frogs, including badgers, weasels, minks, and river otters (Koch and Peterson 1995; Roberts 1997; Pilliod 2001); bears, and coyotes (Turner 1960). Another potential mammalian predator, the raccoon, is increasingly observed and appears to be invading formerly uninhabited areas in northwest Wyoming (e.g., Jackson Hole and Yellowstone National Park).

Among the large number and variety of potential predators, only introduced predatory fish have been identified by researchers as being capable of reducing the abundance and distribution of spotted frogs. There appears to be no information available on how predation by native wildlife species, including garter snakes, affects spotted frog demographics and habitat use. On the other hand, investigators frequently point out that amphibians are an important part of the food web, providing energy transfer from invertebrates to predatory animals higher up the food chain and possibly influencing their occurrence or abundance (e.g., Koch and Peterson 1995; Stebbins and Cohen 1995; Reaser 2000). Frog populations may lack vulnerability to native predators because these predators are generalists that also feed on many other kinds of small-bodied organisms in the habitats occupied by frogs, coupled with low rates of energy expenditure for bodily maintenance by amphibians relative to other vertebrates (i.e., they can remain inactive for long periods when danger is present), and a suite of effective predator-defense mechanisms (below) (Stebbins and Cohen 1995).

The primary defenses of spotted frogs to predation are to remain motionless and concealed whether on land or in water, to dive into water from the banks or edges of streams and ponds, and to sink below the water surface (Patla and Peterson 1997; Reaser and Pilliod 2005). Tadpoles swim to deeper water or hide within aquatic vegetation when startled at the shallow water edges of breeding pools. Behavioral responses of spotted frogs are apparently affected by the presence of certain predators; for example, in lakes with predacious fish, frogs encountered and startled by researchers are more likely to return immediately to shore than in fishless lakes (Reaser and Pilliod 2005). Spotted frogs may thrash wildly and sometimes scream when caught by predators (Reaser and Pilliod 2005). Adults and juveniles produce a mild skin toxin: researchers observe a milky or frothy exudate on frightened, captured frogs and experience dry and irritated skin from frequent handling of spotted frogs, suggesting that the excretion is also an irritant to predators (Reaser and Pilliod 2005; Patla pers obs).

Competitors

Little is known about competition between spotted frogs and other amphibians; Reaser and Pilliod (2005) report that there is little evidence that other species of native amphibians compete for habitat with spotted frogs. Theoretically, spotted frog tadpoles compete with the larvae of other amphibians present in the breeding pools, with the intensity of competition depending on resource (food and space) abundance and the degree of preferred resource overlap (Alford 1999). Investigations of tadpole interactions (of species other than spotted frogs) by ecologists found that both interference and exploitation competition occur, and that competition is lesser within groups of siblings than within groups of unrelated tadpoles (Alford 1999). Amphibian species that spotted frogs are most likely to co-occur with in Wyoming are the tiger salamander (*Ambystoma tigrinum*), boreal chorus frog (*Pseudacris maculata*), the northern leopard frog (*Rana pipiens*), and the wood frog (*Rana sylvatica*). Dunlap (1977) speculated that competition between wood frogs and spotted frogs would be limited by ecological differences in breeding dates and habitat use between the two species. In Yellowstone and Grand Teton national parks, spotted frogs frequently inhabit sites that are also occupied by chorus frogs, tiger salamanders, and boreal toads (Patla and Peterson, unpublished data). Differences in over-wintering strategies and habitats and the flexibility that spotted frogs exhibit in use of foraging habitats suggest that competition, if it occurs, would be most likely at breeding sites shared with other amphibian species.

One study investigated possible competition between spotted frogs and leopard frogs. Dumas (1964) conducted an experiment in northeast Oregon, in an area where spotted frogs and leopard frogs co-occurred, but were found breeding mostly in separate ponds. He seined two ponds of all tadpoles and placed 200 spotted frog tadpoles and 200 leopard frog tadpoles together in each of the two ponds. Seining the ponds 9 weeks later, he found much higher apparent mortality rates in spotted frog tadpoles (74-81%) than in leopard frog tadpoles (53-57%), compared to 56% mortality of spotted frog tadpoles in a pond without leopard frog tadpoles. Furthermore, when he returned to the area 3 years later, nearly all the spotted frogs were gone while leopard frogs and their larvae were numerous. The author speculated that spotted frogs could be sensitive to growth-inhibiting factors released by leopard frog tadpoles, and that leopard frogs can replace spotted frogs due to this differential mortality combined with leopard frogs' greater dispersal rates and greater tolerance of high temperatures and low humidity. However, it is unlikely that leopard frogs are currently replacing spotted frogs given the small area of range overlap in addition to the widespread declines of leopard frogs throughout much of their western range (Stebbins and Cohen 1995; Weller and Green 1997).

Parasites

Factors influencing the occurrence of internal parasites and the vulnerability of spotted frogs to parasitism have not been identified. Reaser and Pilliod (2005) summarized findings on parasitism in Columbia spotted frogs, listing a large variety of organisms known to parasitize the lungs and other internal organs. Spotted frog specimens from Yellowstone in the 1950s hosted helminthic parasites including nematodes and lung flukes, with the heaviest infections occurring in large adult frogs (Turner 1958b). Spotted frog specimens collected in Yellowstone National Park in 1994 and 2000-2002 were diagnosed as hosting a variety of protozoan, myxozoan, and helminthic parasites in the blood, kidneys, bladder and intestines, none of which were considered to be serious or pathological (Green 1996; Green 2004). Similarly, Dumas (1964) found heavy internal parasite infestations in some spotted frogs, but said the parasites appeared to be generally benign in their effects.

Intestinal trematode (flukes) can be serious because they may cause anemia and secondary infections in frog hosts (Green 1996). Infection by trematodes (genus *Ribeiroia*) also causes deformities in frogs, particularly in the limbs and digits (Johnson et al. 2002). *Ribeiroia* has a complex life cycle, parasitizing snails as the first host and tadpoles as the second intermediate host. In tadpoles, tremetodes form cyst-like metacercaria, which interfere with a developing limb bud, causing deformities that become apparent as the tadpole metamorphoses. Recent investigations link *Ribeiroia* prevalence to the eutrophication of frog breeding ponds, which is often caused by an excess of nutrients from farms or cattle operations (Johnson and Chase 2004). Spotted frogs in northern Idaho were found to host trematodes (14–51% of 59 frogs collected from 5 ponds), with large adult frogs hosting the largest infections (Russell and Wallace 1992 as reported in Reaser and Pilliod 2005). Low rates of infection by trematodes (*Ribeiroia ondatrae*) and few individuals with limb deformities were reported by Johnson et al.

(2002) in Columbia spotted frogs from southwest Idaho. Encysted metacercaria (immature flukes, family Diplostomatidae) caused swelling and ulceration in the tail bud area of nearly all the recently metamorphosed spotted frogs at a site in Yellowstone National Park in 2003 (Patla and Peterson 2004); abnormally few juveniles and young-of-the-year were present the following year, suggesting that the parasitism may have lethal and on-going effects (Patla, unpublished data).

Another common parasite is the leach, which sometimes occur at great densities in ponds occupied by spotted frogs. Leaches have been found clinging to larval (Carpenter 1953), juvenile, and adult spotted frogs, and may also prey on eggs. (Licht 1969; Reaser and Pilliod 2005; Patla pers obs). Leaches may be vectors of blood-borne diseases in amphibians (D.E. Green, pers comm).

Disease

Amphibian diseases have been linked to bacterial, fungal, and viral agents. Of particular concern are two emerging infectious diseases: chytridiomycosis and ranavirus, both of which have been documented in species of the genus Rana (Daszak et al. 1999). Many diseases or afflictions go undiagnosed; for example, Reaser and Pilliod (2005) report a "wasting disease", cause unknown, of spotted frogs from Nevada and central Idaho, with symptoms of emaciation, lesions of the skin and eyes, ulcerations of the toes and tarsus, and prolapsed bladder.

Chytrid disease is caused by a microscopic, parasitic fungus (*Batrachochytrium dendrobatidis*) that attacks the keratin in the skin of metamorphosed amphibians. This disease is thought to pose a serious threat to wild amphibians; further discussion is provided in the Threat section of this report. Chytrid fungus was confirmed in sickly Columbia spotted frogs at a pond in the Owyhees of southwestern Idaho in 2001 (Munger et al. 2002), indicating that *R. luteiventris* is a host species (Green 2001). Chytrid disease is known to be present in northwestern Wyoming; it was diagnosed on dead and sick boreal toads in Jackson Hole in 2000 (Patla 2000b), and on dead spotted frogs from two locations in Yellowstone National Park in 2001 and 2002 (Green 2004).

Recent research suggests that ranavirus complex is an emergent amphibian pathogen, meaning that it recently evolved, has recently expanded in geographic range or host species, or has been newly introduced to areas with previously unexposed populations (Collins 2003). Ranavirus has also been identified in spotted frogs collected at 6 sites in Yellowstone National Park, including both larval and adult specimens. This disease is usually associated with mass mortality events of larval populations, but a die-off of adult spotted frogs attributed to ranavirus was documented along a stream in Yellowstone in 2002 (Green 2004). The deaths of some adult spotted frogs in Grand Teton National Park in 2004 may also be attributed to ranavirus (D.E. Green and S. Wolff, pers. comm.)

The fungus *Saprolegnia ferax* has been associated with embryonic die-offs of amphibian populations in the Cascade Mountains of Oregon. The disease it causes (Saprolegniasis) is a common in fish, especially those reared in hatcheries, and the disease is transferable from fish to frogs (Kiesecker et al. 2001a). An ongoing investigation of spotted frog eggs in Idaho and Montana found *Saprolegnia ferax* and other members of the water mold order Saprolegniales to be common (Pilliod and others, unpublished data). The saprophytic vs. parasitic nature of these water molds and the source of these organisms (possibly carried by hatchery fish) is uncertain. The interaction of disease with habitat conditions was demonstrated by a study that found that reduction in water depth due to global climate change (El Niño and oscillation cycles warming the Pacific and altering precipitation levels) caused greater exposure of embryos to harmful UV-B radiation, making them more susceptible to Saprolegnia infections (Kiesecker et al. 2001b).

Although concern about diseases is high and an increasing number of disease-killed specimens has been collected in northwest Wyoming in recent years, relatively little is known about disease types and disease prevalence in wild Columbia spotted frogs. The USGS National Wildlife Health Center is investigating submitted specimens from sites where 2 or more dead amphibians are found, and research by amphibian experts at this facility is likely to provide useful information in the coming years about amphibian diseases in the western U.S.

Interactions

Frogs are important components in native ecosystems, providing transfer of invertebrate energy (e.g., insects) to predators further up the food web. As ectothermic animals, amphibians are very efficient in converting food into biomass (Stebbins and Cohen 1995). Unique among vertebrates due to their biphasic life cycle, amphibians also serve to transfer the high primary productivity of ponds to the terrestrial environment, as herbivorous larvae metamorphose, emerge, and disperse away from ponds, where they can be consumed by other animals. Tadpole grazing of algae and other aquatic vegetation may have important effects on the aquatic ecosystem and its inhabitants. Tadpoles can alter algal species composition and influence nutrient cycling; tadpole feces may be an important source of organic matter for detritivores of many taxa (Alford 1999). A wide variety of parasites (see above) infect frogs and their larvae as hosts. Mutualistic relationships among spotted frogs and other organisms have not been identified. Beavers provide important benefits for spotted frogs by creating, improving, and enhancing habitat. This is a commensal relationship, as beavers receive no apparent benefit from frogs.

Conservation

Conservation Status

Federal Endangered Species Act

The main (northern) population of Columbia spotted frogs, which includes spotted frogs in Wyoming (see *Distribution and Abundance*, below), currently has no status under the United States Endangered Species Act (ESA). However, three smaller, disjunct populations were ranked as warranted for ESA listing but precluded by issues of higher concern by the USFWS in 1993 (USFWS Region 6 2002, Worthing 1993). In April 1998, USFWS determined that the status of the species in Utah had improved and that the spotted frog no longer warranted listing under the ESA (63 FR 16218). With this finding, the Wasatch and West Desert distinct population segments were removed as candidates for listing on October 25, 1999 (64 FR 57533). This action was challenged in federal court with regards to the Wasatch Front spotted frogs. A legal settlement stipulated that the USFWS remand the 1998 "not warranted" finding and start a new status review and 12-month finding on the Wasatch Front population. A status review by USFWS in 2002 confirmed the "not warranted" designation for the Wasatch population (USFWS Region 6, 2002). The Great Basin population was assigned an elevated priority rating (from priority 9 to priority 3, the highest rank possible for a subspecies) in 2001, based on discovery of chytrid disease in the Owyhee subpopulation, declining numbers, and imminent threats (USFWS Snake River Basin Office 2002).

Federal Land Management Agencies

The Columbia spotted frog is currently on the BLM sensitive species list in Wyoming (BLM Wyoming 2001). The USDA Forest Service in Region 2 (USDA Forest Service 1994) and the adjacent Region 4 (USDA Forest Service 1999) classify the Columbia spotted frog as a sensitive species.

State Wildlife Agencies

The Wyoming Game and Fish Department (WGFD) ranks the Columbia spotted frog as a native species of special concern 4 (NSS4) (B. Oakleaf, pers comm.). This classification means that spotted frogs are considered by WGFD to be "common" (widely distributed throughout its native range, population status stable), and that habitat is considered stable.

Natural Heritage Programs

Global heritage ranks (G-ranks) and state heritage ranks (S-ranks) follow a numerical scoring system defined as follows (NatureServe Explorer 2002, Keinath et al. 2003, and Keinath and Beauvais 2003): 1 = Critically Imperiled, 2 = Imperiled, 3 = Vulnerable, 4 = Apparently Secure (although perhaps uncommon), 5 = Secure, ? = Inexact Numeric Rank (e.g., G2?), Q = Questionable Taxonomy (e.g., G2Q).

The Columbia spotted frog is given a global rank of G4 by the Natural Heritage Programs (NatureServe Explorer 2002). A rank of G4 means that it is considered uncommon and widespread (although it may be rare in parts of its range, particularly on the periphery). The species is not considered vulnerable in most of its moderately large range in the Rocky Mountains and northwestern North America, while there may be a cause for concern due to declines in the disjunct southern populations, which face major threats, including habitat loss and degradation (especially dewatering), exotic species, and possibly global climate change. In

Canada, the Columbia spotted frog is considered 'Not At Risk' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Shirley Hamelin, pers. comm.).

As do all state natural heritage ranks, the Wyoming ranks follow the same 1-5 system as the global ranks (see above). Additional clarification of the assignment of state ranks is provided by Keinath and Beauvais (2003). In Wyoming, the statewide population is ranked as S3 (vulnerable), while the Bighorn Mountain population is ranked as T1Q/S1 (critically imperiled) (Keinath et al. 2003). The Natural Heritage Programs of nine other states and provinces rank the spotted frog at widely disparate S-ranks, indicating substantial geographic variation in endangerment. These include: Alaska (S2?), Alberta (S3), British Columbia (S4), Idaho (S3S4), Montana (S4), Nevada (S2S3), Oregon (S2S3), Utah (S1), and Washington (S4).

Biological Conservation Issues

Extrinsic Threats and Reasons for Decline

Biologists have identified multiple factors that threaten amphibians and contribute to population declines, including habitat loss and modification, habitat fragmentation, disease, acid precipitation, chemical contaminants, exposure to high levels of UV-B radiation, adverse climate and weather patterns, exploitation for human uses (food, pets, research), and introduced predators and competitors (Corn 2000; Mattoon 2001). Most of these factors have direct anthropogenic sources. Natural causes of declines may be exacerbated by human-caused environmental perturbations. For example, the effects of naturally-caused drought or floods may be magnified by water diversions or watershed disturbances. Chemical exposure may render animals more susceptible to predators or naturally occurring disease organisms. As discussed below in the section on Intrinsic Vulnerability, some characteristics of amphibian biology and ecology (and of spotted frogs in particular) render them particularly sensitive to such environmental changes (Stebbins and Cohen 1995).

Several authors have specifically investigated and summarized threats to Columbia spotted frogs (Gomez 1994; Perkins and Lentsch 1998; Maxell 2000; USFWS 2002; Munger et al. 2002), and this existing work formed a basis for our assessment of threats. Management actions and natural events that appear most likely to threaten spotted frogs in Wyoming are listed and prioritized in Table 2. Habitat effects (Table 2) are considered in terms of loss, degradation, and fragmentation. "Loss" refers to destruction of breeding, foraging, and wintering habitat components, or changes that render these areas permanently uninhabitable by spotted frogs. "Degradation" refers to changes in habitat components that cause them to be less suitable for frogs (in terms of frog growth, survival, and reproduction), or that reduce the size of habitat components. "Fragmentation" refers to the increased separation of frog habitat components due to movement barriers or uninhabitable conditions. This can occur at two scales: (1) among or between breeding, foraging, and wintering sites used by a local group of frogs; and (2) among or between subpopulations and suitable habitat patches in a region, preventing interchange between subpopulations and/or the colonization of unoccupied habitat.

Direct effects are considered in terms of factors that can cause spotted frog mortality. Mass mortality is most likely to occur when frogs are congregated, such as at breeding and wintering sites or when metamorphs are emerging en masse from breeding ponds and dispersing to wintering sites.Threats considered to be most significant for spotted frogs in Wyoming are discussed below, including a general description of the problems that the threat poses for amphibians and their habitat, and information (if any) about how these threats may affect spotted frogs.

Livestock Grazing

All summaries of threats faced by spotted frogs (Gomez 1994; Perkins and Lentsch 1998; Maxell 2000; USFWS 2002; Munger et al. 2002) list livestock grazing as a major concern. Livestock grazing is likely to pose a variety of problems for amphibians, but research on this topic is scant (Maxell 2000). Spotted frogs of all life stages can be negatively affected by factors including trampling, water quality degradation, water reduction (particularly at sites with tadpoles), prey reduction and microhabitat loss due to vegetation removal, and reduced availability of overwintering sites if cattle trample spring openings and under-cut stream banks or cause reduced oxygen content of water (Munger et al. 2002). Direct mortality of amphibians has been observed due to trampling by livestock, amounting to thousands of recently metamorphosed toads in one published account (Bartelt 1998; Maxell 2000). Most of the problems pertain to indirect effects on habitat. Because cattle make extensive use of riparian and other moist areas used by spotted frogs, there is potential for substantial impact on frogs by cattle (Munger et al. 2002). Site-specific effects depend on and vary with the timing, duration, and intensity of grazing Potential and observed effects include the following:

- Water pollution from livestock wastes and eutrophication may lead to increased numbers of snails hosting the type of amphibian parasites that cause malformations (Johnson et al. 1999; Johnson and Chase 2004).
- Changes in the composition and structure of vegetation can have long term negative effects. Excessive ungulate browsing (by native ungulates or livestock) can result in the degradation and loss of cottonwood, willow, aspen, and associated shrub communities. This reduces the quality of amphibian habitat by removing the riparian vegetation and woody debris that provide shelter for amphibians in the vicinity of ponds and streams (Smith et al. 2004).
- The extirpation of beaver populations results in habitat loss (Smith et al. 2004; see section on beaver eradication, below).
- Other negative effects from grazing include changes in bank structure, causing the collapse of overhanging banks that shelter amphibians in both summer and winter; in soil compaction,

resulting in loss of burrows that also provide shelter for amphibians; and in hydrology, with channel down-cutting and lowered water tables (Maxell 2000 and sources therein; Munger et al. 2002).

Cattle are most often mentioned as a threat to spotted frog habitat, but pastured horses can also adversely affect pond and stream habitat (Patla 1997) (Fig. 13), through substantially the same mechanisms noted above. Herded sheep have the potential to trample areas where frogs are concentrated (e.g., Bartelt 1998). Although high concentrations of native ungulates have the potential to affect habitat, this is a rare occurrence under natural conditions as is not mentioned by any spotted frog investigators other than the associated loss of woody vegetation on the National Elk Refuge in Jackson, Wyoming (Smith et al. 2004), where concentrations of elk are artificially increased through feeding programs.

Despite the negative impacts, there may also be some beneficial effects from grazing, including the opening up of basking areas, potential benefits of eutrophication to larval food resources, and creation of habitat through water impounded for livestock (Maxell 2000 and sources therein). Bull and Hayes (2000) reported no negative effects on Columbia spotted frog reproduction and recruitment from grazing in northeastern Oregon, but confounded potential cattle effects with possible elevation effect (Munger et al. 2002). Considerable caution is needed in trying to interpret results of grazing studies conducted in different habitat types (Munger et al. 2002).

Water manipulation

Because of their dependence on aquatic sites, amphibians are highly vulnerable to projects that take water (i.e., diversions for agriculture or developments), and projects that move or store water for livestock (i.e., spring development). Given that historic water rights have precedence over wildlife issues or in-stream flow requirements, amphibians and their habitat are unlikely to receive consideration, and are particularly vulnerable in drought years. Water impoundments can have a variety of negative effects, including deep-water flooding of desirable shallow-water habitat, fluctuations in water levels that destroy eggs and larvae, lower water temperatures, increased numbers of predators (those that prefer more permanent water bodies versus ephemeral water bodies), increased livestock presence, and concentrated waterfowl causing water quality degradation and loss of wetland vegetation (Maxell 2000). As mentioned previously (*Parasites* and *Disease* sections), reductions in water depth (resulting from diversions or other water manipulations) may be associated with greater exposure to UV-B radiation and higher susceptibility to disease (Kiesecker et al. 2001b). Such diversions can also degrade breeding and wintering habitat of spotted frogs. Spring excavation and development (such as with pipes, boxes, and troughs) can make overwintering sites unusable or inaccessible, or trap frogs that are seeking passage into underground springs (Munger et al. 2002). Ponds formed by spring development may benefit frogs, but may also cause adverse changes in hydrology or cause frogs to be concentrated in smaller areas (Munger et al. 2002).

Roads

Munger et al. (2002) summarized threats of roads posed to spotted frogs as direct habitat loss, disturbance of habitat areas near roads from construction activities, pollution from run-off, and habitat fragmentation. Roads directly affect amphibians by subjecting them to road-kill as they attempt to disperse or migrate across traffic routes. Mortality rates can be high; a recent literature review of the effects of roads on amphibians lists cases documenting 50 to 279 frogs or toads killed during a single night on certain road sections (Jochimsen et al. 2004). The chance of an amphibian safely crossing a road is related to traffic volume, and mortality can be particularly high when amphibian activity patterns, such as spring or fall migrations, coincide with heavy traffic.

Roads also have indirect effects, including habitat loss (wetland fill), degradation (brought about by changes in hydrology and surface features, pollution from water runoff and exhaust, lights, and noise), and fragmentation. Amphibian behavior and movement patterns can be altered by roads, causing disruption of breeding activities and migration (sources in Jochimsen et al. 2004). Where roads act as barriers, amphibians can be prevented from reaching habitat components needed for breeding, foraging, and overwintering. Populations can be isolated from others, resulting in lower chances of successful interchange of individuals, less likely colonization of unoccupied or new habitats, and a higher risk of local extirpation (Vos and Chardon 1998). Long-term, site-specific studies of how roads affect local populations are rare.

A study of Columbia spotted frogs in Yellowstone National Park documented a population decline of approximately 80% between the 1950s (when the population was initially studied) and the 1990s, declining from about 1,500 frogs to 300 frogs. Road construction was identified as one of the most likely contributing causes of the local decline (Patla 1997; Patla and Peterson 1999, Patla and Peterson in prep). The road, constructed in the interval between the two studies, separated a breeding site from overwintering habitat. Thirty years after road construction occurred, the frog population was concentrated in habitat areas clustered on one side of the road, and the migration pattern documented in the 1950s across the area subsequently bisected by the new road was nearly abandoned. Spotted frogs ceased to attempt breeding at the pond nearest the road after 1994, suggesting, as other researchers have noted, that the negative effects of roads on species occurrence may take decades to realize (Patla 1997; Findlay & Bourdages 2000).

Introduced fish

Introduced fish species have been documented as the cause of local declines of amphibian populations worldwide (Bradford 1989; Bradford et al. 1993; Bronmark and Endenhamn 1994;

Brana et al. 1996; Hecnar and M'Closkey 1997; Knapp and Matthews 2000). Considering that 95% of mountain lakes in the western United States were naturally fishless prior to stocking (Bahls 1992), the introduction of predatory game fish (e.g., salmonids) likely caused a significant change in amphibian habitat quality and population distributions. All life stages of amphibians are subject to predation by introduced fishes (Licht 1969, Semlitsch and Gibbons 1988, Liss and Larson 1991). Further, there can be substantial indirect effects of predation, including: adult avoidance of egg deposition sites where predators are present (Resetarits and Wilbur 1989, Hopey and Petranka 1994); decreased larval foraging and growth rates as a result of staying in refuges to avoid predators (Figiel and Semlitsch 1990, Skelly 1992, Kiesecker and Blaustein 1998, Tyler et al. 1998); and decreased adult foraging, growth rates, and overwinter survival as a result of avoiding areas with fishes (Bradford et al. 1983).

Columbia spotted frogs are known to be palatable to fish; tadpoles and metamorphs of this species have been found in trout stomachs (Pilliod 2001). Spotted frog populations are negatively affected by introduced predatory fish (Munger et al. 1997 and 2002; Monello and Wright 1999; Pilliod and Peterson 2000, 2001). A study of Columbia spotted frogs and fish stocking in the mountains of central Idaho found that the abundance of spotted frogs at all life stages was significantly lower in lakes with fish than in fishless sites, even when accounting for differences in habitat (Pilliod and Peterson 2001). In comparing frog populations among mountain basins with varying amounts of fish and fish-less habitat, the authors found that densities of older life stages (>1 year old) of frogs decreased with increases in proportion of habitat occupied by trout, suggesting lower frog survival in basins lacking sufficient deep, fishless habitat. Tadpole survival, juvenile recruitment, and frog abundance were lower in heavily stocked basins compared to basins with less habitat occupied by trout. This study also observed that deep-water, fishless sites allowed the highest overwinter survival of frogs and postulated that the majority of high-quality overwintering habitat had been lost due to fish introductions. The authors warned that loss of adequate winter habitat, coupled with 6 to 8 years of reproductive failures (as shown in the age structure), could result in the imminent disappearance of spotted frogs from some of the fish-dominated mountain basins.

Disease

As discussed above (see *Disease* section), native amphibians are hosts to a variety of parasitic, bacterial, viral, and fungal diseases. Concern about amphibian disease has escalated sharply in the past few years with the recognition that new or previously unknown diseases are causing amphibian die-offs and population declines around the world. A recent global assessment of amphibians found unprecedented levels of "enigmatic decline" (decline not due to habitat loss) of amphibian species relative to other kinds of wildlife, with diseases and climate change cited as the most likely causes (Stuart et al. 2004). Mass deaths of amphibians due to disease outbreaks in diverse geographic locations suggest that disease may be an important factor in population declines (Daszak et al. 1999; Mattoon 2001), including the Rocky Mountains (Livo 2000). Mass mortality events involving the genus *Rana* are reported to have started in the 1970s in the mountains of the western U.S. (Carey 2000). The potentially interacting roles of new pathogens, environmental stressors, and the failure of amphibian immune responses are under investigation but remain poorly understood (Carey et al. 1999; Carey et al. 2003). Unless spotted frog sites are monitored and dead or diseased animals are collected and submitted to an expert for analysis, a catastrophic disease outbreak among spotted frogs in Wyoming is unlikely to be detected or recognized.

Chytridiomycosis and ranavirus are emergent, contagious diseases that are most frequently cited as posing a threat to amphibian populations. Both of these diseases have been found in Columbia spotted frog populations and other native amphibians of northwest Wyoming (see

Disease section). David Earl Green, the USGS pathologist who first diagnosed the presence of the amphibian pathogen chytrid fungus (*Batrachochytrium dendrobatidis*) in Jackson Hole, warned that the finding had potentially dire implications for all species of frogs and toads in western Wyoming, given the virulence of the disease and the apparent inability of affected populations to recover (Patla 2000b1). He reiterated his concern based on additional occurrences of chytrid disease 2000-2002 in Yellowstone National Park, stating that some adult spotted frogs may survive with chytrid infections for months or years, while other individuals die immediately (Green 2004). Ranaviral infections have also been found in spotted frogs in Yellowstone, co-occurring with chytrid disease at two locations. At one of these locations, the largest die-off of adult spotted frogs (>20 dead frogs discovered) documented in northwest Wyoming occurred over a number of weeks in summer, with ranavirus suspected as the immediate cause of death for most individuals (Green 2004). In 2004, 8 or more adult spotted frogs were found dead at a boreal toad study site in Grand Teton National Park, with at least 2 of the deaths attributed to ranavirus (D.E. Green and S. Wolff, pers. comm.).

These occurrences of lethal amphibian diseases in northwest Wyoming signify that spotted frog populations in this area are potentially at risk, particularly where populations are small and immigration is unlikely due to isolation. Amphibian researchers working in the national parks are vigilant in following biosafety measures (e.g., disinfecting waders and field equipment), but potential vectors are numerous: the footwear and boats of anglers and other recreationists; amphibians dispersing from infected sites or used as bait; waterfowl; wildlife; and livestock.

Drought and climate change

Periods of drought are natural events that can threaten amphibians by reducing survival and reproduction rates. Droughts may cause decreases in the size and connectivity of local populations and thus increase the likelihood of local extirpations and long-term effects on a regional population. Drought has been identified as a contributing factor to spotted frog declines in Nevada (Turner 1962a), southeast Oregon, and possibly southwest Idaho (Munger et al. 2002). Threats to spotted frogs from livestock grazing, water manipulation, loss of beaver ponds, roads, reservoir and recreation development, disease, and introduced fish may be exacerbated by droughts (Munger et al. 2002).

Because survival and reproductive success of amphibians are so strongly influenced by climate, climate change is cited consistently as one of the main potential causes of amphibian population declines (e.g., Alford and Richards 1999; Matoon 2001). Climate change was cited as one of two likely factors (the other was disease) contributing to global amphibian population declines in areas where habitat remains intact (Stuart et al. 2004). Changes in temperature patterns and the amount and seasonality of precipitation are thought likely to affect the distribution and abundance of amphibians (Boone et al. 2003). However, demonstrating that long-term changes in precipitation or temperature are the cause of changes in population size is difficult (McCarty 2001; Boone et al. 2003). Normal variation in weather patterns and minor shifts in climate do not represent a threat to amphibians, but climate changes could be occurring faster than amphibians can adjust phenotypically (Ovaska 1997).

In the western US, temperatures have gone up 0.8º C since the 1950s (Service 2004). In response to rising temperatures since the 1950s, snowpack and snow water equivalents (SWE) in the western mountain ranges have declined (15-30% in the northern Rockies), and snow is melting earlier in the spring. Temperatures are forecast to rise between 2º and 7º in the western US in the next century (Service 2004). Snowpack in the Rockies is expected to decline by 30%. Forecasts for trends in precipitation are highly uncertain; climate models produce disparate results (Service 2004). However, warming alone will produce large hydrological changes, as western snowpacks melt sooner and are lost to earlier runoff.

The magnitude of the threat is unknown at this time because of the many uncertainties about the combined effects of warming and the yet unknown shifts in precipitation patterns. The indirect and subtle effects of climate change may have a significant but hard-to-measure impact on amphibians (Corn 2000). Indirect effects include habitat and community-level changes (Ovaksa 1997; AmphibiaWeb 2003). Ovaska's (1997) assessment of vulnerability found that many amphibian species in Canada may be tolerant of predicted climate changes. Where species are currently limited by low temperatures and a short growing season (e.g., high elevations), benefits may exceed costs (Ovaska 1997).

Climate change effects on spotted frogs in Wyoming could be positive or negative. Warmer weather may result in earlier reproduction and more rapid development of larvae (beneficial if this results in higher recruitment) and shorter hibernation periods (beneficial if growth/survival are enhanced). However hotter and drier conditions could cause more rapid or frequent desiccation of ponds, and increased stress or higher mortality in migrating individuals. Corn (2003) hypothesized that montane amphibian populations at lower elevations will show changes in phenology before those at higher elevations, because high elevation sites retain snow longer. Frogs may experience increased physiological stress and decreased immune system function, leading to disease outbreaks. Earlier breeding and an extended growing season could boost reproductive output (where breeding sites remain flooded) but have adverse consequences for adults subjected to drier conditions at foraging and wintering sites. Reproductive failures, leading to adverse effects on population abundance, could become more common with climate warming because: (1) High summer temperatures result in increased evaporation rates, with ponds drying up prior to metamorphosis; and (2) frogs may breed early in response to warm spring temperatures, with subsequent episodes of cold weather and freezing resulting in high egg mortality.

Fire

Wildfire and prescribed fire can result in both negative impacts and benefits to amphibians. A recent literature review of the effects of fire and fuels management on amphibians and their aquatic habitats found that amphibian responses to fire and associated habitat changes are species-specific, incompletely understood, and variable among habitats and regions (Pilliod et al. 2003). Studies involving various ranid species revealed a large variety of fire effects (Pilliod et al. 2003). Whether or not fires benefit spotted frogs in Wyoming is therefore a complex question, with the answers probably depending on the particular characteristics of the watershed (e.g., vegetation, topography, and hydrology) and the characteristics of the fire event (e.g., intensity, patchiness, and timing). Local impacts should be evaluated on a case-by-case basis considering some of the possible effects, some of which are listed below (Pilliod et al. 2003).

Direct negative effects of fire on frogs and their habitat may include:

- Mortality from fire.
- Loss of breeding habitat due to fire suppression.
- Effects on microhabitat due to elimination of important cover, through the combustion of woody debris, litter, and duff, where amphibians normally find moist retreats.
- The loss of moist microhabitats could result in physiological stress, elevated predation rates, reduced foraging and dispersal capabilities, and changes to prey species dynamics.

Direct positive effects of fire may include:

- Increased amounts of solar radiation reach the ground level and elevate water temperatures due to an opened forest canopy.
- Enhanced nutrient cycling and aquatic productivity.
- Increased amounts of standing surface and ephemeral water.

Indirect "fire-related" effects (both positive and negative) may include:

- Where fires are suppressed and high levels of canopy closure occur, amphibian habitat may be degraded to the point that local extirpations occur (Fellers and Drost 1993; Skelly et al. 1999).
- The application of fire retardant and suppressant chemicals may pose a risk for amphibians due to the formation of ammonium compounds, which are toxic or hazardous to aquatic life (Pilliod et al. 2003). Sodium ferrocyanide, an ingredient of fire retardants and suppressants used to inhibit equipment corrosion, oxidizes in the presence of natural solar ultraviolet radiation and releases cyanide. Sodium ferrocyanide is known to be highly toxic to fish and amphibians (including leopard frogs) at very dilute concentrations, particularly with exposure to sunlight (Little and Calfee 2000). Also, byproducts of fire-retardant foams and cyanide can bioaccumulate in amphibian prey and in the bodies of amphibian larvae (Pilliod et al. 2003).
- Firebreaks constructed by firefighters and bulldozers can damage sites used by frogs for breeding, foraging, overwintering, or migrating. Ruts and ditches created by firebreak construction can fill with water and attract amphibians, where they can be tempted to breed unsuccessfully or be crushed by vehicles. New routes constructed for fire fighting can have some of the negative effects discussed above under Roads.

Wildland and prescribed fire can have different effects on amphibians because of differences in timing. Wildfires are most common when conditions are at their driest, and amphibians are likely to inhabit areas close to water. Prescribed fires, often implemented in spring or late fall when conditions are moist, may catch amphibians during active periods of breeding or migrating when they would be more vulnerable to fire-related mortality (Pilliod et al. 2003).

Timber Harvest and Fuel Reduction

Similar to fire, the effects of timber management on amphibians are variable. No studies of Columbia spotted frog responses to forest management have been conducted. Timber harvest has not been noted by other assessments as a threat to the species, probably because spotted frog populations targeted by the assessments do not occur in areas with marketable conifer forests.

The potential for negative effects from timber removal and other forest management activities depends on methods used, spatial extent, location, and timing of projects. A thorough review of forest management and amphibian ecology (deMaynadier and Hunter 1995) found that clearcut harvesting has negative short-term impacts on local amphibian populations as evidenced by declines in abundance, but the long-term effects relating to forest succession are variable. Site preparation practices (e.g., stump removal, roller chopping, prescribed fire, herbicide application, and/or machine planting) largely determine how severe the impacts to amphibian microhabitats are during timber harvest activities. Amphibians are adversely affected where harvested stands lose residual structural components and suffer reductions in the abundance and distribution of microhabitat features including uncompacted litter, coarse woody debris of various sizes and ages, and patches of canopy shade (deMaynadier and Hunter 1995). Temporary pools and ponds can be adversely affected by logging practices that alter soil and water temperature, pond evaporation rates, volume and rate of import of leaf and woody material, and local topography and water-holding capacity, or that disrupt migration routes surrounding the pool (deMaynadier and Hunter 1995).

Mechanical fuel reduction and forest thinning projects to prevent or reduce potential wildfires are increasingly being implemented in western forests, but no studies are available assessing the direct effects of these practices on amphibians (Pilliod et al. 2003). As in timber harvest, the severity of impacts to frogs from thinning and fuel reduction most strongly relates to how much microhabitat remains following treatment, and how the treatment influences local hydrology. Areas managed to remain sanitized of potential fuel (such as in urban interface zones) could be degraded in terms of frog habitat if cool, moist shelter zones are lost due to the removal of woody debris or forest wetlands and migration routes are negatively affected, or if stands become drier and colder due to more air circulation. Given the slow growth of trees in the mountains of Wyoming and the slow rate of coarse woody debris production, these detrimental site-specific effects could be long term.

One local instance of impacts was noted at a long-term spotted frog monitoring study site in Yellowstone National Park. Fuel reduction activities resulted in surface area disturbance (skid road, log skidding and piling, slash piles and burning of piles, removal of coarse woody debris) around a breeding pool and within a migration corridor between the breeding and wintering site, leading to concerns about possible frog mortality, disruption of late-summer migration, and habitat degradation (Patla 1999). The number of juveniles in the population (indicating recruitment from the previous 1-3 years) plummeted after 2000 (2001 through 2003), but it is difficult to separate the interacting effects of drought and habitat disturbances (Patla and Peterson 2004).

Beaver reduction or eradication

Beavers play important roles in creating, maintaining, and enhancing habitats used by frogs. Through dam construction, breeding habitat (ponded water) is created, water tables are elevated leading to enhanced riparian vegetation, and stream flow velocity is reduced, leading to more frog habitat along stream edges. Stored water behind dams is available as habitat for frogs during droughts when isolated and temporary ponds dry up. Also, dams provide wintering sites for spotted frogs. Munger et al. (2002) state that loss of beaver in Idaho likely caused a substantial decrease in breeding and hibernating habitat available for Columbia spotted frogs. Dam repair and beaver reintroduction at a site in southwest Idaho where spotted frogs had declined led rapidly to increased numbers of spotted frogs and re-establishment of frog breeding in the subsequent year (Munger et al. 2002). Past and current beaver reduction in the abundance and distribution of beaver has been caused by trapping, removal, or habitat alteration in Wyoming, where beavers are estimated to occupy approximately one third of their original range (Olson and Hubert 1994 reported in Munger et al. 2002). Impacts of this on spotted frogs in Wyoming are likely to be widespread and locally severe . Protection and reintroduction of beavers could mitigate for threats posed by management activities or natural events.

Pesticides, Herbicides, and Environmental Contaminants

Amphibians are thought to be highly vulnerable to contaminants because of their permeable skin and because their occupation of both terrestrial and aquatic environments may expose them to many kinds of chemicals that are either locally applied or carried from elsewhere by air or water. Amphibians are exposed to chemical hazards through direct uptake from water or by ingestion of contaminants in soils, sediments, and food items (Sparling et al. 2000). Wetlands and ponds occupied by amphibians can accumulate various pollutants that run off the surrounding land, including pesticides, herbicides, fertilizers, and animal wastes. Aquatic habitats may also be contaminated by wastewater and unintended releases of sewage, fuels, solvents, or other chemicals used for maintenance or construction, and heavy metals (e.g., lead, zinc, and cadmium), which may be washed into drainages from mine operations (Lefcort et al. 1998). Early stages (eggs and larvae) of pond-breeding amphibians thus may be exposed to various combinations of harmful contaminants. Tadpoles in particular are at risk given their habits of feeding off both the substrate and algae, and their processing of water for respiration (Lefcort et al. 1998).

Many insecticides, fungicides, herbicides, and piscicides contain active and inactive ingredients that are either directly lethal or have a variety of sub-lethal effects (see below) (Corn 2000). Toxins can bioaccumulate in insects and become concentrated in the bodies of frogs. Furthermore, some man-made chemicals (e.g., DDT compounds, PCBs, synthetic steroids, and many anthropogenic pollutants) interact with cell receptors or block intercellular communication, working to break down, mimic, or interfere with naturally occurring hormones and the endocrine system (Stebbins and Cohen 1995; Crump 2001). These endocrine effects can be severe, given the crucial role that hormones play in development and reproduction. For amphibians, skewed sex ratios, hermaphroditism, malformations, and accelerated rates of metamorphosis have been associated with endocrine-disrupting chemicals (Crump 2001). A recent study found that the widespread herbicide Atrazine causes gonadal abnormalities (feminization) of male leopard frogs, and that most water sources in the U.S., including rain, have more Atrazine than the doses found to affect frogs in laboratory studies (Hayes et al. 2002).

Airborne dispersal of contaminants far from their source has been postulated as an important contributing factor to amphibian declines in protected areas of the western U.S. (Stebbins and Cohen 1995; Drost and Fellers 1996). The decline patterns of the California red-legged frog appear to be related to the amount of upwind agriculture (Davidson et al. 2001). Sparling et al. (2001) found that frogs in Yosemite and Sequoia national parks and at sites near Lake Tahoe had detectable concentrations of pesticides (chlorpyrifos, diazinon, endosulfans, and DDTs) and depressed ChE indicating exposure to organophosphates pesticides.

Chemical pest eradication treatments may affect prey availability and frog survival. Of particular concern are malathion applications, which target wetland areas to reduce mosquito populations but also kill many other kinds of insects. Piscicides such as rotenone are very toxic to aquatic invertebrates (Wilson and McCranie 1994) and thus have the potential to negatively affect frogs by reducing prey populations.

While there is little evidence that contaminants have caused range-wide declines of widely distributed amphibian species (Corn 2000 and sources cited therein), there is increasing evidence of a variety of effects that could lead to declines of local populations. Herbicides, pesticides, and other chemicals have been documented as causing direct mortality to amphibians, e.g. Harfenist et al. (1989) and Sparling et al. (2000). A large variety of sub-lethal effects (not investigated in standard toxicity testing but of increasing interest to researchers) have been implicated, including depressed disease resistance and compromised immune systems, inhibition of growth and development, decreased reproduction, decreased thermal tolerance, inhibition of predator avoidance behaviors, and morphological abnormalities (Johnson and Prine 1976; Cooke 1981; Hall and Henry 1992; Berrill et al. 1993; Berrill et al. 1994; Boyer and Grue 1995; Carey and Bryant 1995; Lefcort et al. 1998; Sparling et al. 2000). Many chemicals may be present in amphibian habitats, and some can have detrimental effects long after they are used. Russel et al. (1995) detected toxic levels of DDT in tissues of spring peepers *(Pseudacris crucife*r) at Point Pelee National Park, Ontario even though DDT had not been used in the area for 26 years. Because of their unique physiology and life histories (e.g, permeable skin and protracted development in aquatic environment), amphibians may be unusually susceptible to toxicants, and environmental guidelines developed from fish and invertebrates are likely to be insufficiently protective (Burkhart et al. 2003).

A memo from Region 1 of USFS (Ulmer 2001) advised managers on primary considerations in analyzing potential effects to amphibian populations from proposed herbicide/pesticide treatments: decomposition rates of the toxicant, sublethal effects, and timing of application. Chemical applications on Forest lands can have more severe effects on frogs than land managers may be aware of, for the following reasons: chemicals intended for and applied to upland areas can be transported into aquatic systems; chemicals can interact in complex and unknown ways to increase their toxicity; and many chemicals approved for use have not been tested on amphibians and may pose higher risks than known or that are listed on the label.

Information specific to spotted frogs is limited. Concerns about mosquito control spraying programs as a potential threat to spotted frogs in Utah were expressed by Perkins and Lentsch (1998), who report that no studies evaluating the effects of chemical toxins on the spotted frog or its environment in Utah have been conducted. Mortality of spotted frogs at a pond in Oregon due to DDT application was documented by Kirk (1988). DDT in solvent and fuel oil was applied over 173,000 ha of forest in Oregon, Washington, and Idaho for control of the Douglas fir tussock moth in June 1974, and 20 dead frogs were found around the pond 3 weeks later. In Idaho, Lefcort et al (1998) found detrimental effects from heavy metals on Columbia spotted frog tadpole growth, development, and survival to metamorphosis, plus reduced avoidance behavior in the presence of a predator (rainbow trout).

Oil/Gas Development and Mining

Potential threats to amphibians and their habitat from oil/gas development and mineral extraction have not been formally assessed, to our knowledge. Threats from minerals management for the boreal toad were identified by the Boreal Toad Recovery Team (Loeffler 2001) and probably also apply to spotted frogs. They include environmental contaminants produced by tailings, released groundwater, mining/transport accidents, acid drainage, and leaching of additional metals from stream and soil substrates. Contaminated settling ponds can be used by toads (and presumably by frogs), exposing them to accumulated heavy metals, some of which (e.g., copper) are acutely toxic to tadpoles (Loeffler 2001). Lefcourt et al. (1998) describe the dramatic impacts of heavy metals on the terrestrial and aquatic environment in northern Idaho. They report that "only remnant, nonrecruiting populations of anurans" occur in upper reaches of the contaminated Silver Valley (northern Idaho). Lefcourt et al. (1998) tested the effects of heavy metals (lead, zinc, cadmium, and combinations) on spotted frog tadpoles and found reduced rates of survival, growth, and response to stimuli. In some areas, spotted frogs are absent from otherwise suitable habitat well within their range where historic mining has occurred, such as Silver City in southwestern Idaho (Munger et al. 2002).

The effects of oil/gas development can be assumed to be detrimental to spotted frogs to the extent that habitat is lost or degraded, including aquatic /wetland habitat used for breeding and over-wintering, and terrestrial habitats used for foraging and migration. The construction of roads and buildings associated with mineral activities can cause direct loss of amphibian habitat and have indirect effects such as pond/stream sedimentation, reduced food availability, and topographic disturbances (e.g., subsidence) (Loeffler 2001).

One unknown effect is the extent to which mineral extraction activities create potential habitat (e.g., ponds) and the risks or benefits of such created habitat. Also unknown is the extent to which restoration activities following mineral exploration and development benefit or harm spotted frogs.

Recreation

Recreation has been cited as a potentially significant threat to boreal toads in the southern Rocky Mountains (Loeffler 2001). Presumably, similar recreation-related problems threaten spotted frogs, including development of riparian areas, multiple dispersed and concentrated uses in frog habitat (hiking, biking, off-road vehicles, camping), the trampling and crushing of frogs by feet and vehicles, stream bank degradation, fecal contamination, and the spread of pathogens (e.g, on waders and vehicles) (Loeffler 2001). Recreationists visiting aquatic sites for fishing or boating can potentially transport amphibian diseases among sites, and import them from sites outside the Forest. Development of recreation sites can threaten amphibians and their habitat, depending on location. For example, a parking lot could separate breeding and overwintering sites, fragmenting habitat and leading to increased mortality of migrating frogs. Maxell (2000) stated that amphibian populations in or near recreation facilities are at risk due to handling and killing by humans and by their pets. Some predators of amphibians (e.g., ravens, raccoons, skunks, foxes, coyotes) inhabit human-influence areas in high numbers due to food sources or the absence of larger predators. Ravens were observed depredating 20% of the western toads gathered at a breeding site near a recreation facility in Oregon (Olson 1989). Artificial night lighting around facilities may disrupt breeding and foraging (Buchanan 1993)

Other potential threats

Introduced bullfrogs (native to eastern and central North America) have been implicated in declines of native frogs, including *Rana pretiosa* west of the Cascades in Oregon and elsewhere in the Pacific Northwest, and several other ranid species (Dumas 1966; Nussbaum et al. 1983; Corn 1994). Bullfrogs can negatively affect native amphibians via predation and competition (particularly predator-naïve native amphibians in the tadpole stage), or by transmitting pathogens (Kiesecker and Blaustein 1997). Bullfrogs occur in Wyoming, but usually at lower elevations than spotted frogs. One exception is a long-established bullfrog population in a warm spring in Jackson Hole (1980 m elevation) (Koch and Peterson 1995), indicating that this species can survive at high elevations under certain, unusual conditions.

UV radiation (especially UV-B) is considered by some researchers to be one of the chief physical factors of concern among potential causes of amphibian population declines, but the role of UV-B as a cause of amphibian population declines is controversial, generating a "seemingly endless debate" (Sparling et al. 2003; Corn and Muths 2004). Although UV-B levels are increasing at higher latitudes (Herman et al. 1999 cited in Boone et al. 2003), some researchers strongly argue that amphibians have a suite of natural defenses against damage from UV-B (Froglog 2004). The main area of current concern among researchers relates to harmful interactions between UV-B and contaminants, climate, and disease (Corn and Muths 2004). UV-B breaks down chemicals in the environment (sometimes producing more toxic substances), and also increases the sensitivity of animals exposed to chemicals (Carey et al. 2001; Burkhart et al. 2003). At this time, exposure to UV-B radiation (increased due to atmospheric pollution) has not been identified as a direct threat to Columbia spotted frogs, based on research indicating that this species has high levels of photolyase enzyme activity, which allows for repair and resistance to solar radiation in embryos. Eggs and developing embryos were not affected by ambient levels of UV-B in field experiments (Blaustein et al. 1999), who concluded that resistance to UV-B evolved under strong selection pressure, given the species' habit of depositing egg masses in shallow, sunlit water where they are only partially submerged.

Acid precipitation has not been identified as a problem for spotted frogs by other assessments. Acid deposition is said to be unlikely to be involved in population declines of amphibians at high elevations in the Rocky Mountains or the Sierra Nevada (reviewed in Alford and Richards 1999).

Trend Information

Information is insufficient to determine if spotted frogs are declining in abundance or distribution in portions of Wyoming outside of the national parks (see *Distribution & Abundance* and *Population Trends* sections of this report). Survey, monitoring, and research efforts for spotted frogs on national forests and BLM lands in Wyoming lag behind efforts on federal lands in other portions of the species range, such as BLM lands in southwest Idaho and national forests in Idaho (Munger et al. 2002). Similarly, the trend of suitable habitat for spotted frogs in Wyoming is unknown. A potential for decline is suggested by the following:

- Wyoming has experienced several years of drought, beginning sporadically in the late 1990's and increasing in extent and severity (NOAA 2003). During the summers of 2000 – 2003, nearly every county in Wyoming experienced severe to extreme drought conditions. Such prolonged and severe drought conditions likely reduced the number and quality of breeding, foraging, and wintering sites for amphibians in Wyoming. Recovery of habitat is likely to be slow even if normal precipitation resumes, depending on how long it takes to replenish ground and surface water resources and aquatic and upland vegetation. Given that drought effects can be exacerbated by land uses (see *Threats* section, above), habitat quality has potentially suffered a substantial decline in recent years.
- Human or forest management activities may be affecting the quantity and quality of suitable spotted frog habitat (see discussions of livestock grazing, water manipulation, roads, game fish introductions, beaver eradication, timber management, chemical use, oil/gas and mineral extraction, and recreation development and activities in the section on *Threats*). A common thread among these activities is their potential for eliminating,

reducing, or degrading ponds, lakes, wetlands (including temporary wetlands), and springs. In addition, these activities may have negative impacts on the terrestrial zones that spotted frogs occupy in summer or migrate through in spring or late summer.

- Human activities may result in the isolation of populations and prevent the interchanges necessary to sustain populations across the region.

To quantitatively determine if anthropogenic and natural factors have resulted in declining spotted frog habitat, assessment by interdisciplinary specialists (e.g., biologist, hydrologist, geologist, GIS expert, silviculturist, plant ecologist, climatologist) of landscape and biotic characteristics (e.g., geological and hydrological processes, hydrological features, vegetation types, fish distribution) are necessary. Site-specific information from occupied and previously occupied areas is needed to determine actual declines in frog habitat.

Intrinsic Vulnerability

Pond-breeding amphibians such as spotted frogs have a suite of characteristics that make them more sensitive and vulnerable to certain kinds of environmental changes than the other kinds of vertebrates:

- Complex life cycle requiring both aquatic and terrestrial habitats.
- Fidelity to breeding and wintering sites.
- Naturally fragmented distributions.
- Skin that is permeable to gases and liquids and shell-less eggs, providing direct exposure to contaminants.
- Feeding habits that expose them to pesticides and other chemicals accumulated in
- ponds and in the bodies of insect prey
- Dependence on sequestered fat reserves during hibernation or estivation (Stebbins and Cohen 1995).
- Basking in sunlight and use of clear, shallow waters for breeding increases exposure to increased ultraviolet light levels.

- Vulnerability to hormone mimics or chemicals that interfere with hormones during metamorphosis.
- Demographic factors including high variability in annual recruitment rates, long time period to reach reproductive age, and the likelihood that some populations act as "sinks", sustaining annual or intermittent breeding efforts but producing few if any recruits.
- Attractiveness as prey for a large number of animals.
- Potential for mass mortality due to disease outbreaks or habitat catastrophes when frogs are congregated at breeding or wintering sites.
- Relatively low dispersal capabilities (cf., many other kinds of vertebrates), making fragmented populations vulnerable to local extinctions.

Within the life history pattern of the spotted frog, there are several stages when the frogs are most vulnerable. Adults congregate at breeding sites soon after snowmelt, and in congregated numbers are more vulnerable to predation, infectious diseases, or other causes of mass mortality. Eggs are often deposited communally, and thus an entire year's reproductive effort can be lost if water levels decline before the eggs hatch or if eggs become infected with a parasitic fungus. Tadpoles are confined within the aquatic breeding site, and premature drying of the breeding pool can lead to complete mortality of a tadpole cohort. Furthermore, pollution, crowding, food depletion, and predation at the breeding pool can greatly reduce or eliminate the larval population. Emerging metamorphs are highly vulnerable to a variety of factors, and must migrate to suitable wintering sites in mid or late summer. Juvenile and adult frogs also must migrate from foraging to winter habitat in many situations, exposing themselves to multiple dangers, such as terrestrial predators or road crossings. At wintering sites, frogs may congregate in large numbers, rendering the population vulnerable to catastrophic decline if conditions become unsuitable during the winter or if an outbreak of infectious disease occurs.

Paradoxically, many of the vulnerabilities cited above also relate to factors explaining the success of amphibians as a stunningly diverse, ancient (in existence for at least 360 million years), and widespread class of vertebrates exploiting an extremely wide range of habitats (Halliday and Adler 1986). As ectothermal vertebrates, they have a number of physiological advantages; for example, they require low rates of energy for metabolism, can withstand long periods of inactivity when conditions are hostile or resources are minimal, and are highly efficient in converting food into growth. The ability to reproduce explosively when conditions are favorable allows populations to increase dramatically and thus withstand periods of decline. Nevertheless, the recent finding that amphibians are more threatened and declining more rapidly than birds and mammals (Stuart et al. 2004) suggests that long-standing ingredients of amphibian success are inadequate for the challenges posed by recent environmental changes, including habitat loss and fragmentation, climate change, the unprecedented spread of new diseases, and pollution.

Conservation Action

Existing or Future Conservation Plans

There are no habitat protection measures specific to spotted frogs within Wyoming. However, generic species plans, such as the Wyoming BLM state sensitive species list (BLM Wyoming 2001) and Forest Service sensitive species lists (USDA Forest Service 1994 and 1999), should provide a mechanism through which management action can be promulgated. Further, species with sensitive status must be addressed in the NEPA process for any project or planning activity requiring such compliance. To evaluate effects on sensitive species and identify mitigating measures, biological evaluations are prepared. Because spotted frogs are not monitored outside the Greater Yellowstone Ecosystem in Wyoming, it may be difficult to accurately evaluate how individual projects may affect the condition of the species outside this area.

A conservation agreement and strategy was prepared for the Columbia spotted frog in Utah (Perkins and Lentsch 1998) as a collaborative and cooperative effort among resource agencies to expedite the implementation of conservation actions for spotted frog. It describes specific actions and strategies and requires annual assessments of actions that are implemented. A habitat conservation assessment and accompanying conservation strategy have been drafted for the Columbia spotted frog in southwest Idaho (Munger et al. 2002). Neither management plans and nor conservation strategies have been written for spotted frog subpopulations in the main population, to our knowledge.

Conservation Elements

Management Approaches

Conservation elements are listed below. The above section on 'Biological Conservation Issues' provides the ecological and biological foundation for the management approaches outlined here. The listed approaches are those that have been used or suggested for conservation management of spotted frogs in other areas or described by the scientific literature.

1. **Determine the distribution of breeding populations.** (This can serve as the basis for survey and monitoring, see *Inventory and Monitoring* section, below).
2. **Delineate important habitats and sites.**
    a. Protect permanent ponds and river and stream habitat within at least 500 m of breeding ponds. (Bull and Hayes 2001)
    b. Assign priorities to populations or areas for protection and monitoring (Munger

et al. 1997)

c. At high-priority areas, determine the location of breeding sites and potential breeding sites, foraging areas, overwintering sites, and movement corridors (Pilliod et al. 2002)

d. Identify and protect critical terrestrial habitats (e.g., movement zones, and seasonally wet areas that are not identified as “wetlands”) as well as breeding sites (Marsh and Trenham 2001; Pilliod et al. 2002)

3. **Protect and maintain suitable habitat.**

    a. Conduct surveys prior to any activities that could impact spotted frog habitat (Munger et al. 1997); when loss or deterioration of breeding, foraging, wintering, or migration habitat is unavoidable, mitigation measures should be devised and implemented (Maxell 2000).

    b. Livestock allotments

        i. Fence critical breeding, foraging, and over-wintering habitat, such as ponds, springs and riparian areas, and movement corridors between breeding and wintering sites (Patla 1997; Perkins and Lentsch 1998; Maxell 2000; Engle 2001; Munger et al. 2002). Monitor the site to see if fencing leads to overgrowth with vegetation (Munger et al. 1997). Where fencing is not feasible, enforce utilization levels that maintain or improve habitat conditions for frogs (Engle 2001). Remove livestock from known hibernation sites (Engle 2001).

        ii. Design and implement Allotment Management Plans that protect spotted frog habitat considering the local situations and enforce sustainable grazing practices, evaluate drought threats and apply livestock closures as needed (Perkins and Lentsch 1998; Munger et al. 2002).

        iii. Manage grazing on stream habitat to avoid compaction, late season vegetative loss, willow damage, stream channelization and down-cutting (Engle 2001; Munger et al. 2002). Do not burn riparian corridors (Engle 2001).

    c. Water projects

i. Maintain and restore natural hydrological characteristics (Perkins and Lentsch 1998); do not alter hydroperiods of water bodies to provide water for livestock (Maxell 2000); do not lower water table in riparian corridors (Engle 2001).
ii. Avoid new water diversions if habitat would be affected (Munger et al. 1997).
iii. Leave springs (frog hibernation areas) undeveloped, including the outflow streams (which serve as movement corridors) (Engle 2001. Protect springs that may be important for spotted frogs (Munger et al. 1997)

d. Roads.
   i. No new road development allowed within 100 feet of known spotted frog habitat (Munger 1997);
   ii. Minimize motorized traffic near breeding sites (Semlitsch 2000); close routes to vehicle use during peak migration periods (Maxell 2000).
   iii. Use culverts or tunnels under roads to direct amphibian movements at known concentration points (Semlitsch 2000); use bridges, oversize culverts, underpasses, or overpasses that attract frog use where roads cross areas connecting critical habitat components (Patla 1997; Jochimsen et al. 2004); install tunnels between upland habitat and wetland breeding areas (Jochimsen et al. 2004).

e. Fish and bullfrog introductions
   i. Do not introduce fish into previously fishless waters in the range of the spotted frog; terminate stocking in lakes with suitable frog habitat that have been stocked in the past but in which fish cannot successfully reproduce (Munger et al. 1997; Pilliod and Peterson 2000).
   ii. Remove introduced fishes if this will open up key sites for occupation by spotted frogs (Munger et al. 1997; Pilliod and Peterson 2000); establish protocols and eradicate or control targeted populations of non-native fish where feasible and in areas that are key habitats for survival of local sets of populations (Perkins and Lentsch 1998; Maxell 2000;

Pilliod and Peterson 2000).

iii. Do not allow fish stocking by non-professionals; ensure that any mistakes in stocking by agencies are rectified by the responsible agency (Munger et al. 1997).

iv. Prohibit introductions of bullfrogs; eradicate or prevent further spread of bullfrog populations in areas of overlap with spotted frogs (Munger et al. 1997; Maxell 2000).

f. Fire

i. Restrict use of fire retardants around aquatic sites (Semlitsch 2000).

ii. Prescribed burns should not be conducted at times when amphibians could be particularly vulnerable and/or the populations are at risk due to isolation or other factors (Maxell 2000).

g. Timber management and oil/gas development

i. Minimize practices that degrade terrestrial habitat near breeding sites (Semlitsch 2000); use harvest practices which minimize the immediate and long-term differences in abundance and distribution of moist microhabitats (e.g., woody debris) between harvested and unmanaged areas (deMaynadier and Hunter 1995; Maxell 2000); avoid skidding or piling logs in occupied habitat (USDI NPS 2002); conduct timber management activities after amphibians have entered their overwintering sites, e.g., after mid October (USDI NPS 2002). Avoid operating machinery in areas likely to host amphibians, e.g., moist swales and snowmelt pools) (USDI NPS 2002).

ii. Maintain natural vegetation buffer zones around ponds; for example, Semlitsch (2000) proposes 160 m from the edge of wetlands and 30-100 m along streams, adjusted for stream width, slope, and site use (Semlitsch 2000). The size of buffer widths needed for spotted frogs has not been specified but a relatively intact buffer around breeding pools is recommended to provide cover for migrating adults and habitat for dispersing young-of-the-year frogs (DeMaynadier and Hunter 1999).

iii. Maintain a diversity of terrestrial habitats; provide corridors or small wetlands to serve as stepping stones for amphibian movements (Semlitsch 2000).

h. Recreation
    i. Restrict ORV and other motorized use to designated roads, trails, or pit areas (Maxell 2000).
    ii. New recreational facilities should not be located within 300 m of key breeding, foraging, or overwintering habitats (Maxell 2000).
    iii. Recreational facilities near documented population centers should have educational signs or pamphlets pertaining to frogs in the area and how they might be impacted by humans and their pets (Maxell 2000)

i. Chemical use
    i. Restrict herbicide and insecticide use near ponds, ditches, and ponds where runoff can find its way into wetlands (Semlitsch 2000); fertilizers, herbicides, and pesticides should not be applied within 100 m of waterbodies and wetlands until lethal and sublethal impacts on frogs are known (Maxell 2000).
    ii. Analyze effects of treatment chemicals to amphibian populations: decomposition rates of the toxicant, sublethal effects, and timing of application (Ulmer 2001).

4. Restore and/or enhance habitat

a. Protect beavers from trapping to prevent further loss of beaver populations; reintroduce beavers in areas where a need for dam-building activities of beavers has been identified (Munger et al. 1997)
b. Stabilize stream banks (Perkins and Lentsch 1998)
c. Restore springs; modify existing spring development to allow passage of frogs and to restore habitat (Munger et al. 1997).

Tools and Practices

Survey, Inventory and Monitoring

Survey generally refers to the act of searching for a species in a given area, while inventory refers to the systematic survey of a species within an administrative unit or a defined geographic region. Monitoring is the extension of surveys and inventories into a formalized method that can be used to demonstrate, with statistical confidence, trends in various population parameters (e.g., number of individuals or population units per species) through time (Heyer et al. 1994).

The presence-absence data produced by an inventory can be used as documentary baseline information, for establishing or verifying geographic or ecological distributions, or for documenting changes in distribution and habitat use (Chapter 3 in Heyer et al. 1994). If monitoring programs (see below) are not established, repeated inventory (e.g., every 10 or 15 years) could reveal if the species persists, or is undergoing changes in distribution. Documenting the presence of spotted frogs is most reliably achieved by searching for tadpoles in temporary or permanent ponds; other life stages may be present but are easier to miss because of their ability to disperse among upland habitats (see *Survey Techniques* section, below). If two or more surveys of potential habitat units are conducted during the time frame when tadpoles should be present (e.g., between mid June and late July in a given year), detection probabilities can be calculated, providing an estimate of how often the species is likely to be missed during surveys (MacKenzie et al. 2002).

The design of amphibian surveys for extensive monitoring (or inventory) at a scale relevant to large blocks of land or management units has received much attention in recent years. Compilations of approaches are provided by Heyer et al. (1994) and Olson et al. (1997). The USGS Amphibian Research and Monitoring Initiative (ARMI) has developed a conceptual model, strategy, methods, and national database for assessing status and trends of amphibians (http://edc2.usgs.gov/armi/ and http://www.fort.usgs.gov/research/rarmi/rarmi_intro.asp). Because ARMI integrates expertise of herpetologists, statisticians, mapping specialists, water quality scientists, database experts, and managers, it provides the best currently available, scientific approach for monitoring amphibians on large blocks of public land. ARMI has implemented its approach on Department of Interior lands across the U.S., and hopes to develop a truly national program by extending the effort to non-DOI agencies through partnerships, such as with USDA Forest Service and state agencies (USGS ARMI Task Force 2001). Another source of monitoring expertise resides in the National Park Service's Greater Yellowstone Network Inventory & Monitoring program (based in Bozeman, MT), which has selected amphibian occurrence as a "Vital Sign" for monitoring in Yellowstone and Grand Teton national parks and Bighorn Canyon National Recreation Area (http://www.nature.nps.gov/im/units/gryn/index.shtml). This program will likely integrate with the USGS Rocky Mountain Region ARMI to implement long-term amphibian monitoring on DOI lands in northwest Wyoming.

The conceptual model for monitoring employed by ARMI is a pyramid, with coarse or broad scale assessment of amphibian occurrence at the base level of the envisioned pyramid, analysis of trends within regions or management units at the mid level, and intensive research geared towards population monitoring (at selected sites) and the causes of declines at the apex. The mid level is most applicable to monitoring the status and trend of the Columbia spotted frog on BLM lands in Wyoming. Elements of the model and procedures (sampling design, data collection, and data analysis) are listed below, with explanations of how they have been used in the GYE and could be applied to determine status and trend of the Columbia spotted frog in other areas.

Sampling Design (for monitoring status and trend)

Define the range of statistical inference, and divide the area to be monitored (e.g., national forest) into sampling units. Select units to be sampled via a probabilistic scheme. Sampling design also entails decisions about habitat monitoring, including the determination of which characteristics (covariates) should be measured or recorded to assess wetland dynamics, habitat change, suitability, and amphibian occupancy.

In the GYE, the two national park units (Yellowstone and Grand Teton) were defined as the range of inference for pilot studies of amphibian occupancy beginning in 2000 (Patla 2002; Patla and Peterson 2003 and 2004). GIS layers were prepared with USGS 7th-level hydrological (or similar) units. To achieve a geographical distribution of sampling areas across the parks, a grid was imposed over the parks' area, and one hydrological unit (catchment) was randomly selected from within each block of the grid. (Alternatively, coarser hydrological units [e.g., 4th level units, such as Snake River, Upper Yellowstone] could be used for the purpose of distributing sampling units.) Within the selected catchment, National Wetland Inventory (NWI) polygons with temporary or permanent surface water were identified for amphibian surveys.

A similar approach could be applied to national forests, using available GIS tools to define watershed units and potential amphibian habitat (wetland sites) within the units.

Data Collection

Conduct visual encounter surveys to determine occupancy rates of the Columbia spotted frog (and other pond-breeding amphibians) at wetlands within the selected units, with emphasis on documenting breeding sites. Collect habitat data for analysis of covariates (as determined during the design phase), providing the same level of effort for apparently unoccupied sites as for occupied sites. Recent scholarship has emphasized the need for assessing detection probability (detectability) when conducting occupancy monitoring (MacKenzie et al. 2002; Bailey et al. 2004; Gu and Swihart 2004). This entails conducting multiple surveys (at least 2) at all or most sites within the same season, during the period when the species is likely to be present (i.e. before metamorphosis and emergence occurs).

In the GYE, amphibian surveys (usually by two-person teams) were conducted at all potential amphibian habitat within the catchments (each containing 10-50 wetland units); wetlands were detected with the use of NWI and topographic maps (Patla 2002). Site variables (e.g., maximum water depth, vegetation type) and sampling variables (e.g., weather, date, time of day) were recorded, and voucher photos were taken of sites and amphibians (all life stages). This was a successful method of identifying active breeding sites for the Columbia spotted frog and other pond-breeding amphibians (tiger salamanders, boreal chorus frog, and boreal toad), as well as documenting the existence of potentially suitable but apparently unoccupied habitat (Patla 2002). Much of the survey work was conducted in remote areas.

This type of survey appears to be feasible for the national forests, given the similarity of Yellowstone-Tetons and the Bighorn and Shoshone national forests in terms of terrain. A benefit of this approach is that the Forests can simultaneously conduct inventory/monitoring for other pond-breeding amphibians in addition to the Columbia spotted frog.

Data Analysis

Use the survey data to determine proportion of sites (or area) occupied (McKenzie et al. 2002). Occupancy statistical tools support the assessment of changes in site occupancy over time, which reflect trends in amphibian abundance. Because this approach provides analysis of how detectability, site variables, and sampling variables affect patterns of species presence or absence, occupancy methodology is a considerable advance over previous methods of simply enumerating changes in the number of breeding sites as a way to determine trends. Software (PRESENCE) for estimating occupancy rates and related parameters may be obtained through the USGS: http://edc2.usgs.gov/armi/PAOEstimator.asp

Estimation of occupancy for the Columbia spotted frog, using ARMI software is in progress for the GYE. The naive occupancy rate (not corrected for detectability and with no variance calculated) estimate for spotted frog breeding sites (eggs, larvae, or metamorphs present) in the two national parks over 4 years (2000-2003) ranged from 14 to 22% per year, detection probabilities ranged from 69 to 95%, and adjusted occupancy ranged from 15 to 27% (Patla and Peterson 2003 and 2004). Full implementation of long-term monitoring in the two national parks is expected to begin in 2005 or 2006. Annual surveys of the set of randomly-selected catchments and analysis of the data with occupancy statistical tools will make it possible to determine if spotted frogs are declining, remaining stable, or increasing within Yellowstone and Grand Teton national parks.

The occupancy approach appears to be highly applicable to publicly managed lands and would provide BLM with statistically defensible data on population trends for Columbia spotted frogs. Sampling design and the selection of habitat variables could enable assessment of how spotted frogs (and/or other amphibians) are responding to management practices (e.g., amounts of woody debris in logged areas, grazing intensity, and prescribed fire). Clarification of monitoring objectives is essential to design and the success of implementation. An effective amphibian monitoring program that meets Forest Service objectives could be integrated with other monitoring efforts in northwest Wyoming, with mutually beneficial partnerships and shared resources.

Additional monitoring needs

More intensive monitoring of specific breeding populations (as opposed to monitoring for trends across a management unit such as a Forest, as described above) may be necessary to determine if populations of management or conservation interest are persisting (e.g., the Bighorn spotted frog population), and to detect if these populations are declining or increasing. The most important types of information to collect for this level of monitoring are the number of egg masses per breeding site, presence and estimated number of tadpoles and other life stages, and whether or not successful metamorphosis occurs. To determine if diseases are present, dead individuals should be counted, collected, frozen as soon as possible, and submitted for pathology diagnosis, along with notes about location, date, and relevant observations. Where multiple dead are found, some should be frozen and other fixed in ethanol. Determining the presence of eggs, tadpoles, and metamorphs frequently requires multiple visits. Amphibians are cryptic during certain kinds of weather and lighting conditions and can be easy to miss even when abundant. The timing of visits is critical; eggs will be missed if the visit is too early; tadpoles or metamorphs will be missed if the visit is too late in the season (see Survey Techniques, below). Tadpoles have the longest residence of these life stages and are thus the most convenient and reliable target of annual monitoring. Relative abundance estimates are not precise and should be used with caution; mark-recapture is necessary for reliable population size estimates. The number of egg masses can be used to roughly estimate the size of the annual effective female population. This is an uncertain indicator of population robustness because it does not include pre-reproductive juveniles and non-breeding females, but is the best available index of population size other than mark-recapture studies, which are extremely labor intensive and time consuming. Mid-summer monitoring can be used to determine the ratio of adults to juveniles, indicating if the young of the previous one to three years have survived. Late summer and fall surveys around known breeding areas may be useful to try to determine the location of migration zones and overwintering sites. Even when the monitoring target is a specific breeding population, the monitoring of groups of ponds in an area rather than single sites has been recommended so that local shifts in breeding activity can be recognized and expansion into new breeding sites can be detected, thus avoiding the hazard of mistakenly assuming that absence of breeding represents a true local decline (Marsh and Trenham 2001).

Habitat monitoring, at the fine scale, can be conducted simultaneously with the above population monitoring, with surveyors documenting impacts of grazing and human activities at breeding and foraging sites. Habitat monitoring at a coarser scale can be part of an inventory/monitoring program, described above, with data collected on habitat variables that can indicate the impacts of forest management practices and natural processes.

Survey Techniques

This section applies to both inventory and monitoring efforts, which seek to determine the presence/absence of spotted frogs. Surveys for spotted frogs are generally conducted during daytime hours, using visual encounter survey protocols described in Thoms et al. (1997). Adults and juvenile spotted frogs often bask on sunny days, and tadpoles utilize the warmest available water within the breeding pools; thus surveys along pond/lake edges or along the shores of low-gradient streams are efficacious in detecting spotted frogs. Dipnetting with a fine-mesh net on a long (1' to 5') handle is useful to detect tadpoles in areas that have aquatic vegetation or cloudy water, and dipnet transects can be conducted across shallow ponds to sample in areas of various depth. Transects (zig-zag or straight lines at intervals) are employed to survey large wetland areas. To detect active breeding sites, the time frame for surveys is restricted from egg deposition to metamorphosis, a time frame that varies with elevation and latitude. Surveys before egg deposition are too early; surveys after tadpoles have metamorphosed and dispersed are too late. Tadpoles that have recently hatched can be difficult to detect, so it can be better to postpone surveys until a few weeks after egg deposition, unless egg-mass count data are being sought. Surveys between mid-June and late July or early August will probably be suitable for most areas in Wyoming inhabited by spotted frogs, with higher elevation areas surveyed last. Paper forms can be used to record data, or personal digital assistants (PDAs) allowing automatic upload into databases. A sample survey data form, previously used for NPS-USGS surveys in Yellowstone and Grand Teton National Park, is provided in Appendix 2. This data sheet probably includes more fields than necessary for monitoring occupancy and would require revision based on program design.

The potential for spreading diseases through surveys and handling of amphibians is a concern among herpetologists, and protocols for minimizing this risk need to be closely followed by survey personnel. Protocols are provided by the Declining Amphibian Population Task Force (www.mpm.edu/collect/vertzo/herp/Daptf/fcode_e.html). In brief, protocols require thorough cleaning of all boots, nets, and equipment used during surveys, following by disinfection with ethanol or bleach. These procedures should be strictly followed whenever people working in amphibian habitat move between sites in different watershed units, or following work conducted in an area where a die-off has occurred.

Captive Propagation and Reintroduction

Captive propagation and introduction of Columbia spotted frogs is highly experimental and still in its infancy. Moreover, due to the large expense and the potential for multiple, serious problems (e.g. disease and genetic issues), captive breeding should only be considered in case of extreme emergency, such as rapidly progressing extirpation of the few known Bighorn Mountain spotted frog breeding populations. Unless populations undergo substantial crashes that threaten imminent extirpation, conservation effort is more fruitfully spent in habitat preservation and restoration.

The Conservation Strategy for spotted frogs in Utah (Perkins and Lentsch 1998) contains several action items with respect to captive breeding: Determine feasibility and methodologies for augmentation and reintroduction, develop protocols for captive propagation and rearing, develop protocols for translocation and introduction, identify and develop brood stock sources and potential rearing facilities, augment populations through stocking where genetic viability may be threatened, and establish additional populations. An experimental translocation of egg masses and adults into an unoccupied area along the Provo River was attempted to test reintroduction methodologies. The egg mass translocation effort was considered successful, but translocation of adults was not (USFWS Region 6 2002).

Information Needs

The distribution and abundance of populations of spotted frogs in much of Wyoming outside the GYE are poorly understood; acquiring this information has the highest information priority. Documented surveys are needed to establish if spotted frogs have as limited a distribution as they appear to have in areas such as the Bighorn Mountains. Previously documented breeding sites should be surveyed to determine if they remain active, and baseline surveys are needed to document new breeding sites and local populations.

The species response to changes in habitat is only roughly known and should be clarified and quantified, particularly as they relate to the specific effects of management (e.g., livestock grazing, timber harvest, fire and fire management, fish stocking and management, chemical use, and road, trail, recreational and water developments) or natural disturbances on reproductive success and year-to-year survival. Controlled studies that examine the response of spotted frog populations to pre- and post-treatment conditions would be especially valuable. Livestock grazing is probably the most widespread activity on BLM lands, with the least amount of information in terms of impacts on amphibians.

Research of the seasonal and daily movement patterns of spotted frogs shows that there is considerable variation among study areas, suggesting that movements are largely determined or influenced by the local environment or configuration of habitat components. This makes it difficult to evaluate effects of habitat change at broad scales. One approach would be to collect spotted frog habitat use data at several areas to determine the spatial configuration and distance among the various habitat components used by the populations. This would assist in broad-scale habitat evaluations, e.g., where is the spatial separation of potential breeding and wintering sites too extreme for spotted frog populations to be supported? The metapopulation concept has not been thoroughly researched for spotted frogs, and research is needed to determine the spatial scale at which metapopulations operate and the applicability of the source-sink population concept. For isolated and small populations of spotted frogs, determination of specific movement patterns could be vital to understanding the effects of management actions and the future of those populations.

There is no detailed information on how insect prey population's response to habitat changes affects spotted frogs. Frogs are opportunistic and flexible feeders, shifting prey type if one group of prey becomes locally scarce due to habitat changes. Future research could investigate how aquatic and terrestrial prey species respond to habitat changes from management actions but may be of less urgency than determining if toxic chemicals have bioaccumulated in insect prey, and if this is being passed up the food chain to spotted frogs. National forests provide valuable research opportunities for determining pesticide or herbicide drift from targeted (private lands) to non-targeted areas.

Some important demographic questions for the species remain. It is unknown how much variation occurs among locations and elevations in demographic factors such age at first breeding, frequency of breeding in females, and how often a female breeds over the course of a lifetime? The reliability of skeletal chronology to determine maximum ages is in question (J. Bowerman, pers. comm.) and needs to be critically reviewed; the maximum and average life spans of spotted frogs are imprecisely known and need further investigation. There have been no formal investigations of the number of egg masses produced by a female in a single season (one is commonly assumed), and the notion that egg mass numbers can be used to derive the effective breeding population size has not been critically reviewed. This is critically important if the number of egg masses is used as an index for monitoring breeding populations. While the demography of spotted frogs has been investigated in Yellowstone and elsewhere in the species range, it is not clear how applicable the information provided by those studies is for spotted frogs throughout Wyoming. Demographic studies are needed particularly in the Bighorns, where the population's long isolation and adaptation to local conditions may have resulted in unknown differences.

Finally, research is needed to determine if diseases that may be causing declines of amphibians elsewhere in the Rocky Mountains (e.g., chytrid disease outbreaks in boreal toads) are affecting spotted frogs in Wyoming. The most important initial task is sampling to detect disease presence in spotted frog populations, making use of the techniques (e.g., PCR-based assays for fungal infections) and knowledge provided by efforts such as the boreal toad recovery project in Colorado (Loeffler 2001; Livo and Loeffler 2003). How vulnerable spotted frogs are to the emergent infectious diseases, chytrid and ranavirus, and what measures should be taken to minimize their spread? Partnerships with research agencies and institutions should be sought for health monitoring and sampling, assessment of risk factors, and formulation of responses to catastrophic die-offs should they occur or are deemed likely to occur.

Tables and Figures

Table 1. Summary of maximum reported seasonal movement distances of Columbia spotted frog populations.

Adults				
Breeding to overwintering site	**Breeding or overwintering to foraging sites**	**Young of the Year: Natal site to over-wintering sites**	**Habitat**	**Source**
600 m	1033 m	350 m	Mountain basin in Idaho, 2300-2800 m elevation	Pilliod et al. 2002
100 m			Riparian zones in sage-juniper brushlands in Idaho, 1325-2035 m elevation	Engle 2001
400 m	620 m	480 m	Coniferous forest and adjacent meadows in Wyoming, 2380 m elevation.	Turner 1960; Patla 1997
	560 m		Coniferous forest and meadows in northeast Oregon, 920-1500 m elevation	Bull and Hayes 2001
	444 m		Coniferous forest and willow bog in Montana, 2040-2070 m elevation	Hollenbeck 1974

Table 2. Potential threats to Columbia spotted frogs and their habitat in Wyoming. Severity of potential threat is rated on a scale of 1 to 3, with 1 most severe.

Threat	Threat* Severity	Rationale	Habitat effects †	Direct Effects (mortality)‡
Livestock grazing	1	Local impacts on small populations could be severe, esp. in drought	Degradation of wetland/moist habitats and water quality	Trampling, desiccation at sites of extreme vegetation loss
Water manipulation: diversions, dams, spring development	1	Existing and future water projects probably not evaluated for their impacts on frogs	Loss, degradation, and fragmentation	Dewatering of breeding and wintering sites leading to mass mortality
Road construction and improvements	1	New roads or increased traffic could affect populations, particularly if small and vulnerable	Loss (wetland fill), degradation (run-off, noise), and fragmentation	Roadkill
Introduced fish	1	Fish stocked at one of the 3 known breeding sites on the Bighorn NF	Loss (frogs may avoid stocked areas), fragmentation	Predation, introduction of diseases
Disease	1	Potential for rapid population decline if introduced		Die-offs
Drought	1	Effects could be exacerbated by human activities and land use	Degradation, fragmentation	Reduced reproduction and survival rates
Wildfire and prescribed fire	2	Fire suppression; timing of prescribed fire	Degradation, fragmentation	Heat and exposure; chemicals in fire retardants
Timber Harvest & hazard fuel reduction	2	Threat minimized if environmental effects of logging on microhabitats are assessed and mitigated	Degradation, fragmentation	Crushing, desiccation
Beaver eradication	2	Cumulative losses of breeding and wintering habitat	Loss, Degradation	
Contaminants (pesticides, herbicides)	2 (locally 1)	What chemicals are applied in R2? Are forests subject to chemical drift from other areas?	Reduced or contaminated prey.	Lethal and sub-lethal effects
Oil & Gas and mining	2	Surface disturbance, hydrological effects, contamination	Loss, degradation, fragmentation	Crushing by equipment, exposure to toxicants
Recreation	2	Will environmental effects of developments and recreation use be assessed and mitigated?	Loss, degradation, and fragmentation	Crushing by vehicles, disease introduction, capture and handling.
Ultraviolet radiation	3	Spotted frogs not very vulnerable		
Human utilization (collection)	3	Probably unlikely to occur at significant levels		Collection for pet trade, food, bait, scientific uses

* Severity of threats was assigned assuming: (1) Isolated populations are more vulnerable than in areas where populations are widespread and numerous; (2) Areas occupied by spotted frogs in Wyoming are (generally) relatively far from large urban centers and agricultural areas, lessening the potential for large-scale habitat conversion and agrochemical.

† Habitat effects are considered in terms of loss, degradation, and fragmentation and can occur at two scales: (1) among or between breeding, foraging, and wintering sites; and (2) among or between subpopulations and suitable habitat patches in a region, preventing interchange between subpopulations and/or the colonization of unoccupied habitat. “Loss” refers to changes that render breeding, foraging, and wintering habitats permanently uninhabitable by spotted frogs. “Degradation” refers to changes in habitat that it to be less suitable for frogs (in terms of frog growth, survival, and reproduction), including patch size. “Fragmentation” refers to increased separation of frog habitat components due to movement barriers or uninhabitable conditions.

‡ Direct effects are considered in terms of factors that can cause spotted frog mortality. Mass mortality is most likely to occur when frogs are congregated (e.g., breeding and wintering sites) or when metamorphs are emerging from breeding ponds and dispersing to wintering sites.

Fig. 1. Adult female Columbia spotted frog. Photo taken in Grand Teton National Park by Matthew Chatfield, Idaho State University and USGS.

Fig. 2. Pigmentation on the underside of a spotted frog. This is a large female with extensive pigmentation. Photo taken in Yellowstone National Park (D. Patla).

Fig. 3. The gender of adult spotted frogs is apparent due to the dark nuptial pads at the base of the thumbs (arrow) of male frogs. Photo taken in Yellowstone National Park (D. Patla, Idaho State University).

Fig. 4. Recently metamorphosed spotted frog, Yellowstone National Park. (D. Patla, Idaho State University)

Fig. 5. Spotted frog tadpole. Photo by Charles R. Peterson, Idaho State University.

Fig. 6A. Newly deposited spotted frog eggs. Photo taken in Yellowstone National Park (D. Patla, Idaho State University).

Fig. 6B. Floating spotted frog egg masses of various ages. Older egg masses are green with algae and spread out on the water surface. Photo taken in Yellowstone National Park (D. Patla, Idaho State University and USGS).

Fig. 7. Distribution of Columbia spotted frog (*Rana luteiventris*) in North America. This map is adapted from Figure 1 in Green et al. (1997). (Permission to use granted by copyright notice, American Society of Ichthyologists and Herpetologists).

Fig. 8. Documented occurrences of Columbia spotted frogs in Wyoming prior to 1993 (historic) and since 1993 (recent) from the Wyoming Natural Diversity Database.

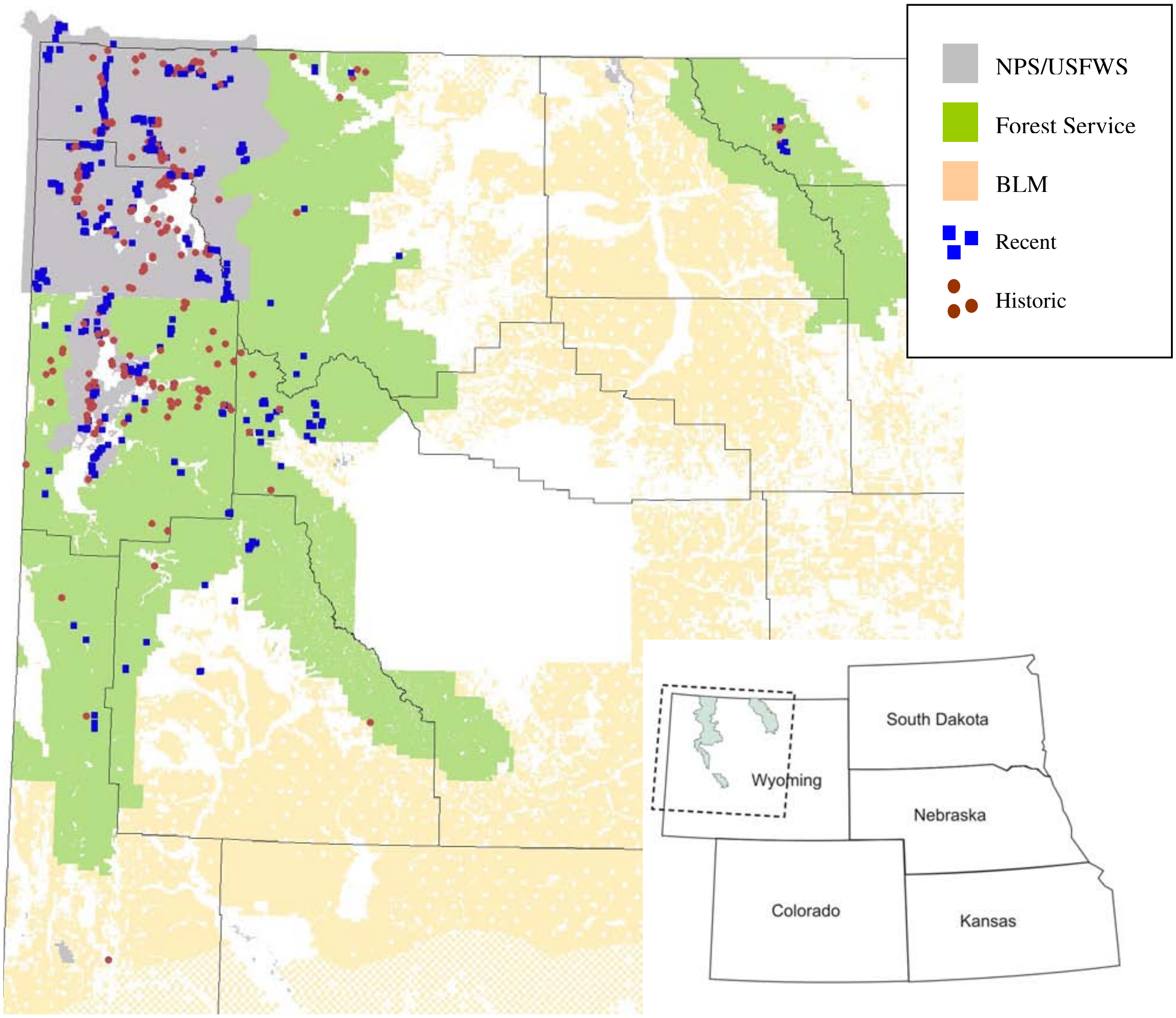

Fig. 9. Documented Columbia spotted frog breeding sites and non-breeding occurrences in Wyoming since 1993, from the Wyoming Natural Diversity Database.

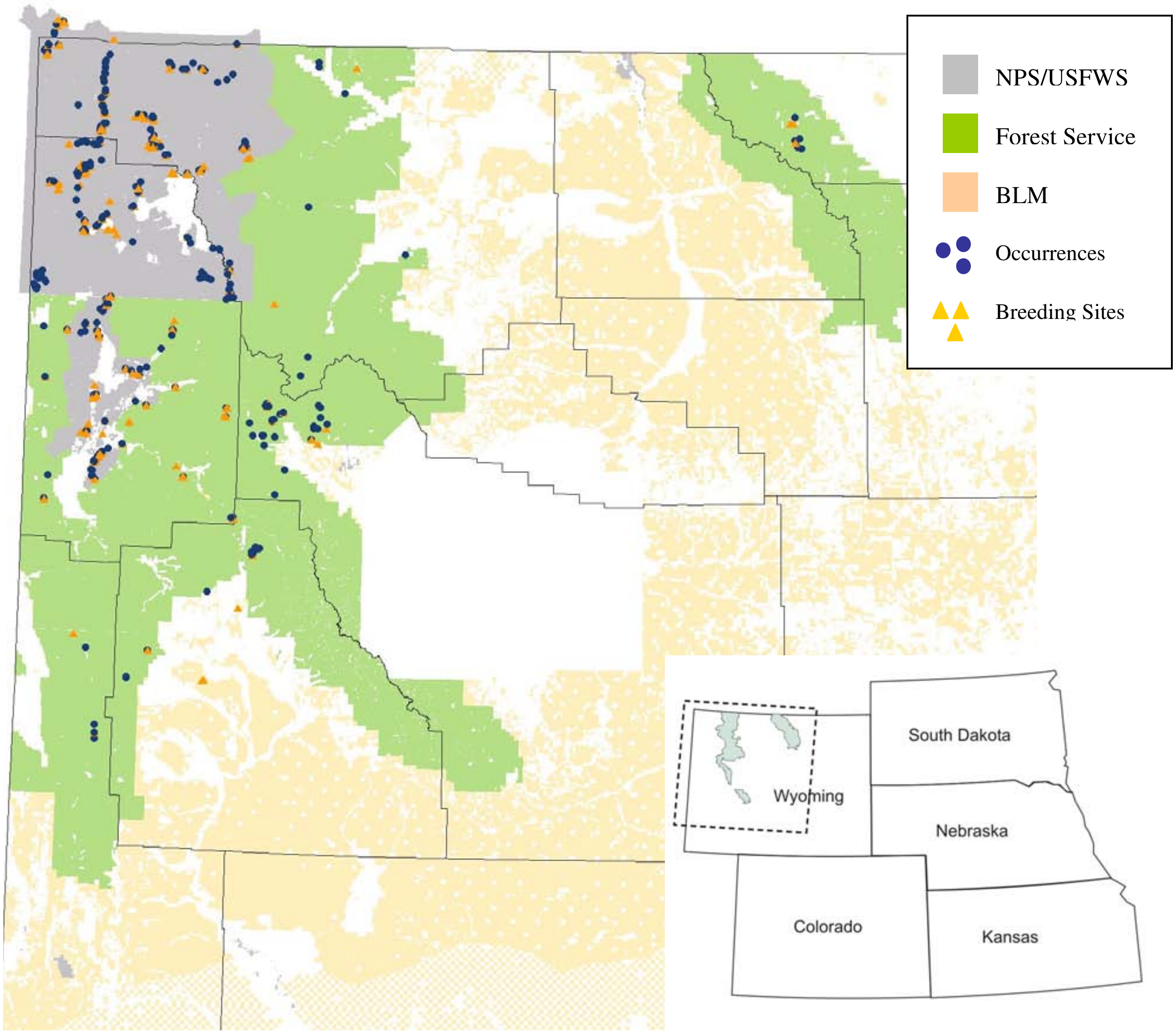

Fig. 10. A Columbia spotted frog breeding site in eastern Yellowstone National Park (M. Chatfield, Idaho State University and USGS).

Fig. 11. A wet meadow used by Columbia spotted frogs for foraging, Grand Teton National Park (D. Patla, Idaho State University and USGS).

Fig. 12. A small spring where Columbia spotted frogs overwinter, located in the sedges immediately to the right of the person (Janice Engle), Yellowstone National Park. Wintering areas can be very inconspicuous but may be detected by observations of spotted frog congregations near such areas in September or October (D. Patla, Idaho State University).

Fig. 13. A spotted frog breeding pool in Yellowstone National Park, showing premature drying, and trampling due to horses. This is one of the breeding sites identified by Fred Turner's spotted frog research in the 1950s (Turner 1960). The pond was fenced after this photo was taken to exclude horses and protect the site. Fencing allows the pool to last longer and retain vegetation, and it provides safety for the emerging metamorphs from trampling. (D. Patla, Idaho State University)

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Acknowledgements

Numerous people assisted with this report by providing documents and responding to specific questions, including Jay Bowerman, Evelyn Bull, Janice Engle, Lauren Livo, Bryce Maxell, James Munger, Christopher Pearl, and Charles Peterson. We are particularly grateful to David Pilliod for review of the draft and valuable suggestions. Harold Golden provided detailed information and many clarifications. His long-term interest and efforts on behalf of spotted frogs on the Bighorn NF are commendable. We also thank Gary Patton and Lynette Otto for their assistance in acquiring information. We appreciated the opportunity to work with Dave McDonald on population modeling and to learn from his insights. Staff at WYNDD provided technical support: Matt McGee assisted with proofreading and improvements of the draft; Suzanne Rittman conducted the literature search and compiled papers for our use; and Jason Bennett compiled location records and provided GIS coverages. Merlin Hare volunteered his computer graphics expertise to prepare the range and occurrence maps. Greg Hayward and two anonymous reviewers of the draft vastly improved this report with their numerous comments, insights, and corrections. Amphibian surveys, monitoring, and research in the Greater Yellowstone Ecosystem conducted by Idaho State University, USGS, and the National Park Service informed many aspects of this report. In particular we wish to acknowledge Chuck Peterson for his leadership role in the investigation of amphibians over the past 16 years in the GYE; and Steve Corn for guiding the efforts to standardize and implement monitoring. Finally, for making a report of this nature possible, we thank the field researchers for their countless hours observing spotted frogs, meticulous written accounts, and ideas on conserving this species, especially Fred Turner, Evelyn Bull, Janice Engle, Chris Garber, Bryce Maxell, Jim Munger, David Pilliod, and Jamie Reaser.