This Thesis for the Master of Environmental Studies Degree

By

Joanne P. Schuett-Hames

has been approved for

The Evergreen State College

By

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Feb. 23, 2004

Date

NORTHERN RED-LEGGED FROG (*RANA AURORA AURORA*) TERRESTRIAL HABITAT USE IN THE PUGET LOWLANDS OF WASHINGTON

By

Joanne P. Schuett-Hames

A thesis submitted in partial fulfillment

of the requirements for the degree

Master of Environmental Studies

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ABSTRACT

NORTHERN RED-LEGGED FROG (*RANA AURORA AURORA*) TERRESTRIAL HABITAT USE IN THE PUGET LOWLANDS OF WASHINGTON

Joanne P. Schuett-Hames
The Evergreen State College
February 2004

From August 2000 to November 2002, I studied northern red-legged frogs (*Rana aurora aurora*) on a 2 ha terrestrial site near Olympia, Washington to better understand their patterns of terrestrial habitat use. As northern red-legged frogs are thought to be terrestrial during most of their active season, understanding how they use terrestrial habitat is crucial to our ability to protect them because terrestrial habitat loss to development is an increasing pattern in the Puget Lowlands. I used time and area-constrained searches, telemetry, drift fences with traps, video records, and measurement of selected environmental and habitat characteristics to obtain demographic and behavioral data on the terrestrial life history of northern red-legged frogs. In 2001, I obtained a Schnabel population estimate of 60 frogs (95% CI +/- 81) for the study site; alternative methods indicated that a minimum of 54, up to a maximum of 78 northern red-legged frogs used the study area. Demographic data revealed that post-metamorphic frogs ranging in size from small juveniles to large adults (36-79 mm snout-vent length) occupied the site from April to November. Individual frogs had an active-season home range that included forest, forest-edge, a forest opening with a yard and garden, and tidal mudflat margins. Some frogs returned to the same home range annually. Spring to mid-fall growth was greater than annual growth ($p = 0.0023$) suggesting terrestrial conditions may be important for feeding. Video analysis revealed that diurnally, frogs were highly conservative in their movements; movements were brief and rapid and frogs remained motionless 99.5% of the time. A preliminary ethology of the northern red-legged frog in its terrestrial environment is presented. Behavior categories include postural, distance and in-place movements, movement patterns and home ranges, physiology, predator/danger responses, habitat modification, vocalization and social structure. I also present a preliminary model to explain the behavior of terrestrial northern red-legged frogs in response to seasonal changes. In spring, moisture and temperatures do not appear to limit habitats available to frogs for feeding and other needs. By mid-summer, dry and warm conditions restrict moist temperature-attenuated habitats and frog behavior patterns shift in ways that appear to be strategies for obtaining moisture and preventing desiccation. Late fall to early winter cool temperatures limit frog activity. Overall, frogs alter their behavior and habitat utilization patterns in differing ways that may allow them to maintain terrestrial activity such as feeding from spring through early winter (including during overwintering). Significant conservation implications of this study were: (1) in terrestrial locations similar to the study area, forest habitat appears to be a requirement for northern red-legged frogs during both active and overwintering seasons, and (2) migration routes that cross roads may present a substantial risk. Based on interviews with amphibian biologists, I outlined a system for achieving the long-term maintenance of robust populations of this species in Washington.

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ACKNOWLEDGEMENTS

I thank my advisor Dave Milne, readers Marc Hayes, Mary O'Brien and Tim Quinn, and MES Program Director John Perkins. I appreciate your extensive support, recommendations, creative thinking, and dedication to healthy ecosystems.

I am very grateful to Dave Schuett-Hames for assistance with making and installing traps, field set-up, assisting with frog capture and photography; Carolyn Comeau and Tiffany Hicks for trap construction; and Nobi Suzuki, Kelly McAllister and Bill Leonard for helpful discussions.

Thank you to Marc Hayes, Klaus Richter, Kelly McAllister, J. Tuesday Shean, and, Mike Adams for participating in conservation surveys.

Winter telemetry data collection represented a cooperative project with Marc Hayes, Tiffany Hicks, Merrie Diehl and Rob Price of Washington Department of Fish and Wildlife. In addition, I appreciated access to the land of neighbors near the study site to search for telemetered frogs, and study assistance and access to the frogs' winter home ranges by Liz, Sam, McKenzie and Cooper Devlin.

I dedicate this thesis to my family.

CHAPTER 1. INTRODUCTION

Need/Rationale and Conservation Overview

Between 2000 and 2020, the human population of counties within the Puget Sound region of Washington State is expected to grow by two million, an overall increase of 29% (Washington Office of Financial Management 2002). This growth will convert undeveloped habitat to landscapes with substantial area that is hostile to northern red-legged frogs (*Rana aurora aurora*), e.g., roads, parking lots and other impervious surfaces and human structures. As roughly half of northern red-legged frog range within Washington lies within the Puget Lowland Ecoregion (Omernik 1987; Fig. 1)[1], this species will be vulnerable to habitat modification through a large portion of its range.

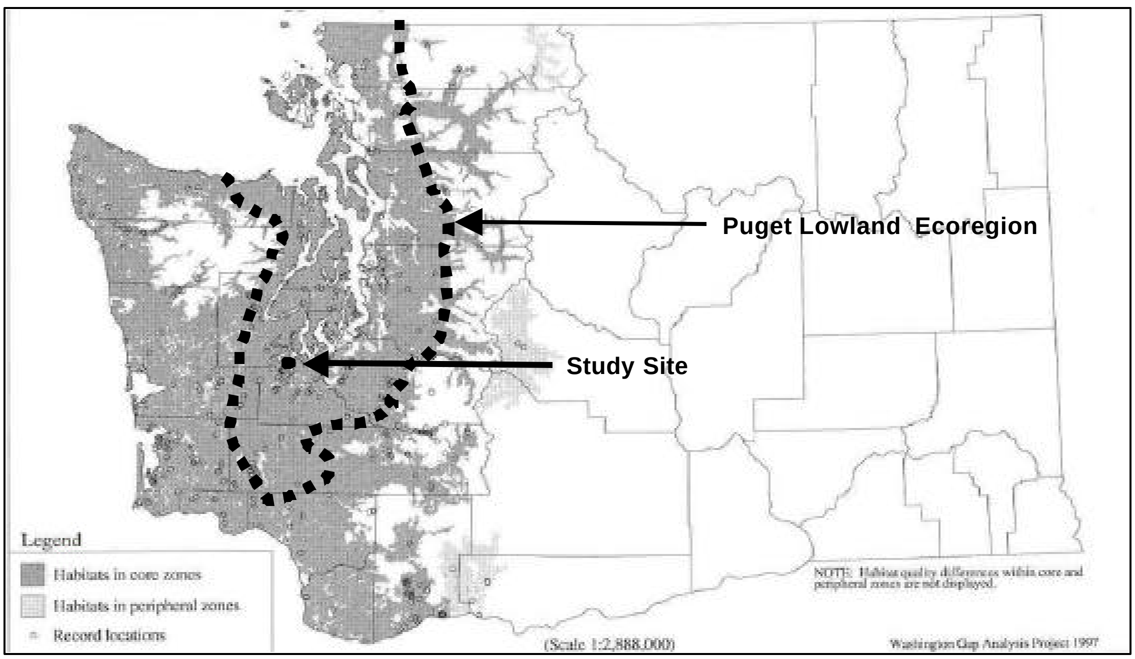

Figure 1. Map of Washington State showing the range of the northern red-legged frog, the Puget Lowland Ecoregion, and the study site. Base map from Dvornich et al. (1997). Ecoregion boundary from Omernik (1987).

In the late 1980s, scientists became aware that amphibian population declines were a global phenomenon. By the early 1990s, documented declines and extinctions focused

[1] I am using data for the Puget Sound region as a rough approximation of the expected trend for the ecoregion. Readers are referred to Washington Office of Financial Management (2002) for additional specifics.

further attention on this issue (Tuxill 1998). Amphibians with permeable skins and unshelled eggs are especially susceptible to environmental insult such as chemical pollutants and increased ultraviolet light. Moreover, their use of both aquatic and terrestrial habitat presents opportunity for a greater range of environmental conditions to adversely affect species survival (Mattoon 2000). Habitat loss, pollution, climatic instability, increased ultraviolet light, disease, and introduced predators are among factors that have been identified in association with amphibian species decline in case studies (Mattoon 2000; Tuxill 1998). Synergisms among factors are also suspected, e.g., climatic change may stress amphibian immune system function, allowing ordinarily benign fungi or bacteria to become virulent pathogens (Mattoon 2000; Tuxill 1998).

In a recent status survey of about one-eighth of the world's amphibian species, 25% were judged to be endangered or vulnerable, and 5% more were nearing threatened status (Tuxill 1998). Amphibian data for Washington State and the Puget Lowland Ecoregion (hereafter Puget Lowlands) (Table 1) also indicate high levels of decline or concern. Of 25 amphibian species indigenous to Washington, 36% have a state conservation designation of endangered (8%), sensitive (4%), or special concern (24%). None of Washington's amphibians are federally listed as threatened or endangered, however, 36% have federal candidate or species of concern status.

Sixteen native amphibian species occupy the Puget Lowlands. Of these, 19% have state conservation designations and 31% have federal designations. Based on state classification, 28% of anurans (frogs) in the Puget Lowlands have a specific conservation status, and at the federal level, 57% have a conservation status (Table 1), indicating conservation concern for Puget Lowland anurans. One species, the western toad (*Bufo borealis*) has incurred a large decline in the Puget Lowlands since the mid-1990s (Adams et al. 1999, McAllister, pers. comm. 2002). Why this ecoregion-wide decline has occurred is unknown (McAllister, pers. comm. 2002).

The northern red-legged frog has no state conservation classification in Washington, but it is included as a federal species of concern (Washington Department of Wildlife 2002). It is however, classed as a sensitive species in both Oregon (Oregon Department

Table 1. Washington and Puget Lowland Ecoregion amphibian conservation status (sources: Washington Department of Fish and Wildlife 2002; Leonard et al. 1993; Dvornich et al. 1997).

	Washington State Indigenous Amphibia[a]						Puget Lowland Indigenous Amphibia[a]					
	Amphibia		*Caudata* (salamanders)		*Anura* (frogs, toads)		Amphibia		*Caudata* (salamanders)		*Anura* (frogs, toads)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Total No. Species	25	100	14	100	11	100	16	100	9	100	7	100
State												
Endangered	2	8	0	0	2	18	1	6	0	0	1	14
Threatened	0	0	0	0	0	0	0	0	0	0	0	0
Sensitive	1	4	1	7	0	0	0	0	0	0	0	0
Candidate	6	24	4	29	2	18	2	13	1	11	1	14
Total:	9	36	5	36	4	36	3	19	1	11	2	29
Addt. Monitor[b]	7	28	3	21	4	36	3	19	2	22	1	14
Federal[c]												
Endangered	0	0	0	0	0	0	0	0	0	0	0	0
Threatened	0	0	0	0	0	0	0	0	0	0	0	0
Candidate	1	4	0	0	1	9	1	6	0	0	1	14
Concern	8	32	3	21	5	45	4	25	1	11	3	43
Total:	9	36	3	21	6	55	5	31	1	11	4	57

[a]There are two established introduced frogs: the bullfrog (*Rana catesbeiana*), and green frog (*R. clamitans*). They are not included in this chart.
[b]For Washington State, all state E,T,S and C species are also priority species and monitor species. Species without E,T,S or C status may be categorized as monitor. This line lists the number of additional monitor species.
[c]All species with federal designations additionally have state designations, except the red-legged frog. This species is a federal species of concern, but has no state designation.

of Wildlife 1997)[1] and British Columbia (COSEWIC 2002)[2].

A separate sub-species of red-legged frog found in California, the California red-legged frog (*R. aurora draytonii*) was listed under the Federal Endangered Species Act in 1996. This sub-species has incurred a 70% reduction in range, and in its southern California range extent, only one of 80 previously known sites is currently known to have this species extant. Decline of this sub-species is attributed to habitat loss and alteration, over-exploitation for food in the late 1800s and early 1900s, and impacts from exotic predators (U.S. Fish and Wildlife Service 2000).

[1]This designation is given to Oregon species that may become threatened or endangered, to assure protective measures are put in place (Oregon Department of Wildlife 1997). The Willamette Valley populations have a sub-class of vulnerable "Species for which listing as threatened or endangered is not believed to be imminent and can be avoided through continued or expanded use of adequate protective measures and monitoring." The Oregon Coast Range, West Cascades, and Klamath Mountain populations are sub-classified as undetermined status "Species for which status is unclear. They may be susceptible to population decline of sufficient magnitude that they could quality for endangered, threatened, critical or vulnerable status but scientific study would be needed before a judgment can be made."
[2] The status in British Columbia is a federal status "special concern" due to "…characteristics that make it particularly sensitive to human activities or natural events."

Although there is no definitive data on population decline for the northern red-legged frog for the Puget Lowlands, there are indications that decline may occur in this ecoregion under development and urbanization scenarios. For example, McAllister (pers. comm. 2002) has observed that the northern red-legged frog is absent from highly urbanized areas, e.g., downtown Seattle, or downtown Olympia. Additionally, in rapidly developing areas within King County, Washington, Richter and Ostergaard (1999) recorded red-legged frogs at 25% fewer wetland sites in 1997 than when they initiated surveys in 1993.

Development almost invariably changes watershed hydrology, and stormwater ponds represent one remediation strategy often implemented to attempt to ameliorate such changes. Ostergaard (2001) studied amphibian use of 52 stormwater ponds in developments within King County. Overall, she found "…some stormwater ponds may function as biological traps for native amphibians, and some may function as sources." Red-legged frogs were found in 50% (26) of the ponds. Her results indicated that landscape condition (percent total impervious surface condition within a 1,000-m radius of a stormwater pond) was the most important of 29 factors measured in explaining northern red-legged frog abundance. Northern red-legged frog abundance was also negatively correlated with maximum water level fluctuation, and egg mass numbers were greater at sites that had not been cleaned out within the last 1.5 years.

Direct sources of mortality observed by Ostergaard (2001) were: (1) egg mass stranding due to rapid water level drops, especially in newer ponds with steep banks; and (2) children "…collecting amphibian eggs and larvae to throw, play with, and take home to raise." Exotic fish that are potential predators of amphibians (koi, *Cyprinus carpio;* goldfish, *Carassius auratus;* and bluegill, *Lepomis macrochirus*), were also found in three stormwater ponds. Bullfrogs were present in 44 of the 97 pond bays and were most abundant in permanent ponds. Ostergaard (2001) did not find a bullfrog effect on native species richness, and bullfrogs were not important in logistic regression models predicting the occurrence of native amphibian eggs and larvae. However, it is unknown as to whether unstudied effects from bullfrogs might be occurring.

Another aspect of habitat loss is the disproportionate loss of small wetlands and shallow portions of larger wetlands (reviewed by Adams 2000). Adams (1999) found survival of larval red-legged frogs to be generally lower in permanent ponds, and he pointed out that maintaining a diverse mix of wetland types, (including ephemeral wetlands), may help promote native amphibian conservation.

Roads can be a substantial source of mortality for amphibians due to the fact that road locations cross landscapes that frogs use seasonally. For example, in a study in southern New York that included telemetry of green frogs (*R. clamitans*) en-route to overwintering habitat, three of four frogs that crossed a busy road were killed by automobile traffic. The frog that survived likely did so due to crossing at 0200 hr (Lamoureux & Madison 1999), presumably during an interval when traffic levels were low.

Citing study results for the green frog that indicate adult overwintering habitat might be as important for sustaining populations as is breeding habitat, Lamoureux and Madison (1999) have highlighted the importance of examining "amphibian habitat requirements at all times of the year, not just during the breeding season." Until recently, northern red-legged frogs were largely unstudied during their active season, which has been shown to be largely terrestrial (Ritson & Hayes 2000; Haggard 2000). Paucity of research has hindered understanding the importance of northern red-legged frog terrestrial habitat.

My study was intended to help develop better understanding of how northern red-legged frogs use terrestrial habitat (including that modified for residential use). I focused on gathering demographic and behavioral data on a 2-ha site of largely mature forest but which contained an opening with a home, yard and gardens. My study site was located in the southern portion of the Puget Lowlands, near Olympia, Washington (Fig. 1).

The primary research question that I attempted to address was:
"*Do northern red-legged frogs show a preference for a human-created forest opening with grasses, forbs, and gardens over adjacent undeveloped forest*?"

I additionally investigated demographic and natural history questions in support of the primary research question, and to add to knowledge of how red-legged frogs use terrestrial habitat. These were:

1) Population demographics
    a) How many frogs use the study site?
    b) What are size, gender, age and mortality characteristics of the frogs?

2) Temporal use of upland habitat and movement patterns
    a) When do frogs use the study site?
    b) What movement patterns do frogs engage in?
3) What are the temporal, spatial and habitat characteristics of frog home ranges?
4) What are observable frog behaviors and activity patterns?

I also performed a series of conservation interviews/surveys with amphibian biologists to clarify conservation issues and status for this species in the Puget Lowlands, and western Washington.

The primary field research period was April through December 2001. Reconnaissance field research occurred August and September of 2000, and supplementary data were collected from April through November of 2002. Conservation interviews were accomplished July 2002.

Geographic Range and Life History Overview

Geographic Range

Northern red-legged frogs range from southwestern British Columbia through western Washington (and in the Columbia River Gorge east to White Salmon), western Oregon, and into northwestern California (as summarized by Leonard et al. 1993; Nussbaum et al. 1983; and Dumas 1966). They occur from sea level to 860 m in Washington, and up to 1427 m in Oregon (Leonard et al. 1993).

This species is relatively widespread and appears to be generally common over most of its range in Washington. Although broad-scale geographic studies are lacking, studies at scattered locations in the Puget Lowlands have revealed occupancy patterns of 50% of study sites. Adams et al. (1998) found red-legged frogs at 58% (23 of 40) of lentic study sites within Fort Lewis. Similarly, Adams et al. (1999) found this species at 58% (14 of 24) of lentic study sites on Navy lands in the Kitsap and Toandos Peninsulas. Ostergaard (2001) observed red-legged frogs at 50% (26 of 52) of surveyed stormwater ponds in King County.

Life History

Breeding, hatching and metamorphosis-- Northern red-legged frogs breed from January to March in western Oregon and Washington (Dumas 1966), and from February to March in British Columbia (Licht 1974). Specifically, Adams (1999) reported red-legged frogs breed at Fort Lewis in Washington in early March. Storm (1960) reported that in the Corvallis, Oregon, area, they breed in January and February, hatch in 6 to 7 weeks, and metamorphose in June and July. Licht (1974) reported metamorphosis in July for British Columbia. Adams (1999) found the beginning of metamorphosis in late July for Fort Lewis frogs. Brown (1975) reported late July for metamorphosis at a breeding area near Bellingham, Washington, whereas Ostergaard (2001) found metamorphosis as early as May in shallow, warm stormwater ponds in King County.

Northern red-legged frogs are thought to reach sexual maturity at 2 years at a size of ca. 50 mm snout-vent length (SVL) for males and ca. 60 mm for females (Storm 1960). In contrast, male frogs near Olympia developed nuptial pads during late summer their first year (Hayes & Hayes 2003) and began to call (Hayes et al. 2004). Females are thought to breed every year (Licht 1974).

Whether northern red-legged frogs have a meta-population structure is unknown (Hayes, pers. comm. 2003).

Size-- Recently metamorphosed juveniles near Corvallis were 20 to 25 mm SVL (Storm 1960), and near Bellingham 26 to 30 mm (Brown 1975). The maximum SVL for adult red-legged frogs near Corvallis was 68 mm for males, and 100 mm for females (Storm 1960). The size range of nine breeding females from the Corvallis area was 72 to 93 mm SVL (mean 84 mm), and for 11 breeding males was 49 to 65 mm (mean 59 mm). According to Nussbaum et al. (1983) males are < 70 mm.

Survival rates-- Licht (1974) found mean survival of eggs to hatching of 91 to 92%, but from hatching to metamorphosis of < 1%. After one year, there was a minimum of 52% survival of those frogs that had metamorphosed the prior year. Licht (1974) also reported a yearly minimum survival rate for frogs > 1 year old, of 69%.

Terrestrial Habitat Use Overview

Terrestrial Habitat Characteristics

In northern California, Haggard (2000) found 52% of telemetered northern red-legged frog observations were in closed canopy thicket/forest macrohabitat. An additional 19% of sightings were in forbs, 17% in emergent (wetland) vegetation, 8% in grassland, and

4% under human-created habitat such as under boards. Although not assessed, Haggard (2000) mentioned sword ferns might be an important microhabitat for the frogs.

Home Range Size

In northern California, Haggard (2000) identified a mean range length (the distance between the expected breeding location and the furthest location that the frog was found) for northern red-legged frogs of 73 m (s = 67.2 m, range: 5 to 221 m).

Seasonal Movement

Collectively, observations indicate that northern red-legged frogs engage in movements during three discreet periods: pre-overwintering (fall), breeding (winter), and post-breeding (spring). In the South Umpqua basin of Oregon, Hayes et al. (2001) found that northern red-legged frogs can travel long distances after they exit the breeding pond seasonally. They reported adults up to 2.4 km from the breeding pond where they had been originally captured, and more recent data has found frogs up to 4.8 km from the breeding pond (Hayes, pers. comm. 2004). At this site, seasonal movement upwards of 1.0 km from the breeding pond appear to be routine (Hayes, pers. comm. 2004). Conversely, Haagard (2000) reported the furthest distance northern red-legged frogs moved from a northern California (expected) breeding area was ca. 20 to 280 m (mean = 149, s = 83.6).

When temperatures dropped in the fall, Ritson and Hayes (2000) found that three female telemetered frogs each made a pre-overwintering move of over 40 m from terrestrial habitat to water at a lower Columbia River site in Oregon (Ritson and Hayes 2000).

In studies conducted near Corvallis, Oregon from 1950 to 1953, Storm (1960) found that male frogs arrived at breeding ponds first (as early as 8 December). No females were seen until at least 11 January. Females appeared to move to the breeding pond after 1 January when air temperatures were 10 C (50 F) or above during at least moderate rains. Licht (1969) reported northern red-legged frogs in southwestern British Columbia emerged from hibernation in February and March, and moved to breeding sites when the air was a minimum of 5 to 6 C.

In a Thurston County, Washington telemetry study completed in 2001, Shean (2002) found post-breeding female red-legged frogs remained at the breeding pond until mid-April. At this time, coincident with warmer air and water temperatures, females moved to other wetlands or in one case, uplands until 25 May 2001, when the study concluded.

Local Movement and Daily Activity Patterns

Haggard (2000) studied the movement ecology of 11 female and one male northern red-legged frogs at Freshwater Lagoon, Humboldt County, California. Through the use of telemetry, she determined for the March to July 1999 period of study, that most of the frogs (11 of 12) stayed on land 90% of the time, and although daily moves of up to 87.5 m were made, most moves were 5 m (mean = 3.7 m, s = 5.1 m). She found no seasonal or daily weather response pattern, and no synchronous pattern of movement between study frogs for movements 20 m. Overall, the frogs "tended to stay 5 m from water."

Storm (1960) describes northern red-legged frog terrestrial use as follows: "Frogs often forage in damp well-shaded areas during the day and are active during warm rains at night." Chan-McLeod (2003) studied northern red-legged frogs May through October in terrestrial plots. She found they were often not visible, and were "burrowed into coarse wood, ground vegetation, loose ground substrate, or cavities."

Chan-McLeod (2003) found northern red-legged frogs primarily utilized forest rather than clearcut habitat. When movement into a clearcut occurred, it was more likely to be by a frog with a larger mass, and to be positively related to rainfall.

Overwintering Behavior

Ritson and Hayes (2000) found three adult female northern red-legged frogs along the lower Columbia River in Oregon, overwintered and remained in water when it was cold, but emerged onto land during warmer winter intervals. Licht (1969), reporting overwintering in southern British Columbia in "both river and woods" may have found a similar pattern, but his study was not focused on overwintering.

Diet and Feeding

Nussbaum et al. (1983) summarized the scant literature, largely based on Fitch (1936) on diet items of northern red-legged frogs. The frogs eat beetles, caterpillars, isopods, and other small invertebrates. They may occasionally eat vertebrates that are small enough; Rabinowe et al. (2002) reported ingestion of a 45-mm Columbia torrent salamander, *Rhyacotriton kezeri*, that was subsequently rejected.

Licht (1974) found in a sample of 104 collected northern red-legged frogs, that all had food in their stomachs. He also tested starvation tolerance for 20 newly metamorphosed northern red-legged frogs and found that 50% died at a mean age of 32 days.

Moisture Requirements and Adaptations

Rates of hydration and dehydration-- Dumas (1966), studying Pacific Northwest Ranidae, separated them into "pond frogs" (*R. pretiosa, R. luteiventris* and *R. cascadae*) and "wood frogs" (*R. aurora* and *R. sylvatica*) based on their natural history. In particular, he described pond frogs as rarely "found more than a few yards from water." In contrast, wood frogs "are not as closely confined to the immediate vicinity of water as are the pond frogs. Adult *aurora* are commonly found among rank, damp herbaceous vegetation or among tangled complexes of logs as much as 1,000 yards [ca. 920 m] from the nearest [fresh] water."

To support his categorizations, Dumas (1966) performed tests among the five species to determine whether differences existed in rates of dehydration and rehydration. For all taxa, the rate of water loss was greatest in the first hour and the most rapid rehydration rate occurred in the second ½ hr. Dumas (1966) found that wood frogs lost and gained water more rapidly than pond frogs. He surmised that it could be ecologically useful for a wandering terrestrial frog to rapidly gain moisture if it was approaching a lethal desiccation level.

Hydrotaxis-- To further test the difference between wood and pond frog groups, Dumas (1966) placed five each of *aurora*, *cascadae* and *pretiosa* within an enclosure 13.4 m (44 ft) from a shallow pan of water. By 42 min, all of the *cascadae* and *pretiosa* found the water, but it took 87 min for all the *aurora* to find the water. This suggests water is important to all the taxa studied, however getting to water fast may have been less important to *aurora*, possibly due to a greater tolerance to dehydration (e.g., see Shoemaker et al. 1992).

Behavior during drought-- The Pacific Northwest has a temperate, maritime, wet climate. However, Norse (1990) describes another aspect, summer drought: "Although renowned for wetness, it experiences summer drought unknown in moist regions of east

Asia, eastern North America, or western Europe." Chan-McLeod (2003) identified that extreme high temperatures decreased the likelihood that northern red-legged frogs would enter a clearcut as compared to an old growth forest. However, behaviors used to survive drought have not been described.

Temperature Requirements and Adaptations

Preferred body temperature -- In studies of preferred temperatures, Brattstrom (1963) reported a body temperature mean of 13.3 C (range: 9.8 – 19.0 C, n = 13) for *R. aurora*[1], which was the lowest mean of the 12 *Rana* species studied. The mean for the Ranidae was 21.6 C.

Mechanisms of heat gain and loss-- Brattstrom (1963) reported that *R. aurora* uses solar radiation (e.g., basking) to raise its body temperature. However he noted "…the species usually remains in cool, moist places apparently so that the body temperature will not reach high levels." Brattstrom (1963) found that the primary ways amphibians gain heat are basking in sun, conduction from substrate and water, and convection from air. Heat loss occurs through conduction and radiation to the substrate (water and air), convection to air, and evaporative cooling. These mechanisms allow amphibians to be at somewhat different temperatures from those of the surrounding environment.

Critical thermal maximum and minimum-- These data are lacking for northern red-legged frogs. Brattstrom (1968) presents data from amphibian tests of the critical thermal maximum and minimum (the high and low temperatures where an amphibian turns onto its back, and is unable to escape from conditions that result in death). Of these, information for *R. cascadae, pretiosa, boylei* and *sylvatica* from British Columbia and California are likely the most relevant to *R. aurora*. Critical thermal maxima for these species were between 30.3 and 34.8 C. The critical thermal minimum (*R. cascadae* and *pretiosa* only) was –1.0 C. Brattstrom and Lawrence (1962) found that acclimation to lower or higher temperatures for 1 to 3 days lowered or raised (respectively) the critical temperature for amphibians. Specifically, the critical thermal minimum for *R. pipiens* decreased by 3.3 C, and the critical maximum increased for *R. palustris* by 1.7 C and *R. clamitans* by 5.1 C.

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[1] This study does not specify subspecies or location making it possible that the California red-legged frog (*R. aurora draytoni*) was either the focus of or was included in these results.

Response to Active Season Habitat Loss

No studies directly addressing effects of active season habitat loss on northern red-legged frogs exist. However, the results of one study (Chan-McLeod 2003) indicate that clearcutting forest habitat sharply reduces northern red-legged frog active season use of that habitat. Chan-McLeod (2003) found 86% of frogs during 120 trials, each averaging 22 days, used old-growth forest habitat nearly exclusively as compared recent clearcut habitat. Those frogs that primarily used the old growth forest but also used the clearcut only moved short distances into the clearcut and only for short (unspecified) lengths of time.

The remaining 14% of the frogs stayed in the clearcut for several days, or moved through it (Chan-McLeod 2003). A higher proportion of frogs (28/40) ventured into a clearcut with a young stand of trees < 4 m high, than into clearcuts with sparse newly planted young trees (3/40 and 5/40). In addition, frogs that moved into the clearcut stayed close to the forest edge (12.7 m) whereas those in the forest stayed 44.3 m from the edge.

Causes of Mortality to Terrestrial Red-Legged Frogs

Predators of the red-legged frogs during terrestrial habitat use include the common garter snake (*Thamnophis sirtalis pickeringii*) (Gregory 1978, 1979; Shean 2002), mink, otter, and potentially raccoons (Appendix I). Human caused (or related) terrestrial mortality factors include vehicle traffic (Beasley 2002). Although skin toxins of northern red-legged frogs are generally thought to be effective in preventing predation by domestic cats (Hayes, pers. comm. 2002) domestic cats have been observed to catch and play with this species, which can lead to mortality (Milne, pers. comm. 2002).

CHAPTER 2. METHODS

Site Description

The 1.95-ha study area (Fig. 2) is in the Puget Lowland Ecoregion (Omernik 1987), within Thurston County, Washington. The climate is temperate, with cool wet winters, and warm dry summers. Annual precipitation in this ecoregion is 88 to 125 cm (Omernik and Gallant 1986). Approximately 40% of the study area perimeter (along the north and west sides) is bordered by forest. The other 60% of the perimeter is tidal. A tidal cove borders the east portion of the site, and an estuarine channel runs along the southern boundary. The upstream-most 20 m of estuarine stream at the site is tidally inundated only at the highest tides, whereas the rest of the channel is typically inundated at every high tide.

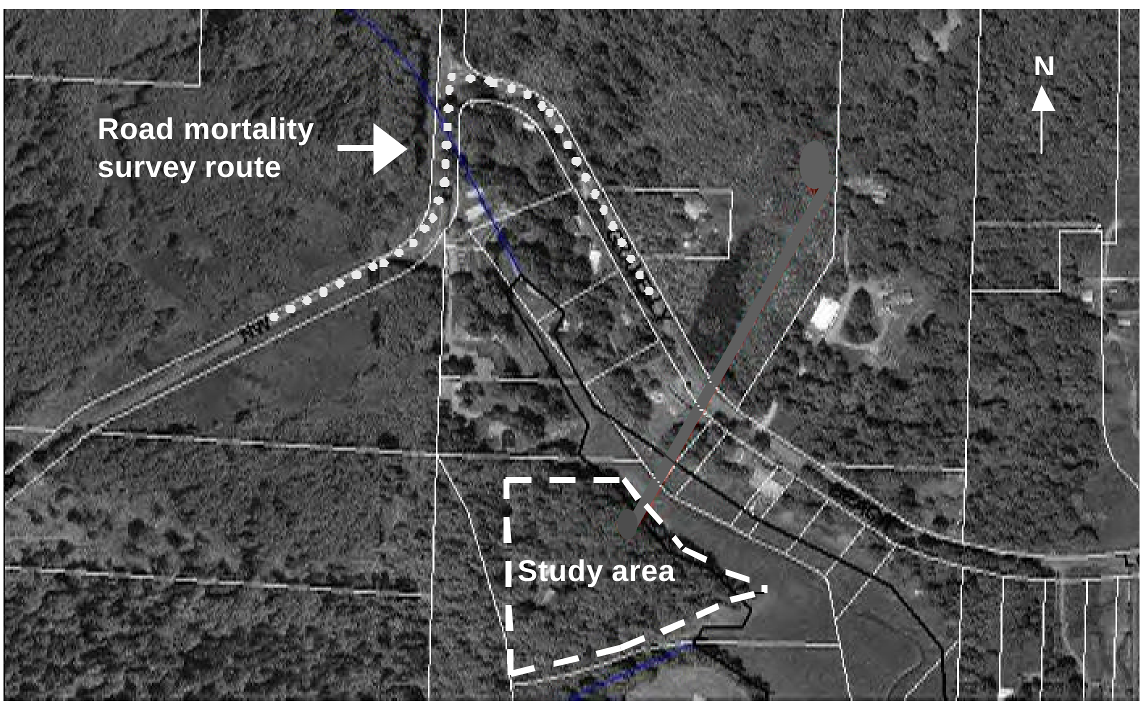

Figure 2. The study area location and the road mortality survey route. Base photo from Thurston County Geodata.

The study site includes 1.59 ha of forest and 0.36 ha of open habitat. The forest has mature trees including grand fir (*Abies grandis)*, big-leaf maple (*Acer macrophyllum)*, Douglas-fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*) and red alder

(*Alnus rubra*). The shrub layer is dominated by sword fern (*Polystichum munitum).* In spring the herbaceous layer has dense candyflower (*Montia sibirica),* water-leaf (*Hydrophyllum* sp.) and bleedingheart (*Dicentra formosa*), most of which die back by late summer. Abundant coarse and fine downed wood, combined with leaf litter and shrubs create a complex near-ground structure through most of the forest.

The open habitat is a human-created opening within the forest. It includes areas of grass/forbs, garden, shrub, and remnant forest/shrub. This area also includes a house, gravel driveway, and wood chip paths. Interspersed remnant patches of forest exist within the opening.

Potential predators of the northern red-legged frog that I have observed at the study site are river otter (*Lutra canadensis*), mink (*Mustela vison)*, raccoon (*Procyon lotor*), great blue heron (*Ardea herodias*), and garter snake (*Thamnophis sirtalis*).

Additional animal species that I have observed at the study area that typified the animal community include black-tailed deer (*Odocoileus hemionus*), chickaree squirrel (*Tamiasciurus douglasi*), northern flying squirrel (*Glaucomys sabrinus*), opossum (*Didelphis virginianus*), barred owl (*Strix varia*), belted kingfisher (*Ceryle alcyon*), winter wren (*Troglodytes troglodytes*), golden-crowned kinglet (*Regulus satrapa*), American robin (*Turdus migratorius*), black-throated gray warbler (*Dendroica nigrescens*), Wilson's warbler (*Wilsonia pusilla*), spotted towhee (*Pipilo maculatus*), song sparrow (*Melospiza melodia*), northwestern salamander (*Ambystoma gracile*), long-toed salamander (*Ambystoma macrodactylum*), rough-skinned newt (*Taricha granulosa*), western red-backed salamander (*Plethodon vehiculum*), ensatina (*Ensatina eschscholtzii*), Pacific chorus frog (*Pseudacris regilla*), banana slug (*Ariolimax columbianus*), Western tiger swallowtail butterfly (*Papilio rutulus*), and Clodius parnassian (*Parnassius clodius*). Non-native species present included: domestic dog, cat, and various slugs.

Demographics

Study Site Set-Up and Location Reference

The study area had a staked 10 by 10 m (100 m^2) grid established for use with random selection of visual encounter survey quadrats. I recorded data within each 100 m^2 area to an accuracy of 6.25 m^2 by locating 1/16 sections within the larger area. I used aerial photography to determine the locations of telemetered frogs that traveled outside the study area.

Study Site Stratification

The sample design utilized forest and open areas as strata. Within the forest, substrata (macro-habitats) were shrub, herbaceous, shrub/ravine, shrub/slope to shoreline, shrub/shoreline cliff, tidal channel, and branch pile. Open area substrata were grass/forbs, garden, shrub, and remnant forest/shrub.

Off-site forest substrata were shrub/hillslope plateau and shrub/hillside.

Survey Techniques

Time-constrained searches-- Prior to completion of the site grid, I conducted seven 1-hr time-constrained searches April through the end of May 2001. Each survey included 20 min in the open stratum, and 40 min in the forest stratum. Surveys were done by walking with no specific pattern, but through as much of a stratum as possible within the indicated time limits, closely observing and listening for any signs of frogs. The netting on a butterfly net was used to lightly disturb ground and shrub vegetation for a swath ca. 1.5 m, in front and to the sides of the walking path. If a frog was observed, the time was stopped, and then restarted after data collection on the frog and habitat was completed.

Area-constrained searches-- From June through October 2001, I conducted area-constrained surveys in the forest and open strata using a stratified random sample design. Sample quadrats were randomly chosen each week based on the use of an octal table (Heyer et al. 1994), and I alternated the survey start order between open and forest strata each week. During each weekly survey, I searched for 6 min in each of nine 100 m^2 quadrats in the forest and six 100 m^2 quadrats in the open for a total search time of 90 min. The boundaries of quadrats to be searched were typically roped at waist level the day prior to the survey to provide clear delineation of survey areas.

Surveys were done by walking an inside perimeter corridor and searching a ca. 3 m swath, and then searching between both sets of opposite corners with a focus on the interior area of the quadrat, while observing for frogs, and listening for noise that could be from frog movement. As in time-constrained searches, a butterfly net was used to lightly disturb ground and shrub vegetation for a swath ca. 1.5 m along the walking path.

As time allowed, downed wood was picked up, or lightly jostled, and the area beneath sword ferns was more closely observed. If a frog was observed, the time was stopped, and then restarted after data collection was complete.

Drift fence/trap arrays-- I also captured frogs using drift fence arrays. I established 10 arrays. Seven were in the forest, two were in the open area, and one was on the edge between open and forest strata (Fig. 3). I randomly selected the placement of arrays with the additional constraints that arrays could not be within 20 m of each other, and that forest arrays would be dispersed within different sectors of the forest. The latter dispersion was accomplished based on breaking the full forest area into three ca. equal-sized areas which each had two randomly placed arrays, and one area that was ca. ½ the size of the other three, that had one randomly placed array.

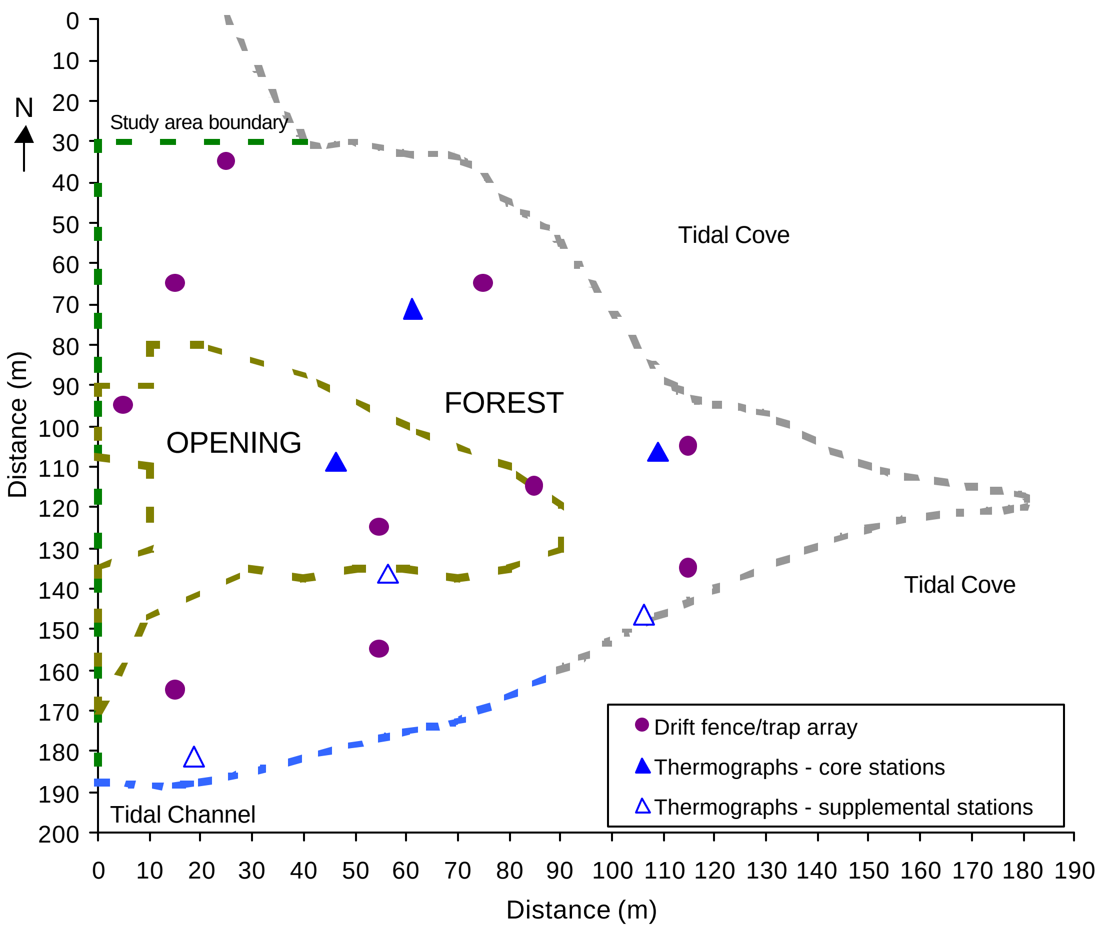

Figure 3. Locations of drift fence/trap arrays and thermographs.

Each array had three drift fence spokes; each spoke was 4 m long and at least 20 cm high. Spokes were joined at one end in the center of each array and placed at equidistant angles, with one spoke facing east. I used logs, wood planks, or garden fabric for fence material. The base of each fence was buried or positioned in a manner to prevent frogs from traveling under.

Each array included six funnel traps. These traps were placed mid-way along each side of each fence. I constructed traps from 0.9 cm mesh plastic garden fencing. Each trap was 70 cm long, had a 20 cm radius, and had a 6 cm wide inverted funnel entry at each end. I used plastic cups to close the funnels and ensure that animals did not enter when the traps were not in use. I concealed traps with pieces of old wood, moss, and clipped sword fern fronds.

From July to November 2001, I opened traps following the completion of weekly area-constrained searches. My standard protocol was to leave the traps open for 2 days and during this time, and to check each trap once daily. However, during hot weather, I only kept traps open for 1 day, and I checked traps in warmer exposed locations twice daily to lessen the likelihood of trapped animal mortality. In the fall, traps were checked daily but left open for longer periods of time (maximum 7 days).

Initially, I left traps concealed as described above and investigated for frog catch by looking into the traps with a flashlight. However, using this method caused me to overlook three frogs (all the same week), that subsequently died before the next week's surveys. After this occurrence, I changed my methodology to completely remove traps from their concealed location to ensure I found any trapped frogs.

Drift fence arrays were operated for 33 days. All but the first two days included the full set-up of 10 arrays, with six traps per array, giving an overall trapping effort of 1894 24 hr trap days.

Opportunistic sightings-- The opportunistic sightings survey type included any frog that I observed at the study area that was not part of the other survey techniques described above.

Road mortality-- Road mortality surveys were done by foot on 6, 8, 9 and 10 November 2002 along a 0.5 km stretch of road (Fig. 2). I chose this timing as it was after a heavy rainfall during the fall, making it likely that frog movement would be occurring. I conducted the surveys by closely observing one lane and the road edge while walking one side of the road, and then doing the same in a return loop along the other side of the road. All animals found were removed to prevent recounting on subsequent trips. Most animals were pulverized and dispersed, preventing their measurement and preventing an exact count. Snout-vent length was measured if possible, and general size categories of small, medium, or large were used where reasonable. Other amphibian species besides northern red-legged frogs were recorded during the surveys.

Frog Data and Techniques

Standard data were taken when a frog was observed. These included date and time, frog measurements, tag number (see below), behavioral observations, habitat characteristics, environmental measurements, and location. I was not able to catch all frogs that I observed. I collected data as follows for those frogs that were caught (study years 2001 and 2002), (1) SVL and shank length to the nearest mm, (2) weight with a 100 g Pesola scale to the nearest 1 g as a mass equivalent, (3) frog gender (or potential characteristics where I was not able to discern gender), (4) moisture condition (categories of dry, moist, wet, determined typically by holding the frog: dry was dry to my touch, moist was some moisture evident, and wet was where a frog exuded water, causing my hand to drip), (5) condition appearance (ventral skin folds evident versus appearing well-fed and rotund), and (6) behavioral observations. In 2000, only frog location and SVL were taken. Frog measurements were typically taken at monthly intervals in 2001 if frogs were recaptured. In 2002, measurements were taken weekly if recaptures occurred.

Using sterile techniques, I inserted a passive integrated transponder (PIT) tag (Biomark, Inc., 134 N. Cloverdale Road, Boise, ID) under the dorsal skin of all frogs caught (except those that escaped before I was able to insert the tag). The tags were 125 kHz, 11.5 by 2.1 mm in size. Each tag contained a unique 10-digit alphanumeric code that allowed individual frogs to be subsequently identified. I used a Destron Pocket Reader model HS9250L1 which can scan a tag that is within 5 cm, to read the tags.

Captured frogs were held until the end of the survey (typically a maximum time of 3 to 5 hr) in mesh minnow traps, and then released at their capture locations.

Environmental Conditions

Environmental Data Taken at Frog Observation Sites

Environmental data that I collected at each frog observation site included (1) air temperature 1 cm above ground, (2) ground temperature 1 cm below the ground, and (3) ground surface moisture. Air and ground temperatures at frog sites were taken 5 to 20 min following the frog capture or observation time. Air measurements in 2001 were taken with a digital thermo-hygrometer (accuracy 0.1 C), and ground temperatures were taken with a Taylor temperature probe (read to the nearest degree C). In 2002, a model Temp 5 Oakton electronic thermometer (accuracy 0.2 C) with probe was used for all temperature measurements.

Ground surface moisture was determined using the following scale: (1) dry, no evidence of moisture; (2) moist, soil color looks damp and soil feels damp to the touch; and, (3) saturated with soil visibly full of water and wet to the touch.

Study Site Environmental Measurements

Additional data were taken to provide a broader characterization of survey quadrats and the study area. These measurements included (1) quadrat moisture condition, (2) air and ground temperature, (3) precipitation, and (4) tidal channel salinity. In addition, off-site precipitation and air data were obtained.

Quadrat ground moisture condition-- Quadrat moisture condition was determined during area-constrained searches through visual observations of surface moisture, and by examining leaf duff and wood to check for indications of moisture. I visually estimated the ca. surface area percent of the quadrat that contained moisture.

Temperature-- Continuously recording thermographs were installed at the study area to characterize differences between strata, and between ground and air, and one branch pile. Air thermographs were installed at three "core" sites on 4 June 2001 to provide broad scale coverage of near shoreline, in forest, and open (near garden) study area conditions. On 9 August 2001, ground thermographs were added to the core sites, and "supplemental" thermographs were additionally installed at three locations where frogs had been observed (Fig. 3). Table 2 provides information on thermograph make, model, settings, and field deployment locations. Air temperature data from The Evergreen State College were used for dates that preceded the installation of study site thermographs.

Table 2. Thermograph and station characteristics[a].

Location	Description	Type	Stratum	Start	End	Make	Model
Core							
Open site A[b]	Near garden	Air	Open	4-Jun-01	11-Jan-02	Onset	Stowaway XTI
Open site A[c]	Near garden	Ground	Open	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site A[d]	Near shoreline	Air	Forest	4-Jun-01	11-Jan-02	Onset	Stowaway XTI
Forest site A[e]	Near shoreline	Ground	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site B[f]	In forest	Air	Forest	4-Jun-01	11-Jan-02	Onset	Stowaway XTI
Forest site B[g]	In forest	Ground	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Supplemental							
Forest site C[h]	Cliff at shoreline	Air	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site C[i]	Cliff at shoreline	Ground	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site D[j]	Ravine	Air	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site D[k]	Ravine	Ground	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site E[l]	Edge branch pile	Air	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Forest site E[m]	Edge branch pile	Under pile	Forest	9-Aug-01	11-Jan-02	Onset	Optic Stowaway
Roving		Air	All	9-Aug-01	11-Jan-02	Onset	Optic Stowaway

[a]Settings for all instruments: interval frequency 1 hr, 100 points, average mode. Pre and post calibration results excellent. All instruments within 0.25 C of each other.
[b]Installed 20 cm above ground, 100% cover, site with remant vegetation.
[c]Buried 4 cm under soil, plus under 7 cm of light duff, site with remnant vegetation.
[d]On tree side 20 cm high, 100% shade. Site has slight slope aspect toward cove.
[e]Buried 4 cm under soil, plus under 7 cm of light leaf duff. Slight slope aspect toward the cove.
[f]On post 20 cm from ground. Partial sun, probe case covered with leaves for additional shade.
[g]Buried 4 cm down in soil, plus under 6 cm of light duff. Partial sunlight.
[h]Placed in opening under root wad. This site 2.0 m above mudflats, in overhanging ledge on 3.0 m high cliff. Site faces SE to mouth of tidal channel.
[i]Buried 4 cm under soil and 6 cm of leaf duff. Rest same as for note h.
[j]Placed at top of duff (16 cm deep) on tree. Site has south aspect. Instrument is 5.0 m from stream, 3.5 m high on side of ravine.
[k]Buried 4 cm under soil and under 10 cm of leaf duff. Rest same as for note j.
[l]Placed 4 cm above ground, shaded by large down wood.
[m]Under old branch pile. Instrument inserted 60 cm deep into middle of pile, close to ground. Pile is 0.7 m high, 4.0 m long and 1.2 m wide.

Thermographs were calibrated according to Schuett-Hames et al. (1999). All temperature equipment was checked against a certified reference thermometer (HB model 23421) to ensure instrument accuracy.

Precipitation-- The primary source of precipitation data was the weather station at The Evergreen State College, 3.5 km southeast of the study area. I estimated missing records using data from the National Weather Station gage located at the Olympia Airport, 15.5 km southeast of the study site.

Tidal channel salinity-- I used a Hach conductivity meter, model 2510 with an accuracy of +/- 2% of full scale to measure salinity. I took salinity measurements during an incoming tide at 12 locations within the flowing channel that forms the southern boundary of the study site, each at 10 m intervals longitudinally along the channel. Samples taken at distances 100 m and 110 m were of incoming tidal waters, all other stream samples were taken upstream of tidal waters. I also took samples from five pits (dug for this purpose) within 2.5 m of the flowing stream and within the tidal zone, to represent potential locations where a frog might sit. The pits were left to fill through subsurface infiltration for 1 hr before sampling.

Salinity readings were taken in micromhos/cm and converted to mg/l sodium chloride through use of a conversion chart provided with the instrument. For analyses, this data was further converted to ppt sodium chloride.

Flow was estimated at the upstream end of the channel within the study area using a rough approximation of flow depth, width, and velocity.

Terrestrial Natural History and Behavior

Radio Telemetry

I attached radio transmitters to 10 frogs between mid-July and the end of December 2001. No more than two or three frogs were tracked simultaneously. I used standard (BD-2G) and temperature sensitive (BD-2GT) transmitters (Holohil Systems, Ltd., 112 John Cavanaugh Road, Carp, Ontario, Canada KOA 1LO). An external waist belt was used to attach transmitters to frogs. It was made of either satin ribbon (0.3 mm to 0.6 mm wide) or bootlace material (0.7 mm wide) sewn to a custom-sized fit on each frog. Varying transmitter/belt combinations weighed 2.0 g to 2.5 g.

Transmitters can impede frog movement, potentially affecting frog behavior, so transmitter mass should not exceed 10% of an animal's mass (Richards et al. 1994). Based on this I attached radios only to frogs with a mass 30 g (7% of frog mass). I radio-tagged only females because no males were large enough to meet the criterion. In my original study design, I had planned to use only frogs found during trapping or area-constrained searches, but due to the difficulty in finding enough suitably sized frogs, I ended up using any frogs found that met the mass criterion.

Abrasion from attached belts can cause open sores on anurans (Rathbun & Murphey 1996; Chan-McLeod 2003). I treated the first signs of dorsal abrasion with antibiotic cream (Neosporin, Polymyxin B Sulfate – Bacitracin Zinc – Neomycin Sulfate). If sores reached 3 mm in length, I removed the telemetry gear.

I located telemetered frogs typically once a week using a Telonics Model RA-14 antenna with a Telonics TR-4 receiver. Either apparent loss of reception from selected transmitters or inability to find frogs (i.e., reception occurred but the frog could not be found) led to less frequent data collection intervals in some cases. Intensive effort on additional days (such as during video data collection) also occurred. During October to December 2001, with assistance from Washington Department of Fish and Wildlife personnel, frog locations were checked as often as daily to better resolve possible seasonal movements.

Video

Video data were taken of frogs in undisturbed locations and postures on 13 and 26 August, and 4, 13, 17 September (late summer), and 23 September (early fall) 2001. During these sessions, four different frogs were taped. One of these frogs was observed on 3 days, one on 2 days, and two each on 1 day.

A Sony 24x Digital Zoom 8 mm camera, model CCD-TRV21 was used. The camera was attached to a tripod, and set up 1.5 to 7.0 m away from an individual frog, which was beyond the typical flight distance I observed of ca. 0.5 m. Using the zoom function, the frog was brought into close-up view, with between 10 and 20 cm of surrounding habitat also visible. After set-up, I left the area to reduce the likelihood that human presence affected frog behavior, and typically returned once per hour to assure that the frog was still in the observation area and that the camera was still running. Video footage was taken until the tape or battery ran out, the frog left the video location, or it became too dark for observation.

Frog Data and Techniques

Standard data were taken when a frog was observed as described earlier. Additional observations included a description of movement behavior (e.g., number of hops) if the frog had moved when I approached. If the frog was observed in an undisturbed location, body posture and structural location (e.g., on ground or elevated on fern) were described.

Habitat Data Taken at Frog Observation Sites

Habitat characteristics recorded were (1) stratum and sub-stratum (described earlier), (2) microhabitat (i.e., a brief description of the 5 cm area around the frog), (3) distance to the stratum edge if it was within 5 m, and (4) distance to and description of refuge habitat containing complex vegetative or wood structure.

Data Analysis

Demographics

Catch per unit effort (CPUE)-- I calculated CPUE for time and area-constrained searches for spring, early summer, mid-to-late summer, early fall, and mid-fall.

Population numbers-- Estimates were developed for 2001 data using three methods.

1. The number of frogs caught during area-constrained searches was expanded to the full study area by multiplying the number of frogs per sample quadrat in each stratum by the number of quadrats in the stratum, and then adding the totals for the two strata together. This was accomplished for each survey week, and the sum for the week with the largest extrapolated value was used for the population estimate.

2. The total number of uniquely identified frogs from all survey types in 2001 was determined. This was derived from a direct count of PIT tagged individuals and non-tagged trap mortalities.

3. A Schnabel mark and recapture population estimate based on recaptures of PIT tagged frogs was performed. Tag and non-tag data from area-constrained searches and from frogs found opportunistically during area-constrained search days were used for the Schnabel population estimate (following Smith 1974). This method allows for accumulation of captures and recaptures. One condition of the method is that the population be closed, but because some of the study frogs were likely migratory, I cannot assume this condition was met. Confidence intervals for the Schnabel estimate were based on Hall (1992).

Capture rates in open versus forest strata-- I used a non-parametric Wilcoxon Rank Sum Test to evaluate whether rates of frog capture for the two strata (forest, open) were significantly different.

Size, gender and age-- Analysis of size, gender and age was done only for those frogs that were caught, and with the exception of three frogs from 2000 that lacked PIT tags, all data was for frogs to which I gave unique marks. In the analysis of these parameters I assume that the untagged frogs were not recaptured.

I found gender difficult to determine. I identified the larger, round-shaped frogs as females, however, I was unable to determine the gender for many frogs of small and intermediate sizes. Hayes (pers. comm. 2001, 2002) identified the gender of two frogs. I based positive identification of males on the presence of darkened thumb-pads. During data analysis I further identified any frogs that were > 69 mm and not already identified to gender, as females, based on Nussbaum et al. (1983).

I computed annual changes in SVL and mass for frogs with more than one year of data using measurements with the closest dates to a one-year interval. I computed within-year SVL and mass growth rates for frogs with more than one measurement date over a minimum interval of 4 weeks. To do this, I used the earliest and latest (through mid-fall 27 November) measurements within the year for each frog. I normalized both sets of data by computing a daily rate.

I used a t-test based on unequal variances to determine the significance of differences between within-year and annual SVL growth rates.

Environmental Conditions

Seasons-- Seasonal periods used in analyses were based on the standard dates for spring, summer, fall and winter. I further divided the seasons (e.g., early summer) based on visual analysis of the 2001 temperature and precipitation data, for intervals where the environmental conditions were changing.

Study area moisture conditions-- I analyzed the percent of open and forest habitat in the study area that contained ground level moisture (i.e., moist soil, humus, leaf-duff, low plants and downed wood) for bi-weekly intervals from early April to late December 2001. For this analysis, I utilized quadrat moisture conditions from area-constrained surveys (June through late October 2001), and developed a mean moisture condition for each survey, for both open and forest habitat, and then developed the mean for the bi-weekly periods by averaging the means from each consecutive two adjoining weeks. For time intervals before and after the completion of area-constrained surveys, I relied on field notes and precipitation data to estimate the ground moisture condition.

Air and ground temperature variances-- I used a two sample F-test for variances to determine whether the mean daily maxima for the ground for the three core stations fluctuated less than the mean daily maxima for the air at the three core stations. Data tested were from 9 August to 31 December 2001.

Natural History and Behavior of Terrestrial Northern Red-Legged Frogs

Fall movement patterns-- I computed the ratio of newly captured and tagged frogs within each season, to the total number of uniquely identified frogs caught within that season, to discern movement into the study area by frogs in the fall. I also used seasonal differences in catch per hour for area-constrained searches to infer whether fall movement might be occurring.

Active season and winter home ranges-- Active season home ranges were developed as follows. A length was determined for the distance between the two observation points furthest from each other. A maximum width was determined by taking the greatest width (perpendicular to the maximum length line) of the polygon drawn around all observation points.

Video-- I transferred 8 mm imagery to VHS and analyzed frog movement by observing the images on a VHS equipped television. I briefly described each frog movement. Time, behavior category (based on a system I developed for this study), and movement duration in seconds were determined. Total time for each frog observation period was determined through a time stamp on the footage, or through the embedded time system in the tape. Many activities occurred in 1 sec, but all activities were allocated a minimum of 1 sec for data analyses.

CHAPTER 3. DEMOGRAPHIC RESULTS

Based on all survey types except telemetry, I recorded a total of 116 frog sightings or captures in 2001 (Appendix A). Of these, nine were from time-constrained searches, 29 from area-constrained searches, 69 from opportunistic encounters, and nine from traps.

In this chapter I report population numbers for 2001 using three different analyses: CPUE for time and area-constrained surveys, a direct count of uniquely identified individuals, and a Schnabel mark and recapture population estimate. I also report size and gender data for a longer interval (2000 to 2002), and provide limited data on frog age, deformities, and mortality.

Population Numbers (Year 2001)

CPUE

The CPUE[1] combined average for all time-constrained and area-constrained searches was 1.0 frog per hour (Table 3). Area-constrained searches had a lesser overall CPUE of 0.9 frogs per hour. Seasonally, I observed substantial changes in CPUE among the five time intervals where area-constrained searches could be compared. Mid-fall (CPUE 1.5) was the most productive interval. This was followed by early summer (CPUE 1.0), early fall (CPUE 0.9), and mid-to-late summer (CPUE 0.8), which had similar values. Spring (CPUE 0.4) had the lowest value among area-constrained intervals.

Drift Fence Catch

Drift fence efficiency was low (Table 4). Nine frogs were captured in the traps for a mean of 4.8 frogs per 1000 trap days. Five of the frogs were caught in the same array (located in the forest near the shoreline) in the fall; of these, four were caught in the same trap. The two western-most arrays in the forest caught frogs in late summer (two frogs were caught at different traps in one array, and the other array caught one frog). These latter three trapped frogs escaped my detection and died in the traps. In early fall, an array in the open stratum caught one frog. Between 16 October and the termination of trapping on 5 November, frogs were only observed through trap catch (n = 3), or through telemetry.

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[1] In this context, catch also includes frogs that were observed but which evaded capture.

Table 3. Time-constrained and area-constrained search catch per hour (2001).

	No. Surveys	No. Hours/ Survey	No. Hours Total	No. Animals Total	Catch/ Hour
All time-constrained and area-constrained surveys[a]	28	1.5	42.0	43	1.0
Area-constrained only					
Spring	3	1.5	4.5	2	0.4
Early Summer	2	1.5	3.0	3	1.0
Mid to Late Summer	7	1.5	10.5	8	0.8
Early Fall	5	1.5	7.5	7	0.9
Mid Fall	4	1.5	6.0	9	1.5
Totals for area-constrained surveys	21	1.5	31.5	29	0.9

[a]Time-constrained surveys were before 4 June and were each 1 hour. For this calculation, the pre 4 June number of animals was multiplied by 1.5.

Table 4. Drift fence catch per trap day (2001 data).

	No. Survey Days	No. Traps[a]	No. Trap Days Total	No. Animals Total	Catch/ Trap Day
Early Summer	2	17	34	0	0.0000
Mid to Late Summer	7	60	420	3	0.0071
Early Fall	9	60	540	2	0.0037
Mid Fall	15	60	900	4	0.0044
Totals for all survey days	33	60	1894	9	0.0048

[a]Trap surveys were 1 day (24 hours) each. On 3 July, 14 traps were used; on 4 July, 20 traps were used. All other days had 60 traps.

Area-Constrained Catch Totals

A total of 29 frogs were caught (or observed) during the 21 area-constrained surveys (Fig. 4, Appendix B). These data do not differ significantly from a Poisson distribution (Chi-square test: $\div^2$ = 0.8070; p = 0.6669).

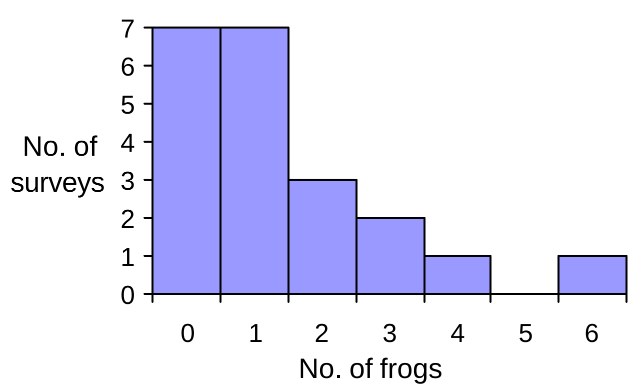


Figure 4. Frequency distribution: number of frogs found during 2001 area-constrained searches.

Based on area-constrained catch results, I caught a mean of 1.38 frogs per survey with 95% confidence limits of 0.65 and 2.11. When samples were extrapolated to the entire study area (i.e., 195 100 m^2 quadrats), the mean number of frogs represented was 18, but the weekly-extrapolated numbers ranged from 0 to 78 (Appendix B).

Frog Observation Numbers Open Versus Forest

I had a higher rate of frog capture (and non-capture observations) during area-constrained searches in the open versus the forest habitat strata (Appendix B). The mean number of frogs located per 100 m^2 quadrat was 0.12 in the open stratum (i.e., 1 frog for every 833 m^2 searched) and 0.07 in the forest (i.e., one frog for every 1,429 m^2 searched). Due to the large number of surveys with no catch (62% of forest surveys and 48% of open stratum surveys), catch data were extremely skewed. The capture rate in the open habitat was not significantly greater ($p = 0.14$) than that in the forest.

Frog Numbers Based on Unique Identification

In 2001, I recorded 51 different frogs using unique PIT tag marks. With the addition of three non-tagged frogs found dead in traps, I estimated a minimum population size of 54 frogs.

Schnabel Mark and Recapture Population Estimate

Through all study methods, the 51 tagged frogs were involved in 84 captures for 2001. Figure 5 shows the frequency of capture for tagged frogs (excluding data from telemetry). Most frogs, (n = 34), were captured just once. A total of 14 frogs were captured two or three times. Additionally, three frogs were captured four, five and seven times.

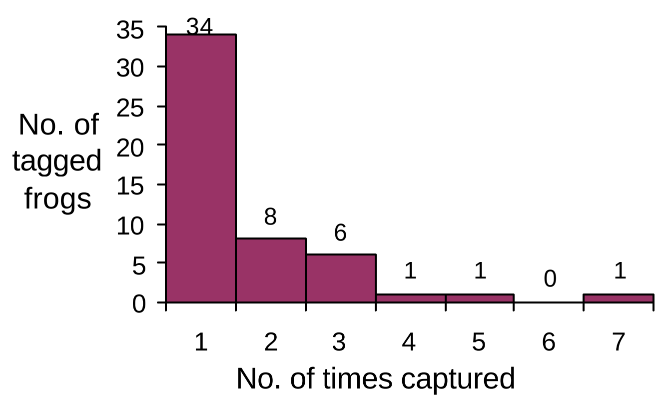


Figure 5. Frequency of tagged frog capture through all survey types, during 2001.

Due to the overall low recapture frequency of tagged frogs, I utilized all data for frogs that were captured on area-constrained search days for the Schnabel population estimate.

Thus a total of 35 frog observations including seven recaptures were used for the analysis (Appendix C).

The mark-recapture analysis indicated a maximum study area population estimate of 60 (95% confidence interval of 60 +/- 81) frogs for 15 October 2001 (Table 5). This was based on 25 marked individuals and seven recaptures over the analysis interval.

Table 5. Schnabel population estimates (using frog observations from area-constrained search days in 2001).

Date	A No. Caught	No. Marked	B No. Marked in Area	(A)*(B)	(A)*(B) Sum	Recap-tures	C Sum of Recaptures	(A)*(B) Sum/(C) Est. Pop.
4-Jun	1	1	----------------	--------------	0	------------	-----------------	------------------
18-Jun	2	2	1	2	2	0	0	------------------
25-Jun	2	1	3	6	8	0	0	------------------
16-Jul	2	1	4	8	16	1	1	16
30-Jul	1	1	5	5	21	0	1	21
6-Aug	2	1	6	12	33	1	2	17
13-Aug	1	1	7	7	40	0	2	20
20-Aug	1	1	8	8	48	0	2	24
26-Aug	6	5	9	54	102	0	2	51
3-Sep	4	3	14	56	158	1	3	53
10-Sep	1	1	17	17	175	0	3	58
17-Sep	2	0	18	36	211	2	5	42
24-Sep	2	2	18	36	247	0	5	49
30-Sep	4	2	20	80	327	2	7	47
8-Oct	3	3	22	66	393	0	7	56
15-Oct	1	1	25	25	418	0	7	60

Summary of Population Estimates

The three estimates of the study population size are similar (Table 6). The direct count of uniquely identified animals provided the lowest value. Analysis of seasonal ratios of newly tagged frogs (Table 7) indicates that new frogs were found at a rate of 50% or higher throughout the study.

Table 6. Population comparison (2001).

Method	Total Frogs Est.	95% C.I.
Area-constrained searches weekly estimates	0 - 78	
Direct count of uniquely identified frogs[a]	54	
Schnabel estimate	60	+/- 81

[a]PIT tagged individuals and three frogs found dead in traps.

Table 7. Ratio of newly tagged versus total number of frogs caught seasonally (2001).

	Total No. Frog Captures[a]	No. of Frogs Newly Tagged	Ratio New/Total
Spring - Early Summer (2 May - 8 Jul)	20	15	0.75
Mid - Late Summer (9 Jul - 21 Aug)	20	10	0.50
Early Fall (22 Aug - 24 Sep)	27	15	0.56
Mid - Fall (25 Sep - 3 Nov)	17	11	0.65

[a]May have more than one recapture per frog. Note: on 21 August three no-tag frogs died in traps. Because they were unable to become part of the tag data set, they were not included in these numbers. In addition, frogs found and caught through telemetry are not included.

Maximum population estimates based on area-constrained searches (n = 78) and the Schnabel estimate (n = 60) were both larger than the direct count. Figure 6 shows that between 26 August and 15 October, the Schnabel estimates cluster between 42 and 60 frogs. The peak of 78 on 30 September from the area-constrained surveys estimate is also in the same time interval.

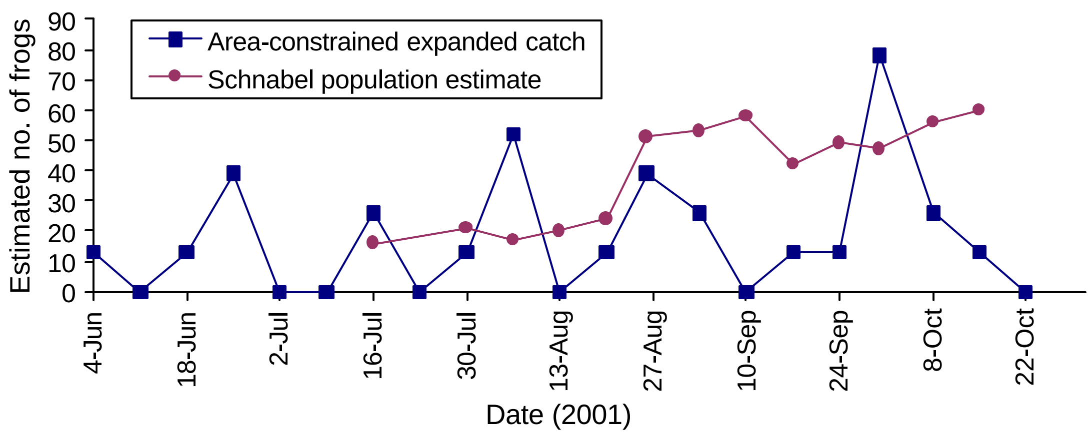


Figure 6. Comparison between area-constrained data expanded to the full study area, and the Schnabel population estimate.

Size, Gender, and Age

Gender, lengths, weight, and, where possible, an estimate of age for frogs caught during 2000 to 2002 are provided in Appendix D Table D-1. I made 136 measurement episodes on frogs. Of these, I measured 56 frogs only once. The remaining 80 episodes involved repeated measurements on 24 different frogs. In 2000, SVL was the only measurement taken. From 2000 to 2002, I obtained 135 SVL, 113 shank measurements, and 115 masses. Gender was identified on 25 different frogs: three were males and 22 were females.

SVL

Frog SVL ranged from 36 to 79 mm. The SVL of known females during 2000 to 2002 ranged from 49 to 79 mm. The mean of the maximum SVL measured for known females in 2001 was 69.3 (n = 16; *s* = 3.0). The SVL of known males ranged from 51 to 59 mm (mean of the maximum yearly SVL 2000 to 2002 = 55 mm, *s* = 3.5, n = 5[1]).

Figure 7 shows SVL data. Known females comprised the larger frogs, whereas known males fell into the middle and lower portions of the size range. The SVL measurement history for 23 frogs (nine females, three males, and 11 of unknown gender) illustrates growth.

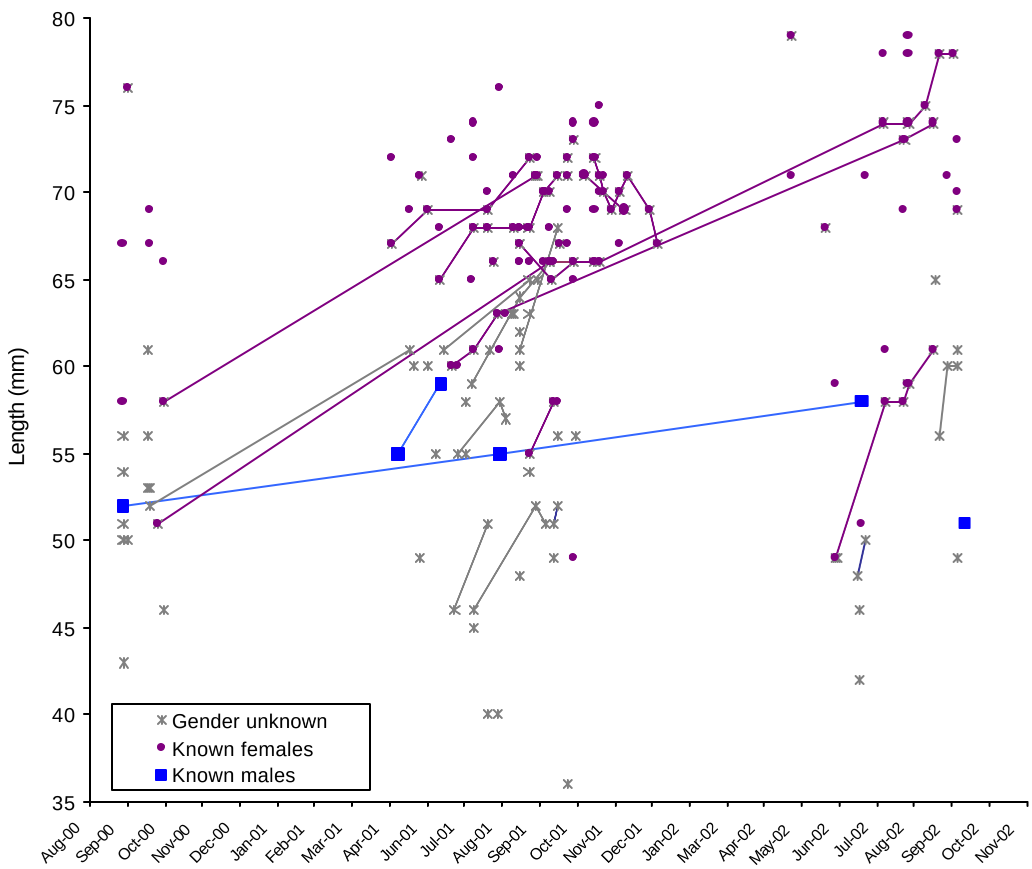


Figure 7. Red-legged frog snout to vent length measurements by gender, August 2000 through November 2002. In addition, the length growth patterns for 23 frogs with repeat measurements are indicated.

[1] One male was measured in 2000, 2001, and 2002.

Growth data are within-year and multi-year. Six frogs had multi-year SVL data (Fig. 7; Appendix E Table E-1). Of these, four females with recaptures spanning two years had a mean annual growth of 13.1 mm (range: 9.92 to 15.29 mm). One male caught in each of the three survey years grew 3.2 mm between 2000 and 2001, and 3.3 mm between 2001 and 2002. A frog of unidentified gender grew 13.9 mm between 2000 and 2001. The mean annual growth for all six frogs was 10.37 mm (range: 3.19 to 15.29 mm), equivalent to a mean daily growth of 0.03 mm (range: 0.01 to 0.04 mm).

I had within-year SVL growth data for six females (one had data for each of the 2 years), one male, and six frogs of unknown gender (Fig. 7; Appendix E Table E-2). The mean daily growth for females was 0.06 mm (range: –0.01 to 0.14 mm, n = 7), for the one male 0.11 mm, and for frogs unidentified to gender 0.11 mm (range: 0.05 to 0.21 mm). The mean daily growth for all frogs with within-year growth data was 0.09 mm (range: –0.01 to 0.21 mm) and was significantly greater than the annual rate (expressed as a daily rate) (Student t-test: $p = 0.0023$).

Shank Length

Shank lengths ranged from 21 to 45 mm (Appendix D Table D-1). Those of known females during 2001 to 2002 ranged from 28 to 45 mm. The mean of the maximum shank length measured for 15 known females in 2001 was 40.2 mm. Three known males in 2001 to 2002 had shank lengths that ranged from 30 to 36 mm.

Mass

Frog masses ranged from 3 to 48 g (Fig. 8; Appendix D Table D-1). May to November 2001 the masses of most frogs clustered between 10 and 36 g, and fewer data for 2002 showed a similar pattern. Larger frogs were female, and the masses of males overlapped little with known females. Small frogs (5 to 6 g) appeared in late July and early August 2001, and only large frogs (35 to 48 g) were found November through December 2001.

The masses of known females during 2001 to 2002 ranged from 11 to 48 g. The mean of the maximum mass measured for known females in 2001 was 35.8 (n = 16; $s = 5.4$). The masses of known males ranged from 11 to 23 g. Of the two known males in 2001, one was 16 g and the other was 23 g ($s = 5.0$).

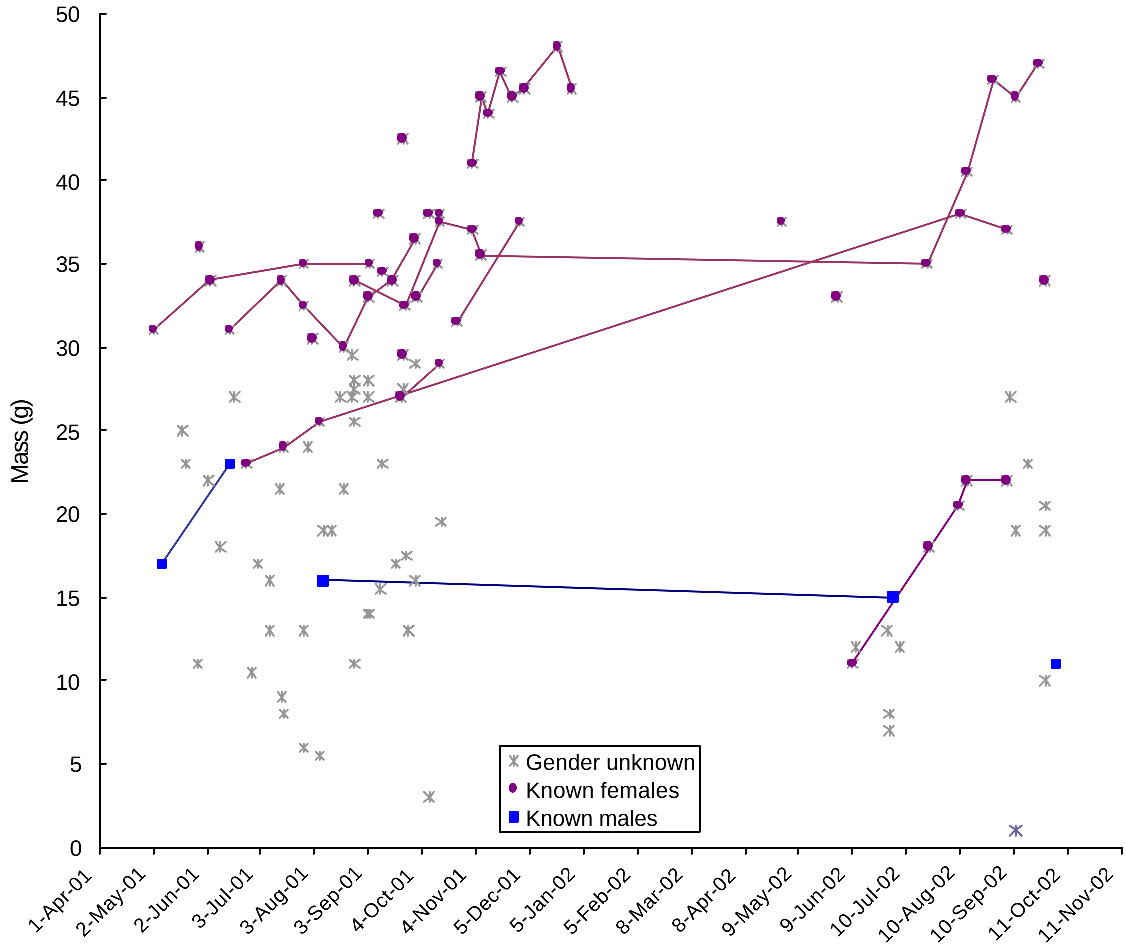


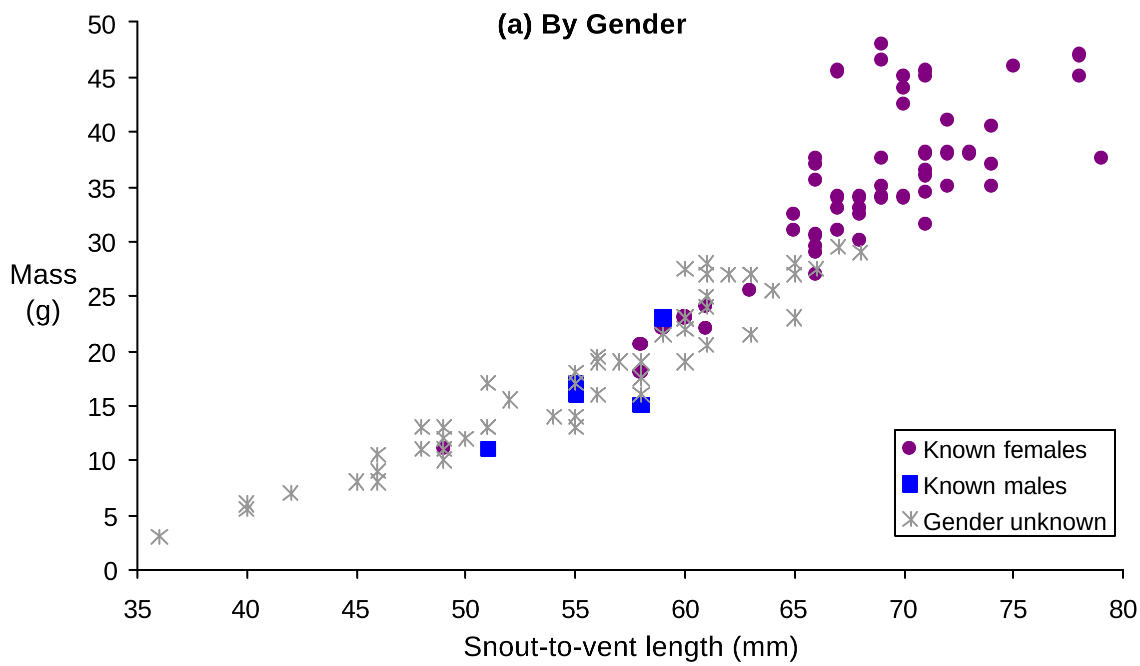
Figure 8. Red-legged frog weights by gender May 2001 through October 2002. In addition, the weight (mass) histories for frogs with more than one measurement point are indicated by lines that connect measurement points.

The measurement histories for 20 frogs with greater than one mass measurement indicate growth (Fig. 8). Appendix E Tables E-3 and E-4 provide analyses of multi-year and within-year mass data. For two female frogs that each had a year's data, the mean yearly increase in mass was 13.5 g (range: 12.4 to 14.5 g; daily increases in mass were 0.03 and 0.04 g). However, the one male with data over nearly a year lost 1.0 g, and therefore showed no daily mass increase.

In contrast, for 13 frogs where within-year data were taken, the mean daily increase in mass was 0.08 g (s = 0.01). The six known females had a mean daily increase of 0.08 g (s = 0.07), the single known male's daily increase was 0.16 g, and six frogs of unknown gender had a daily increase of 0.06 g (s = 0.04).

SVL and Mass Relationships

Mass varies with SVL (Fig. 9). Notably, the relationship between mass and SVL of known females > 64 mm was widely variable (Fig. 9a). This variability however was not evident in spring as compared to summer through early winter (Fig. 9b).



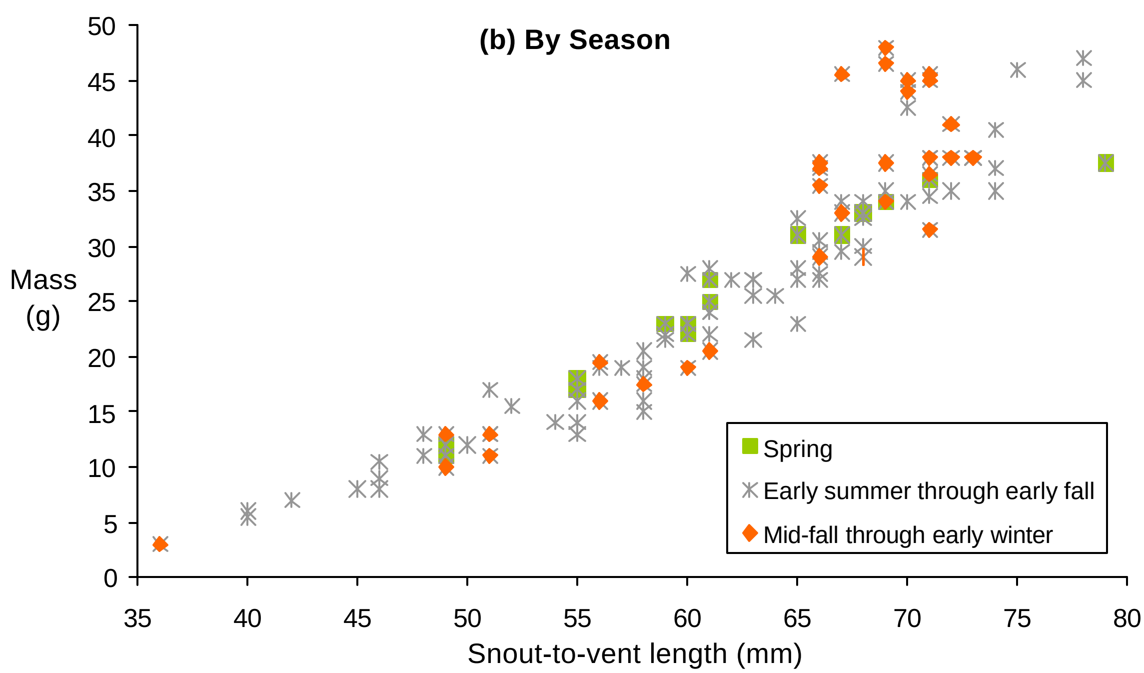


Figure 9. Northern red-legged frog snout-to-vent length and mass, by gender (a), and by season (b).

Deformity and Mortality Characteristics

Deformities or Injuries

I rarely encountered frog deformities or injuries. During 2000 I observed no frogs with abnormalities. During 2001 I found one frog that was missing an eye, and during 2002 I found one frog with no right hand and misshapen digits on its left hand. Based on the number of PIT-tagged frogs in each year, this represented an injury/deformity value of 2% for 2001 (n_{PIT} = 51), and 6% for 2002 (n_{PIT} = 16).

Mortalities

The only mortality I recorded on the study site involved three frogs that I found dead that had been caught in traps on 21 August 2001.

Fourteen piles of raccoon scat scanned with the PIT tag reader revealed no evidence of expelled PIT tags. I found no indication of mortality among telemetered frogs over the time interval (2 May 2001 to 29 December 2001) that I followed them.

However, using telemetry, I located a fall migration pathway used by at least some frogs from the study site. This pathway crosses a residential road. Between 6 and 10 November 2002 I found a minimum of 15 dead red-legged frogs on a 0.5 km survey stretch of this road (Fig. 2). The exact number was difficult to discern as most of the frogs were not intact. I also found 34 dead Pacific chorus frogs (*Hyla regilla*), one dead ensatina (*Ensatina eschscholtzii*), and one dead rough-skin newt (*Taricha granulosa*) during the same period.

CHAPTER 4. ENVIRONMENTAL CONDITION RESULTS

This chapter includes year 2001 temperature, moisture, and channel salinity results.

Study Site Temperature and Moisture Conditions

Seasonal Variation

Temperature and rainfall varied spring through early winter at the study site (Fig. 10). Early summer had the lowest seasonal percent of days with rain (17), and mean daily rainfall and air temperature values fell between values found in spring, and mid-summer through early fall.

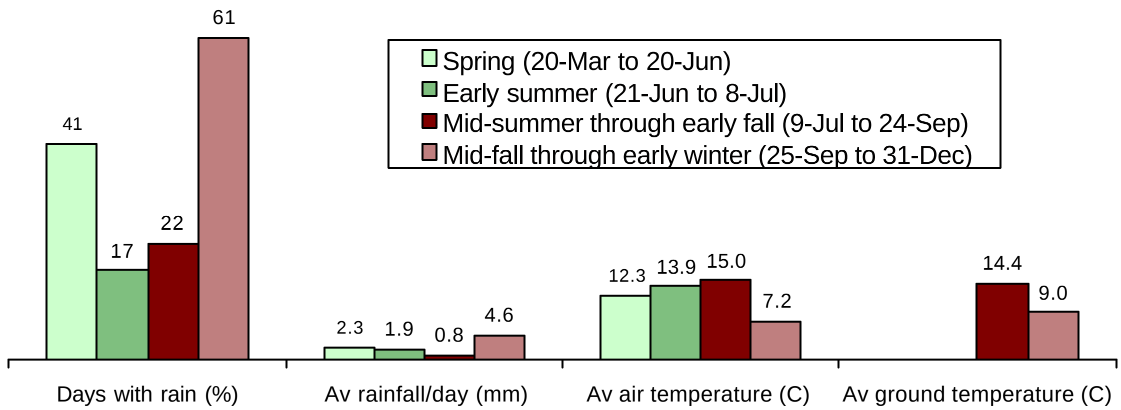


Figure 10. Seasonal precipitation and temperature regime at the study site in 2001.

The driest, warmest study interval was the 78-day mid-summer through early fall period; the mean air temperature was 15.0 C and the mean precipitation was 0.8 mm/day. The 98-day mid-fall through early winter period was the wettest of the study; mean precipitation was 6 mm/day and 61% of days had rain. A sharp drop in the mean air and ground temperatures occurred during this period. Appendix F Table F-1 provides greater detail on the variation in seasonal conditions.

Figure 11 illustrates precipitation, and air and ground temperatures during the 2001 study period. I recorded higher temperatures during extended periods of reduced precipitation. The only substantial precipitation event that occurred between mid-summer and early fall occurred 21 to 24 August. During this 4-day interval, 53.9 mm of rain was recorded. For the prior 54 days a total of only 5.9 mm had fallen, and only 1.5

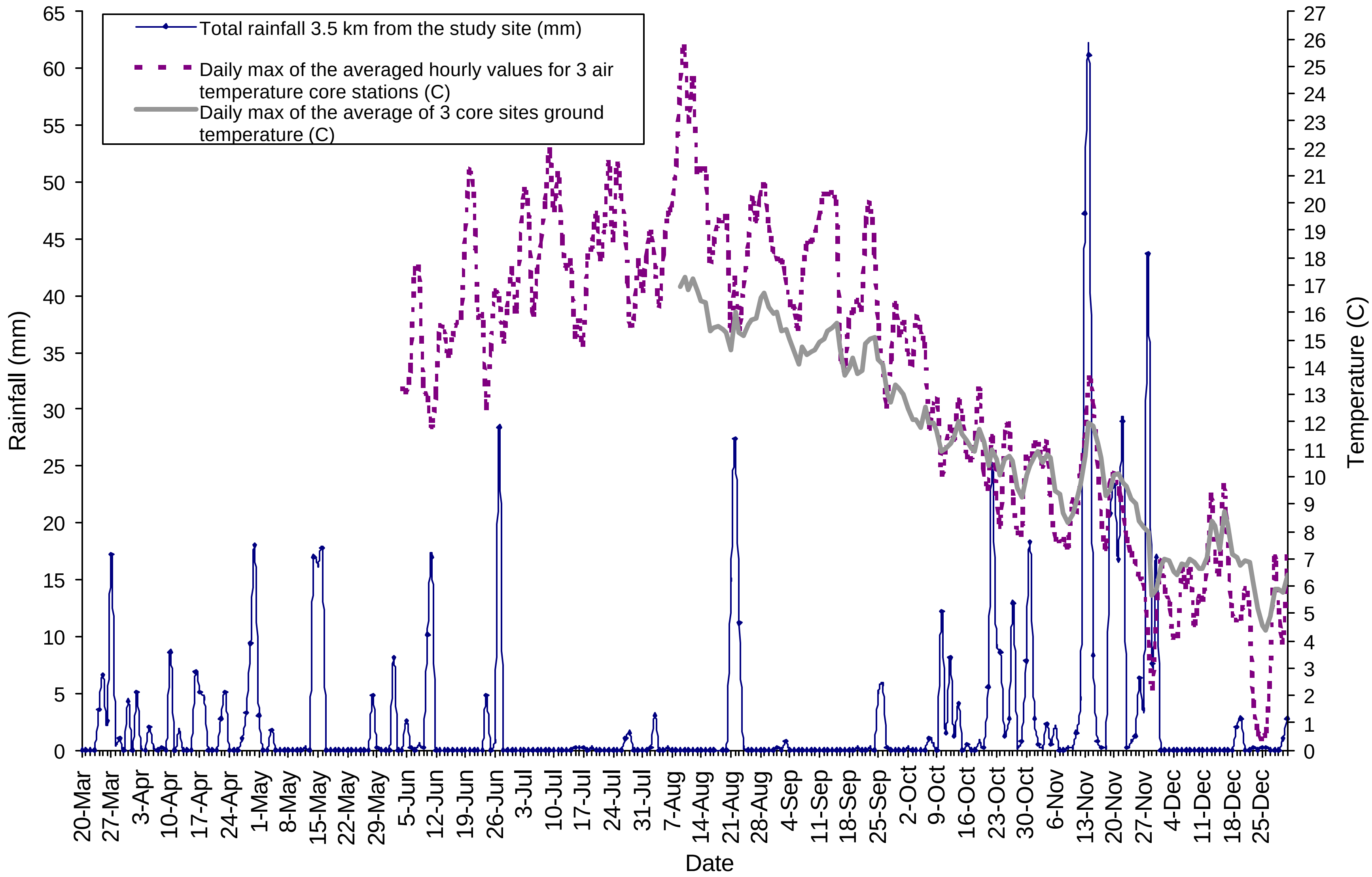


Figure 11. Precipitation, and air and ground temperatures during spring through early winter 2001.

mm of rain fell for the 31 days following this rain event. Rain of the magnitude of the 21 to 24 August storm did not recur until the second half of October. The heaviest rainfall during the 2001 study period occurred 10 to 16 November. The total rainfall for this event was 124.0 mm; the peak daily value was 61.2 mm on 14 November.

On 28 November 2001, ca. 21 cm of snow fell at the study area and at a nearby location where two telemetered frogs had moved. By 2 December, the snow had melted in exposed areas, but some remained several days longer in shaded locations.

Ground/Surface Moisture

Moist ground (e.g., soil, leaf litter, low growing herbaceous plants such as mosses, and downed wood) at the study site had ca. 100% area coverage in the spring, and from mid-October through December. However, during early summer through mid-October droughty, warm conditions, the forest and open habitat were less moist (Fig. 12). In early summer the surface moisture began to dry, but moisture could be found in the soil, and in humus and leaf litter under the skirt of sword ferns as well as in downed wood. As the summer progressed, the soil and humus dried, and by 23 July, leaf litter under the sword ferns was no longer moist.

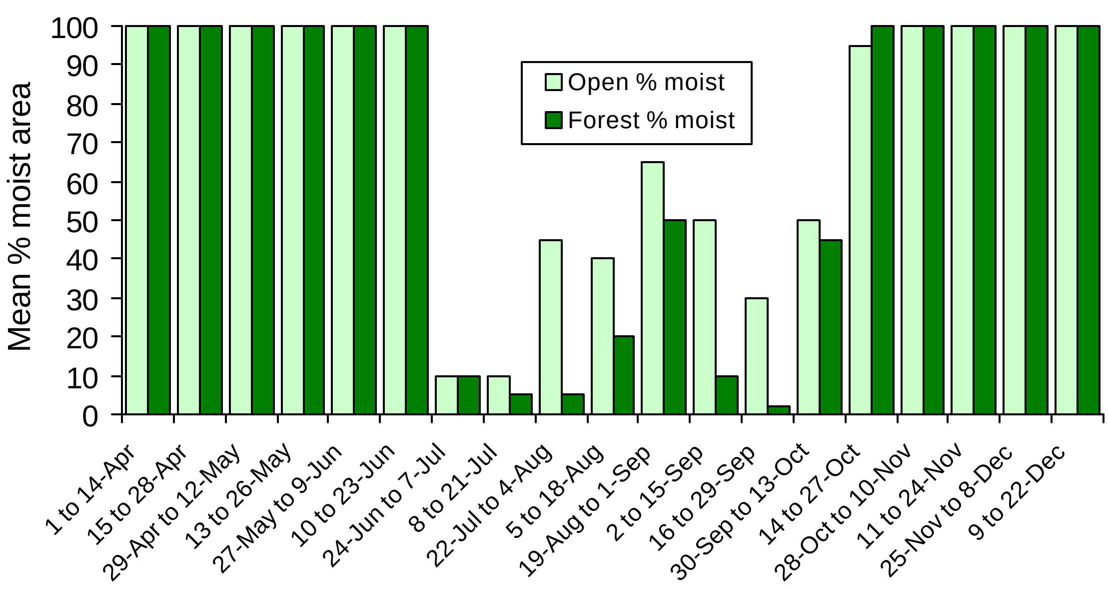


Figure 12. Bi-weekly estimated mean moisture conditions in the study area open and forest habitats in 2001.

Interestingly, and evident in Figure 12, was that throughout the droughty part of the 2001 study, I observed a pattern of open habitat having more moisture available than forest habitat. In addition, tidal shoreline remained permanently moist or flooded through this interval. During mid-summer (9 July) through mid-October, intermittent rains remoistened the ground surface, but this was typically spotty (e.g., 0.25 mm of rain on 15 July 2001 only reached the ground in locations in the forest where there were tree gaps).

As early as 9 July, in the early morning, open grass and forbs habitat had dew and guttation moisture, whereas the forest did not. For example, on 20 August, open habitat quadrats with grass and forbs had 60 to 80% of their surface area with dew and guttation moisture, whereas in forest quadrats I only found moisture on the underside of downed wood (ca. 1% of the quadrat surface).

By 13 August the forest and open habitats were predominantly dry. On this date I estimated that only 1% of the ground area within the forest quadrats was moist; the only moisture I found in the day's area-constrained nine forest survey quadrats was along the bottom of downed wood, and in an area of creeping buttercup (*Ranunculus repens)*. On this same day I found moisture in 3% of the open habitat quadrats surveyed. These moist areas were similarly in downed wood, and in an area of creeping buttercup.

By early fall, rains began to re-moisten leaf litter in the forest while the soil remained dry. As the sun angle became lower in the fall along with cooler air temperatures, a ca. 10 by 30 m area of the open habitat with grass and forbs no longer received sun and became constantly moist to saturated from cumulative days of accumulating dew and guttation moisture. On two occasions in the fall (22 and 24 September), I observed fog drip (i.e., the forest trees intercept and accumulate fog until it drips similar to a light rainfall) in the forest. This was coincident with warm days and cool nights. In mid-October, the soil below leaf litter began to re-moisten. Under sword fern skirts, the top layer of leaves had become moist, but the inner core area of leaves was still dry.

Leaf-Fall

Big-leaf maple leaves began to fall in early September. On 8 October, ca. 30% of the forest floor was covered with new leaf-fall from both maple and alder trees. By 15 October, ca. 90% of the forest floor was covered with new leaf litter. At the end of October, 75% of the leaves were off of the trees, and completion of leaf-fall occurred late November.

Air and Ground Temperature Relationships

A prominent pattern found was that ground temperatures (as daily maxima) fluctuated less on a day-to-day basis than did the daily maxima air temperatures (F-test two sample for variances, $p < 0.0001$). In addition, air temperatures were typically warmer than ground temperatures summer through early fall, but beginning in mid-fall, ground temperatures became warmer than air temperatures with increasingly greater frequency. By late fall, ground temperatures were almost always greater than air temperatures. Figure 13 shows the detail of this reversal for the three core temperature stations.

Table 8 presents air and ground temperatures for the three core temperature stations and the three supplemental stations. The open habitat site had the highest maximum air and ground temperatures for the late spring through early fall seasons as well as the coolest minimum air temperatures early summer through early fall. Mid-fall through early winter the warmest average air was at the shoreline cliff, and the warmest average ground temperature was in the forest near the shoreline. The coolest average air temperatures mid-fall through early winter were in the open site and at the forest edge near a branch pile; the coolest ground was in the ravine.

Table 8. Core and supplemental station temperatures (2001).

Temperature Station	Late Spring 6-Jun to 20-Jun			Early Summer 21-Jun to 8-Jul			Mid-Summer through Early Fall 9-Jul to 24-Sep						Mid-Fall through Early Winter 25-Sep to 31-Dec					
	Air (C)			Air (C)			Air (C)			Ground (C)			Air (C)			Ground (C)		
	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av
Core Group [a]																		
Open site A (near garden)	5.4	23.0	12.6	7.9	22.0	14.0	6.4	26.9	15.1	11.5	20.8	15.2	0.2	16.2	6.9	2.0	14.7	8.8
Forest site A (near shoreline)	7.2	20.2	12.2	9.5	19.7	13.8	8.0	26.0	15.0	12.1	15.7	14.0	0.1	16.7	7.5	0.9	13.8	9.4
Forest site B (in forest)	5.3	20.7	12.2	8.3	20.6	14.0	7.2	24.8	15.0	11.3	16.6	14.2	-0.7	16.4	7.2	3.6	14.3	8.8
Supplemental [a]																		
Forest site C (cliff at shoreline)							11.3	19.5	15.6	12.8	18.9	15.5	1.0	15.5	8.0	1.4	15.6	9.1
Forest site D (ravine)							8.8	19.6	13.9	12.0	15.8	14.1	0.3	14.2	7.2	3.6	13.9	8.6
Forest site E (edge branch pile) [b]							7.6	22.2	14.6	5.7	21.0	13.8	-0.2	15.2	6.9	-0.3	15.2	6.7

[a] Core group ground data and all supplemental stations data start mid-summer, 9 August.
[b] Ground column data is for a location above ground, but beneath a branch pile.

Tidal Channel Salinity

I took channel salinity data on 4 September 2001. I estimated a flow of 0.04 cfs in the freshwater channel on that date. Salinity sample results are shown in Figure 14. The lowest salinity measurements (0.05 to 0.07 ppt NaCl) were found in the furthest upstream 40 m of the channel. From 50 to 90 m, salinity increased from 0.15 to 1.50 ppt. At the stream flow/tidal water confluence (distance 100 m) the salinity was 6.00 ppt. Salinity at

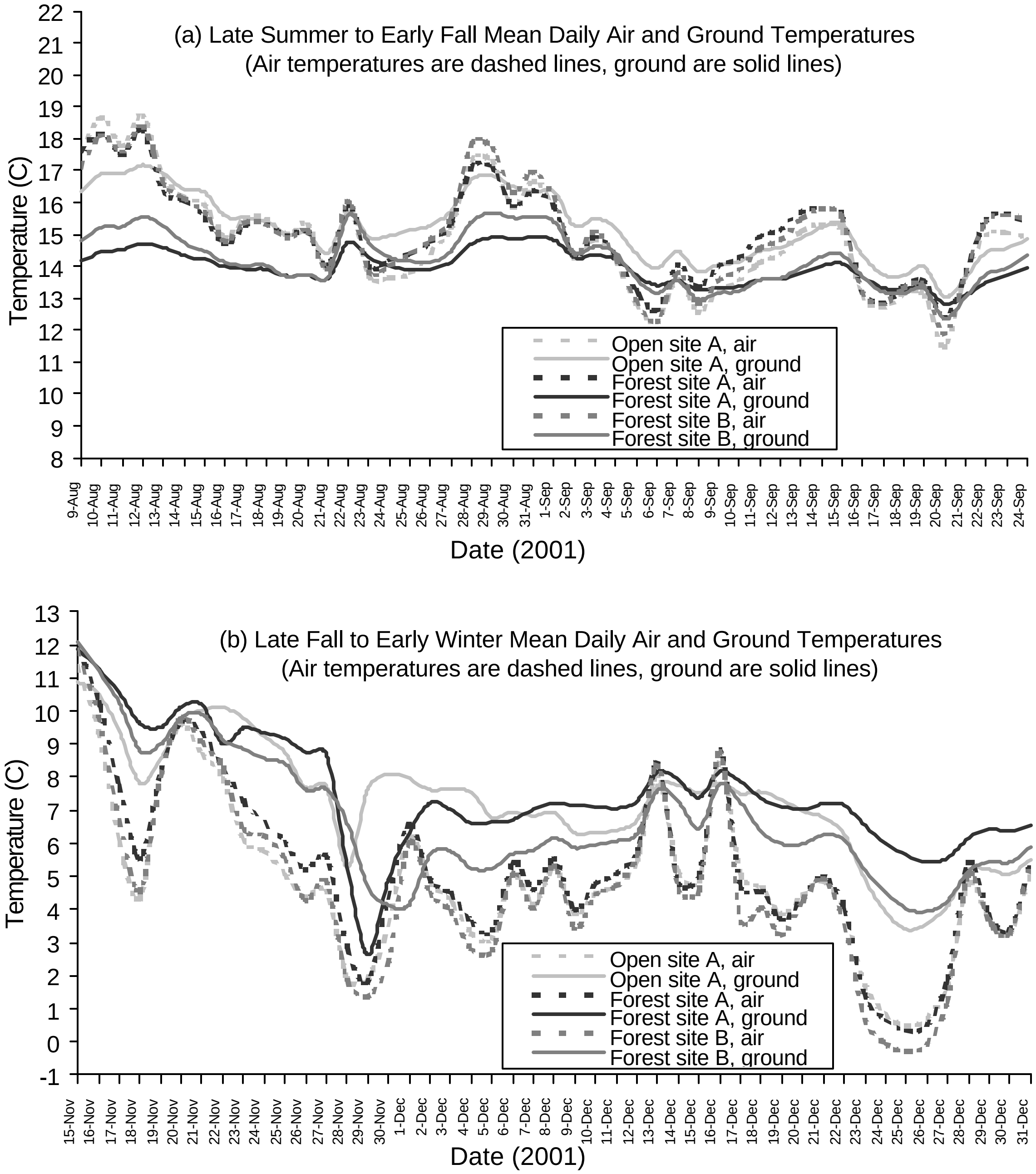


Figure 13. Mean daily temperatures at core sites showing reversal of air versus ground temperatures between late summer to early fall (a), and late fall to early winter (b).

the last sample site (110 m) was of incoming tidal water; salinity at this site was 11.50 ppt. Results from substrate samples taken adjacent to the channel generally showed a parallel trend, but had uniformly higher salinity than stream samples at the same distance.

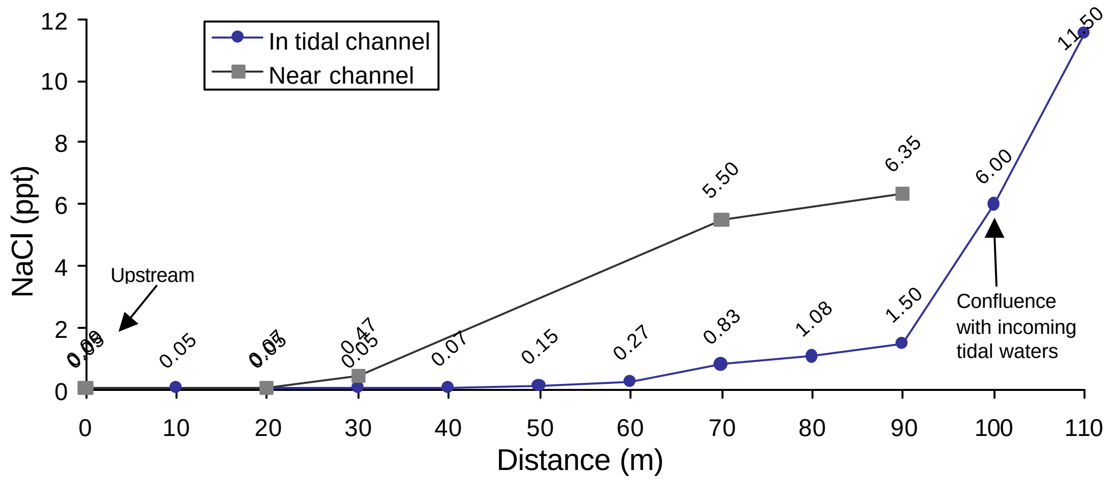


Figure 14. Salinity in the tidal channel and in sand bar or mudflat substrate within 2.5 m of the channel. Measurements were taken 4 September 2001, during an incoming tide. Points 100 m and 110 m were of incoming tidal waters; all others were taken when tidal waters were absent.

CHAPTER 5. NATURAL HISTORY AND BEHAVIOR RESULTS

This chapter describes some natural history, behavioral, and physiological data about northern red-legged frogs using terrestrial habitat. I begin first with a brief overview of telemetry data, and then utilize a composite of data types for remaining sections.

Telemetry

I radio-tracked frogs between 16 July and 29 December 2001. Figure 15 and Appendix G Table G-1 provide overviews of the telemetry results. These data are briefly described here, and used elsewhere throughout the remainder of the results.

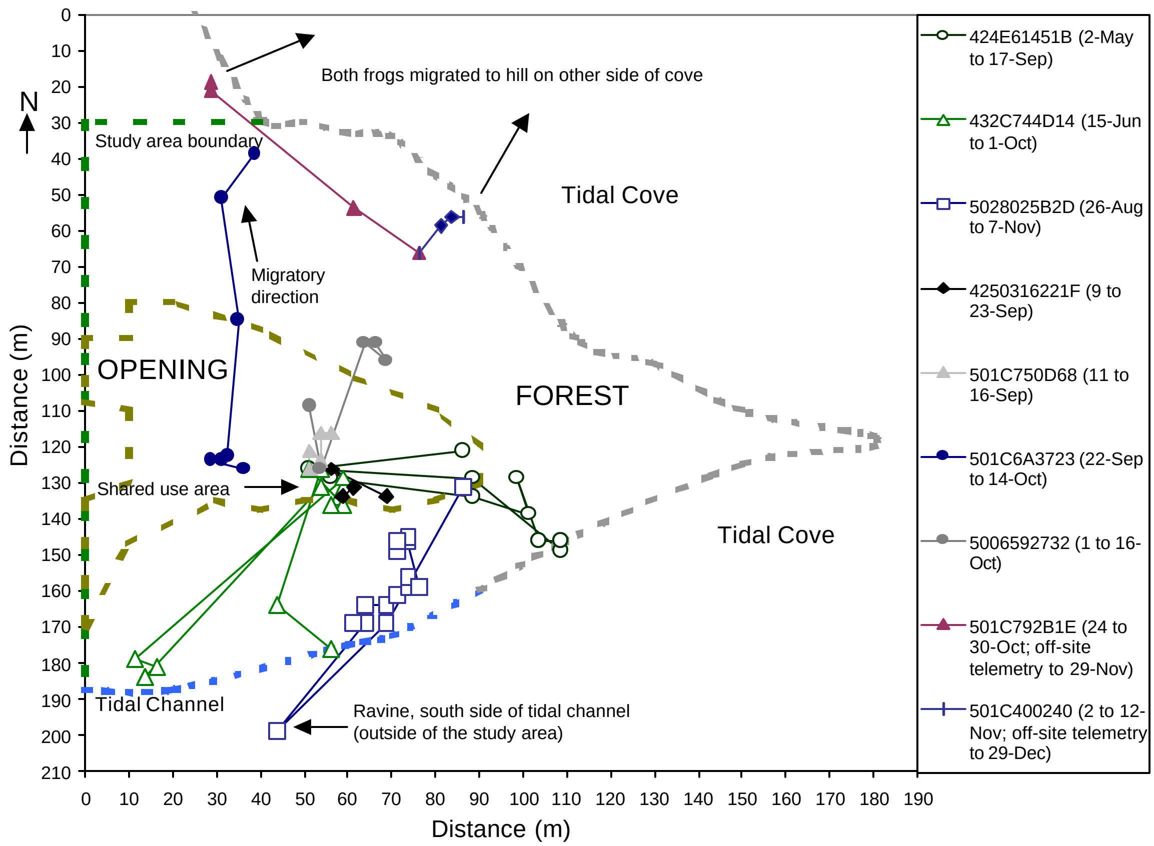


Figure 15. Telemetered frogs home ranges and migratory patterns in 2001. Map includes data from telemetry and other survey types.

I initiated telemetry with seven frogs captured in the open stratum (five from opportunistic captures, and two from area-constrained searches). The remaining four frog captures for telemetry were in the forest stratum (one from opportunistic capture, one from an area-constrained search, and two from traps). Frog 432C744D14 had telemetry gear during two intervals (hence 10 different frogs were telemetered during 11 intervals). I lost reception on one frog after the first day. In five cases (frogs 424E61451B, 5028025B2D, 432C744D14, 425031621F and 501C6A3723), I augmented telemetry data through captures made before or after telemetry occurred. I also made three observations of frogs carrying radio transmitters without the aid of telemetry. I obtained a total of 79 frog observation days (counting one observation per frog per day found) through telemetry.

I ended telemetry on individual frogs for three reasons: injuries associated with the attachment belts, dropped or slipped transmitters, and loss of reception. In four cases (at 22, 36, 37 and 73 days of carrying the transmitter) I removed transmitters because the frog developed dorsal sores   3 mm long beneath the attachment belt. I reattached a transmitter to frog 432C744D14 40 days after removal, since its injury had healed. Three frogs slipped transmitters 1 to 2 weeks after they had been put on. I had four occurrences of lost reception that resulted in my losing the frog with the transmitter still attached. As these transmitters had had some previous use, I was unable to precisely estimate remaining battery life.

Temporal Extent of Terrestrial Use

In 2001 I recorded frogs in the study area from 21 April until 12 November, and at an off-site terrestrial location until 29 December. In 2002, I found frogs from 29 April to 17 November. The earliest three frogs I observed in 2001 were females (the first two frogs were observed but not caught and their SVL was estimated at between 65 and 70 mm, the third frog was measured at 67 mm SVL). I did not observe the first male in 2001 until 7 May (SVL 55 mm). In 2002, the first frog was a 79 mm SVL, unmarked female. The first frog I observed known to be a male was on 2 July 2002. However, I observed a ca. 45 mm SVL frog on 29 May 2002 of unknown gender making it possible that male frogs were present before 2 July.

In fall 2001, between 8 and 15 October I caught six frogs without using telemetry or traps. These frogs were 36, 56, 66, 71, 72, and 73 mm SVL indicating that adults and juveniles were still present.

After 15 October 2001, I found only adult females (n = 4), and found them solely through trapping and telemetry. I had initiated telemetry on two of these females prior to 15 October. One (5006572732) lost its transmitter between 16 to 19 October. I tracked the second frog (5028025B2D) until 7 November (when I removed the transmitter due to sores). During this period, this frog made only short moves; the longest move recorded between 24 September and 7 November was 13 m over a 2-day period on 1 to 2 November (Appendix G Table G-1).

I initiated telemetry on the other two frogs after 15 October when each was caught in a trap. Both made long-distance moves (e.g., 501792B1E moved an estimated 511 m, and 501C400240 moved an estimated 297 m). One, 501C792B1E left the study area between 26 and 27 October, and the second (501C400240) left during the interval 12 and 18 November. Both moved to terrestrial locations where at least one remained until 29 December 2001.

Migratory Patterns and Migratory Stop-Overs

Spring Movement Patterns

In the two weeks prior to the first northern red-legged frog sighting in 2001 (21 April), 50% of days had rain, the largest rainfall event was 8.6 mm, and the daily mean was 2.0 mm. Thus, no storms brought heavy rainfall during this period, but conditions were continuously either moist or wet. The mean air temperature for the 7 days prior to 21 April 2001 was 9.3 C (TESC weather station, Fig. 11). This was the highest 7-day mean spring value recorded to date.

I captured the first frog in 2002 over 2 consecutive days (29 to 30 April), during which time it traveled 26 m in a southerly direction (opposite to the dominant fall movement direction I observed in 2001).

I obtained eight captures of six different frogs during the April to May 2001 interval. Of these, one (424E61451B) later became telemetered and was observed at the study area every month, May through September. A second frog (424D19136) represented three of the eight April to May captures. Overall, it was observed at the study site five times from 7 May to 18 June. Of the remaining four frogs, three (424F2E3128, 432E53200E, and

432E56314B), were only captured once and the fourth was captured once in 2001 (19 May), but it had been previously captured and tagged 25 September 2000.

Small Frogs

In 2000 I saw no small frogs < 10 g. However in 2001 I observed five small frogs (< 10 g). These frogs were captured each once, on 15 July, 16 July, 28 July, 6 August and 8 October with respective masses of 9.0, 8.0, 6.0, 5.5 and 3.0 g. Additionally in 2002, I found two frogs < 10 g; both were found on 30 June, and they had masses of 7 and 8 g.

Fall Movement Patterns

In early fall 2001 the ratio of newly tagged to total frogs caught increased from 50% to 56% (Table 7). In mid-fall 2001, this ratio increased to 65% newly tagged frogs. In addition, the CPUE for area-constrained surveys mid-fall was 50% greater than during earlier seasons (Table 3).

I observed a diversity of patterns and timings of movements in the fall of 2001. For example, while telemetered frog 5028025B2D stayed within the same vicinity until at least 7 November (Appendix G Table G-1), frog 501C792B1E, a previously untagged frog trapped 24 October, made a 49 m move on 26 to 27 October, and 105+ m move 30 to 31 October.

In fall some frogs moved when substantial rain interrupted summer dry conditions. During 21 and 24 August 2001 53.9 mm of rain fell. Following this on 25 to 26 of August, I captured eight frogs of which seven had not been previously tagged (a ratio of newly captured to total frogs of 0.88). I also determined that three dead trapped frogs had been caught on 21 August, which brought the ratio of new to total frogs caught to 0.91. In contrast, the new to total frog ratio for 20 frogs caught 9 July to 20 August 2001 was 0.45.

The recapture and movement data from six untagged frogs caught 25 to 26 August provides an indication of the diversity of movement patterns seen in the fall. Four frogs were not recaptured. I relocated one frog on 30 September 2001, 31 m southwest of the original capture location. I radio-tracked the sixth frog (5028025B2D) and found that it remained in the study area through at least 7 November 2001.

For 2002, the data show a unique set of frogs during the dry 14 August to 6 September interval that had all been located earlier in the summer. However, I began to find untagged frogs a day after it had rained (8 September) and onwards. In addition to finding frogs at this time, I found them in a group, and or using the same localized habitat. After finding the first of these frogs on 8 September, I found a different frog in the same 6.25 m^2 subquadrat on 11 September 2002. I subsequently refound this second frog within a 5-m distance on 18, 19 and 28 September. On 19 September a new frog was present 5-m away, and on 28 September at least three more untagged frogs were present within 5 m of each other. After 28 September, through fall of 2002 I no longer found frogs at this location.

Telemetry data from two female frogs (501C792B1E, 501C400240) in fall indicated a large directional movement. Both moved northeast to the opposite side of the tidal cove to a southwest facing forested slope and nearby forested hilltop plateau (Figs. 15&16). Frog 501C792B1E traveled northeasterly near the shoreline edge, and then was next located on the opposite side of a 30 to 40-m wide portion of the cove. Frog 501C400240 followed a similar route: both frogs crossed the road where I found vehicle-killed frogs.

Cold Weather Migratory Stop-Overs

Figure 16 shows the forested location along the shoreline used by frog 501C400240 during a mid-fall, cold weather period. Between 5 and 12 November 2001, average daily temperatures at the study site were cold (4.6 to 9.3 C) and this frog made only minor moves (e.g., < 1.0 to 4.0 m). Figure 17 shows the temperature and rainfall patterns during the 20 October to 20 November 2001 interval when this and a second frog (501C792B1E) made only minor moves when mean daily temperatures across study site core group stations were at or below 9.3 C. When temperatures warmed, which in both cases was concurrent with large rainfall events (peak rainfall of 18 mm on 31 October, and 61 mm on 14 November), these two frogs resumed making longer directional moves.

Home Ranges

I identified two types of home ranges: primary active season ("primary"), and late fall to early winter ("winter").

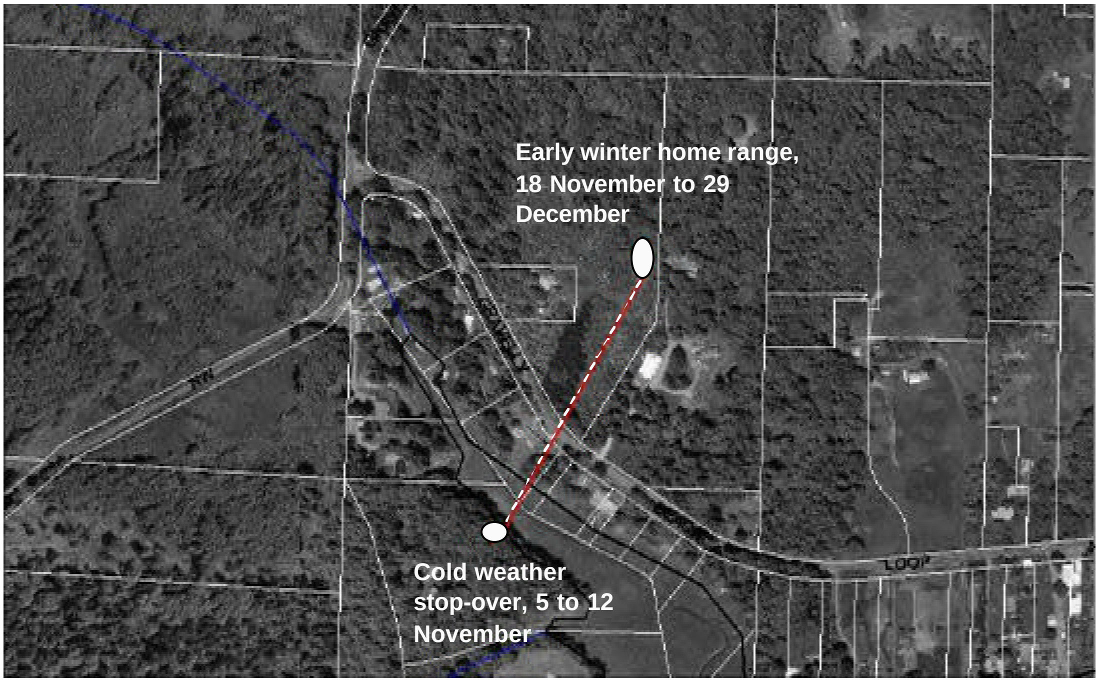


Figure 16. Telemetered frog 501C400240 map of 2001 mid-fall cold weather migratory stop-over, mid-fall possible migratory route, and mid-fall through early winter home range. Base photo from Thurston County Geodata.

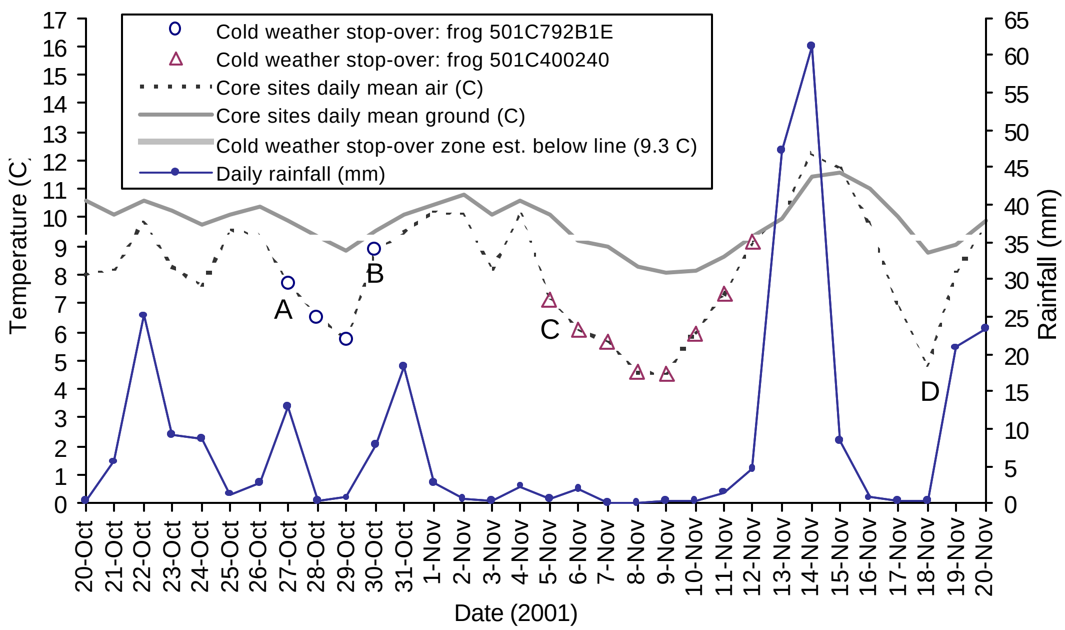


Figure 17. Cold weather migratory stop-over temperature and rainfall conditions. Point A: frog 501C792B1E moved 49 m since the previous day. As temperatures dropped and then increased during the 4 days shown by A to B, the frog moved 0 to 2 m/day. Point B: between this date and the next 24 hr the frog moved ca. 105 m. Point C: between this date and the next 7 days frog 501C400240 made only minor moves within a 12.5 m^2 area. Point D: frog 501C400240 was located ca. 297 m distant, where it remained at a late fall to early winter home range until at least 29 December 2001.

Primary Home Range Size and Habitat

Frogs used diverse habitats within their primary home range. Female frog 424E61451B was located between 2 May and 17 September 2001 in both open and forest strata, and in substrata ranging from tidal mudflats and forest/sword fern, to open/grass and open/buttercup (Fig. 18). The home range of this frog was 11 by 62 m. Similarly, female 432C744D14, observed from 15 June to 1 October, ranged over an area 18 by 71 m, and female 5028025B2D, observed 26 August to 7 November, ranged over an area 9 by 80 m. Locations of these largely non-overlapping ranges are shown in Figure 15.

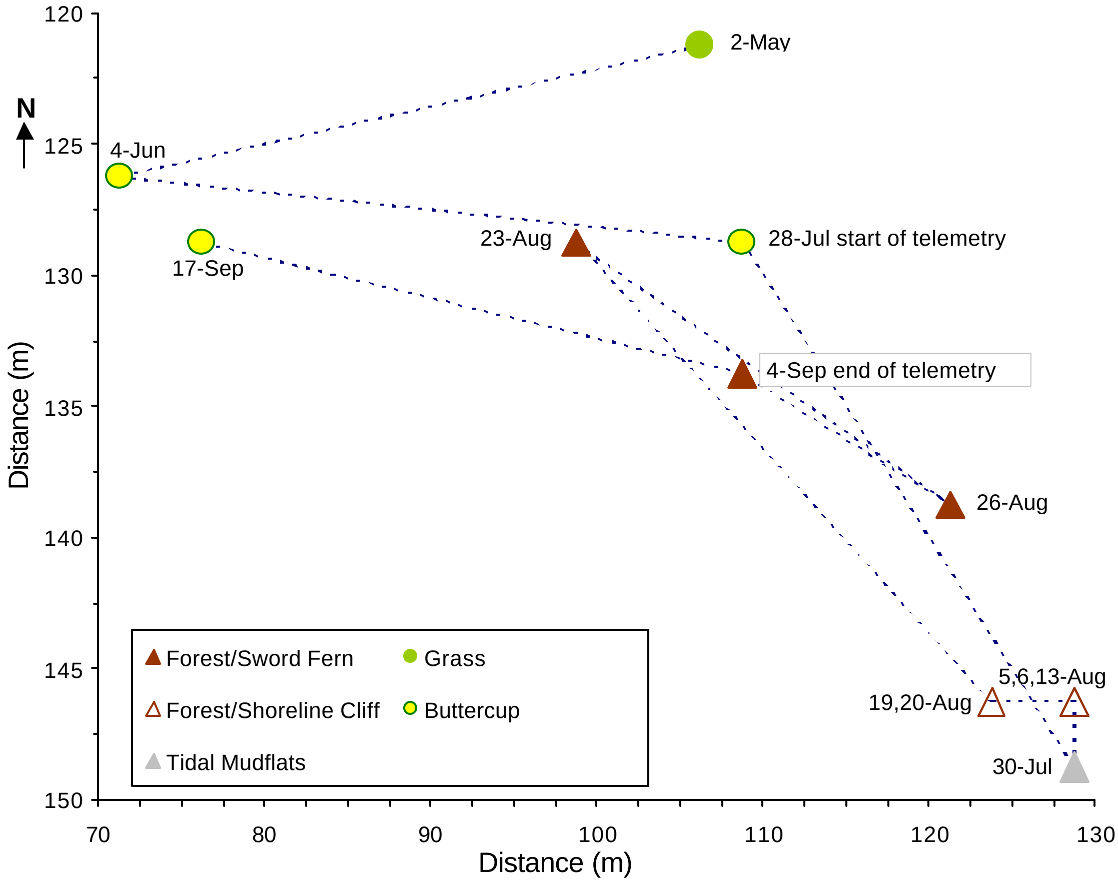


Figure 18. Spring through summer (2 May to 17 September 2001) home range and macro-habitat use by female telemetered frog 424E61451B. Distances are from the NW and SW corners of the study area (see Fig. 3).

Movement within Primary Home Ranges

The predominant movement pattern that I identified within female home ranges was that of short distances (Table 9). My observation frequencies for the three female frogs were 0.09 to 0.27 days. Frogs relocated at points 0.2 to 69.1 m apart between observations, and mean distances traveled between observations ranged from 8.4 m to 15.6 m. I estimated mean daily travel distances between 1.4 and 2.3 m. Similarly, for 12 observations where location data were taken on consecutive days for these three frogs the mean distance moved was 1.6 m (range: 0.2 to 4.4 m; see Appendix G Table G-1).

Table 9. Distances moved by frogs within their home ranges (2001).

Home Range Type	Frog No.	Observation Duration	Total No. of Days	No. of Obser-vations	Return Visit Freq[a]	Range of Dist Moved between Visits (m)	Mean Dist Moved between Visits[b] (m)	Mean Dist Moved/ Day[c] (m)
Primary	424E61451B	2-May to 17-Sep	139	13	0.09	<1.0 to 38.0	15.6	1.4
Primary	432C744D14	15-Jun to 1-Oct	109	12	0.10	<1.0 to 69.1	20.9	2.1
Primary	5028025B2D	26-Aug to 7-Nov	74	21	0.27	0.2 to 39.4	8.4	2.3
Winter	501C400240	18-Nov to 29-Dec	41	16	0.37	0.0 to 13.6	3.4	1.3

[a]This is the number of observations minus one, divided by the total number of days in the observation period.
[b]For this calculation all measurements such as <1.0 m were treated as =1.0 m.
[c]This is calculated for comparative purposes only; the actual movement distance per day is not known.

Multi-year use of primary home ranges-- From 2 July to 6 September 2002, I made 13 opportunistic frog observations of five different frogs. Of these frogs, 2002 was the second observation year for two, the third year for one, and, the first year for two. Thus, three returning frogs revealed that at least some of the same frogs return to primary home ranges. Figure 19 displays the locations found, by year, for each of the three frogs.

Winter home range-- I documented the off-site, winter home range used by frog 501C400240 from at least 18 November to 29 December 2001 (Fig. 16, Appendix G Table G-1). The general pattern of use was of small, but frequent moves (Table 9). The frog exclusively used forest habitat with complex shrub, wood, and dense leaf litter.

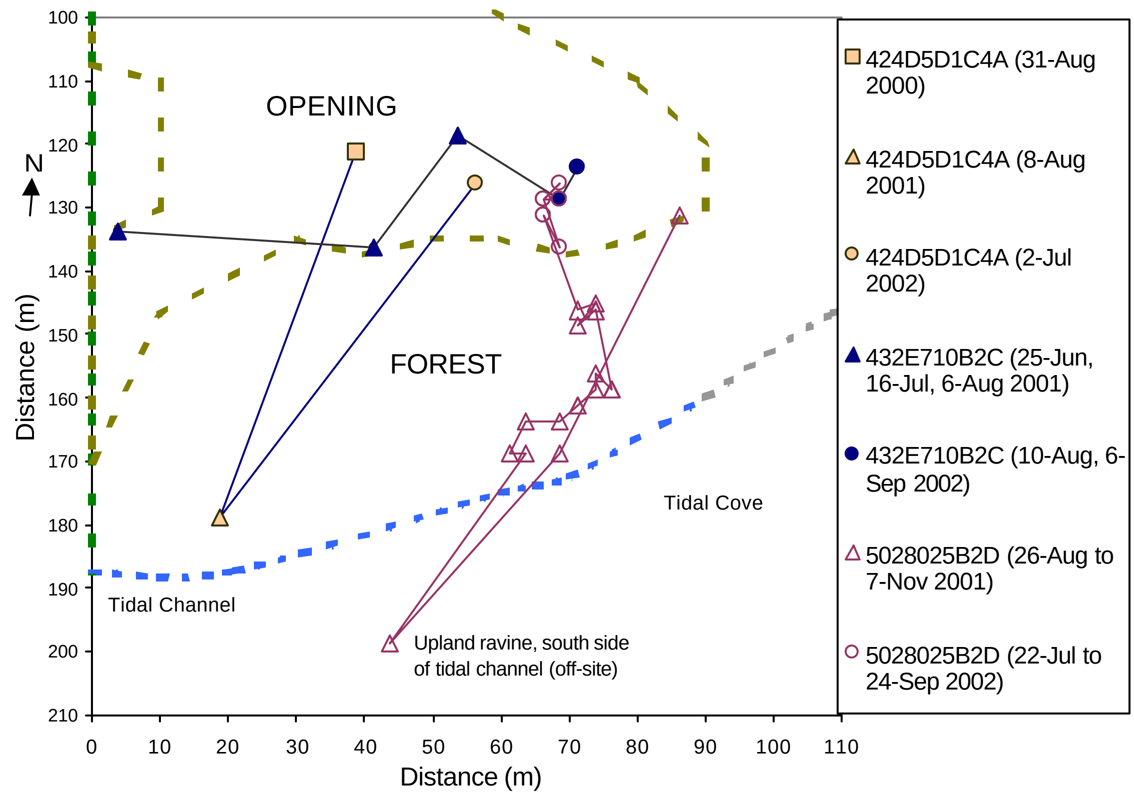


Figure 19. Locations of three frogs found during summer 2002, that were previously found in 2000 and/or 2001. The year 2000 datum is square, 2001 data are triangles, and 2002 data are circles. Distances are from NW and SW study area corners (see Fig. 3).

Northern Red-legged Frog Ethology and Natural History in Terrestrial Habitat

Preliminary Ethology

I found terrestrial frogs were usually concealed (e.g., by remaining motionless, by employing cryptic coloration, and by using cover), and jumped upon my approach (typically within 0.5 m). Data from my observations of undisturbed frogs (typically found through telemetry), from video footage of frogs, and from other study data are organized into a preliminary characterization of terrestrial northern red-legged frog ethology and natural history (Table 10).

This ethology encompasses: postural behaviors, variation in movements (including distance and in-place movements, movement patterns, and home ranges), vocalization, physiology, responses to predators, local habitat modification by frogs, and general aspects of social structure. Table 10 provides an overview of the categories and included behaviors, and Appendix H provides additional description for selected behaviors.

Table 10. Preliminary northern red-legged frog ethology and natural history in its terrestrial habitat. (Postural, movement, physiology, and vocalization behaviors are described in Appendix H. Most other listed behaviors are described within the results.)

Postural
- Sit
- Crouch
- Lay

Distance Movement
- Hop
- Walk
- Dive
- Climb

In Place Movement
- Head Turn (or Upward, or Downward)
    - Prey-tracking
    - Other-tracking
    - Unknown
- Head Nodding
    - With or Post Feeding Lunge
    - Other
- Feeding Lunge
    - Successful
    - Not Successful
    - Unknown
- Repositioning
- Body Turn
- Other Minor
    - (Flinches, Jerks, Slight Movements)

Movement Patterns and Home Ranges
- Primary, Long Seasons Home Range
- Secondary, Winter Home Range
- Migratory Stop-Over
- Spring and Fall Migrations

Physiology
- Eye Retraction
- Breathing (throat movement)
- Cryptic Coloration
    - Warm Light
    - Cold Dark
- Water Absorption
- Evaporative Cooling (assumed)

Predator/Danger Responses
- Before, or Not Caught
    - Crypsis
    - Hop(s) and Crypsis
    - Use of Covered Habitat to Move Away
- At/After Being Caught (human, minnow trap)
    - Expel Liquid from Vent
    - Vocalization
    - Vigorous Attempt to Jump
    - Move/Squeeze through Small Space
    - Climb

Habitat Modification
- Crouch Depression/Pad

Vocalization
- Distress Calls (when human caught)
    - Soft Cortling
    - Squeaky Scream
- Male Breeding Call

Social Structure
- Shared Important Resource Areas
- Migratory Grouping
- Other, Pairs

Video results and analysis-- I recorded nearly 11 hours of video tape. Table 11 provides an overview of the video data and analysis. The analysis showed frogs rarely moved. Specifically, movement occurred a mean of 0.46% (range: 0.33 to 1.73%) of the time; conversely, frogs were motionless 99.54% of the time (range: 98.27 to 99.67%). All frogs spent a combined total of only 181 sec moving. During those 181 sec, I observed 123 movement episodes (activities), comprised of 149 individual behaviors. The mean length of any activity was 1.5 sec. Table 12 provides an analysis of the

Table 11. Red-legged frog video analysis overview. An activity is a movement episode. Each activity may have one or more individual behaviors.

Frog No.[a]	Date Season	Time: Start and End Times[c] hr:min:sec	Time: Observation Length hr:min:sec	Movement: Activities no.	Movement: Behaviors no.	Movement: Seconds no.	Movement: Time %	Movement: Mean Activity Length sec	Description[b]
424E61451B	13-Aug-01 Mid/Late Summer	17:27:00 18:31:24	1:04:24 3864 sec	11	17	16	0.41	1.5	Frog on small cave-like ledge on cliff face, overlooking cove. Video from above. Dry sunny condition. Air 17.6 C. Ground 16.5 C. Successful feeding.
424E61451B	26-Aug-01 Early Fall	15:47:00 16:22:36	0:35:36 2136 sec	5	6	7	0.33	1.4	Frog in crouch posture on moist forest floor. Air 18.8 C. Ground 14.0 C. Includes head turn toward ant: frog does not pursue ant.
424E61451B	4-Sep-01 Early Fall	09:20:36 10:27:11	0:45:08 2708 sec	12	17	15	0.55	1.3	Frog in crouch posture, elevated 20 cm on moist, moss covered log. Air 14.2 C. Ground 14.0 C. Video includes repositionings, head turns, and a hop.
501C750D68	13-Sep-01 Early Fall	12:58:00 17:12:03	3:05:58 11158 sec	35	41	65	0.58	1.9	Frog in crouch posture, grass/forbs habitat. Dry condition. Mean air 19.2 C. Mean ground 15.3 C. Video includes a head turn, feeding lunge, head nodding sequence.
501C750D68	14-Sep-01 Early Fall	13:50:03 18:55:30	4:42:10 16930 sec	41	47	57	0.34	1.4	Frog in sit posture, in dry grass/forbs, 5 m from 13-Aug-02 location. Mean air 19.2 C. Mean ground 16.1 C. Includes feeding, and non-feeding beetle and spider interactions.
425031621F	17-Sep-01 Early Fall	19:04:00 19:36:02	0:32:02 1922 sec	5	6	7	0.36	1.4	Frog in sit posture at dusk in dry forest edge 0.5 m from cleared edge of open habitat. Air 13.4 C. Ground 14.0 C. Frog does not pursue flying insect.
424E56143B	23-Sep-01 Early Fall	15:00:00 15:13:31	0:13:31 811 sec	14	15	14	1.73	1.0	Frog is elevated 33 cm on wood in sun, in flower garden. Air 19.4 C. Ground 13.7 C. 7 unsuccessful lunges at mosquito. Dive out of video.
Totals:			10:58:49 39529 sec	123	149	181			
Mean values:							0.46	1.5	

[a]All frogs with the exception of 424E56143B were found through telemetry.

[b]Temperatures are from closest installed air and ground thermographs.

[c]Includes additional time when video was not running; the observation length is correct.

Table 12. Video analysis of number of frog movement behaviors and seconds of movement activity[a]. Movement types are described in Appendix H.

Frog no., Date	Dist. Movement: Hop	Dist. Movement: Walk	Dist. Movement: Dive	In-Place Movement: Head Turn/Up/Down: Prey-tracking	Head Turn/Up/Down: Other-tracking	Head Turn/Up/Down: Unknown	Feeding Lunge: Successful	Feeding Lunge: Not Successful	Head Nodding: With Lunge	Head Nodding: Other	Repositioning	Body Turn	Other Minor	Physiology: Eye Retraction	Total
424E61451B, 13-Aug-01															
no. of behaviors	0	0	0	0	0	5	1	1	1	0	0	0	2	7	17
sec/activity	0	0	0	0	0	3	5	1	1	0	0	0	1	5	16
424E61451B, 28-Aug-01															
no. of behaviors	0	0	0	0	1	1	0	0	0	0	1	0	1	2	6
sec/activity	0	0	0	0	1	1	0	0	0	0	3	0	1	1	7
424E61451B, 4-Sep-01															
no. of behaviors	1	0	0	0	1	4	0	0	0	0	2	0	3	6	17
sec/activity	1	0	0	0	1	4	0	0	0	0	3	0	3	3	15
501C750D68, 13-Sep-01															
no. of behaviors	0	1	0	1	0	3	1	0	1	1	2	3	19	9	41
sec/activity	0	5	0	1	0	5	1	0	4	0	2	6	22	19	65
501C750D68, 14-Sep-01															
no. of behaviors	0	0	0	0	1	7	1	0	1	1	4	2	14	16	47
sec/activity	0	0	0	0	1	7	1	0	0	0	11	2	15	20	57
425031621F, 17-Sep-01															
no. of behaviors	0	0	0	0	0	0	0	0	0	1	0	0	3	2	6
sec/activity	0	0	0	0	0	0	0	0	0	0	0	0	3	4	7
424E56143B, 23-Sep-01															
no. of behaviors	0	1	1	0	0	0	0	7	0	0	2	2	2	0	15
sec/activity	0	1	1	0	0	0	0	7	0	0	2	1	2	0	14
Grand Totals															
no. of behaviors	1	2	1	1	3	20	3	8	3	3	11	7	44	42	149
sec/activity	1	6	1	1	3	20	7	8	5	0	21	9	47	52	181

[a]Where an activity includes more than one behavior, seconds are allocated to what appeared to be the primary behavior.

number of each type of movement observed, and the number of seconds involved in each movement. In-place movements were the most frequent behaviors (103, 69%) and comprised the greatest fraction of time movement behaviors occurred (121 sec, 67%). Within this category, other minor movements (e.g., quick jerks, or flinches of a portion of the frog) were the behavioral category most frequently scored (44) and took up the most time (47 sec). Other minor movements accounted for 30% of all movements.

The next largest number of observations of a behavior for the in-place movement category was head turn (or upward or downward). This behavior was involved in prey tracking once (the prey was subsequently taken); three times it involved observations of insects that the frogs did not attempt to take as prey; and 20 times I could not determine the behavior purpose.

Four video sessions included a feeding lunge or lunges; three of these included successful capture of prey. Based on this limited sample, the frogs had an insect capture rate of one per 3.7 hr. In one case, the prey was a ca. 8 mm flying insect, another was a large, winged insect. Seven unsuccessful lunges by one frog were taken towards a mosquito.

Feeding included up to five associated behaviors. For example one feeding episode by frog #501C750D68 on 13 November 2001 included four such behaviors:

13:25:19	< 1 second duration	Head turn (prey tracking)	Quick movement of frog's head and uppermost body to right.
13:25:35	<1 second duration	Feeding lunge	Frog propels forward using hind legs (exposing telemetry gear and legs), while head is thrust forward under a leaf and into grass. Frog retracts back to starting location using forelegs to reposition.
13:25:40	4 seconds duration	Head nodding	Head moves up and down quickly, ca. 6X.
13:29:35	1 second duration	Repositioning	Left fore foot moves, then upper torso and head move, followed by movement of all legs; frog appears to now be closer to the ground.

All three successful feeding lunges included head nodding. Not included in the above example, but present in both other successful feeding lunges was eye retraction. On 14

September 2001 frog #501C750D68 incorporated head nodding and eye retraction into the feeding lunge:

14:06:36	1 second duration	Feeding lunge; head nodding; eye retraction	Frog extends with a forward/upward lunge ca. 70 mm and captures insect in its mouth. This movement is hind leg propelled, which (with feet appearing to remain planted on the ground) act as springs to thrust the frog upward and then back down again. As the frog moves back down, its head moves quickly up and down 5X; concurrently its eyes close and open.

The movement category with the second largest number of occurrences was physiology. In this category, the eye retraction behavior was observed 42 times (28.2% of all observed behaviors) and was the primary behavior activity for 52 sec (28.7% of all movement seconds). Eye retraction occurred by itself, as well as with the feeding lunge, head nodding, head turn and upward and downward movement, repositioning, body turn, other minor motions, hop, and walk.

Distance movement (i.e., movements where the frog did not return to its original location) was taped only four times, with a total of 8 sec of movement. The same frog performed two distance movements; the first was a walk, followed ca. 2 min later by a dive from wood the frog was on. This movement sequence was as follows (distance component is bolded):

15:11:38	1 second duration	Body turn	Frog turns body by moving feet and torso 45 degrees.
15:11:48	1 second duration	Body turn/**walk**	Frog turns further and walks 10 cm to edge of wood ending in a lay position with front feet and head perched over edge of wood (elevated 33 cm above ground).
15:13:28	<1 second duration	Repositioning	Front legs and head drop down 3 – 5 mm.
15:13:31	<1 second duration	**Dive**	Frog propels out and down from wood and moves out of video field of view.

The second frog for which a distance movement was scored hopped from downed wood and the third frog walked. Distance movements by the three frogs caused them to move out of the video, however searches within 30 min to 8 hr revealed each frog to still be present within 1 m of the observation location in all cases.

Video Case Study

Frog 501C750D68 was observed between 11 and 16 September 2001 for nearly 8 hr (7 hr 48 min 08 sec) over two days by video, and through additional non-video observations. I use the data for this frog to detail an individual frog's behavior, and to provide greater context for the video data.

This frog moved 122 sec out of 7.8 hr of video observation, and was motionless 99.6% of the time (Fig. 20). During the 122 sec of movement she exhibited 88 individual behaviors, including two successful feeding lunges (Fig. 21).

Spatial locations used by this frog, daily temperature information, and a chronology of observations are presented in Figure 22. Overall, the frog stayed within an area ca. 11 m long by 3 m wide. The habitat included an opening with grass and forbs, partially shaded by tree canopy, and remnant patches of native trees and shrubs. On most days, she was observed at a new location. The frog was observed in open habitat with two exceptions, when she was in remnant edge vegetation, at an old-growth cedar log. On 12 September, the frog hopped to the base of this log when I accidentally disturbed her, and through telemetry I found that she spent the night and morning between 13 and 14 September under the log. On 14 September, the frog stayed within 20 cm of its daytime location into the night, and was visible by flashlight under low cover at 2215. At 0700 the next morning, she was still within 25 cm of the previous day's location in a dense patch of grass under 100% cover. She stayed within or at the margins of this dense grass at least until the last sighting at 1024 on 16 September.

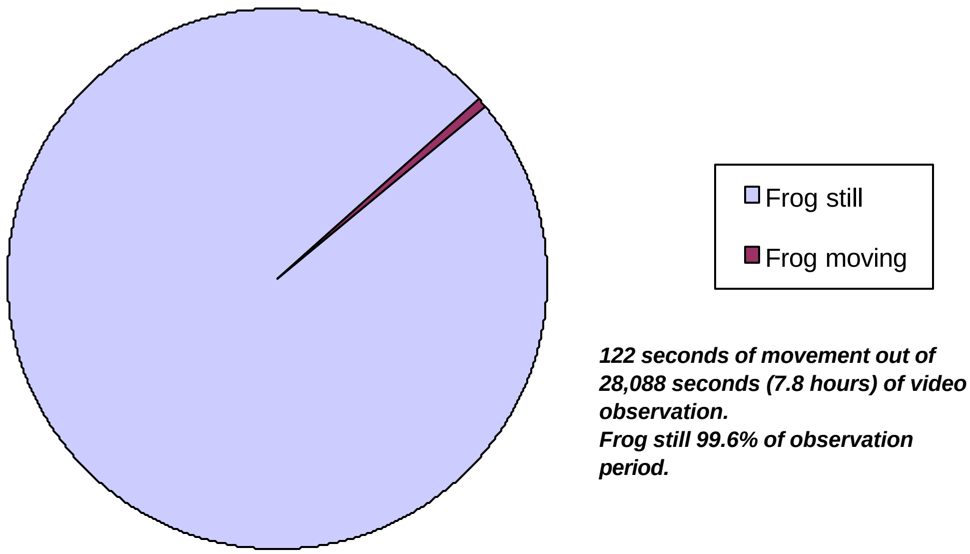


Figure 20. Movement rate for frog 501C750D68 (13 to 14 September 2001).

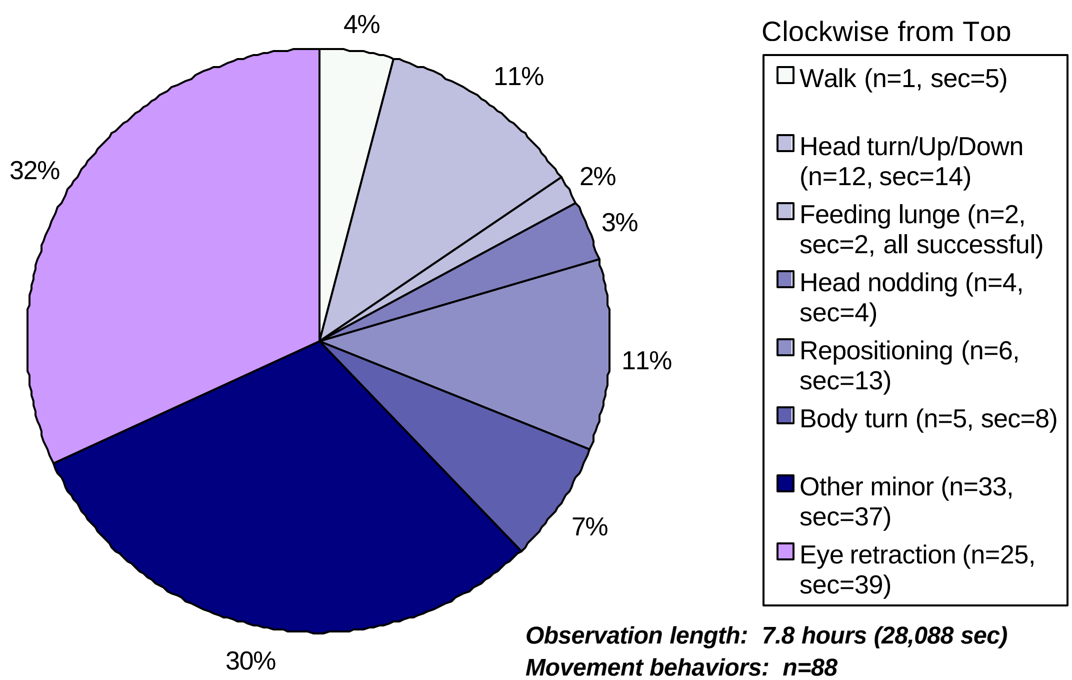
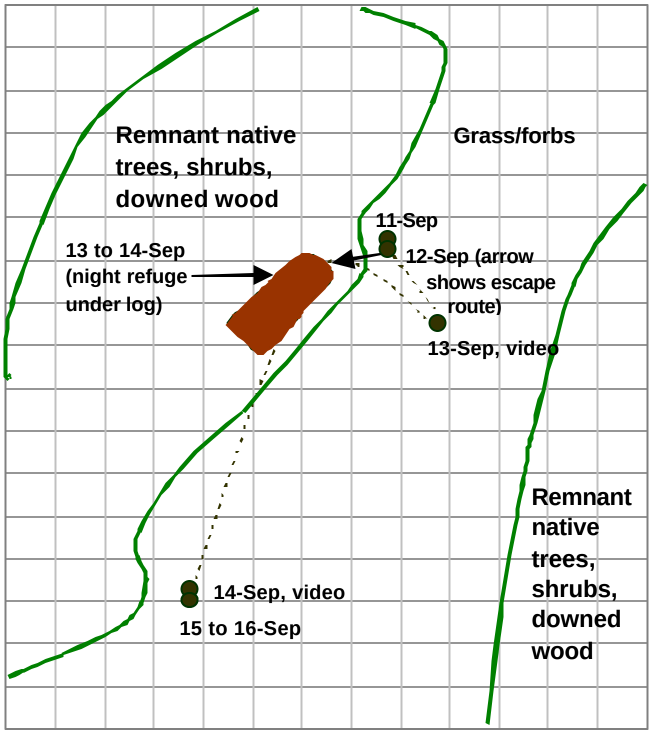


Figure 21. Proportion of each type of behavior in 122 total seconds of movement for frog 501C750D68 (13 to 14 September 2001).



Frog location. Scale: 1 sq = 1 sq m.

Temperatures (C)[a]

Date	Type	Time	Air	Grd
11-Sep	Day low	0742	9.0	13.0
	Day high	1642	19.4	16.6
	Observ.	1916	17.5	16.2
12-Sep	Day low	0742	9.2	12.9
	Day high	1642	20.1	16.8
	Observ.	1118	16.3	13.2
13-Sep	Day low	0742	9.9	13.3
	Day high	1642	20.2	17.1
	Observ.	1231	17.5	13.8
	(video)	1542	19.4	14.9
	Observ.	1854	19.4	16.9
	Observ.	2000	17.8	16.6
14-Sep	Day low	0742	11.0	13.9
	Day high	1642	20.1	17.2
	Observ.	1004	13.7	13.9
	Observ.	1312	17.5	14.2
	(video)	1842	19.1	17.1
	Observ.	2215	15.9	16.1
15-Sep	Day low	0742	10.7	13.9
	Day high	1642	20.1	17.4
	Observ.	1110	14.4	13.9
	Observ.	1920	18.4	17.2
16-Sep	Day low	0742	11.8	13.9
	Day high	1742	14.9	14.7
	Observ.	0800	11.8	14.1
	Observ.	1025	12.4	13.9

11-Sep. I found the frog at dusk (1916) in dry grass/forbs. The frog was very wet, i.e., it obtained moisture elsewhere. The most recent rain was 8 days prior. SVL: 71 mm; weight: 34.5 g; gender female. This frog was a new catch for the study area making it likely that it had not been at the study site through the summer. I inserted a PIT tag and attached a telemetry transmitter.

12-Sep. I relocated the frog at 1118 within 0.25 m of its 11 September catch location. I saw the transmitter under 20% grass cover and thought it had come off the frog. However, upon reaching for it, I found it was still on; the frog made two hops, to the base of old growth cedar log with sword ferns.

13-Sep. 1231: I found the frog within 2 m of the 12 September location on on dry leaf litter, under 20% cover from herbaceous plants, 65% canopy cover. I made video observations between 1258 and 1712. The frog remained in this location until 1712 when based on the video tape it walked out of view.

1854: I located the frog 15 cm from its earlier location.

2000 (dark): frog had moved under an old growth, downed piece of a cedar log.

14-Sep. 0720, 0840,1004: the frog remained under the log.

1312: frog was visible with 10% cover from grass, 73% canopy cover. I video taped from 1350 to 1855.

2019 and 2215 (dark): the frog was at or within 20 cm of its daytime location.

15-Sep. 0700: I found the frog 0.25 m from the prior day's location. It was in a 0.25 m^2 grass/forbs patch that provided 100% cover. Canopy cover was 63%. This partially open habitat was saturated with dew. I made additional observations at: 0720, 0910, 1110, 1310, 1511, 1711, 1920 (dusk). In all observations the frog remained under cover, within 0 to 20 cm of its 0700 location. It was likely that the frog was able to actively observe and feed within the covered location, but it was not visible and thus could not be video taped.

16-Sep. 0800: I located the frog within 0 to 5 cm of yesterday's dusk location. Dew was on the vegetation.

1024: last time I saw the frog; I found its transmitter within 0.25 m of this location on 1-Oct-01.

[a]Temperatures are from installed thermographs within 20 m of frog location. Ground temperature times are 1 - 2 hours after time shown for daily high and low.

Figure 22. Case study for frog 501C750D68, 11 to 16 September 2001.

Behavior Patterns in Response to Seasonal Environmental Variables of Temperature and Moisture

As moisture and temperature conditions varied by season, I observed frog behavior patterns as environmental variables changed. In early summer, the ground began to dry, and I found frogs in remnant moist surface locations. As summer temperatures warmed and the period of drought increased, the forest floor became dry, with only some downed wood, vegetation, and adjacent tidal mudflats remaining moist. However, during otherwise dry conditions, dew and guttation moisture were present on grass/forbs vegetation during early morning in the open habitat stratum. By mid-October moist conditions were again becoming nearly ubiquitous at the study site (Fig. 12). In this section I present observations and data that allow an inference of frog behaviors related to temperature and moisture.

Summer to Early Fall Drought Conditions and Frog Use of Moist Open Habitat Near the Forest Edge

On several occasions, I observed frogs in the open 0.3 to 2.8 m from the forest edge when dew and/or guttation moisture was present. For example, at 0745 hr on 9 July 2001 (11 days since the last rain), I encountered a frog opportunistically in a location as described above. However, during the day's area-constrained searches conducted between 0812 and 1116, no additional frogs were found.

I made similar observations on 14, 17 and 20 July 2001. One was for telemetered frog 432C744D14, located at 1300 on 16 July 2001, under an old branch pile (50 cm high, 5.2 m long and 2.2 m wide) inside the forest edge. At 0630 the next morning I observed this frog 2.8 m out from the forest edge in 11 cm high grass, 8.3 m from its previous day's location.

Summer to Early Fall Drought Conditions and Observations of Very Wet Frogs

During the extended drought, I found very wet frogs in dry microhabitats within forested and open habitats. These frogs were water saturated such that when picked up, copious water flowed from them. I made the first observation of a very wet frog on 8 August 2001. I found this frog near the top of a small cliff along the shoreline. I had bumped an overhanging dry mass of live and dead sword fern leaves and the wet frog catapulted out of the leaf mass. I re-encountered this frog at dusk (2030) on 13 August

2001, this time down on the moist tidal mudflat near the cliff base. Other than the mudflats (mudflat salinity 20 m upstream was 6.35 ppt), no obvious sources of moisture were evident nearby. I also found telemetered frog 432C744D14 "very wet" on 20 August 2001, covered by dry leaves, in the ravine 4 to 5 m from the tidal stream.

Telemetered frog 501C750D68 (earlier described in the video case study) was very wet in a dry, visible location at dusk (1916) on 11 September. On both 13 and 14 September it was observed through video in dry, warm conditions, actively feeding.

On 10 September 2001 frog 425031621F emerged wet from an environs of moist moss, as I disturbed the site while trying to locate the frog by telemetry. I relocated this frog on 17 September 2001, 7 m from the prior noted location in a dry, openly visible location at the forest edge.

Summer to Early Fall Drought Conditions and Frog Use of Moist Garden Soils, Crouch Position and Crouch Depressions

During hot droughty conditions in the summer of 2002, I observed frog 5028025B2D (23 July and 18 August; see Fig. 23) and frog 501C6F1873 (14 August) to be visibly moist, while crouched on sandy loam soils. The locations were within 10 m of the forest edge, in a flower garden that I kept watered.

On three occasions in 2002, I observed cleared, slight depressions the shape of the frog's ventral side, in locations where I had been observing a frog in the crouch position. At one of these sites (frog 5028025B2D, 23 July, Fig. 23), within 30 min of the frog's arrival to the location, I observed the hind legs of the frog moving laterally outward and then back to the frog's torso, motions that may have been clearing debris. In all three observations, the depressions lacked the small soil clumps or other debris found immediately outside the depression.

Figure 23. Frog 5028025B2D visibly moist while in a deep crouch position on moist garden soil on a hot summer day (23 July 2002). Air 22.6 C, ground 19.7 C.

Observed Pattern of Home Ranges Included the Tidal Channel

All three primary home ranges included one or more locations along the tidal channel (Fig. 15). Two frogs (424E61451B, 432C744D14) telemetered during dry summer conditions showed the same pattern of moving to the channel vicinity at the end of July and remaining until at least 20 August. Following the 21 August peak summer rainfall, both frogs moved from the channel vicinity.

Shared Resource Area

The three identified primary home ranges were largely non-overlapping, but five of nine telemetered frogs were found at least once in an open stratum location ca. 5 by 15 m (Fig. 15). For example, on 17 September 2001, two previously telemetered frogs were found within this area, and another two previously telemetered frogs were located within 10 m of this site. Other frogs, including the aforenoted group of migratory frogs from fall 2002, used this location as well. This "shared resource area" is a linear depression vegetated by creeping buttercup (*Ranunculus repens*) and grass (*Gramineae sp*.), partially shaded by remnant mature red alder and western red cedar trees. Roughly 0.5 ha of open and forest habitat drain to this location. Other potential moisture sources include a nearby septic mound, and native moss mulching of shrubs along the depression margin.

Seasonally, Frogs More Observable After Rain

Early summer through early fall, I found frogs more readily observable after rainfall. The 3-day antecedent rainfall value was a useful predictor during this interval for finding frogs (Table 13). Fourteen area-constrained surveys were done between 24 June and 29 September 2001. For seven of these surveys, the 3-day antecedent rainfall was 0.00 mm. Of these seven surveys, only two had frog observations. In contrast, frogs were found during all surveys with some level of 3-day antecedent rainfall. The greatest numbers of frogs were found when rainfall was greater than 3.0 mm.

Table 13. Area-constrained survey number of frog observations and 3-day antecedent rainfall, early summer through early fall.

3-Day Antecedent Rainfall (mm)	Total No. of Surveys	% of Surveys	No. of Surveys w/Frogs	% of Surveys w/Frogs	Total No. Frogs Observed	Range of Frog No. Observed	CPUE (Mean No. Frogs Observed/ Survey)
0.0	7	50	2	29	2	0 to 1	0.3
>0.0 to 3.0	4	29	4	100	6	1 to 2	1.4
>3.0	3	21	3	100	10	3 to 4	3.3
Totals:	14				18		

Early Fall Frog Use of Moist Open Habitat

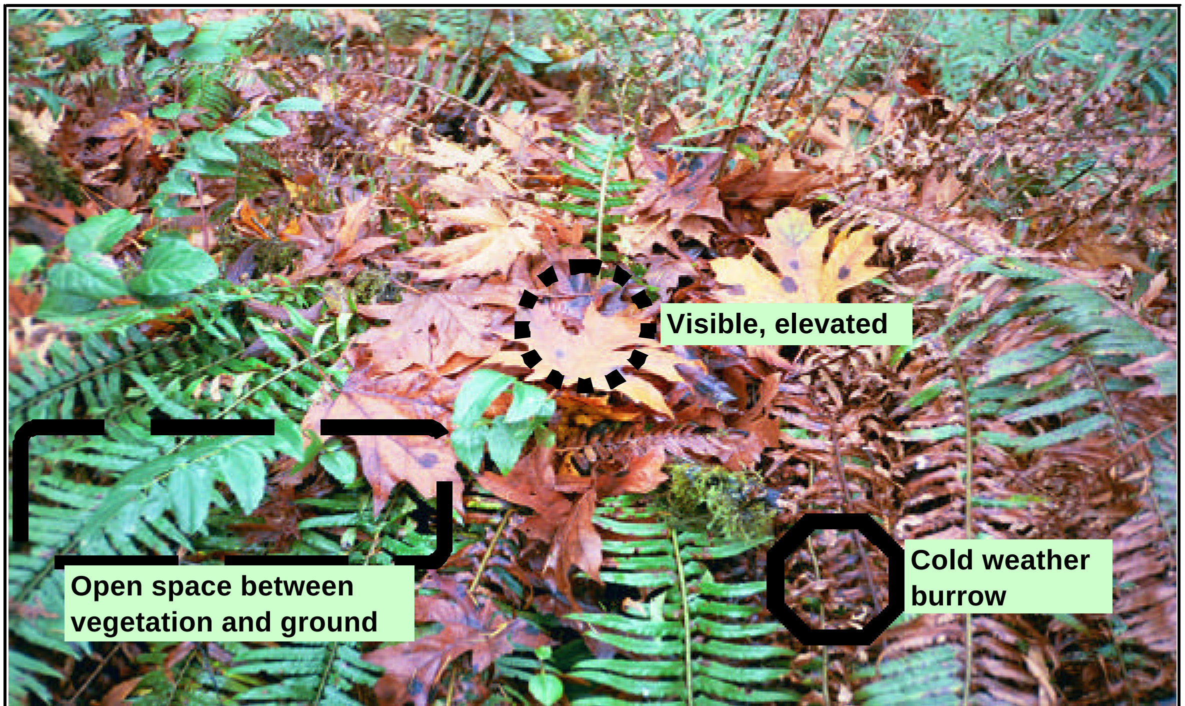
In early fall while the forest remained dry, portions of the open grass/forbs habitat was shaded all day due to the increasingly lower sun angle. Such habitat became very moist through cumulative days of dew and guttation moisture. During the 24 September 2001 area-constrained survey, tidal mudflats, and down wood were the only areas with moisture in the forest quadrats. However in the open stratum, one surveyed quadrat in the shaded grass/forbs habitat had moisture evident over 90% of the area. This quadrat had the greatest percent of moisture of the six open habitat quadrats surveyed, and was the only location during the day's area-constrained surveys where a frog was found. I opportunistically found a second frog in an adjacent similar quadrat within 4 m of the first frog.

Mid-Fall Coloration Change

The cryptic coloration of red-legged frogs changed in mid-fall. Throughout the dry summer through early fall[1], frog coloration closely resembled dry, big-leaf maple leaf-litter. By November, this coloration had darkened and now closely resembled the darker brown of water saturated big-leaf maple leaves. This color change can occur rapidly, as I have two observations where frogs I captured changed from the dark to the light coloration within 30 min and 1 hr.

Mid-Fall to Early Winter Cold Temperatures Limit Activity and Frogs Use Complex Habitat

Colder temperatures mid-fall through early winter were associated with altered patterns of frog activity. The movement interruptions at temperatures below 9.3 C (Fig. 17) are an example. Figure 24 shows sword fern/maple leaves habitat used by frog 501C400240 during November 2001. This complex habitat provided an array of micro-habitats, including a burrow location utilized at cold temperatures (< 7 C air and ground); concealed open space between the extended sword fern skirt and the ground used at a moderate temperature (9 C air and ground); and a visible, elevated location utilized when air and ground temperatures were 12 and 11 C, respectively. For all frogs for which a location could be precisely identified between 16 October and 29 December, I found them exclusively in such complex native forest vegetation. This complexity was lacking in grass/forbs and manicured shrub environments of the open stratum.



7-Nov-2001 (1105). Cold weather burrow. Air and ground 7 C. Frog located in a 10 cm tall chamber at the base of a sword fern. The location was vertically under a 15 cm high, leaf and sword fern frond matrix, and horizontally behind 25 cm of sword fern fronds and maple leaves. Upon disturbance, the frog traveled below the vegetation 0.4 m, where it was refound through telemetry.
11-Nov-2001 (0950). Above ground opening under dense cover. Air and ground 9 C. Frog in opening beneath roof of sword fern fronds, Oregon grape (*Berberis nervosa*), and maple leaves. This location is connected to the cold weather burrow through at least one opening. Frog is probably able to feed within this opening.
12-Nov-2001 (1417). Elevated on sword fern frond, visible. Air 12 C, ground 11 C. Frog presumed able to feed in this open location.

Figure 24. Mid-fall structural locations within a sword fern and maple leaf complex that were used at differing temperatures by female frog 501C400240.

Frog Visibility, Structural Location, and Temperature

Figure 25 shows six categories of frog visibility and structural location, relative to air and ground temperatures. Frogs were found in sub-surface locations during cold temperatures (ground and air 2.0 to 9.0 C). Sub-surface locations in which I found frogs included: a 2.5 cm high crevice in soils along a slope (n = 1); small mammal excavations or openings below or within sword fern boles (n = 2); location under dense twig and leaf litter accumulations at the base of a log (n = 1); and an opening created by two

[1] An exception was a wet, dark colored frog fround 0642 hr on 10 August 2002.

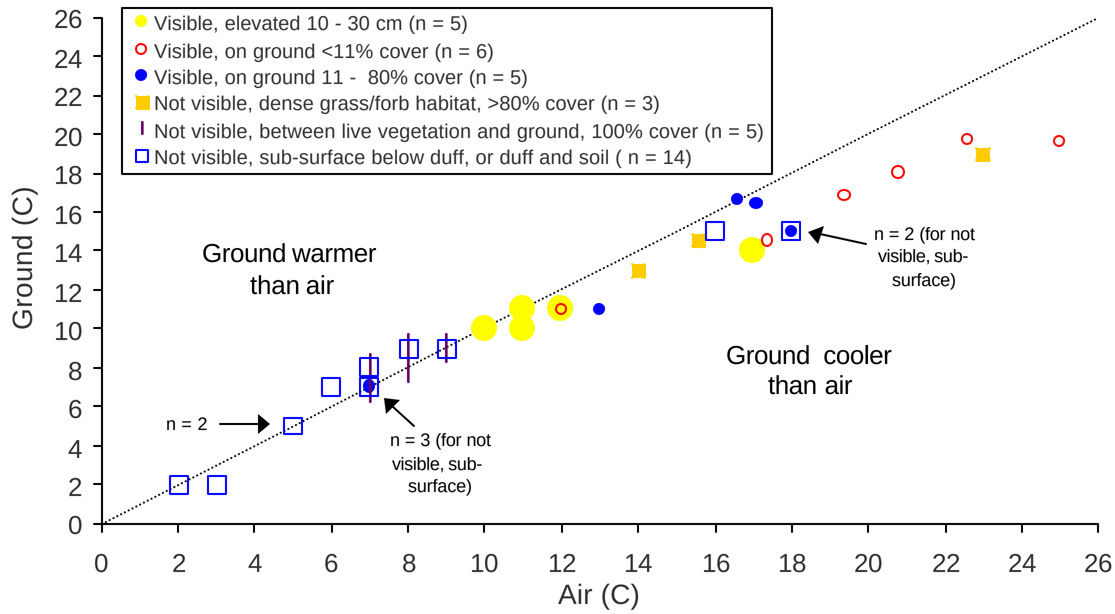


Figure 25. Frog visibility, structural location, and temperature. Temperatures were taken at the frog site.

developing chanterelle (*Cantharellus* sp.) fruiting bodies (mushrooms) that were pushing a dense twig, duff and leaf layer upward as they developed below the ground.

At air and ground temperatures 10 C air and ground, frogs were found either elevated on wood or vegetation, visible on the ground with varying amounts of cover, or concealed beneath leaf litter. Below 10 C air and ground, frogs were found either under 100% nearspace cover (above ground but beneath live vegetation), or in the sub-surface locations I have described previously. An exception to this was on 21 December 2001; at air and ground temperatures of 7 C, I observed frog 501C400240 with 70% of its body concealed by leaves, but its head and one foreleg were visible. Below air and ground temperatures of 7 C, frogs were exclusively found sub-surface.

Summary of Terrestrial Behavior

Figure 26 (a to d) uses data from area-constrained searches, telemetry, and trapping to provide a visual summary of the locations of terrestrial frog observations at the study area by season in 2001. During spring and early summer (Fig. 26a), frogs were found in a dispersed pattern throughout the study area during area-constrained surveys. Telemetry had not yet started, and limited trapping provided no data.

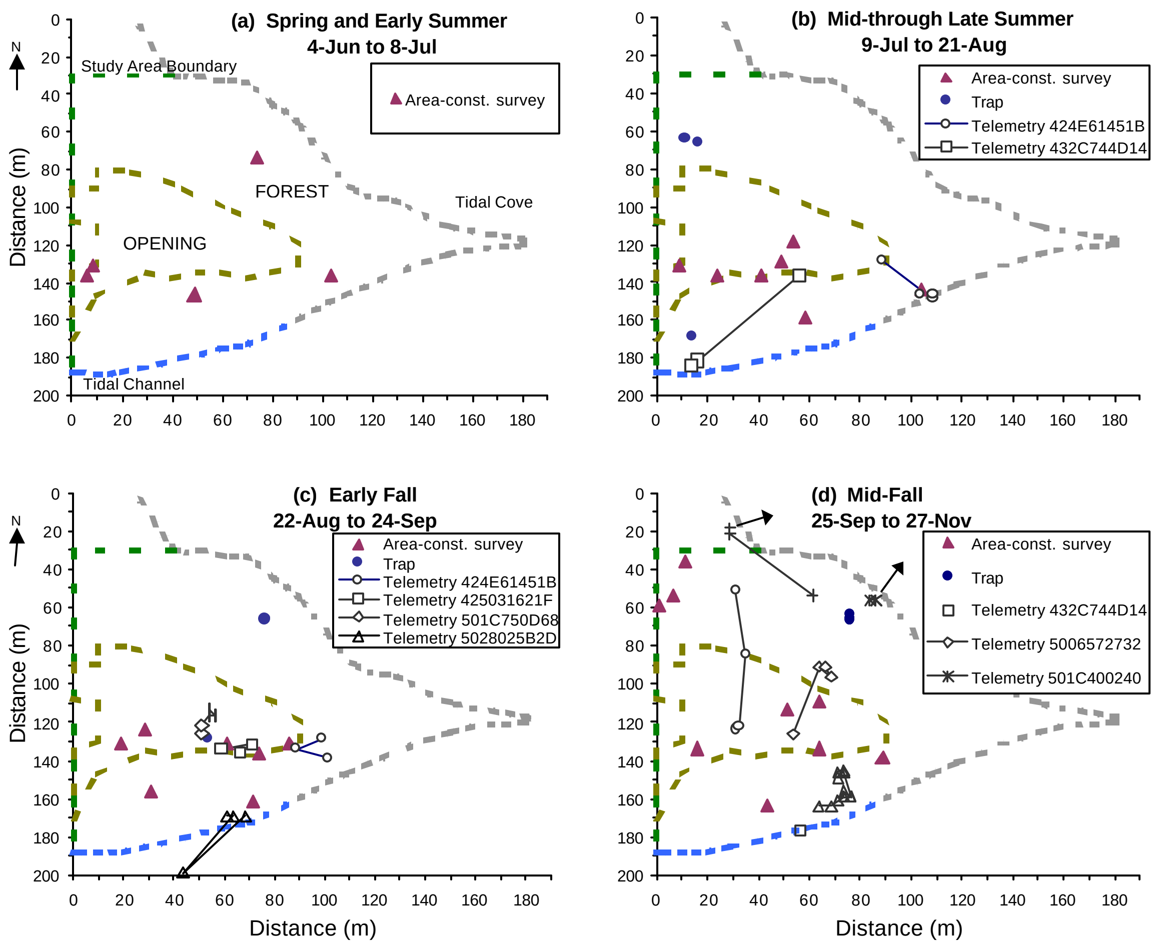


Figure 26. Seasonal frog use of the study area in 2001.

In mid-to-late summer (Fig. 26b), temperature and moisture conditions were typically warm and dry. During area-constrained surveys I only found frogs in the southern-half of the study area. Several of the area-constrained survey frogs were found along the edge between the forest and open strata. The two telemetered frogs both traveled to far ends of their primary home ranges to locations near the tidal channel. Both remained near the channel until at least 20 August 2001. The largest rain of the summer began August 21. On this day three untagged frogs were caught in traps near the western edge of the study area.

During early fall (Fig. 26c), both telemetered frogs that had been along the tidal channel moved away from the channel (one was no longer telemetered and therefore is not shown). Except for one frog caught in a trap in the northern portion of the site, all frogs were found in the southern half of the site. The forest and open edge, and the open stratum location with accumulated dew were where most frogs were found. Telemetry data shows a concise use-pattern of relatively small distances for three frogs, and one frog was found to be using immediately adjacent sides of the tidal channel.

Mid-fall (Fig. 26d) revealed a broad spatial use of the study area by frogs. During area-constrained searches, I found most frogs in the southern-half of the study area. However three frogs[1] found during area-constrained searches in the northwest corner of the study area and frogs caught in traps in the northeast portion of the study area indicated a broader spatial use of the study area, and movement pattern. One telemetered frog was found along the tidal channel and another maintained a primary home range in the forest near the channel until at least 7 November 2001. Using telemetry, two frogs were tracked making longer movements along the tidal cove and both were subsequently observed northeast of the study area across the tidal cove. Both interrupted movement during cold weather before crossing to the other side of the cove.

[1] Two were caught and one escaped. Of the two caught, one had not been previously caught and tagged, and the other had been tagged 4 days prior.

CHAPTER 6. DEMOGRAPHIC, ENVIRONMENTAL CONDITIONS, AND NATURAL HISTORY AND BEHAVIOR DISCUSSION

In this discussion, I consider elements of observed terrestrial northern red-legged frog use including demographics, and my research hypothesis regarding a possible preference for human created terrestrial openings. I also provide a synthesis of moisture and temperature data and frog behaviors.

Demographics

Population Estimate

Terrestrial northern red-legged frogs were difficult to census with a high degree of certainty. Marking with unique PIT tags was useful for providing a minimum number of known, unique frogs. PIT tag data analysis indicated seasonal ratios of newly tagged frogs were found at a rate of 50% or higher throughout the study (Table 7), providing evidence that the number of uniquely tagged frogs was a low estimate. The study methodology of utilizing stratified random area-constrained search-day catch data along with PIT tagged individual frogs, with the Schnabel population estimation technique, was most useful for population enumeration.

Some frogs clearly stayed within an active season home range at the study area, but with the exception of the time intervals of warm droughty conditions, I could not rule out that there may have been movement not associated with a home range throughout much of the active season. Small frogs (5 to 9 g), undoubtedly young of the year, were first found at the study area at least 2 months after the first adults were observed. In addition, my results and observations indicated migratory movement to overwintering habitat might extend from mid-August into November. I also cannot rule out that this migratory period could extend later. An implication of this for census work is that closed-population requirements of estimation methods such as the Schnabel population method will be difficult to meet. However, focusing on the expected non-migratory interval before mid-August should provide the best approach.

Mortality is likely to occur as well. Licht (1974) reported the requirement for no mortality was unable to be met in his Schnabel estimates for *R. aurora aurora* and *R. pretiosa pretiosa* in British Columbia. However, he compared the Schnabel estimates with results from the Lincoln Index and the Schumacher method and reported finding "nearly identical results" for metamorph life history estimates, lending confidence to the methodology.

Traps were useful, but not effective at catching many frogs. I suspect some frogs were caught and then escaped; on one occasion I put a robust mid-sized frog in a trap in the evening and it was gone by morning. An improved trap design may have been able to prevent this from occurring. In addition, setting a drift fence with traps along an expected migratory or movement route may be more successful than random placement of arrays. For example, the one array in my study that had the most catches appeared to be in a migratory pathway.

Frog Growth Data

An important finding related to the three size measurements (SVL, shank length and mass) was evidence that the primary period of frog growth was during spring through mid-fall. Licht (1974) found postbreeding female northern red-legged frogs did not develop eggs before July and therefore observed that food eaten before July was apparently not used for egg production. During July on, food eaten was assumed to include utilization for egg production. He also found larger females tended to have more eggs. Thus the overall size and fecundity of female frogs may be dependent upon habitat conditions conducive to feeding and growth.

Frog Ages

Frog ages were difficult to discern. Based on size, the very smallest frogs (e.g., with masses in the 3 to 9 g range) were probably young of the year. The third year finding of male 425D5D1C4A, (age minimum 2+, mass 15 g), indicates that low-mass frogs can be at least 2 years old. Snout-vent length data for female frogs with two data years showed a pattern indicating roughly three size groups, which may reflect three age classes. These group are: 50 to 60 mm, 60 to 70 mm, and > 70 mm. For example, two females had measurements of 51 and 52 mm (respectively) their first capture year. The second capture year, they were 66 and 61 mm. A different two females had SVL measurements of 60 to 63 mm, and 65 to 67 mm (respectively) the first year caught. During their second year, they measured 73 to 74 mm, and 74 to 78 mm, respectively.

Mortality Factors

Both natural and human caused sources of mortality may exist at the study site, but with the exception of trapping mortality none were evident. The largely motionless behavior and cryptic coloration of the northern red-legged frogs may be a successful strategy for preventing detection, which likely makes them less vulnerable to predation. However I was unable to adequately assess whether predation was a key factor within active season habitat (i.e., on the study site) as the fate of most frogs that were captured only once was unknown.

Periods of terrestrial movement, especially longer movements such as occur between breeding, active season, and overwintering habitats, may be significant intervals during the terrestrial life history during which northern red-legged frogs are vulnerable. These major moves tend to occur during rainfall events and at night (e.g., Nussbaum et al. 1983; Licht 1969; and my observations), both which likely provide some protection. The cover of darkness and a rainfall screen may interfere with the visual field of potential predators; moreover, rainfall could possibly reduce scent-tracking abilities of some mammalian predators.

In developed areas, frog movement across roads is clearly a direct source of mortality to northern red-legged frogs and other amphibians (this thesis; Beasley 2002; Lamoureux & Madison 1999). This is an important issue that should be hypothesized as being one of a major group of threats to northern red-legged frog populations in areas of development.

Analysis of Hypothesis Regarding Attraction to Human-Created Openings

Telemetry was essential for learning about patterns of use of the study area and environs by the frogs. The complexity of this use exceeded my initial conceptual expectations. The primary research question "*Do northern red-legged frogs show a preference for a human-created forest opening with grasses, forbs and gardens over adjacent undeveloped forest?*" implicitly suggested that some frogs might use open habitat, while other frogs might use natural forest habitat. While I did have a higher rate of frog observations during area-constrained surveys in the open versus forest habitat, this was not significantly different (p = 0.14, see results). In addition, frogs may have been easier to find in open habitats, voiding the comparability of encounter rates in open versus forest habitats.

However, the pattern of habitat use by northern red-legged frogs proved to be much more complex. Importantly, through varied techniques, I discerned that the same frog could be using both open and forest strata (e.g., Fig. 18). The open habitat was more often moist during the warm summer through early fall, warm droughty conditions (Fig. 12), and for some frogs, may have provided critical moisture needs during otherwise droughty conditions. In addition, use of the open area by frogs found in the forest edge indicated that open habitat was used in tandem with forest habitat. My observations were similar to those of Chan-McLeod (2003) who reported a quick retreat into the forest from northern red-legged frogs that moved into a clearcut, as well as their maintaining a close distance (12.7 m) to the forest edge, and to Haggard (2000) who found that where northern red-legged frogs were in grassland near thicket/forest habitat, they were "usually near or at the edge of the thicket/forest." Thus it is possible that open terrestrial habitat without nearby complex forest habitat could be unsuitable for northern red-legged frog active season use.

Furthermore, after mid-October when conditions became moist but cool, I only found frogs in native forest habitat with complex shrub, leaf and wood accumulations. These inferences suggest that at terrestrial locations similar to the study area, forest habitat is a requirement for northern red-legged frogs during both the active and overwintering seasons.

Synthesis of Moisture and Temperature Data and Behaviors

"Pity the poor frog, his behavioral and physiological problems are so complicated and interrelated, it is amazing that we can understand them and that he is alive at all!!"

Bayard Brattstrom (1979).

Northern red-legged frogs switch from being in water most of the time immediately post-breeding (Shean 2002), to becoming mostly terrestrial during the active season (Haggard 2000; this thesis). Patterns of habitat use and environmental conditions that I observed lead me to hypothesize that feeding is a primary driver for frogs in their active season. However, as conditions become dry and warm as summer progresses, reduced availability of moisture and thus potentially increased risk of desiccation, may limit frog activity and the ability to be surface active and feeding. Late fall to early winter, the presence of frogs above ground at temperatures 7 C leads me to additionally hypothesize that feeding remains a priority.

This study demonstrated that the highest frog growth rates occurred spring through mid-fall. Thus, it may be that conditions suitable for feeding and favorable for growth and survival during the extended active terrestrial and overwintering intervals are critical for northern red-legged frogs. I hypothesize that a limiting environmental factor during warm droughty terrestrial conditions is moisture, and during cooler moist conditions a limiting factor is temperature.

Preliminary Model for Hypothesized Limiting Factors (Moisture and Temperature)

Figure 27 provides a preliminary season-based model to explain northern red-legged frog use of terrestrial habitat as a function of temperature and moisture.

Spring through early summer-- A focal assumption of the model is that until early summer, moisture conditions (e.g., see Figs. 10, 11, 12) typically do not limit frog activity. However, in early summer, a transition period occurs during which the prism of moist habitat quickly begins to contract (Fig. 12), and moist sites became patchy on the landscape. Surface visible frogs that I located during this time were found in these moist patches. Haggard (2000) reported a similar observation for northern red-legged frogs in northern California. Hence, the first pattern observed associated with the changing moisture regime was the use of habitat that remained moist.

Northern red-legged frogs may prefer moist substrate, and use it as long as possible before initiating dry habitat behaviors. This use pattern appears similar to that which Heatwole (1961) identified for wood frogs. When wood frogs were provided with a choice of wet muck or leaf litter and bark, the frogs were always on the moist muck. However, when he allowed the substrate to begin drying, the frogs showed an increased preference for being under cover.

SPRING (20-Mar to 20-Jun)

Moisture and thermal regimes: All habitat typically moist to saturated (av. rainfall 2.3 mm/day, 41% of days have rain); temperatures moderate (av. air 12.3 C).

Frog response and limitations: Feeding and movement opportunities readily available.

Assumption: Moisture not limiting for frog activities; temperatures above ca. 9.3 C provide movement opportunity.

EARLY SUMMER (21-Jun to 8-Jul)

Moisture and thermal regimes: Habitat begins to dry (av. rainfall 1.9 mm/day, 17% of days have rain); temperatures moderate (av. air 13.9 C).

Forest habitat becomes increasingly dry; microhabitats, e.g., downed wood and leaf accumulations at sword fern bases continue to retain moisture.

Open habitat may have morning dew and guttation moisture.

Intermittent rains provide moisture to many habitats, but most quickly dry. Areas at the base of concave topographic locations, and under dense cover retain moisture longer.

Frog response and limitations: Frogs begin to use the moist spectrum of habitats. This spectrum spatially and temporally expands with rainfall. Use may be related to feeding, moisture retention and absorption, temperature regulation, or other needs.

Assumption: Moisture and temperature are becoming limiting for frog activities.

MID-SUMMER THROUGH EARLY FALL (9-Jul to 24-Sep)

Moisture and thermal regimes: Most habitat is dry (av. rainfall 0.8 mm/day, 22% of days have rain), temperatures warm to hot but begin to cool early fall (av. air 15.0 C), av. ground temperatures cooler than air (14.4 C).

-In forest, only decaying down wood routinely retains moisture.

-Open habitat may have morning dew and guttation moisture; human watering creates moist patches.

-Intermittent rains create ephemeral moist conditions with less observed moisture under conifers than under deciduous trees or in open areas.

-Small tidal/freshwater channel and nearshore tidal habitats are moist.

Frog response and limitations:

-Use of dry sub-surface habitats presumably for protection from heat and dehydration.

-Use of rain events to become more active (e.g., emerge from sub-surface habitat, and/or move to different locations than being used during prolonged dry spells).

-Absorption of moisture from limited sources.

-Burrowing after absorbing moisture within or under dense dry leaf litter.

-Use of dry open habitat for feeding, after obtaining moisture elsewhere.

-Cool early morning use of open habitats near forest edge for feeding (and possible moisture absorption).

Assumption: Moisture and temperature conditions are limiting.

MID-FALL THROUGH EARLY WINTER (25-Sep to 31-Dec)

Moisture and thermal regimes: Habitats moist to saturated (av. rainfall 4.6 mm/day, 61% of days have rain); temperatures increasingly cool (av. air 7.2 C), ground on av. (9.0 C), is warmer than air.

Frog response and limitations:

-Below 10 C air and ground, frogs are primarily below 100% near-space vegetation cover, and below 7 C frogs are subsurface below leaf duff or duff and soil.

-Feeding possible in sheltered locations during cool weather (e.g., 7 to 10 C air and ground) and openly visible locations when air is warmer, including conditions where air is warmer than ground (e.g., air 12 C, ground 11 C).

-Frogs may use large rain events to travel to winter home ranges. When temps. drop below ca. 9.3 C, migration halts and frogs use migratory stop-over sites with complex native vegetation.

Assumptions: Cold temperatures limit frog activity.

Figure 27. Model showing observed responses to moisture and temperature gradients by northern red-legged frogs at a terrestrial study site in the Puget Lowland Ecoregion from spring through early winter.

Mid-summer to early fall dry, warm conditions-- Varied behavior patterns were associated with dry, warm terrestrial conditions mid-summer through early fall. My observations of visibly moist northern red-legged frogs in crouch positions on watered garden soils, suggest that the frogs were absorbing soil moisture cutaneously, and utilizing evaporative cooling. Research on other anurans supports this possibility. For example, Shoemaker et al. (1992) summarize literature on amphibian use of soil moisture to obtain body moisture. They report that amphibians use close contact with the soil, as well as accumulation of solutes to reduce the animal's water potential, as adaptations that allow intake of soil water. Carter (1979) provides an overview of literature that documents the permeable nature of frog skin including the exceptional permeability to water of some ventral skin areas. He also states: "It is known that many frogs adopt a distinctive posture when absorbing water from a moist surface." Carpenter and Gillingham (1987) presumed that giant toads (*Bufo marinus*) were absorbing moisture where they appeared to be flattened into tire tracks, or onto a moist log.

I am not aware of literature specific to the use of evaporative cooling by northern red-legged frogs. However, literature reviews and discussion by Brattstrom (1963, 1979) provide a basis for its occurrence during heat related stress and also as a "normal mechanism of thermoregulation." This physiological adaptation may allow amphibians to be "more active longer" (Brattstrom 1979).

Research by Carter (1979) suggested that water absorbed through anuran skin may be collected in lymph spaces. This could account for the "very wet" frogs I observed during dry conditions, and potentially indicate an adaptation of northern red-legged frogs that allows for water collection and storage during drought conditions.

Finding northern red-legged frogs on tidal mudflats during the warm and dry mid-summer to early fall period was unanticipated. However, Balinsky (1981, cited in Shoemaker et al. 1992) has reported that 61 species of anurans inhabit or tolerate brackish water. Hayes (pers. comm. 2002) studied the California red-legged frog at Pescadero Marsh (south of San Francisco along the California coast) in the 1980's. Here at levels of 4.5 ppt salinity, embryos died, and at 8.0 ppt salinity frogs vacated the area.

Three different frogs in my study were found in areas routinely flooded by tidal waters[1], and a fourth frog was found on the other side of the channel, indicating that it had crossed the channel. Tidal channel, and near channel substrate salinities (Fig. 14) measured near locations where I found frogs were below the 8.0 ppt salinity level reported as causing California red-legged frogs to leave. Frogs at my study area may have been obtaining water in the tidal zone. However, this environment may not have been preferred, as indicated by the movement away from the shoreline by two telemetered frogs following the 21 August 2001 rainfall. Microsite investigation of salinity variation, freshwater inputs, and specific northern red-legged frog locations would be useful to provide a better understanding of this species' possible use of the tidal area for obtaining moisture.

Northern red-legged frogs at my study area had home ranges that appeared to include primary and backup areas for obtaining water during warm droughty conditions. In particular, for two telemetered frogs with identified primary home ranges, one end of each frog's range had an apparent primary source, the buttercup and grass "shared resource area". Presumably when it no longer provided adequate moisture, the frogs used the tidal channel as a backup source.

The highest measured air temperature during the study was 26.9 C and the highest ground temperature was 21.0 C. Mean air temperatures for the three combined core stations (spring, 12.3 C; early summer, 13.9 C; and mid-summer through early fall, 15.0 C), reflect conditions conducive to the preferred body temperature of 13.3 C for *R. aurora* reported by Brattstrom (1963)[2]. The mean air temperature mid-summer through early fall, taken 3.5 km from the study area in a developed, non-forested portion of The Evergreen State College, was nearly a degree higher (15.8 C), suggesting the importance of the forest and shoreline moderated climate at the study site.

Mid-fall to early winter-- Colder temperatures mid-fall through early winter appeared to limit frog activity as I only found frogs in subsurface burrows at temperatures

[1] My three direct observations of frogs in the tidal zone all occurred when the tide was out. I observed frog 424E61451B (see Appendix G) turning toward incoming tidal waters and then away, eventually hopping to shore, and up a small cliff, when tidal waters approached within 10 cm.

[2] Note that Brattstrom (1963) does not indicate subspecies for this data hence it is possible that data for the California red-legged frog (*R. aurora draytoni*) may be included.

< 7 C. Based on this, it appears that should temperatures drop to a critical minimum[1] the frogs would be in protected locations moderated by the ground temperature.

During the increasingly cold mid-fall to early winter period, frogs may be selecting habitat locations with a warmer microclimate. Average air and ground temperatures at the shoreline cliff and the near shoreline site were the warmest recorded at the study site mid-fall through early winter (Table 8). Both frogs telemetered throughout November used migratory stop-over habitat on a slope within 5 to 10 m of the cove and may have benefited from the warmer conditions. Winter habitat used by these same two frogs may also represent selection for a warmer microclimate. One frog was on a south-facing hillslope, and the other was on the nearby hillslope plateau. Both locations had favorable insolation, but temperature data would be needed to verify a temperature advantage to these locations.

[1] I assume this would be similar to the -1 C critical minimum identified for *R. cascadae and R. pretiosa* by Brattstrom (1968).

CHAPTER 7. SPECIES CONSERVATION

This chapter and its associated Appendix I, provide a focus on conservation needs of northern red-legged frogs in the Puget Lowlands, and more broadly within Washington State. The methods, results, and discussion for conservation interviews/surveys are presented, as is a section discussing this study's contribution to knowledge of the northern red-legged frog, and recommendations for further study.

Introduction

Due to the rapid development expected within the next 20 years for the Puget Sound (Washington Office of Financial Management 2002) and thus expected extensive incremental habitat loss, northern red-legged frog populations in the Puget Lowlands face considerable uncertainty for the future. It is unlikely that the current, widespread and common nature of this species can be retained without specific knowledge of its life history needs and protective measures focused toward these needs.

Northern red-legged frogs face double jeopardy from human impacts to both land and water environments. One frog may not only require breeding, active-season, and overwintering habitats, but migratory stop-over locations among these frequently spatially distinct habitats may also be important (this thesis). All of these segments of northern red-legged frog habitat are vulnerable to varying degrees to human-caused changes. In addition, migration routes must increasingly cross roads and driveways adding what may be a substantial direct source of mortality.

Work done by the Science and Environmental Health Network (2001) on the role of science in the face of uncertainty and lack of data, provides a basis to consider northern red-legged frog needs in developing landscapes. They advocate applying the precautionary principle as a guide. This principle, as written in the Icicle Creek Statement (Science and Environmental Health Network 2001), is as follows:

"*When an activity or condition raises credible threats of harm to ecosystems, precautionary measures should be taken, even if cause-and-effect relationships are not fully established*."

O'Brien (2003) discusses two approaches for use of this principle. The traditional use is as a "triggered brake", a way of estimating where, for example, a specific activity will drive a species to an unrecoverable population, and in the face of uncertainty, taking precautionary measures to provide protection. A second approach is using the principle "*as a means to achieve positive public and environmental health goals*." This process is initiated by developing a positive environmental health goal. A complex of activities is then developed and implemented to achieve the goal, and a monitoring/feedback loop to assure the process is effective at achieving the goal is included as part of the process.

For the purposes of this thesis, I adapted concepts from the above approach as a framework for interviewing/surveying amphibian biologists during July of 2002. For the survey, I specified a proactive conservation goal for red-legged frogs in Washington as follows: ***"****To maintain robust populations of red-legged frogs throughout their historical range within Washington State.****"***

Although the emphasis of my research has been the Puget Lowland Ecoregion, the survey specified the broader spatial area of the state. The purpose for the surveys was to gather the following information:

1. Alternatives to enable achieving the proactive population goal, and,
2. Population status and vulnerability of the northern red-legged frog in Washington.

Methods: Conservation Surveys

During July 2002 I interviewed five scientists regarding northern red-legged frog conservation in Washington. The persons I interviewed were: Marc Hayes, Research Scientist, Washington Department of Fish and Wildlife; Klaus Richter, Senior Ecologist, King County Department of Natural Resources; Kelly McAllister, Regional Wildlife Biologist, Washington Department of Fish and Wildlife; J. Tuesday Serra Shean, Wetland Biologist, Washington State Department of Transportation; and, Mike Adams, Research Ecologist, US Geological Service. Interviews were held in person with Marc Hayes, Klaus Richter and Kelly McAllister, through written responses with J. Tuesday Serra Shean and Mike Adams, and they included additional written responses from Klaus Richter.

Results and Discussion

Respondents described Washington populations as being in the heart of the species' range, which was expected to lend benefits for survivability. However, populations in rapidly developing areas (e.g., much of King County) were felt to be vulnerable. Overall, the survey documented that we have small amounts of demographic data, broad but not specific location information, poor status and trends data, poor information on thresholds of concern for population decline and for habitat loss; and some local efforts, but no broad monitoring programs that include this species.

Based on survey results I erected a system with six components for achieving the above-noted goal. Components are (1) a research and monitoring effort to support all aspects of protection, (2) immediate protection needs for rapidly developing areas where red-legged frogs are currently most vulnerable, (3) public education about the needs of northern red-legged frogs, (4) inclusion in and adjustments to the state conservation status program, (5) exotic species measures, and (6) adaptive management to assure new information is incorporated into protective components and that the system is effective at achieving the overarching goal. This system is outlined in Table 14. Further details and additional survey results are provided in Appendix I.

Table 14. Components of a system to achieve the goal: "*To maintain robust populations of northern red-legged frogs throughout their historical range within Washington State*."

1. Research and Monitoring
- a. Geographic presence linked with population condition index sites
- b. Demographic and habitat research
- c. Landscape analysis for rapidly developing areas

2. Protection in Rapidly Developing Areas
- a. Habitat needs and normal hydrology
- b. Protection of population core areas
- c. Protection of ephemeral wetlands
- d. Stormwater pond measures

3. Education
- a. Volunteer egg mass surveys
- b. Children's programs
- c. Brochures for habitat needs
- d. News and television programs

4. State Conservation Status
- a. Inclusion in state monitor status
- b. Update of state conservation system to address regional needs

5. Exotic Species
- a. Prevent the spread of exotic fish
- b. Remove exotic fish from some areas
- c. Maintain bullfrog-free wetlands

6. Adaptive Management
- a. Share and incorporate new information into system
- b. Assure that system is achieving goal

Each system component, potentially in combination with other wildlife protective work, is a unit that can be accomplished. System components complement each other and all provide worthwhile endeavors in support of Washington's red-legged frog populations.

This Study's Contribution to Conservation of the Northern Red-Legged Frog, and Recommendations for Further Study

There has been limited research to date focused on terrestrial habitat use by northern red-legged frogs. This study importantly has provided a framework for recognizing some of the complexities that are involved in terrestrial use, (e.g., demographic components, moisture and thermal requirements, movement and differing seasonal habitat requirements and other patterns of behavior). Overall study results indicate numerous avenues of susceptibility to population impact from landscape changes that result from development. It is imperative that we better understand how northern red-legged frogs use habitat, directed at providing information that can be used for their protection.

As such, complementary to elements listed in Table 14, I recommend the following research regarding northern red-legged frog terrestrial habitat use and conservation:

- Terrestrial active season and overwintering habitats.
    1. What are key characteristics of terrestrial active season, and overwintering habitats (e.g., plant communities, proximity to streams or other waters including breeding areas, factors that may elucidate insolation advantage for overwintering habitat, and how habitat is linked to trophic structures and northern red-legged frog diet)?
    2. Development of a model that will assist with knowing where terrestrial habitat use is most likely to occur.
- Movement between breeding, active season, and overwintering habitats.
    1. Clarification and specifics regarding when the frogs are most likely to be moving (e.g., seasons and dates, climatic conditions).
    2. What are characteristics of where the northern red-legged frogs move on the landscape? Can these be identified and modeled before an area is developed to provide protection for migratory pathways?
    3. What measures would be effective at protecting the frogs from vehicle mortality?
- Meta-population structures.
    1. Do meta-population structures exist for northern red-legged frogs?
    2. If so, how do they function, and what are necessary measures to assure their protection?

CHAPTER 8. KEY FINDINGS

Demographics

- Based on a Schnabel population estimate, the number of frogs using the study area in 2001 was estimated to be 60 (95% confidence interval of +/- 81). This equates to 31 frogs per ha. Based on expanded data from 2001 area-constrained searches the maximum population was 78 frogs. Fifty-four frogs were uniquely identified in 2001.
- Frogs ranged from 36 to 79 mm SVL, and from 3 to 48 g. The mean of the maximum SVL measured for known females in 2001 was 69.3 mm. The SVL of known males (n = 3, for 2000 to 2002) ranged from 51 to 59 mm. The mean of the maximum mass measured for known females in 2001 was 35.8 g. The masses of known males (n = 3) ranged from 11 to 23 g.
- Daily growths rate (as SVL) and increases in mass were greater spring through mid-fall as compared to the full year (SVL: $p = 0.0023$), suggesting the importance of this interval in relation to feeding.

Behavior

- Frogs utilized terrestrial habitat from April through December.
- A higher rate of capture for frogs occurred in the open stratum (during area-constrained surveys) than in the forest stratum, but capture rates were not significantly different between strata ($p = 0.14$) and potentially confounded by differential detection rates between strata.
- Primary active season home ranges were used for at least 4 to 5 months. Three primary home ranges identified were 62 to 80 m long, and 9 to 18 m wide. Individual home ranges included open and forest habitats as well as a tidal channel.
- At least some frogs returned to the same active season home ranges in subsequent years. In 2002, of five frogs present during the summer, two were also observed in 2001, and one had also been observed in both 2000 and 2001.
- Two female frogs were tracked to winter home ranges. They were located on a southwest facing forested hillslope, across the salt-water cove from the study area.
- A preliminary ethology of northern red-legged frog behavior in its natural terrestrial environment was developed. Categories are: postural, distance movement, in-place

movement, movement patterns and home ranges, physiology, predator/danger responses, habitat modification, vocalization and social structure.

- Video footage taken August and September 2001 showed frogs were motionless 99.5% of the time. There were 181 sec of movement during 11 hr of observation. During these seconds, there were 123 movement episodes, and these included 149 individual behaviors (i.e., some episodes had > 1 behavior). The frogs had an insect capture rate of one per 3.7 hr.
- Spring through early winter moisture and temperature regimes elicited behavior patterns from the frogs that suggested being able to remain actively feeding was important. The frogs used multiple approaches to obtain moisture that presumably allowed surface activity such as feeding to continue. A preliminary model was developed to explain observed responses.
- During early summer through early fall, the 3-day antecedent rainfall was a useful predictor of the mean number of frogs observed during area-constrained surveys. Most frogs were observed when there had been > 3.0 mm of rain. Only two frogs were found during the seven surveys that had no 3-day antecedent rainfall.
- At 10 C air and ground temperatures frogs were found sub-surface, on the ground, and elevated on vegetation or wood. Between 7 and 10 C air and ground, frogs were almost always found below 100% near-space cover, or in sub-surface burrows. Below 7 C air and ground, frogs were only found in sub-surface burrows.
- Spring and fall migrations included a diversity of timings and patterns. Migration stopped in the fall when temperatures were below ca. 9.3 C, and reinitiated when conditions warmed up, concurrent with rain.
- After mid-October, frogs were only found in native forest habitat with complex shrub, leaf and wood accumulations.

Conservation

- At terrestrial locations similar to the study area, forest habitat appears to be a requirement for northern red-legged frogs during both active and overwintering seasons.

- The major source of observed mortality to adult frogs was vehicle travel on a residential road crossed by frogs during spring and fall. This serious issue should be hypothesized as being within the top group of threats to northern red-legged frog populations in areas of development.
- Based on surveys of amphibian biologists, I outlined a system to achieve long-term robust populations for this species throughout its range in Washington. Components are research and monitoring, protection in rapidly developing areas, education, state conservation status, control of exotic species, and an adaptive management process to assure that progress is being made in achieving protection.

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APPENDIX A. Year 2001 survey type and number of frogs.

Table A-1. Frog survey data. Gray indicates no survey. Data exclusively from telemetry were not included.

Season	Date	Time/ Area No.	Oppor- tunistic No.	Trap No.	Grand Total
Spring	3-Apr	0	0		0
20-Mar to	21-Apr		1		1
20-Jun	23-Apr	0	1		1
	2-May	1	0		1
	7-May	4	0		4
	15-May	0	0		0
	19-May		1		1
	21-May	2	0		2
	28-May	2	0		2
	29-May		1		1
	3-Jun		1		1
	4-Jun	1	2		3
	10-Jun		1		1
	11-Jun	0	0		0
	15-Jun		2		2
	18-Jun	1	1		2
Early	25-Jun	3	1		4
Summer	28-Jun		1		1
21-Jun to	1-Jul		1		1
8-Jul	2-Jul	0	1		1
	3-Jul		0	0	0
	4-Jul		0	0	0
	8-Jul		2		2
Mid through	9-Jul	0	1		1
Late	12-Jul		1		1
Summer	14-Jul		1		1
9-Jul	15-Jul		3		3
21-Aug	16-Jul	2	1		3
	17-Jul		0	0	0
	18-Jul		0	0	0
	23-Jul	0	0		0
	24-Jul		0	0	0
	28-Jul		3		3
	30-Jul	1	0		1
	31-Jul		0	0	0
	2-Aug		1		1
	6-Aug	4	1		5
	7-Aug		2	0	2
	13-Aug	0	1		1
	14-Aug		0	0	0
	18-Aug		1		1
	19-Aug		1		1
	20-Aug	1	0		1
	21-Aug		0	3	3

Season	Date	Time/ Area No.	Oppor- tunistic No.	Trap No.	Grand Total
Early Fall	25-Aug		4		4
22-Aug to	26-Aug	3	3		6
24-Sep	3-Sep	2	2		4
	4-Sep		1	1	2
	9-Sep		1		1
	10-Sep	0	1		1
	11-Sep		1	1	2
	12-Sep		0	0	0
	13-Sep		1	0	1
	14-Sep		1	0	1
	15-Sep		2	0	2
	17-Sep	1	2		3
	18-Sep		0	0	0
	19-Sep		2	0	2
	20-Sep		0	0	0
	22-Sep		1		1
	23-Sep		3		3
	24-Sep	1	1		2
Mid-Fall	25-Sep		1	1	2
25-Sep to	26-Sep		3	0	3
27-Nov	27-Sep		0	0	0
	30-Sep	6	0		6
	1-Oct		1	0	1
	8-Oct	2	2		4
	9-Oct		0	0	0
	14-Oct		2		2
	15-Oct	1	0		1
	16-Oct		0	0	0
	22-Oct	0	0		0
	23-Oct		0	0	0
	24-Oct		0	1	1
	30-Oct		0	0	0
	31-Oct		0	0	0
	1-Nov		0	0	0
	2-Nov		0	1	1
	3-Nov		0	1	1
	4-Nov		0	0	0
	5-Nov		0	0	0
Total all seasons:		**38**	**69**	**9**	**116**

Number of surveys
Time-constrained: 7 (60-min, prior to 4 June)
Area-constrained: 21 (90-min, starting 4 June)
Trap days: 33

APPENDIX B. Area-constrained survey data.

Table B-1. Area-constrained survey catch totals (2001).

Survey Date	Forest Frogs/ 9 100 m^2 Quadrats	Open Frogs/ 6 100 m^2 Quadrats	Total Frogs/ 15 100 m^2 Quadrats	No. Frogs Estimated for Full Study Area[a]
4-Jun	1	0	1	13
11-Jun	0	0	0	0
18-Jun	0	1	1	13
25-Jun	2	1	3	39
2-Jul	0	0	0	0
9-Jul	0	0	0	0
16-Jul	2	0	2	26
23-Jul	0	0	0	0
30-Jul	0	1	1	13
6-Aug	2	2	4	52
13-Aug	0	0	0	0
20-Aug	1	0	1	13
26-Aug	1	2	3	39
3-Sep	1	1	2	26
10-Sep	0	0	0	0
17-Sep	0	1	1	13
24-Sep	0	1	1	13
30-Sep	4	2	6	78
8-Oct	0	2	2	26
15-Oct	0	1	1	13
22-Oct	0	0	0	0
Total all surveys:	14	15	29	377
Mean all surveys:	0.67	0.71	1.38	17.95
Mean/100 m^{2}[b]:	0.07	0.12	0.09	0.09
Mean/km^2:			92.06	

[a]The weekly estimate for the full study area = 13 times the total frogs per 100 m^2 for the 15 surveyed quadrats. The total number of quadrats in the study area is 195, i.e., 13 x 15.

[b]Based on a Wilcoxon Rank Sum Test, population locations for the forest and open strata are not significantly different ($p = 0.14$).

APPENDIX C. Schnabel population estimate.

Table C-1. Tag status of area-constrained search day frog captures. This data set was used for the Schnabel mark and recapture population estimate.

Date	Frog ID	Survey Type	PIT Tag No.[a]	Tag New on Area-Constrained Days
4-Jun-01	6-4-01#1	opportunistic	**424E61451B**	yes
18-Jun-01	6/18/01#1	area-constrained	**43297F2700**	yes
18-Jun-01	6/18/01#2	opportunistic	424D19136C	yes
25-Jun-01	6/25/01#1	area-constrained	had no tag	escaped before marking
25-Jun-01	6/25/01#4	opportunistic	**432E710B2C**	yes
16-Jul-01	7/16/01#2	area-constrained	43297C7D06	yes
16-Jul-01	7/16/01#3	area-constrained	**432E710B2C**	no
30-Jul-01	7/30/01#1	area-constrained	432C7B7329	yes
6-Aug-01	8/6/01#1	area-constrained	**432E710B2C**	no
6-Aug-01	8/6/01#2	area-constrained	432E765C59	yes
13-Aug-01	8/13/01#2	opportunistic	432E6A3571	yes
20-Aug-01	8/20/01#1	area-constrained	4329777564	yes
26-Aug-01	8/26/01#1	area-constrained	had no tag	escaped before marking
26-Aug-01	8/26/01#2	opportunistic	**501D1A7724**	yes
26-Aug-01	8/26/01#3	opportunistic	50277C513C	yes
26-Aug-01	8/26/01#4	area-constrained	5028025B2D	yes
26-Aug-01	8/26/01#5	area-constrained	432C732F25	yes
26-Aug-01	8/26/01#7	opportunistic	501C4C1C0D	yes
3-Sep-01	9/3/01#1	area-constrained	**43297F2700**	no
3-Sep-01	9/3/01#2	opportunistic	**432C744D14**	yes
3-Sep-01	9/3/01#3	area-constrained	50283B2579	yes
3-Sep-01	9/3/01#4	opportunistic	50282F7027	yes
10-Sep-01	9/10/01#1	opportunistic	432E775132	yes
17-Sep-01	9/17/01#2	opportunistic	**432C744D14**	no
17-Sep-01	9/17/01#3	opportunistic	**424E61451B**	no
24-Sep-01	9/24/01#1	area-constrained	501C6A3723	yes
24-Sep-01	9/24/01#2	opportunistic	501C746C25	yes
30-Sep-01	9/30/01#2	area-constrained	**501D1A7724**	no
30-Sep-01	9/30/01#3	area-constrained	**432C744D14**	no
30-Sep-01	9/30/01#5	area-constrained	5027194621	yes
30-Sep-01	9/30/01#6	area-constrained	501C6D0436	yes
8-Oct-01	10/8/01#1	opportunistic	502043436A	yes
8-Oct-01	10/8/01#2	opportunistic	501C795F00	yes
8-Oct-01	10/8/01#4	area-constrained	501C77077D	yes
15-Oct-01	10/15/01#1	area-constrained	50283B0B12	yes

[a]Bolded cells are those with recaptures on area-constrained search days.

APPENDIX D. Frog size, gender and age.

Table D-1. Frog measurements. Frogs with more than one measurement date are gray.

Pit Tag No.	Date	SVL[a] (mm)	Shank[b] (mm)	Mass (g)	Gender	Age	No. Yrs Found
4232624532	31-Aug-00	52					1
4329641501	18-Aug-01	63	39	27.0			1
4329777564	20-Aug-01	63	32	21.5			1
5006572732	1-Oct-01	67	39	33.0	F		1
5006572732	13-Oct-01			35.0	F		1
5020521121	26-Sep-01	49	31	13.0			1
5027194621	30-Sep-01	56	32	16.0			1
42337F4E24	23-Sep-00	56					1
423A3A5332	23-Sep-00	61					1
423B2F1D33	1-Sep-00	52					1
423F27203A	1-Sep-00	43					1
423F40416A	31-Aug-00	54					1
424B0F344E	1-Sep-00	50					1
424D19136C	7-May-01	55	35	17.0	M		1
424D19136C	15-Jun-01	59	36	23.0	M		1
424D5D1C4A	31-Aug-00	52			M		1
424D5D1C4A	8-Aug-01	55	34	16.0	M	min 1+	2
424D5D1C4A	2-Jul-02	58	32	15.0	M	min 2+	3
424E124E23	7-Oct-00	46					1
424E511349	5-Sep-00	76			F		1
424E56143B	1-Oct-00	51			F	min 0+	1
424E56143B	23-Sep-01	66	38	29.5	F	min 1+	2
424E5C1D6E	25-Sep-00	52				min 0+	1
424E5C1D6E	19-May-01	61	36	25.0		min 1+	2
424E5D0C27	25-Sep-00	53					1
424E61451B	2-May-01	67	39	31.0	F		1
424E61451B	4-Jun-01	69	40	34.0	F		1
424E61451B	28-Jul-01	69	42	35.0	F		1
424E61451B	4-Sep-01	72	42	35.0	F		1
424F183401	23-Sep-00	53					1
424F1D0F35	31-Aug-00	51					1
424F2E3128	28-May-01	49	29	11.0			1
42500D1C53	31-Aug-00	50					1
425031621F	7-Oct-00	58			F	min 0+	1
425031621F	9-Sep-01	71	40	38.0	F	min 1+	2
4329433F18	28-Jul-01	40	23	6.0			1
4329657A24	10-Jun-01	55	35	18.0			1
432972620F	28-Jun-01	46	29	10.5			1
432972620F	28-Jul-01	51	31	13.0			1
43297C7D06	16-Jul-01	45	27	8.0			1
43297F2700	18-Jun-01	61	36	27.0			1
43297F2700	3-Sep-01	65	37	28.0			1
432B543D48	8-Jul-01	55	35	13.0			1
432C732F25	14-Jul-01	59	34	21.5			1
432C732F25	26-Aug-01	64	37	25.5			1
432C732F25	23-Sep-01	66	39	27.5			1
432C744D14	15-Jun-01	65	39	31.0	F		1
432C744D14	15-Jul-01	68	40	34.0	F		1
432C744D14	28-Jul-01	68	40	32.5	F		1
432C744D14	20-Aug-01	68	42	30.0	F		1
432C744D14	3-Sep-01	68	39	33.0	F		1
432C744D14	17-Sep-01	70	42	34.0	F		1
432C744D14	30-Sep-01	71	40	36.5	F		1
432C7B7329	30-Jul-01	61	37	24.0			1
432D000A12	2-Aug-01	66	40	30.5	F		1
432D641F2F	3-Jun-01	60	36	22.0			1
432D747F39	25-Aug-01	62	38	27.0			1
432E53200E	29-May-01	71	39	36.0	F		1
432E56314B	21-May-01	60	36	23.0			1
432E6A3571	1-Jul-01	55	35	17.0			1
432E6A3571	8-Aug-01	58	34	19.0			1
432E6A3571	13-Aug-01	57	33	19.0			1
432E710B2C	25-Jun-01	60	36	23.0	F	min 1+	1
432E710B2C	16-Jul-01	61	38	24.0	F	min 1+	1
432E710B2C	6-Aug-01	63	38	25.5	F	min 1+	1
432E710B2C	10-Aug-02	73	42	38.0	F	min 2+	2
432E710B2C	6-Sep-02	74	42	37.0	F	min 2+	2
432E717657	8-Jul-01	58	36	16.0			1
432E765C59	6-Aug-01	40	25	5.5			1
432E775132	15-Jul-01	46	27	9.0			1
432E775132	10-Sep-01	52	32	15.5			1
432E775132	19-Sep-01	51	33	17.0			1
501C400240	2-Nov-01	72	41	41.0	F		1
501C400240	7-Nov-01	71	41	45.0	F		1
501C400240	11-Nov-01	70	41	44.0	F		1
501C400240	18-Nov-01	69	42	46.5	F		1
501C400240	25-Nov-01	70	41	45.0	F		1
501C400240	2-Dec-01	71	42	45.5	F		1
501C400240	21-Dec-01	69	41	48.0	F		1
501C400240	29-Dec-01	67	41	45.5	F		1
501C4A103A	4-Sep-01	55	32	14.0			1
501C4A103A	25-Sep-01	58	32	17.5			1
501C4C1C0D	26-Aug-01	60	37	27.5			1
501C6A3723	22-Sep-01	66	37	27.0	F		1
501C6A3723	14-Oct-01	66	38	29.0	F		1
501C6D0436	26-Sep-01	51	30	13.0			1
501C6D0436	30-Sep-01	52					1
501C6F1873	9-Jun-02	49	28	11.0	F		1
501C6F1873	23-Jul-02	58	34	18.0	F		1
501C6F1873	9-Aug-02	58	35	20.5	F		1
501C6F1873	14-Aug-02	59	36	22.0	F		1
501C6F1873	6-Sep-02	61	38	22.0	F		1
501C6F7358	28-Sep-02	69	40	34.0	F		1
501C70012C	29-Apr-02	79	44	37.5	F		1
501C711D1A	30-Jun-02	46	28	8.0			1
501C746C25	23-Sep-01	70	43	42.5	F		1
501C75OD68	11-Sep-01	71	40	34.5	F		1
501C765374	29-Jun-02	48	29	13.0			1
501C765374	6-Jul-02	50	29.5	12.0			1
501C77077D	8-Oct-01	72	40	38.0	F		1
501C79216C	11-Sep-01	65	35	23.0			1
501C792B1E	24-Oct-01	71	38.5	31.5	F		1
501C792B1E	29-Nov-01	69		37.5	F		1
501C795F00	8-Oct-01	36	21	3.0		0+	1
501C7D7167	4-Oct-02	51	30	11.0	M		1
501D1A221A	11-Jun-02	49	29	12.0			1
501D1A7724	26-Aug-01	61	36	28.0			1
501D1A7724	30-Sep-01	68	38	29.0			1
501D1B4040	8-Sep-02	65	38	27.0			1
501D1C5807	31-May-02	68	39	33.0	F		1
501D1F5C6E	30-Jun-02	42	24	7.0			1
501D213F44	25-Aug-01	67	39	29.5			1
501D23252F	28-Sep-02	61	38	20.5			1
501D25283B	11-Sep-02	56	35	19.0			1
501D25283B	18-Sep-02	60	37	23.0			1
501D25283B	28-Sep-02	60	37	19.0			1
501D263153	28-Sep-02	49	31	10.0			1
502043436A	8-Oct-01	71	41	38.0	F		1
50204D0501	14-Oct-01	73	42	38.0	F		1
50277C513C	26-Aug-01	48	30	11.0			1
5028025B2D	26-Aug-01	67	41	34.0	F	min 1+	1
5028025B2D	24-Sep-01	65	41	32.5	F	min 1+	1
5028025B2D	14-Oct-01	66	42	37.5	F	min 1+	1
5028025B2D	2-Nov-01	66	42	37.0	F	min 1+	1
5028025B2D	7-Nov-01	66	42	35.5	F	min 1+	1
5028025B2D	22-Jul-02	74	42	35.0	F	min 2+	2
5028025B2D	14-Aug-02	74	43	40.5	F	min 2+	2
5028025B2D	29-Aug-02	75	43	46.0	F	min 2+	2
5028025B2D	11-Sep-02	78	45	45.0	F	min 2+	2
5028025B2D	24-Sep-02	78	45	47.0	F	min 2+	2
50282F7027	3-Sep-01	54	33	14.0			1
50283B0B12	15-Oct-01	56	33	19.5			1
50283B2579	3-Sep-01	63	38	27.0			1
8/31/00#3	31-Aug-00	52					
8/31/00#4	31-Aug-00	56					
9/5/00#3	5-Sep-00	50					

[a] SVL is a measurement from the frog's snout to vent.
[b] This is a measurement from the frog's knee to heel.

APPENDIX E. Growth data.

Table E-1. One-year snout-to-vent length growth, by gender, for six frogs.

Gender	Frog No.	Date[a]	SVL (mm)	Growth (mm)	No. of Days	Growth per Day (mm)	Growth per Year (mm)
Female							
	424E56143B	1-Oct-00	51				
		23-Sep-01	66	15	358	0.04	15.29
	425031621F	7-Oct-00	58				
		9-Sep-01	71	13	338	0.04	14.04
	432E710B2C	6-Aug-01	63				
		10-Aug-02	73	10	368	0.03	9.92
	5028025B2D	24-Sep-01	65				
		24-Sep-02	78	13	366	0.04	12.96
	Mean females					0.04	13.05
	s females					0.006	2.30
Male							
	424D5D1C4A	31-Aug-00	52				
		8-Aug-01	55	3	343	0.01	3.19
		2-Jul-02	58	3	329	0.01	3.33
Unknown							
	424E5C1D6E	25-Sep-00	52				
		19-May-01	61	9	237	0.04	13.86
All							
	Mean all frogs					0.03	10.37
	s all frogs					0.014	5.13

[a]Measurements with the closest dates to a one-year interval were used.

Table E-2. Within-year snout-to-vent length growth, by gender, for 12 frogs[a].

Gender	Frog No.	Date[b]	SVL (mm)	Growth (mm)	No. of Days	Growth per Day (mm)	Growth per Year (mm)
Female							
	424E61451B	2-May-01	67				
		4-Sep-01	72	5	124	0.04	14.72
	432C744D14	15-Jun-01	65				
		30-Sep-01	71	6	106	0.06	20.66
	432E710B2C	25-Jun-01	60				
		6-Aug-01	63	3	41	0.07	26.71
	501C6F1873	9-Jun-02	49				
		6-Sep-02	61	12	88	0.14	49.77
	5028025B2D	26-Aug-01	67				
		7-Nov-01	66	-1	72	-0.01	-5.07
	5028025B2D	22-Jul-02	74				
		24-Sep-02	78	4	63	0.06	23.17
	Mean females					0.06	21.66
	s females					0.05	17.79
Male							
	424D19136C	7-May-01	55				
		15-Jun-01	59	4	38	0.11	38.42
Unknown							
	432972620F	28-Jun-01	46				
		28-Jul-01	51	5	29	0.17	62.93
	43297F2700	18-Jun-01	61				
		3-Sep-01	65	4	76	0.05	19.21
	432C732F25	14-Jul-01	59				
		23-Sep-01	66	7	70	0.10	36.50
	432E6A3571	1-Jul-01	55				
		13-Aug-01	57	2	42	0.05	17.38
	432E775132	15-Jul-01	46				
		19-Sep-01	51	5	65	0.08	28.08
	501D1A7724	26-Aug-01	61				
		30-Sep-01	68	7	34	0.21	75.15
	Mean unknown gender					0.11	39.87
	s unknown gender					0.07	23.91
All							
	Mean all frogs					0.09	31.36
	s all frogs					0.06	21.39

[a]One female was measured two years bringing the total number of frogs listed to 13.

[b]Measurements used were the earliest and latest (through mid-fall 27 November) for each frog.

Table E-3. One-year mass growth, by gender, for three frogs.

Gender	Frog No.	Date[a]	Mass (g)	Growth (g)	No. of Days	Growth per Day (g)	Growth per Year (g)
Female							
	432E710B2C	6-Aug-01	25.5				
		10-Aug-02	38.0	12.5	368	0.03	12.40
	5028025B2D	24-Sep-01	32.5				
		24-Sep-02	47.0	14.5	364	0.04	14.54
	Mean females					0.04	13.47
	s females					0.00	1.51
Male							
	424D5D1C4A	8-Aug-01	16.0				
		2-Jul-02	15.0	-1.0	329	0.00	-1.11
All							
	Mean all frogs					0.02	8.61
	SD all frogs					0.02	8.48

[a]Measurements with the closest dates to a one-year interval were used.

Table E-4. Within-year mass growth, by gender, for 12 frogs[a].

Gender	Frog No.	Date[b]	Mass (g)	Growth (g)	No. of Days	Growth per Day (g)	Growth per Year (g)
Female							
	424E61451B	2-May-01	31.0				
		4-Sep-01	35.0	4.0	124	0.03	11.77
	432C744D14	15-Jun-01	31.0				
		30-Sep-01	36.5	5.5	106	0.05	18.94
	432E710B2C	25-Jun-01	23.0				
		6-Aug-01	25.5	2.5	41	0.06	22.26
	5028025B2D	26-Aug-01	34.0				
		7-Nov-01	35.5	1.5	72	0.02	7.60
	5028025B2D	22-Jul-02	35.0				
		24-Sep-02	47.0	12.0	63	0.19	69.52
	501C6F1873	9-Jun-02	11.0				
		6-Sep-02	22.0	11.0	88	0.13	45.63
	Mean females					0.08	29.29
	s females					0.07	23.75
Male	424D19136C	7-May-01	17.0				
		15-Jun-01	23.0	6.0	38	0.16	57.63
Unknown	432972620F	28-Jun-01	10.5				
		28-Jul-01	13.0	2.5	29	0.09	31.47
	43297F2700	18-Jun-01	27.0				
		3-Sep-01	28.0	1.0	76	0.01	4.80
	432C732F25	14-Jul-01	21.5				
		23-Sep-01	27.5	6.0	70	0.09	31.29
	432E6A3571	1-Jul-01	17.0				
		13-Aug-01	19.0	2.0	42	0.05	17.38
	432E775132	15-Jul-01	9.0				
		19-Sep-01	17.0	8.0	65	0.12	44.92
	501D1A7724	26-Aug-01	28.0				
		30-Sep-01	29.0	1.0	34	0.03	10.74
	Mean unknown gender					0.06	23.43
	s unknown gender					0.04	15.05
All							
	Mean all frogs					0.08	28.77
	s all frogs					0.01	4.14

[a]One female was measured two years bringing the total number of frogs measured to 13.
[b]The earliest and latest measurements (through mid-fall, 27 November) were used for each frog.

APPENDIX F. Study site temperature and moisture conditions.

Table F-1. Seasonal temperature and moisture regimes at the study site (2001).

Season	Days	Rainfall[a]				Temperature[b]					
		Days w/ Rain		Rain-fall	Av Rain per Day	Air			Ground		
						Max	Min	Av	Max	Min	Av
	No.	No.	%	(mm)	(mm)	(C)	(C)	(C)	(C)	(C)	(C)
Spring (20-Mar to 20-Jun)	93	38	41	210	2.3	21.2	6.0	12.3			
Early summer (21-Jun to 8-Jul)	18	3	17	34	1.9	20.5	8.6	13.9			
Mid-summer through early fall (9-Jul to 24-Sep)	78	17	22	63	0.8	25.7	7.2	15.0	17.3	11.7	14.4
Mid-fall through early winter (25-Sep to 31-Dec)	98	60	61	447	4.6	16.4	-0.1	7.2	14.3	3.4	9.0

[a]Rainfall is from a gage at The Evergreen State College, located 3.5 km from the study site. Missing records were filled with National Weather Service Olympia Airport data taken 15.5 km from the study site. On 28 November the precipitation was snowfall.

[b]These temperatures were derived from average hourly readings by combining data from three core sites in the study area. Spring air temperatures are from 4 to 20 June only. Mid-summer through early-fall ground temperatures are from 9 August to 24 September.

APPENDIX G. Telemetry results.

Table G-1. Overview of telemetry results for 10 female northern red-legged frogs.

Key **Frog identification number/Site use type** • Observation time-frame • Total days within observation time-frame • Number of days with observations • Home range, use area length and width (m)	Date	Sea-son[a]	Telemetry Start and End	Observation Type	Strata and Sub-Strata	Dist. from Last Loc. (m)	Frog 5 m from Forest/ Open Edge?
Frog #424E61451B							
Primary active season home range. • Time-frame: 2-May-01 to 17-Sep-01 • Total days: 139 • Observation days: 13 • Greatest home range size: L=62, W=11 **Notes:** 30-Jul: Frog on tidal flats by down tree. It hopped 2.5 m to shore when tidal waters were within 10 cm. 13-Aug: Frog on overhanging ledge/opening in cliff, 1 m down from top of cliff. 23-Aug: Location change concurrent with largest rainfall (27 mm on 22-Aug) since 27-Jun. 4-Sep: Transmitter removed due to belt sores.	2-May-01	Sp		Time Search	Open (grass/forbs)		Yes
	4-Jun-01	Sp		Opportunistic	Open (grass/forbs)	35.6	No
	28-Jul-01	MLS	Start	Opportunistic	Open (grass/forbs)	38.0	Yes
	30-Jul-01	MLS		Telemetry	Forest (tidal channel)	28.1	No
	5-Aug-01	MLS		Telemetry	Forest (shrub/shoreline cliff)	2.5	No
	6-Aug-01	MLS		Telemetry	Forest (shrub/shoreline cliff)	<1.0	No
	13-Aug-01	MLS		Telemetry	Forest (shrub/shoreline cliff)	<1.0	No
	19-Aug-01	MLS		Telemetry	Forest (shrub/shoreline cliff)	5.0	No
	20-Aug-01	MLS		Telemetry	Forest (shrub/shoreline cliff)	<1.0	No
	23-Aug-01	EF		Telemetry	Forest (shrub)	18.1	No
	26-Aug-01	EF		Telemetry	Forest (shrub)	10.4	No
	4-Sep-01	EF	End	Telemetry	Forest (shrub)	13.8	Yes
	17-Sep-01	EF		Opportunistic	Open (grass/forbs)	32.8	No
Frog #432C744D14							
Primary active season home range. • Time-frame: 15-Jun-01 to 1-Oct-01 • Total days: 109 • Observation days: 12 • Greatest home range size: L=71, W=18 **Notes:** 17-Jul: Early AM visual sighting. 20-Aug: Frog very wet under dry leaves. Transmitter removed due to belt sores. 30-Sep: Telem. restarted, belt sores 95% healed. 1-Oct: Frog elevated 20 cm on wood (tide out), then moved to shore. No reception after 1-Oct.	15-Jun-01	Sp		Opportunistic	Open (grass/forbs)		No
	15-Jul-01	MLS	Start	Opportunistic	Forest (branch pile)	12.5	Yes
	16-Jul-01	MLS		Telemetry	Forest (branch pile)	2.5	Yes
	17-Jul-01	MLS		Opportunistic	Open (grass/forbs)	7.5	Yes
	28-Jul-01	MLS		Opportunistic	Forest (shrub/ravine)	69.1	No
	6-Aug-01	MLS		Telemetry	Forest (shrub/ravine)	5.8	No
	19-Aug-01	MLS		Telemetry	Forest (shrub/ravine)	3.4	No
	20-Aug-01	MLS	End	Telemetry	Forest (shrub/ravine)	<1.0	No
	3-Sep-01	EF		Opportunistic	Open (grass/forbs)	66.0	Yes
	17-Sep-01	EF		Opportunistic	Open (grass/forbs)	5.0	No
	30-Sep-01	MF	Start	Area-const.	Forest (herbaceous)	38.8	No
	1-Oct-01	MF	End	Telemetry	Forest (tidal channel)	17.9	No

Table G-1 continued.

<table>
<tr><th>Key
Frog identification number/Site use type
• Observation time-frame
• Total days within observation time-frame
• Number of days with observations
• Home range, use area length and width (m)</th><th>Date</th><th>Sea-son[a]</th><th>Telemetry Start and End</th><th>Observation Type</th><th>Strata and Sub-Strata</th><th>Sea-son[1]</th><th>Frog 5 m from Forest/ Open Edge?</th></tr>
<tr><td colspan="8">Frog #5028025B2D (Year 2002 data are shaded)</td></tr>
<tr><td rowspan="28">Primary active season home range.
• Time-frame: 26-Aug-01 to 7-Nov-01 & 22-Jul-02 to 24-Sep-02
• Total days: Yr 2001 – 74; Yr 2002 - 65
• Observation days: 28
• Greatest home range size (2001): L=80, W=9
Notes:
4-Sep-01: In sub-surface opening under leaves at bole of sword fern.
10-Sep-01: Off study area, far side of tidal channel.
24-Sep-01: Under dry leaf.
16-Oct-01: Belt sores first noticed.
7-Nov-01: Transmitter removed due to belt sores.
Yr 2001 to 2002 closest distance = 10.7 m.
22-Jul-02: Belt sores well healed. Frog found early AM (0723) in garden sandy loam pathway that had been watered the previous day. It moved only 0.4 m between 0723 and 2019. By dark at 2131 it had moved 1.0 m further, to a location under a shrub, still easily visible. It spent the night here.
23-July-02: Frog observed intermittently 0822 to 2146 (dark). Similar short amount of distance movement as previous day, same habitat conditions.
14-Aug-02: Frog found very wet in dry forest edge shrubs near watered garden.
18-Aug-02 to 24-Sep-02: All sightings in the garden. Frog appeared to be utilizing the watered garden area as a moisture source during this summer.</td><td>26-Aug-01</td><td>EF</td><td>Start</td><td>Area-const.</td><td>Open (shrub)</td><td></td><td>Yes</td></tr>
<tr><td>4-Sep-01</td><td>EF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>36.3</td><td>No</td></tr>
<tr><td>10-Sep-01</td><td>EF</td><td></td><td>Telemetry</td><td>Forest (shrub/ravine)</td><td>39.4</td><td>No</td></tr>
<tr><td>17-Sep-01</td><td>EF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>35.8</td><td>No</td></tr>
<tr><td>24-Sep-01</td><td>EF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>2.5</td><td>No</td></tr>
<tr><td>1-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>5.9</td><td>No</td></tr>
<tr><td>14-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>5.0</td><td>No</td></tr>
<tr><td>16-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>3.8</td><td>No</td></tr>
<tr><td>19-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td><2.5</td><td>No</td></tr>
<tr><td>22-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>3.8</td><td>No</td></tr>
<tr><td>26-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>2.5</td><td>No</td></tr>
<tr><td>27-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>3.8</td><td>No</td></tr>
<tr><td>28-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>0.1-0.2</td><td>No</td></tr>
<tr><td>29-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>0.1-0.2</td><td>No</td></tr>
<tr><td>30-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td><0.5</td><td>No</td></tr>
<tr><td>31-Oct-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td><0.5</td><td>No</td></tr>
<tr><td>2-Nov-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>13.0</td><td>No</td></tr>
<tr><td>3-Nov-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td><1.0</td><td>No</td></tr>
<tr><td>4-Nov-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>3.8</td><td>No</td></tr>
<tr><td>5-Nov-01</td><td>MF</td><td></td><td>Telemetry</td><td>Forest (shrub)</td><td>est. 4.4</td><td>No</td></tr>
<tr><td>7-Nov-01</td><td>MF</td><td>End</td><td>Telemetry</td><td>Forest (shrub)</td><td>est. 2.5</td><td>No</td></tr>
<tr><td>22-Jul-02</td><td>MLS</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td></td><td>Yes</td></tr>
<tr><td>23-Jul-02</td><td>MLS</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td><2.5</td><td>No</td></tr>
<tr><td>14-Aug-02</td><td>MLS</td><td></td><td>Opportunistic</td><td>Forest (shrub)</td><td>8.1</td><td>Yes</td></tr>
<tr><td>18-Aug-02</td><td>MLS</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td>10.6</td><td>No</td></tr>
<tr><td>29-Aug-02</td><td>EF</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td>3.8</td><td>No</td></tr>
<tr><td>11-Sep-02</td><td>EF</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td>3.8</td><td>No</td></tr>
<tr><td>24-Sep-02</td><td>EF</td><td></td><td>Opportunistic</td><td>Open (garden)</td><td>2.5</td><td>No</td></tr>
</table>

Table G-1 continued.

Key **Frog identification number/Site use type** • Observation time-frame • Total days within observation time-frame • Number of days with observations • Home range, use area length and width (m)	Date	Season[a]	Telemetry Start and End	Observation Type	Strata and Sub-Strata	Dist. from Last Loc. (m)	Frog 5 m from Forest/ Open Edge?
Frog #432D000A12							
Use type not known. • Time-frame: 2-Aug-01 • Total days: 1 Notes: No reception after initial date.	2-Aug-01	MLS	Start/End	Opportunistic	Open (grass/forbs)		No
Frog #425031621F (Year 2000 data shaded)							
Possibly migratory stop-over (2001). • Time-frame: 7-Oct-00 & 9-Sep-01 to 17-Sep-01 • Total days: Yr 2000 - 1; Yr 2001 – 9 • Observation days: 5 • Greatest length and width of use area: L=32, W=4 **Notes:** Yr 2000 to 2001 closest distance = 17.5 m. 23-Sep-01: Transmitter found off, different location from 17-Sep-01 sighting.	7-Oct-00	MF		Time Search	Open (grass/forbs)		No
	9-Sep-01	EF	Start	Opportunistic	Open (garden)		Yes
	10-Sep-01	EF		Telemetry	Open (grass/forbs)	14.7	No
	17-Sep-01	EF	End	Telemetry	Forest (shrub)	7.1	Yes
	23-Sep-01	EF		Telemetry	Forest (shrub)	3.8	Yes
Frog #501C750D68							
Possible migratory stop-over. • Time-frame: 11-Sep-01 to 16-Sep-01 • Total days: 6 • Observation days: 6 • Greatest length and width of use area: L=11, W=3 **Notes:** Intensive study, see write-up in Chapter 5. 13 to 14-Sep: Evening 13-Sep to mid-day 14-Sep frog under large old down log. 16-Sep: Last day frog seen, transmitter found off 1-Oct at same location.	11-Sep-01	EF	Start	Opportunistic	Open (grass/forbs)		No
	12-Sep-01	EF		Telemetry	Open (grass/forbs)	<1.0	No
	13-Sep-01	EF		Telemetry	Open (grass/forbs)	5.0	No
	13,14-Sep	EF		Telemetry	Open (remnant	3.8	No
	15-Sep-01	EF		Telemetry	Open (grass/forbs)	6.3	No
	16-Sep-01	EF	End	Telemetry	Open (grass/forbs)	<1.0	No

Table G-1 continued.

Key **Frog identification number/Site use type** • Observation time-frame • Total days within observation time-frame • Number of days with observations • Home range, use area length and width (m)	Date	Season[a]	Telemetry Start and End	Observation Type	Strata and Sub-Strata	Dist. from Last Loc. (m)	Frog 5 m from Forest/ Open Edge?
Frog #501C6A3723							
Not known, likely migratory.	22-Sep-01	EF		Opportunistic	Open (grass/forbs)		No
• Time-frame: 22-Sep-01 to 14-Oct-01	24-Sep-01	EF	Start	Area-const.	Open (grass/forbs)	8.1	No
• Total days: 23	25-Sep-01	MF		Telemetry	Open (grass/forbs)	2.5	No
• Observation days: 7	26-Sep-01	MF		Telemetry	Open (grass/forbs)	est. 1.9	No
• Greatest length and width of use area: L=88,	1-Oct-01	MF		Telemetry	?	----	?
W=2	7-Oct-01	MF		Telemetry	?	est. 7.5	?
Notes:	13-Oct-01	MF		Telemetry	Forest (shrub)	34.0	No
22-Sep: Found in dew-coated grasses, 0755. 1&7-Oct: Poor reception, open/forest vicinity. 14-Oct: At dusk saw and caught frog. Transmitter removed due to belt sores and poor reception.	14-Oct-01	MF	End	Opportunistic	Forest (shrub)	14.5	No
Frog #5006572732							
Not known, due to late dates, possibly fall	1-Oct-01	MF	Start	Opportunistic	Open (grass/forbs)		
migratory stop-over.	7-Oct-01	MF		Telemetry	Open (remnant	17.6	No
• Time-frame: 1-Oct-01 to 16-Oct-01	13-Oct-01	MF		Telemetry	Forest (shrub)	36.3	No
• Total days: 16	16-Oct-01	MF	End	Telemetry	Forest (shrub)	6.9	No
• Observation days: 5 • Greatest length and width of use area: L=37, W=8 **Notes:** 19-Oct: Transmitter found off, at different location than 16-Oct observation.	19-Oct-01	MF		Telemetry	Forest (shrub)	5.3	No

Table G-1 Continued.

Key **Frog identification number/Site use type** • Observation time-frame • Total days within observation time-frame • Number of days with observations • Home range, use area length and width (m)	Date	Sea-son[a]	Telemetry Start and End	Observation Type	Strata and Sub-Strata	Dist. from Last Loc. (m)	Frog 5m from Forest/ Open Edge?
Frog #501C792B1E							
Fall migration, migratory stop-over, and likely fall to early winter home range. • Time-frame: 24-Oct-01 to 12-Dec-01 • Total days: 50 • Observation days: 9 • Observed size for migration route/use area: L=579, W=2 **Notes:** 22-Oct had rainfall of 25 mm, largest rainfall since 22-Aug; this likely triggered migration to trap. 30,31-Oct: est. location, frog may have already crossed salt-water cove. Reception difficult. 2-Nov to 7-Dec: 11 days where received transmission from frog, but could not locate. 12-Dec: Reception from broad vicinity as 29-Nov, but could not find frog. After this date, no reception.	24-Oct-01	MF	Start	Trap	Forest (shrub)		No
	26-Oct-01	MF		Telemetry	Forest (shrub)	17.0	No
	Frog left primary study area.						
	27-Oct-01	MF		Telemetry	Forest (shrub/slope to shoreline)	49.0	No
	28-Oct-01	MF		Telemetry	Forest (shrub/slope to shoreline)	0-1	No
	29-Oct-01	MF		Telemetry	Forest (shrub/slope to shoreline)	0-1	No
	30-Oct-01	MF		Telemetry	Forest (shrub/slope to shoreline)	est. 2	No
	31-Oct-01	MF		Telemetry	Open (remnant forest/shrubs	est. 105	No
	Frog moved to location across saltwater cove, and to hilltop plateau.						
	29-Nov-01	LF		Telemetry	Forest (shrub/hill plateau)	est. 406	No
	12-Dec-01	LF	End	Telemetry	Forest (shrub/hill plateau)	?	No

Table G-1 Continued.

Key **Frog identification number/Site use type** • Observation time-frame • Total days within observation time-frame • Number of days with observations • Home range, use area length and width (m)	Date	Sea-son[a]	Telemetry Start and End	Observation Type	Strata and Sub-Strata	Dist. from Last Loc. (m)	Frog 5 m from Forest/ Open Edge?
Frog #501C400240							
Fall migration, fall migratory stop-over, and late fall to early winter home range. • Time-frame: 2-Nov-01 to 29-Dec-01 • Total days: 58 • Observation days: 22 • Greatest length observed for migration route: L=338 est. • Greatest length and width observed for migratory stop-over: L=18,W=2 • Greatest length and width observed for late fall to early winter home range off-site: L=27, W=13 **Notes:** 3-Nov: Frog found in trap adjacent to one it was in 2-Nov. To prevent this happening again, the frog was moved 7 m from the traps. 5 to 12-Nov: Cold period with only minor precipitation. The frog made no major moves during this migratory stop-over. 12 to 18-Nov: Between these dates frog moved to land across cove and up onto hill. This was concurrent with the 14-Nov largest rain (61 mm) of the primary study period (20 Mar to 29 Dec 2001). 29-Dec: Last day frog was seen, reception lost after this date. Frog may have made major move to a breeding pond.	2-Nov-01	MF	Start	Trap	Forest (shrub)		No
	3-Nov-01	MF		Trap	Forest (shrub)	<1	No
	3-Nov-01	MF		(I moved frog)	Forest (shrub)	7.0	No
	5-Nov-01	MF		Telemetry	Forest (shrub/near shoreline)	4.0	No
	7-Nov-01	MF		Telemetry	Forest (shrub/near shoreline)	2.5	No
	11-Nov-01	MF		Telemetry	Forest (shrub/near shoreline)	<1.0	No
	12-Nov-01	MF		Telemetry	Forest (shrub/near shoreline)	<1.0	No
	Left primary study area by at least 17-Nov and moved to S facing slope on hillside, across the saltwater cove.						
	18-Nov-01	MF		Telemetry	Forest (shrub/hillside)	est. 297	No
	20-Nov-01	MF		Telemetry	Forest (shrub/hillside)	1.0	No
	21-Nov-01	MF		Telemetry	Forest (shrub/hillside)	0.5	No
	25-Nov-01	MF		Telemetry	Forest (shrub/hillside)	7.0	No
	27-Nov-01	MF		Telemetry	Forest (shrub/hillside)	<1.0	No
	29-Nov-01	LF		Telemetry	Forest (shrub/hillside)	8.6	No
	2-Dec-01	LF		Telemetry	Forest (shrub/hillside)	<1.0	No
	4-Dec-01	LF		Telemetry	Forest (shrub/hillside)	1.0	No
	7-Dec-01	LF		Telemetry	Forest (shrub/hillside)	7.3	No
	12-Dec-01	LF		Telemetry	Forest (shrub/hillside)	2.8	No
	14-Dec-01	LF		Telemetry	Forest (shrub/hillside)	<1.0	No
	18-Dec-01	LF		Telemetry	Forest (shrub/hillside)	13.6	No
	21-Dec-01	EW		Telemetry	Forest (shrub/hillside)	1.8	No
	24-Dec-01	EW		Telemetry	Forest (shrub/hillside)	<1.0	No
	27-Dec-01	EW		Telemetry	Forest (shrub/hillside)	0.0	No
	29-Dec-01	EW	End	Telemetry	Forest (shrub/hillside)	4.0	No

[a]Seasons are: Sp, spring = 20 March to 20 June; MLS, mid-through late summer = 9 July to 21 August; EF, early fall = 22 August to 24 September; MF, mid-fall = 25 September to 27 November; LF, late fall = 28 November to 20 December; EW, early winter = 21 to 31 December.

APPENDIX H. Behavior descriptions.

Postural, movement, physiological and vocal behaviors observed during this study and listed in Table 10, are described below.

Postural

There were three observed postures that describe how upright or lateral to the ground the frog's body was: sit, crouch and lay.

Sit: frog was the most upright, with head and chest up, angle of body (head to vent) roughly 45 degrees. This was the common pose seen in a frog that had jumped due to being disturbed. It was also observed, for example, in video footage (frog 424E56143B) as the return pose after a feeding lunge, and as the starting pose for subsequent lunges.

Crouch: in this posture, the frog's torso, including much of the chest, was low to the ground but its head was up off the ground. This posture was observed only in undisturbed frogs. It has intermediary body angles between the sit posture, and the lay posture described below.

Lay: the frog has all ventral surfaces, including head, prostrate to the ground (or otherwise in a flattened position). This posture was with one exception, found beneath 100% cover. The exception was a video observation of a frog in a flat, linear position elevated on wood, before the frog made a dive off the wood.

Distance Movement

Hop, walk, dive and climb were the observed movements used by frogs to travel to a new location.

Hop (or jump): this distance movement, propelled by its legs, typically brings the frog in an arc, up and out, and then down. Typical distances observed in a hop were 0.1 to 0.5 m (visual estimates). There may be one to many hops in a row. Abundant observations of hopping frogs occurred during the survey efforts. However, most of these were of frogs hopping when I approached within 1.0 m. I only observed undisturbed hopping three times. Of these, one was of a frog leaving the mudflats when the incoming tidal waters approached within 10 cm. The second was a spring mid-day observation of a (likely) migratory frog hopping across an open portion of the study area.

The third was a video observation where the frog hopped off an elevated location on down wood, out of the camera view.

Walk: in this movement the frog stayed close to the ground, and moved directionally forward using all legs. This may be commonly used by frogs, but was less conspicuous than the hop, and was not observed often. Video footage included two examples of walking. In one, the frog turned its body and walked out of the video focus area. It was found 1 ½ hrs later, through telemetry, to be 15 cm away. The second example was of a frog elevated 33 cm on wood. This frog turned its body and then walked ca. 10 cm to the edge of the wood, where it subsequently made a dive off the wood.

Dive: observed by video as described in the walk description. In this movement the frog was positioned flat, with its head and forehands perched over the edge of the wood. Its front legs and head then dropped an estimated 3 to 5 mm, followed 3 sec later by the frog propelling out and down from the wood.

Climb: only observed while frogs were held within nylon net rectangular traps. The frogs were able to climb up the sides of the traps.

In-Place Movement

These movements were mostly observed in close-up video observations of frogs in undisturbed locations. They are classed as head turn (or head upward or downward), head nodding, feeding lunge, repositioning, body turn, and other minor.

Head Turn (or Head Upward, or Downward): sub-classifications used were: prey-tracking, other-tracking (e.g., ant and beetle), and unknown. Frogs were observed using a head turn in response to nearby insect activity as well as for unknown reasons. Examples include a distinctive head turn toward a prey species that was caught and eaten by the frog 16 sec later, and a head turn in the direction of an ant that had come near a frog and was moving away. Head upward was included as a close variation. It occurred alone, or with a head turn as in the following example: "Head pulls up quickly and to the right 20 degrees. An estimated 12 mm long beetle approached the frog, possibly bumping the upper chest of the frog before moving away. The frog turned its head in the direction of the beetle." Head downward was observed as a movement that in some cases followed the upward movement.

Head Nodding: sub-classifications were With or Post Feeding Lunge, and Other. Head nodding was movement of the head in an up and down sequence. This was seen in two variations after prey had been caught. One that followed prey catch (by 3 min 47 sec) was a single event where the frog's head stretched up until the snout was vertical, followed by an immediate return of the head to the starting position. In two cases, the movement was more closely tied to the feeding lunge, one occurring as part of the retracting portion of the lunge, and the other occurring 5 sec later. These movements included six and five (respectively) quick movements up and down of the frog's head. There were three other occasions where a frog was observed by video to use a similar movement where prey capture was not involved. These were single sets of head movement up and down. In all three the movement followed eye retraction.

Feeding Lunge: sub-classifications were successful, not successful, and unknown (success). In this movement, the frog's body propelled forward to capture prey, then recessed back to the near original location, using hind legs like a spring. In one observation, it appeared that a lunge of less extent occurred with the head and upper torso primarily stretching forward with a quick motion to capture the prey. Close-up video footage of one frog showed the frog's tongue extending out at the peak of the lunge.

Repositioning: the frog changes aspects of its in-place location. An approach that included movement of the full body involved the frog moving its legs one or two at a time and putting them in new alignments. Its body may move up and down as this is occurring, and the frog may end up with a lowered overall height. A different approach included in this behavior was lowering of the frog's head and front torso in preparation for a dive from an elevated location.

Body Turn: this is a major movement by the frog to change body direction. Its use by the frog may be similar to the head turn. It includes nearly instantaneous moves as well as slower ones. Examples: "Instant pivot by frog ca. 45 degrees to left, all of body including legs move." "Frog quickly (< 1 sec) pivots 45 degrees to the left." This occurred when a spider (ca. 15 mm long) was moving under vegetation near the frog's posterior end, and likely touched the frog. When the frog changed position, the spider appeared to be propelled to the surface; it then moved away from the frog. A slower turn was observed 3 min after the broad turn of a frog's head and upper torso as follows:

"…frog aligns rest of body to same direction as head." This was a complex movement. "All legs sequentially moved at least once and the frog's torso moved upward on respective sides along with leg movement. Duration 4 sec."

Other Minor: this included quick flinches, jerks, or slight movements that are not in other named behaviors. They occurred over small (such as a specific leg) or large portions of the frog's body. They represented 29.5% of observed movement behaviors in the video observations. It is possible that some episodes were in response to an insect such as a mosquito, landing on the frog, but it was typically not clear as to what caused the movement. Example: "Six small jerks up and down of body, duration 4 sec."

Physiological

There were several physiological behaviors or characteristics observed. These included movement and non-movement types.

Eye Retraction: during this movement I observed the eye to first close, then retract into the head, re-emerge, and then open. This often occurred in combination with other movements. The purpose of this behavior may be (1) to keep the eyes lubricated, (2) to protect the eyes during movement, and (3) it may additionally be involved in swallowing.

Breathing (throat movement): I observed this but took no data. In an otherwise motionless frog, throat movement in and out as part of breathing was evident.

Cryptic Coloration: the most observed terrestrial colorations were light brown (e.g., the color of dry big leaf maple leaves) during the warm, dry seasons, and dark brown (e.g., the color of wet big leaf maple leaves) during the cool, wet late fall through early winter.

Water Absorption, and Evaporative Cooling: As described in the results, I found evidence that indicated frogs were obtaining moisture through several means in the terrestrial habitat, and likely the tidal channel associated habitat as well. On warm to hot days I observed undisturbed frogs in deep crouch positions with most of their ventral surface adpressed to moist sandy-loam soils. In some observations, the frogs were glistening moist leading to the likelihood that they were using evaporative processes to remain cool, by concurrently absorbing moisture from the soil.

Vocalization

Distress Calls: the frogs vocalized on occasion when I caught and held them. Typically the vocalization was a soft chortling sound. On one occasion, a frog made a loud squeaky scream of ca. 1 sec duration, repeated three times. This frog was near three other frogs (that may have been a migratory group) leading to the possibility that this call had a group function.

Male Breeding Call from terrestrial non-breeding location: I heard this only on one occasion. The call was a soft “cluck, cluck, cluck”. The calling frog was 5.0 m distant from a second frog. This observation was included in Hayes et al. (2004).

APPENDIX I. Conservation Surveys.

During July 2002 I interviewed five scientists regarding northern red-legged frog conservation in Washington. The persons I interviewed were: Marc Hayes (M.H.), Washington Department of Fish and Wildlife Research Scientist; Klaus Richter (K.R.), Senior Ecologist, King County Department of Natural Resources; Kelly McAllister (K.M.), Regional Wildlife Biologist, Pierce and Thurston Counties; J. Tuesday Serra Shean (J.S.), Wetland Biologist, WSDOT Environmental Affairs; and, Mike Adams (M.A.), Research Ecologist, USGS Forest and Rangeland Ecosystem Science Center. Interviews were held in person with M.H., K.R. and K.M., through written responses with J.S. and M.A., and included additional written responses from K.R. (I use the respondents' names and initials within this appendix. Where used, these should be considered to be personal communications, 2002, from the respective person.)

The interviews included two components. One part asked for alternatives that would keep northern red-legged frog populations robust throughout their range in Washington. Table 14 summarized these responses into a system of components to achieve a robust population maintenance goal. Part A of this Appendix provides additional detail. The second part included conservation status related questions. The answers to these questions are provided in Part B of this Appendix. Cumulatively the interview responses provide a wealth of insights and information regarding northern red-legged frogs and their conservation needs.

Part A. System to Achieve Conservation of the Northern Red-Legged Frog in Washington

1. Research and Monitoring

This component is needed for the development and documentation of demographic, location, and habitat needs for northern red-legged frogs. This three-piece component is the hub that provides necessary information to the rest of the system.

a. Geographic presence monitoring linked to high-resolution population condition index sites. We need monitoring that will enable us to know that frog populations are remaining robust throughout their range in Washington. The flip side of this is the critical need to know if we have populations in decline and in trouble. Marc Hayes recommended a two-tiered approach. The first tier is a geographic system that will tell us where northern red-legged frogs are. We have general range maps (Dvornich et al. 1997, Leonard et al. 1993) but these do not provide the specificity to tell us where protection measures are needed or where populations may have problems. For this, finer resolution such as the atlas documentation for portions of King County (Richter and Ostergaard 1999), and the inventory of U.S. Navy lands on the Kitsap and Toandos Peninsulas (Adams et al. 1999) is needed. Broad presence information needs to be linked with the second tier, high resolution population monitoring, to tell us about population condition. Monitoring of egg mass numbers is the most direct approach to observe population condition.

b. Demographic and habitat research (including relationships with exotic species). A scarcity of basic demographic and habitat use data for these frogs in Washington exists, and detailed demographic and habitat studies are needed.

Adams (1999, 2000) researched the relationship between northern red-legged frog abundance and presence in wetlands, with wetland habitat, water permanence, and presence of exotic species (bullfrogs and fish). At Fort Lewis, in Pierce County Washington, he found negative survival effects from exotic species. However, other untested factors associated with pond permanence were more important for low survival of northern red-legged frog larvae (Adams 2000).

c. Landscape level analysis for rapidly developing areas. Klaus Richter is accomplishing research to understand native amphibian protection needs for rapidly developing areas of King County. This includes a GIS-based system to evaluate habitat availability for each life history stage of amphibian species present. These habitats cover oviposition sites with the correct water depth, velocity and hydrology; larval habitat (including stable hydrology); metamorph habitat (transitional habitat around the perimeter of larval waters where small, easily desiccated animals can remain until large rains wet the upland habitat and provide opportunity for dispersal); juvenile habitat; and adult habitat. The latter two habitats can be spatially separated by considerable distances and necessitate secure movement pathways between each. This system is being “truthed” by evaluating characteristics of locations where amphibian species have been lost. The evaluation looks at the core wetland or lake buffer zone and a larger 1,000 m radius for amount and patterns of development, and vegetation characteristics. The evaluation will provide information on characteristics of development that cause loss of amphibian species diversity.

2. Protection for Northern Red-Legged Frogs in Rapidly Developing Areas

Protective focus is a critical need for areas in the path of development. This component has four parts.

a. Habitat needs. Normal hydrology is needed for northern red-legged frog egg survival. To provide adequate protection for hydrology of the wetlands systems, 65% of the basin affecting hydrology of the wetland needs to be left in forest/native vegetation, and < 10% of the developed portion should be in impervious surfaces (K.R.). Similarly Kelly McAllister recommends a mosaic of forest and wetlands with some openings, breeding habitat with benefits from warm water conditions, forest area that retains moisture for adults, floodplains maintained in natural vegetation, and allowance for beaver activity that floods areas, kills trees and allows light to get in. In addition, preserving and protecting intact connected aquatic habitat with high cover and complexity are needed (J.S.).

b. Determination of and protection of population core zones. This system is being developed by Klaus Richter to provide a science-based framework for species protection. Wetland systems in areas that will be developed are evaluated to determine likely locations for amphibian population core zones. Mapped wetlands are evaluated with 200 m buffers, and 1000 m wide habitat zones necessary for juvenile and adult life history stages. Through this approach, overlapping wetland and habitat zones can be seen, and areas likely to be population core zones are determined and can become a focus for protection.

c. Protection of ephemeral wetlands. Ephemeral wetlands need focus for two reasons. First, they have been disproportionately lost, and second, northern red-legged frog larval survival is typically less in permanent wetlands (Adams 1999, 2000). Loss of shallow wetlands needs to be mitigated by creating shallow wetlands, instead of replacing shallow wetlands with deep ones (M.A.).

d. Special protective measures for amphibian use of stormwater ponds. Ostergaard (2001) provides recommendations for making stormwater ponds amphibian friendly. She found that the ponds attract amphibians and if characteristics lead to good egg and larval survival they may be source areas. However, without consideration of amphibian needs, they may be population sinks. She recommends: site stormwater ponds within 2 km of each other and with adjacency and connectivity to forest, other open space, or protected areas to provide for re-colonization of ponds over time; discouraging amphibian use by locating ponds away from retained natural areas if water quality is expected to be poor; cleaning ponds late summer to fall when amphibian use is low, and cleaning only ½ of a pond to retain habitat; designing ponds to dry in late summer to prevent colonization by bullfrogs; and posting signs at ponds explaining protection needs for amphibians.

3. Education

Most survey respondents specifically identified education as important for achievement of the population goal. The following inclusions were recommended: volunteer egg mass surveys, education that makes frogs an important part of children's experiences, a flyer/brochure for how to promote frogs in your backyard, news stories and other media opportunities regarding frogs and including the importance of beavers in maintaining diverse aquatic habitat.

4. State Conservation Status

This component has two parts.

a. Inclusion in Washington's conservation status categories as a "monitor" species. Northern red-legged frogs were previously a state priority species, but they currently have no state status. This is due to being relatively common, along with limited resource availability for other species with definitive risk. In addition, local government critical area ordinances (CAOs) use a rating system to determine buffer width. If priority species are present, maximum buffer widths are required. Previously northern red-legged frogs triggered maximum widths for a vast majority of wetlands although it had not been intended for a relatively common species to trigger the maximum buffer width (K.M.). In light of this history, but taking into account population vulnerabilities for northern red-legged frogs, at a minimum, inclusion in the state's "monitor" status is appropriate. This status makes the species a priority for inclusion in the state's data collection and mapping system.

b. Include regionally-based conservation needs in the state conservation system. The northern red-legged frog is a species that regionally (e.g., much of the Puget Lowlands) could become extirpated while frog populations in coastal areas remain healthy. The current conservation status system for Washington provides one statewide status and does not differentiate threats between regions. Updating this system to include ecoregion or basin level focus is needed. Oregon is an example of a state that has such a system. Oregon includes smaller land units in its listing approach and is therefore better able to define areas of concern for northern red-legged frog populations (Oregon Department of Fish and Wildlife 1997).

5. Bullfrogs and Exotic Fish

Based on Adams (1999, 2000) bullfrogs and exotic fish have negative effects on northern red-legged frog survival, however other poorly understood factors appear more important. Thus, bullfrogs and exotic fish should be reduced, but this should not lessen attention to other components. Suggestions include preventing the spread of non-native fish, and, possibly removing fish from some wetlands to create a mosaic of fishless habitat (M.A.) and, maintaining bullfrog-free wetlands (J.S.). Adaptive management may allow refining this approach and focusing on selected exotic fish that appear to be of greater concern for northern red-legged frogs and other amphibians (M.H.).

6. Adaptive Management

The primary purpose of adaptive management in this system is to assure that measures being taken to achieve long-term protection for the frogs are succeeding. To accomplish this, data and new information must be gathered and must be adjusted as necessary.

Opportunities, Barriers (i.e., Obstacles), Resources, Potential Harms, and Uncertainties Related to Implementation of Alternatives

I asked questions related to feasibility and challenges associated with implementation of conservation measures. This is a summary of the responses.

Opportunities exist for implementation of the alternatives through best available science use as required by the state Growth Management Act, tax relief for preserving wetland buffers larger than required, the greater protection afforded to federal lands, allowing beavers to create habitat, timing water fluctuations with amphibian requirements, controlling/confining bullfrog populations (e.g., by allowing waters to dry out in the summer), and, preventing the spread of invasive species or anything that will decrease habitat diversity and complexity.

Barriers identified include cost and lack of funds (e.g., King County has eliminated funding for the amphibian monitoring program), pressure to lessen existing buffer protection for wetlands and to not take property "rights" away from people, urbanization, exotic species, and beavers being considered a nuisance.

Resources for implementation include interest, money, information, and county weed boards.

Potential harms and uncertainties noted were that management for one species may discriminate against other species.

Part B. Conservation Questions and Responses

1. What do we or don't we know about northern red-legged frog populations in Washington?

M.H. GAP Analysis (Dvornich et al. 1997) gives us a general idea. From this we know that the northern red-legged frogs are at the low elevations. It doesn't tell us where there are problems. We think the problems are where there is development. Overall at the geographic level we know very little. The King County study by Klaus Richter and the Fort Lewis study by Mike Adams are the only geographic studies. We need a system that can both detect the frogs and tell you about the population condition. Areas with low population densities will be difficult to have detection and will be prone to type II errors (i.e., assuming they are not there when they are). Coastal systems are the stronghold for this species. This is the same in California as well. No populations have been studied demographically in Washington. The only studies are small pieces, mostly of movement. These pieces do not yet provide predictive ability for habitat needs. In southwestern Oregon, there are 5 years of data for the Umpqua.

K.R. Very little. We could infer knowledge from habitat relationships but atlas data is missing, and beyond that we know even less about populations (trends, age/gender ratio, habitat use, etc.).

K.M. This species is still common and present throughout where its home range is thought to be. It has been extirpated from major urban areas such as Seattle and Tacoma. We are in the heart of the range for this species, and they seem fairly resilient. The biggest challenge is in the developing lowlands.

2. What are sources of mortality to the frogs (embryo, larval, metamorph, juvenile, adult)?

M.H. Embryonic mortality is usually minimal e.g, if there is > 3% mortality to egg masses this is a concern. This is due to the early timing of breeding, which corresponds with few predators being out. Leeches will take a few embryos. The biggest problem is *Saprolegnia* (water mold) which is associated with UVB (ultraviolet-B light). Ninety percent of mortality occurs during the larval and metamorph life stages. Larval mortality is rarely < 70%. Of the invertebrates, larval diving beetles and dragonflies are the biggest predators of the tadpoles and metamorphs, followed by backswimmers and other invertebrates such as water scorpions. Of the vertebrates, common garter snakes (they have 95% of their diet from still-water amphibians) are important. These snakes are the major predator of the metamorph stage. Wading birds such as the great blue heron and green-backed heron can be locally important predators. For frogs older than one year, garter snakes are still an important predator. They will take even large frogs (e.g., Shean 2002, includes an observation of an 80 mm telemetered female frog within a snake). Raccoons are known to take leopard frogs, and might be predators for northern red-legged frogs. Klaus Richter has observed a mink taking a northern red-legged frog. Mink have been found in Oregon to have a winter diet that includes Oregon spotted and bull frogs (1/3 of bones in scat were from these species). Also, a road-kill otter in Oregon was found to have six adult red-legged frogs in its stomach. Both felids and dogs avoid amphibians. Road kill is an issue but is difficult to assess.

K.R. In urbanizing areas we have habitat fragmentation, hydrological changes associated with impervious surfaces etc. This causes loss of depth and duration of water, invasion of exotics and aggressive natives, and bullfrog and other exotic introductions. In rural areas and farmlands we have water quality, bullfrogs, sunfish, bass and others.

K.M. Juveniles are a favorite food of the common garter snake and northwest salamander larvae. Common garter snakes, great blue herons, river otter, and mink eat adult frogs. It is not known how significant road kill is, but it must be if it is a busy road. UV effects are unknown for northern red-legged frogs.

M.A. I think that fish introductions and habitat changes (shift from shallow, ephemeral to deep permanent) habitats are the two biggest factors that we know about. Bullfrogs don't seem to be a big factor in Washington. We don't know anything about upland habitats. We see some evidence that road density has a negative association with red-legged frogs in Oregon.

3. Have northern red-legged frog declines been observed in some areas?

M.H. Not aware of decline data for Washington. Willamette Valley Oregon, yes.

K.R. Yes, but other areas we know little about.

K.M. Only on a coarse scale: Seattle, Tacoma, and for Olympia they are at the outskirts in Watershed Park.

M.A. They have certainly lost habitat but status and trends aren't well known.

4. What are thresholds of concern for population decline?

M.H. These are unknown.

K.M. First what will happen is that people who have been working in wetlands and streams will note that they don't see frogs any more. It would be good if broad amphibian monitoring was occurring, but lacking this we will need to rely on peoples' observations. This would be the first sign of decline. This would then start a more formal effort to assess the concern. This approach is not as good as a long-term program. For some frog species (e.g., back east) call routes can be driven. This species is much more difficult to survey because it does not have a loud call. People must go out in the wetlands for this species.

5. What are thresholds of concern for habitat loss in the range of the frog?

M.H. We know development is a problem, but what degree of development is a problem is unknown.

K.M. We need to be able to define what habitat loss is. We don't know this yet. Asphalt would be clear habitat loss, but there are many degrees of loss and we don't know which are important.

J.S. At the microhabitat scale they need at least 50% cover based on Thurston County data.

6. Do we have a monitoring system in place that includes this species?

M.H. For Thurston County a beginning of a monitoring system is in place. There are a few scattered efforts with egg mass surveys. These are community based.

K.R. No. A 9-year program for King County was terminated this year.

K.M. No, we are relying on common knowledge. (See #4 above.)

M.A. Not that I know of.

7. How are conservation rules set up at the state and local level?

K.M. At the state level candidate and monitor lists are updated yearly. Biologists with WDFW submit new information to the state endangered species program for species that should be on these lists, or where data shows they can be removed. Other persons can also petition WDFW similarly, with species information. Candidate lists are prioritized for species most in need of listing. A status report is done. This goes to the Fish and Wildlife Commission, and a public review is held for recommended listing decisions. The monitor list drives data entry, and is considered a scientific basis of information. Federal Habitat Conservation Plans (HCPs) have value for this species. The DNR HCP is good for frogs by leaving more trees, and providing for more down logs, and decaying wood. Both the City of Seattle (for water supply system watersheds) and the USFS have mandates for biological diversity. These efforts provide mid-elevation protection for northern red-legged frogs. The biggest challenge is in the developing lowlands. In these areas for Pierce and Thurston Counties, typically developers leave more than the minimum protection required. This hasn't tested how well the local protection ordinances protect these species. There are important initiatives occurring in the state. One is the ecosystems project. This is a GIS-based analysis of the locations in the state of important habitats and species. In theory this can be used for regulatory preservation.

K.R. No teeth.

8. Are our conservation rules geared towards thinking about species needing different habitats at different times, and migration routes?

M.H. Poorly, a general view is that amphibians don't need much space. On a spatial scale, red-legged frogs use a larger space.

J.S. Previous thoughts had been that red-legged frogs leave the wetland immediately after breeding. This was not true in my Thurston County study. Emergent and forested wetlands were important; scrub-shrub was used transitionally.

K.R., K.M. No.

9. Should the northern red-legged frog in Washington have a specific conservation status?

M.H. Yes, but with a regional qualifier, based on degree of development.

K.R. We don't have enough information on this species. During listing discussions 5 years ago we didn't feel that they were disappearing or decreasing in numbers. There are regional vs local concerns. In a system built for statewide concerns, when do you list based on local concerns?

10. Can the species conservation management system be proactive?

M.H. Yes. But to do so we need a geographic level system to tell us where the frogs are, linked with a higher scale inventory to tell us about population condition.

K.R. No. We need a landscape approach that protects ecosystem structure and function utilizing principles of conservation biology, landscape ecology and population biology. The current high cost situation with salmon (re ESA) shows that we had a false economy. We have the same false economy with amphibians.

J.S. We need to create land and wildlife management standards that include amphibians. They are often overlooked as important components of ecosystems.

11. What will allow people to care?

M.H. Education at a variety of levels. Ownership in a process and the ability to influence. Two levels of needing to care are: (1) non-altruistic where frogs are an indicator of habitat quality for frogs and for people; and, (2) intrinsic, where people have a general respect for the natural system.

K.R. Ability to make money. If it doesn't cost financially or entail personal sacrifice.

K.M. People are diverse, some will care and some won't. Education is very important, especially while people are young. Children in an urban setting have a hard time getting to understand nature's importance. We have to find a way to make sure frogs are a part of children's experience. News stories are also an opportunity.

J.S. Education about amphibians in general, and about northern red-legged frogs and their habitat requirements will encourage people to have the desire to help preserve this species.