COSEWIC
Assessment and Status Report

on the

Red-legged Frog
Rana aurora

in Canada

SPECIAL CONCERN
2002

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE IN
CANADA

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ESPÈCES EN PÉRIL
AU CANADA

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COSEWIC
Assessment Summary

Assessment Summary – May 2002

Common name
Red-legged frog

Scientific name
Rana aurora

Status
Special Concern

Reason for designation
This species' range is restricted and fragmented as it occurs on Vancouver Island and on the mainland without any possibility of dispersal across salt water. Some declines in populations have occurred in urban areas. Notably, the species is considered endangered (United states Endangered Species Act) in its southern range in the United States. The species has a limited range in Canada and is susceptible to habitat degradation as well as predation and competition from introduced bullfrogs and green frogs.

Occurrence
British Columbia

Status history
Designated Special Concern in April 1999. Status re-examined and confirmed Special Concern in May 2002. Last assessment based on an existing status report.

COSEWIC
Executive Summary

Red-legged Frog
Rana aurora

The Red-legged Frog, *Rana aurora*, is found in extreme south-western British Columbia, Washington, Oregon, and northern California. This relatively large, secretive frog is associated with streams, ponds, or marshes, or can be found in moist forest conditions far from open water. It tends to be dark brown, gray, olive, or reddish with many small black spots on the back, and the skin on the belly and under the legs is bright red.

This species breeds early in the spring, and breeding usually lasts for 2 to 4 weeks only. Egg masses are attached to vegetation below the surface, and most hatch in early May. The developmental rate of the embryos is slow compared to other species, but the embryos hatch at a larger size and are more developed. The growth rate of tadpoles is strongly correlated with the number of degree-days since hatching, but they usually begin to metamorphose in late July. Survival of eggs tends to be very high, while very few tadpoles survive to metamorphosis and very few juveniles survive to maturity.

The B.C. Ministry of Environment, Lands and Parks has placed *R. aurora* on the Yellow List, and the Conservation Data Centre considers it to be "frequent to common with restricted distribution". Many historic collection sites are in provincial or regional parks, but there have been few intensive surveys documenting population size or trends and much of its range in B.C. encompasses areas undergoing extensive human development.

The main threats to the survival of this species are degradation or loss of habitat, and predation and competition from bullfrogs (*Rana catesbeiana*). Changes in the environment that increase water temperature and introduction of exotic fish species could provide a competitive advantage for bullfrogs over native ranids.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) determines the national status of wild species, subspecies, varieties, and nationally significant populations that are considered to be at risk in Canada. Designations are made on all native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fish, lepidopterans, molluscs, vascular plants, lichens, and mosses.

COSEWIC MEMBERSHIP

COSEWIC comprises representatives from each provincial and territorial government wildlife agency, four federal agencies (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership), three nonjurisdictional members and the co-chairs of the species specialist groups. The committee meets to consider status reports on candidate species.

DEFINITIONS

Species	Any indigenous species, subspecies, variety, or geographically defined population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.
** Formerly described as "Not In Any Category", or "No Designation Required."
*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

Red-legged Frog
Rana aurora

in Canada

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1999

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INTRODUCTION

Within the genus *Rana* in northwestern North America, *Rana aurora* is considered to be one of three "brown frog" species (along with *R. cascadae* and *R. pretiosa*) belonging to the *R. boylii* group, based on karyological evidence (Green 1986a). Electrophoretic data indicate that of this group, *R. cascadae* and *R. aurora* are most closely related (Green 1986b; Green et al. 1996).

There are two subspecies of *R. aurora*, *R. a. aurora* and *R. a. draytonii*. This separation is based on morphological, genetic and behavioural differences (Hayes and Miyamoto 1984; Green 1985; Green 1986b), although the karyotypes of the subspecies are almost identical (Green 1986a). *Rana a. aurora* occurs in British Columbia south to northern Sonoma County, California (Green 1985), whereas *R. a. draytonii* is found from this point to Baja California (Hayes and Miyamoto 1984). All references to "aurora" in this report will mean *R. a. aurora* specifically, unless otherwise indicated.

Rana aurora tends to have a dark brown, gray, olive, or reddish back with many small, irregular, indistinct black spots and flecks (Fig. 1). The prominent dorsolateral folds tend to be lighter in colour, and there is a dark mask on the side of the face above a cream upper lip stripe. The throat and chest are white with black or gray flecks, and the skin on the lower belly and under the leg is bright red (the red colour appears to be under the surface of the skin). Juveniles have little or no red, and the red is more extensive on older frogs. There is a mottled green patch on the lower flanks, and the arms and legs are darkly barred. The skin of the lower leg is translucent so that the bones are visible, and webbing on hind feet does not extend to the last segment of the longest toe. The sexes tend to be difficult to tell apart, but the males have darkened thumbs during breeding, and enlarged forelimbs and webbing. Females can reach 100 mm, but males are usually less than 70 mm; both sexes are usually smaller in British Columbia. This species has relatively long legs; the heel of an adpressed hind limb reaches or passes the nostril (Nussbaum et al. 1983; Cook 1984; Green and Campbell 1984; Stebbins 1985; Leonard et al.1993).

Figure 1. Adult *Rana aurora*, from Rush Creek near Nanaimo, B.C., July 1996. Photo by Heather Waye.

The tadpoles are greenish-brown with light and dark flecks on the back and a pinkish-white belly. The eyes are on top of the head (Green and Campbell 1984). In hatchlings, the tail is 1 to 1.5 times the body length and angles up from the body. The dorsal fin is tall and translucent gray, and there is a small gold line along each side of the back. The tail of larger tadpoles is 1.5 times the length of the body or less, and the dorsal fin is taller than the thickness of the tail trunk near its base. Tadpoles have 3 tooth rows on top, the first row complete and the second and third with a small gap, and 4 tooth rows on bottom, the first row with a gap and the other three complete; each of these rows is shorter than the one previous (Nussbaum et al. 1983; Corkran and Thoms 1996).

Collections of *R. aurora* in the Royal British Columbia Museum span 1941 to 1981, and 1923 to 1989 in the National Museum records. Early published accounts mainly deal with *R. aurora* in captivity (Cowan 1941; Carl 1952; Guppy 1960). Research about behaviour, breeding, survival, and population dynamics was published in the late 1960s and early 1970s, mainly by L. Licht (Dickman 1968; Licht 1969a, 1969b, 1971, 1974, 1975; Calef 1973a, 1973b), whereas the most recent work reports the results of brief surveys of historic sites (Knopp 1996; Haycock 1996), the relationship between *R. aurora* and other ranid species (e.g. Green 1985, 1986a), tadpole behaviour (e.g. Blaustein et al. 1993; Lefcort and Blaustein 1995), and the effects of UV-B on development (Ovaska et al. 1997).

DISTRIBUTION

In Canada, the Red-legged frog is only found in British Columbia. The Northern Red-legged frog (*R. a. aurora*) is found in southern British Columbia on Vancouver Island and the Gulf Islands, on the mainland adjacent to the Strait of Georgia, and through the Fraser Valley to Hope (the Georgia Depression and southern Coast and Mountains ecoprovinces) (Fig. 2). The locations plotted on this map are based on specimens in the Royal British Columbia Museum and the National Museum, sightings by the author, the distribution map presented in Green and Campbell (1984), and locations mentioned in Green (1978). The specimens collected at Kingcome and Powell River are housed at the National Museum in Ottawa, and should be reidentified to verify that *R. aurora* occurs north of Vancouver on the mainland.

Rana a. aurora range from British Columbia through Washington to southern Oregon and northern California on the western side of the coastal mountain ranges (Fig. 3). In Washington it is found in the Olympic Peninsula/S.W. Washington, Puget Trough, and Western Slopes and Crest physiographic provinces. In Oregon it occurs in the East Slope Cascades, Klamath Mountains, Oregon Coast Range, West Slope Cascades, and Western Interior Valleys physiographic provinces (Corkran and Thoms 1996). *Rana a. draytonii* is found from northwest California south along the coast to northwest Baja California and through the centre of the state (Stebbins 1985). This subspecies was introduced to Nevada in the 1940s but has not been encountered in recent surveys there (Reaser 1996).

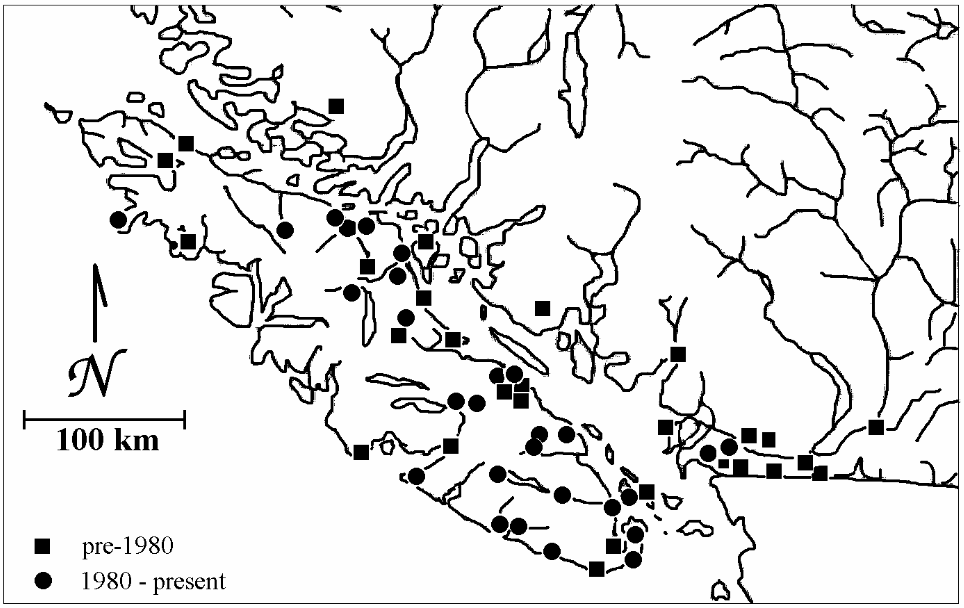

Figure 2. Location of capture sites of *Rana aurora* in British Columbia.

Figure 3. North American range of *Rana aurora*, from Stebbins (1985).

PROTECTION

All native amphibian species in British Columbia are protected from collection under the Wildlife Act of 1982. The B.C. Ministry of Environment, Lands and Parks places *R. aurora* on the Yellow List (of conservation concern) and the B.C. Conservation Data Centre considers it to be "frequent to common with restricted distribution; perceived future threats" on both global and provincial levels (Table 1). The Nature Conservancy also considers this species to be "not rare" in Washington and Oregon but "imperiled" in California. The U.S. Forest Service considers this species to be "sensitive", and the Bureau of Land Management lists it as a "tracking species" in Washington and Oregon. *Rana aurora* is legally protected from taking in Oregon, and is considered "sensitive" by the Oregon Department of Fish and Wildlife (Corkran and Thoms 1996). *Rana a. draytonii* has been given "threatened" status by the U.S. Fish and Wildlife Service.

Table 1. Status of *Rana aurora aurora* and *R.a. draytonii* in Canada and the United States.

	Rana aurora aurora	***Rana aurora draytonii***
British Columbia	Ministry of Environment Wildlife Branch - Yellow list (of conservation concern); Conservation Data Centre - S4 (frequent to common with restricted distribution; perceived future threats)	
Washington	Bureau of Land Management - tracking species; Forest Service - sensitive; The Nature Conservancy - S5 (widespread and abundant)	
Oregon	Department of Fish and Wildlife - Pr-S/u (legally protected from taking, sensitive/undetermined status); Bureau of Land Management - tracking species; Forest Service - sensitive; The Nature Conservancy - S4 (not rare, but of long-term concern)	
California	Department of Fish and Game - species of special concern (vulnerable to extinction); The Nature Conservancy - S2 (imperiled)	Department of Fish and Game - species of special concern (vulnerable to extinction); The Nature Conservancy - S2 (imperiled)
United States (federal)		U.S. Fish and Wildlife Service - threatened; Forest Service - sensitive
Global	Conservation Data Centre/The Nature Conservancy - G4 (not rare, but of long-term concern)	The Nature Conservancy - G4 (not rare, but of long-term concern)

In B.C., Washington and Oregon, this frog is protected from collection, but habitats are not managed specifically for the species. The majority of historical sites in British Columbia are not in parks or protected areas, although *R. aurora* have been found in Little Campbell River Regional Park, Miracle Beach Provincial Park, Morrell Nature Sanctuary, Garibaldi Park, Strathcona Provincial Park, Stanley Park, Rithets Bog Nature Sanctuary, Spectacle Lake Provincial Park, and Trevlac Municipal Park in Victoria.

Table 2. Population data for *Rana aurora* at two locations near Vancouver, British Columbia.

	Little Campbell River*		Marion Lake†	
	1968	1969	1969	1970
# egg masses	36	33	618	620
mean # eggs per mass	680 (194-921)	same	531+19 SE	same
# adults	67	46	1770+280 SE^	3600+775 SE^

*Licht 1974
†Calef 1973a,b
^breeding males only

POPULATION SIZE AND TREND

Population size

There is no information available on current numbers of individuals in any population. There were "several hundred" frogs breeding in Marion Lake in 1968 and 1969 (Licht 1969a); the population estimates available are at two sites between 1968 and 1970 (Table 2). It seems that several hundred or even several thousand adult frogs can exist associated with a large pond or lake, and it is possible to find many frogs quickly and easily outside of breeding season in some locations. Surveys in Washington's Puget Trough during 1989 to 1991 found that *R. aurora* and bullfrogs (*R. catesbeiana*) were the most common ranids; *R. aurora* was the only one at 26 sites, and the two species were found together at 3 sites (McAllister et al. 1993). *Rana aurora* occupies a relatively restricted range in Canada, but tends to be locally abundant where it does occur. However, there are no recent population estimates, and many sites have not been visited in decades. Likewise, there are few records of year-to-year population fluctuations, which can be very large in amphibian populations (Pechmann and Wilbur 1994); the studies cited in Table 2 show little change in the number of egg masses from one year to the next, but each only covers two years.

A three-year drift fence and pitfall study in Oregon (Storm and Pimentel 1954) caught a total of 13 *R. aurora*, compared to 377 *Hyla regilla*; two *R. aurora* were recaptured in the second year of the study, and three in the third. Pitfall trapping in the Oregon Coast Range over three years (1988-1990) captured 0.03 to 2.80 *R. aurora* per 1000 trap nights (a total of 39 frogs); the capture rates varied greatly between years (Cole et al. 1997). This could suggest that a population of *R. aurora* can be sustained by a small number of individuals, although it is not known whether these populations persisted in the long term.

Population distribution and persistence

Rana aurora is thought to be "exceedingly common" throughout most of western Washington, except at high elevations (K. McAllister, pers. comm.). It is not known if any Canadian populations have been extirpated, but with the amount of development in the Lower Mainland and on Vancouver Island it is likely that many small ponds and other suitable habitats have been destroyed, eliminating populations of frogs (L. Friis, pers. comm.).

Two recent surveys of the Fraser Valley area found *R. aurora* at 14 sites, some of them sites where the species had been recorded before, but failed to find the species at 25 sites where it was expected to be (Haycock 1996; Knopp 1996). These surveys took place in April/May (Haycock 1996) and May to July (Knopp 1996) of 1996, but only a short time was spent surveying any particular site, so it is possible that species were missed. The potential of this species for recolonization is not known, but *R. aurora* can move far from water under the right conditions (Corkran and Thoms 1996). It is possible that the loss of a single 'source' population could adversely affect and eventually destroy other surrounding populations (e.g. Drost and Fellers 1996). In addition, the presence of tadpoles or juveniles does not necessarily mean that a particular population is successfully breeding, as dispersing juveniles can make it appear that other sites are successful when they might not be (Seburn et al. 1997).

Trends

Rana aurora was abundant in the Willamette Valley of Oregon until the mid-1970s, but now is very rare, and has not been observed breeding there for over 20 years (Blaustein et al. 1994). Almost all anuran species, including *R. a. draytonii*, have shown declines or local population loss in the Yosemite area of the California Sierra Nevada mountains between 1915 and 1992. *Rana a. draytonii* was not found at any of the three sites it was originally recorded in, and was at only one of seven other suitable sites (Drost and Fellers 1996). It is likely that many sites in B.C. have been lost, and the assumption that the species is still abundant has not been tested. However, almost complete urbanization is apparently required for extirpation (K. McAllister, pers. comm.).

Rana aurora and *R. catesbeiana* were found together at only two of six locations searched on Vancouver Island (Hamilton Swamp and Bell Lake); over a hundred bullfrogs were sighted at Bell Lake (Green 1978). This could indicate that these two species cannot co-exist. Bullfrogs are spreading within the range of *R. aurora* and are thought to have a negative impact on native ranid species. There were many bullfrogs as well as *R. aurora* in Hamilton Swamp in 1994 (pers. obs.), so if there is a negative impact on *R. aurora* they may have declined at this site (or they may have been affected by recent highway construction through this area). A pond in a small municipal park near Prospect Lake in Victoria has had *R. aurora* for many years (it is on private property and the owners watch the frogs every year). Bullfrogs were first heard calling at this site four years ago, and this year there were fewer *R. aurora* seen there than in the past (P. Price, pers. comm.). Conversely, *R. aurora* was "found in numbers" at sites in the Fraser Valley and Little Campbell River several years ago, along with large numbers of green frogs and bullfrogs. The only sites where they were not found was where land had been cleared for agriculture (S. Orchard, pers. comm.).

Rana aurora is thought to still be common around Long Beach and at the north end of Vancouver Island, and is still very common at some interior Vancouver Island sites (e.g. Jordan Meadows) (P. Gregory, pers. comm.). This year, many *R. aurora* were spotted at a site on Saltspring Island, and at a lake near Prospect Lake in Victoria (S. Orchard, pers. comm.). They appear to be locally common at some locations, but these sites and many others have not been formally surveyed.

HABITAT

Habitat definition

Rana aurora tend to be restricted to lower altitudes (to 920 m (Corkran and Thoms 1996) or 1427 m in Oregon (Leonard et al. 1993)). Adults breed in cool ponds or lake margins, slow-moving streams, marshes, bogs, or swamps at least 50 cm deep with suitable vegetation (Leonard et al. 1993; Corkran and Thoms 1996). This species will use both temporary and permanent bodies of water; the main requirements seem to be little or no flow, enough water to last until metamorphosis, and emergent vegetation for egg mass deposition (Nussbaum et al. 1983). Tadpoles move to warmer parts of the pond while they grow, so there must be some exposure to sunlight (Licht 1969a) and they tend to stay in vegetated habitats (Wiens 1970). Adults and juveniles live along streams or in other moist habitat in the summer, spending the day under cover, and can be found in forests far from open water during moist conditions (Orchard 1984; Corkran and Thoms 1996). They prefer mature forests, with plenty of leaf litter and fallen logs (Orchard 1984), and tend to move up forest streams during the summer months (D. Green, pers. comm.). In Oregon, *R. aurora* was more abundant in deciduous forest than in shrub, open sapling-pole, large saw timber, or old growth conifer stands, and was found much more frequently in riparian than upslope areas (Gomez and Anthony 1996). However, in the southern Washington Cascade Range *R. aurora* was more abundant in mature forest (Aubry and Hall 1991). It is likely that they are more dependant on characteristics such as stream flow and presence of predators than on a particular vegetative type (Gomez and Anthony 1996). In California, *R. a. draytonii* is mainly found in and around ponds, and is not found as far from water as *R. a. aurora* (Green and Campbell 1984).

This species seems to be widespread and able to use a range of moist habitat types. The habitat patches are likely fragmented within urban and suburban areas, but fairly continuous or connected in larger parks and wetlands.

Habitat trends

Most of the loss of habitat has been in the lower Fraser Valley area, as the urbanization of Vancouver and surrounding areas expands. The southeast portion of Vancouver Island also has seen much recent development, including a new highway. The Island Highway has been widened between Victoria and Campbell River, including 128 km of new roadway.

The construction of the new parts involved clearing a wide swath through forested area between Parksville and Campbell River, apparently with very little regard to the potential effect on amphibians in the area. Many small streams and marshy areas were affected by the construction, while the impact on amphibian populations (e.g. habitat loss or degradation, disruption of migration routes) is unknown. As the human population of the lower mainland and Vancouver Island increases, more and more of these relatively undisturbed areas will be affected or destroyed. This growth has been steady for many years, and is likely to continue.

Most of the locations where *R. aurora* has been collected are in settlements or near human habitation; it is likely that there are many undisturbed areas where *R. aurora* occurs but has not yet been recorded. A few specimens have been collected between Vancouver and Kingcome, suggesting that this species could range up the coast to 50^{o}N; relatively little human growth has occurred in this area, or on the west coast or interior of Vancouver Island. Human impact in these areas consists mainly of logging activities, which likely have some impact on populations of *R. aurora*. The area of forest harvested in the Ministry of Forests Vancouver region between 1981 and 1995 averaged over 33 000 ha each year; about one-third of the forest in this region is immature (Harding 1994). The Coastal Douglas-fir biogeoclimatic (BGC) zone, along the south-eastern edge of Vancouver Island, is more than 90% fragmented by roads (i.e. areas of more than 5000 ha make up less than 10% of this zone). Various subzones or variants of the Coastal Western Hemlock and Mountain Hemlock BGC zones are also highly fragmented by roads (Harding 1994). The effect of this fragmentation on the distribution of *R. aurora* is unknown.

Habitat protection

On Vancouver Island, the majority of historic locations are on the east side of the island (probably due to more people being there to find frogs, but also possibly because there are more low, wetland sites). A large portion of this land is privately owned, mainly by forestry companies. Most of the land on the west side of Vancouver Island is crown land, leased out to the forestry companies for logging. *Rana aurora* in Oregon did not seem to be affected by logging and burning in a red alder/Douglas-fir forest, at least in the short term (Cole et al. 1997). However, a study involving terrestrial amphibians on Vancouver Island found that there were 3 to 6 times more amphibians in old growth Douglas-fir stands than in mature or young forest (Dupuis 1997). A study examining the effects of forest fragmentation on *R. aurora* is currently underway on northern Vancouver Island, and should provide more information on the impact forestry practices have on this species.

Many of the known sites on the mainland are in parks, but a large proportion of these are small parks within Vancouver and surrounding communities, so even if the land itself is protected, habitat degradation and fragmentation is still of concern.

As *R. aurora* is not currently listed by the British Columbia government as endangered, there are no efforts to obtain land specifically for this species; however, wetland conservation in general is of interest. The current level of protection is probably adequate, but there are many areas within the range of this species where they have not yet been recorded and there is no protected land. Threats to these lands include encroaching development, which could degrade water quality and destroy corridors between sites, and logging and other activities within otherwise protected areas. Urban biodiversity can be lost directly through development, or indirectly from fragmentation of microhabitats, pollutants entering storm drains, and changes in drainage patterns (Schaefer 1994). One example is Rithets Bog in Victoria; the marshy area is home to *R. aurora* (pers. obs.), but the recent heavy development around the nature sanctuary diverts so much water that the marsh is drying and vegetation is quickly filling it in. The introduction of exotic species (fish and amphibian) also degrades otherwise suitable habitat (Hayes and Jennings 1986).

GENERAL BIOLOGY

Reproduction

Breeding adults first become active when air temperatures are at least 5º C for several days, whereas subadult frogs appear several weeks after breeding is over and air temperatures are above 10º C. The breeding males arrive at the pond a week before females, and do not feed over the next few weeks. They start to vocalize a week after arriving but will amplex if presented with a female before they start calling. Air and water temperatures must be above 6ºC for several days before calling begins (Licht 1969b). Breeding lasts for 2-4 weeks and is usually finished by the end of March (Licht 1974).

Males call in water that is 4 to 9º C, but the minimum water temperature for egg-laying is 6º C (Brown 1975). Males often call under a skin of ice, and eggs are often in 4 or 5º C water for many days if the weather cools after egg laying begins (Calef 1973a). The males call underwater in submerged weed beds, and mating and egg laying follow immediately with most egg masses attached to grass or branches near shore (Calef 1973a, Brown 1975), in water 5 cm to 5 m deep (Calef 1973b). Frogs remain still on the bottom or in vegetation (Licht 1969b) and call mostly at night; females spawn only at night (Licht 1971). The few males that call above the surface do so only briefly. They call from several feet apart, from a particular location that they return to after surfacing for air. The mating call is low in volume, and does not carry well either in air or water. Once the males start calling, they do not stop if the temperature drops again. Males call more when other males are near, or when there is movement nearby. This species engages in axillary amplexus, and the male calls a single note once per second while grasping the female, possibly to keep her responsive (Licht 1969b).

Males tend to be recaptured less than 300 m away from previous capture sites during a breeding season, and are often captured in the same place and time in following years (Calef 1973b). There are no aggressive displays between breeding males (Calef 1973b), and it is not known if males are territorial (Licht 1969b). Males may mate more than once in a breeding season, but many males fail to breed (Calef 1973b). Nonreceptive females call and vibrate when grabbed by a male, then roll onto their sides and become stiff until they are released (Licht 1969a). Adult females of this species probably breed every year (Licht 1974).

Most of the females spawn within 2 weeks after the first egg mass is laid (Licht 1969b). Individual egg masses are laid in the same general area but about 60 cm apart and generally in deeper water away from shore (Licht 1969b, 1971, 1974). Some egg masses are laid in water less than 30 cm deep, whereas others are found deeper than 3 m (Calef 1973a), but the majority are attached to stalks of vegetation in water between 30 cm and 90 cm deep (Licht 1969b). Egg masses are deposited in slow, quiet water in areas where the males were calling and that are exposed to sunlight for most of the day (Licht 1969b). The average female deposits 680 eggs in one mass, but smaller females tend to lay fewer eggs (Licht 1974). Most eggs hatch during the first 2 weeks of May, and the tadpoles remain together for about a week before dispersing. They begin to metamorphose in late July/early Aug, but can still be found metamorphosing until early October (Calef 1973a). Young larvae selectively associate with siblings over non-siblings, but as they develop they lose the ability to distinguish between siblings and non-siblings and associate with any conspecific tadpoles (Blaustein et al. 1993).

Adults are sexually mature by the third year after metamorphosis (Licht 1974). Generally, the sex ratio of adults outside the breeding season is 1:1 (Calef 1973b). Current recruitment and/or death rates for any population are not known, but it appears that some populations at least are persisting. There could be a good potential for population growth if predators were limited or removed, either under natural or managed conditions. Populations are probably able to withstand a year or two of low recruitment, as adults are apparently able to live for several years after maturity and survival of adults tends to be fairly high (Cowan 1941; Licht 1974).

Physiology

Breeding adults are active at temperatures lower than juveniles and nonbreeding adults (Licht 1969b). The lower lethal temperature for eggs is around 4º C, whereas the upper limit is around 21º C; these upper and lower thermal tolerance limits are the lowest for North American species (Licht 1971). Egg masses are normally submerged during development, and therefore are protected from direct sunlight and thermal extremes (Licht 1971).

As amphibians (and therefore ectotherms), frogs thermoregulate by choosing microhabitats that provide the temperature they need (e.g. Lillywhite 1970); for example, eggs are laid in vegetation that is exposed to sunlight for part of the day (Licht 1969b) and tadpoles move to warmer parts of the pond once they hatch from the eggs (Licht 1969a). Adult frogs will bask to raise body temperature if there is enough moisture to balance water loss (Lillywhite 1970), but they tend to be limited to the range of temperatures offered by the microhabitats available to them.

The developmental rate of *R. aurora* embryos is slow compared to other cold-adapted species, probably due to the large size of the eggs, but the embryos hatch at a larger size and with more yolk than the embryos of other ranid species (Licht 1971). The long period of larval development results in a larger frog at metamorphosis, which improves survival in dry summer conditions (Brown 1975). The early breeding behaviour, egg and egg mass characteristics, low maximum and minimum temperature tolerance limits, and late stage of hatching all are adaptations that increase developmental success in cool water (Licht 1971).

Food habits

Adults eat beetles, caterpillars, isopods, and a wide variety of other small invertebrates (Nussbaum et al. 1983), and tadpoles eat filamentous green algae (Dickman 1968). Overall, not much is known about specific feeding habits (Nussbaum et al. 1983). There is probably some competition with other insectivorous species, but food does not appear to be a limiting factor for *R. aurora*.

Growth and survivorship

Eggs take about 1400 hours to reach stage 20 at 4.5º C, and about 120 hours at 20º C; the embryos are well-developed when they hatch at stage 21. The rate of development increases greatly in response to small increases in temperature at the lower end of the tolerance range (Licht 1971). Eggs in a pond in Washington took 35 days to develop, at an average water temperature of 6.2º C, and the larvae were 12.4 mm on average when they hatched. The larval growth rate ranged from 0.62 to 0.99 mm/day (Brown 1975). The growth rate of tadpoles varies between years and between areas in any particular lake, but is strongly correlated with the number of degree-days since hatching; overall, growth is approximately 5 mm per month (Calef 1973a).

At the Little Campbell River site in 1968, survival from egg deposition to hatching was 92% in the pond and 91% in the river (Licht 1974). In one study in Oregon, *R. aurora* egg masses showed 91 to 98% survival to hatching in natural habitats (Hays et al. 1996). This survival rate is high for aquatic eggs; 71% of *R. pretiosa* eggs survived to hatching (Licht 1974) and only 48% of *Hyla rosenbergi* eggs survived (Kluge 1981). After hatching in Little Campbell River, the initial mortality rate was high, but decreased and levelled off as the tadpoles grew, with overall survival of 5.3% from tadpole stage to transformation (Licht 1974).

The overall survival rate to transformation was 4.82%, while for *R. pretiosa* at the same site this survival rate was 5.18% (Licht 1974). In Marion Lake, the decline in tadpole numbers was rapid until the tadpoles were too big for salamanders to eat; at metamorphosis about 5% of the tadpoles were left (Calef 1973a). The survival rate for *R. catesbeiana* tadpoles to metamorphosis was found to be 11.8 to 17.6% (Cecil and Just 1979).

Of an estimated 522 juveniles recruited in 1968, 272 were recaptured in 1969, for a survival rate of 52% (Licht 1974). As 15 000 to 30 000 juvenile frogs leave Marion Lake every year, and no more than 1200 adults are needed to maintain the present breeding population, a potential mortality rate of 90-95% between metamorphosis and maturity is suggested (Calef 1973a). Marion Lake could support to metamorphosis one hundred times the number of tadpoles that actually survived (Calef 1973a), giving support to the hypothesis that most tadpole and adult mortality is from predation (Licht 1974).

Animals that are known to eat tadpoles include leeches, giant water bugs, predacious diving beetles, backswimmers, water scorpions, dragonfly nymphs, fish, salamander larvae, newts, and garter snakes (Licht 1974). Predators on the adults include raccoons, great blue herons, belted kingfishers, garter snakes, cutthroat trout, red-tailed hawks, marsh hawks, hooded mergansers, great horned owls, red foxes, striped skunks, mink, and feral house cats (Licht 1974). Large adult ranid frogs are known to occasionally prey on newly-metamorphosed individuals of their own and other species (Licht 1986). There are other causes of mortality; for example, in 1969 at Marion Lake, 2.4% of the eggs were infected with fungus, and some egg masses were exposed by receding water and desiccated or were frozen at the edge of the lake (Calef 1973a), but these other sources of mortality tend to be minor.

Adults have an average annual survivorship of 69% (Licht 1974), although male survivorship tends to be higher (Briggs and Storm 1970). In comparison, adult *R. cascadae* had 59% survival for males, and 46% for females (Briggs and Storm 1970), while *R. pretiosa* males had 45% and females had 67% survival (Licht 1974). Average adult longevity is unknown, but two females in captivity lived to 12-13 years and 15 years (Cowan 1941). The population age structure, and its stability, are not known, but the age structure of anuran populations can vary greatly from one year to the next (Bertram and Berrill 1997; Green 1997). The heaviest predation occurs between hatching and tadpole metamorphosis (Licht 1974), so the individuals most critical to the survival of the population are probably mature adults, to carry the population through years of low or no recruitment.

Hibernation

Rana aurora overwinter in water or on land from November to late February, and emerge from the aquatic sites when the ice melts (Licht 1969a, 1974).

The species is not known to be freeze-tolerant or freeze-resistant. The requirements of the hibernation site have not been described, but it is likely that the main criterion is that the site does not freeze.

Behaviour

During breeding, the males are spaced about 1 m away from each other and tend to remain in the same place while calling, which could indicate territoriality around a calling site (Licht 1969a). Other than this, there is no evidence of territoriality. This species seems to be relatively tolerant of human disturbance, since it persists in suburban habitats, although this has not been examined closely or over a long period of time. The species can be vulnerable during movements to and from hibernation and breeding sites, but overall it tends to be secretive and "extremely wary" (Leonard et al. 1993).

For most of the active season *R. aurora* are mainly terrestrial and sit in the open on dry land (Licht 1986), and when threatened by a predator they leap into nearby water and stay there (Gregory 1979) or more often, they escape through the undergrowth and hide in vegetation (Licht 1986; Leonard et al. 1993). Differences in escape behaviour could be due to whether there are aquatic predators (e.g. fish or adults of other ranid species) in a particular body of water. They are able to jump relatively far for their body size, and rely on their jumping behaviour rather than swimming to escape predators (Licht 1986).

Movement and migration

Juvenile dispersal and adult migrations to and from breeding sites have not been described for this species, but individuals can be found far from water under the right conditions (Corkran and Thoms 1996) and at least some individuals must travel from hibernation sites to breeding sites (Licht 1969a). *Rana aurora* does not appear to hibernate in large concentrations.

The proximity of breeding, foraging, and overwintering sites to each other varies from one site to another, but at most locations these habitats are probably contiguous to some degree. Breeding and overwintering sites can overlap, as some frogs hibernate in water, and breeding and foraging sites overlap, as adults stay around water for most of the summer. Under moist conditions, the frogs move into nearby wooded areas to forage, and some probably hibernate there as well.

Migration routes can cross roads; on the night of Sept. 30, 1995, I saw at least 10 *R. aurora* flattened on a road between houses and a marsh. The frogs appeared to be moving towards the marsh, perhaps to hibernate. Such mortality is probably widespread, as many historic sites are now urbanized.

Vulnerability

This species might be vulnerable to changes in the environment that increase water temperatures (e.g. reduction in stream flow, removal of riparian vegetation) (Hayes and Jennings 1986). Populations of *R. aurora* in suburban and rural areas could be exposed to various herbicides and pesticides, as well as other chemicals used in industry. In one study, ranid tadpoles had the same sensitivities to pesticides as various fresh-water fish. Low concentrations did not have any effect but higher concentrations resulted in mortality or abnormal behaviour (Berrill et al 1997). Application of glyphosate (a herbicide) in the fall to logged sites in Oregon did not seem to affect *R. aurora* (Cole et al. 1997). However, agricultural pollutants have been shown to cause mutagenic effects in amphibian populations (Bonin et al. 1997). The potential effect of toxicants in the environment on *R. aurora* is not known, but current research on the effects of agricultural pollutants on red-legged frogs in the Fraser Valley should provide valuable information.

Abnormally low water levels might affect breeding success if the majority of tadpoles are stranded before they can metamorphose, but the water level would have to drop substantially after breeding to expose the egg masses. Tadpoles infected with *Candida humicola*, a parasitic yeast transmitted through water and faeces, are more susceptible to predation through changes in behaviour (Lefcort and Blaustein 1995). A decrease in water level that causes tadpoles to concentrate in shallow water could not only expose them to greater risk of predation but allow parasites to pass more easily between tadpoles.

High water temperatures could affect adversely the development of the eggs, as *R. aurora* embryos have the lowest maximum temperature tolerance of North American ranids (Licht 1971); the eggs have been known to survive lows of 4º C and breeding adults have been known to call while under ice (Calef 1973a), so abnormally low spring temperatures would probably not greatly affect breeding success. The overwintering requirements of this species are not known, so the effects of severe winter conditions are unclear. One possibility is if the ice becomes much thicker than usual, the frogs hibernating in the water could die if the oxygen in the water is depleted or if the frogs actually become frozen.

Rana aurora in Oregon was tested for sensitivity to increased levels of UV-B and the eggs were not affected by ambient UV-B, possibly due to high levels of photolyase in the eggs (Blaustein et al. 1996); levels of UV-B 30% higher than ambient in Victoria, B.C. can reduce hatching success and larval survival (Ovaska et al. 1997). It appears that the increased UV-B causes the jelly coat surrounding the embryos to disintegrate, and exposed larvae display skin burns and eye cataracts (Ovaska et al. 1997).

Global effects such as climate warming will probably place stress on amphibian populations; increased water temperatures could affect the survival and development of eggs and tadpoles, especially for cold-adapted species like *R. aurora* (Ovaska 1997). Drier summer conditions could restrict movement and activity patterns, and habitat loss would occur when small water bodies dry (Ovaska 1997).

LIMITING FACTORS

The disappearance of *R. a. draytonii* in California has been attributed to a combination of overharvesting, the introduction of bullfrogs, habitat alteration (Moyle 1973; Jennings and Hayes 1985), and the introduction of exotic fish (Hayes and Jennings 1986). The most likely cause for any declining numbers of *R. a. aurora* in B.C. is habitat destruction, possibly coupled with the introduction of the bullfrog (MacIntyre and Palermo 1980). The bullfrogs eliminate other ranid species through competition for food and space and predation on the smaller native frogs (Moyle 1973), and have been shown to have a large impact on amphibian communities (Hecnar and M'Closkey 1997). Bullfrog adults and tadpoles are both known to prey on tadpoles of other species, and were observed to prey on *R. aurora* tadpoles (Kiesecker and Blaustein 1997). Tadpoles from populations of *R. aurora* exposed to bullfrog predation have developed appropriate antipredator behaviours over a relatively short period of time (less than 60 years), suggesting that newly-introduced bullfrogs present strong predation pressure (Kiesecker and Blaustein 1997). *Rana aurora* may be able to adapt to the presence of bullfrogs, but if additional pressures are placed on the population, the combination may overwhelm it.

Licht (1974) felt that *R. catesbeiana* will be a threat to the survival of *R. aurora*; the first bullfrogs at his study site in the Little Campbell River marsh were seen in 1970, and a recent survey there found bullfrogs but no *R. aurora* (Haycock 1996). However, large numbers of *R. aurora* were seen there a few years ago during another survey (S. Orchard, pers. comm.). Anecdotal evidence seems to indicate a decline in the number of *R. aurora* in at least one pond in Victoria after the introduction of bullfrogs (P. Price, pers. comm.).

Rana catesbeiana requires warmer water habitats with low amounts of emergent cover so habitat changes that provide these conditions (e.g. through forestry or agriculture practices) benefit bullfrogs and disadvantage *R. aurora*. A loss of cover also increases opportunities for predation by bullfrogs (Hayes and Jennings 1986) and other predators. Bullfrog tadpoles appear to have a higher survival rate than *R. aurora* tadpoles, and are less vulnerable to predation, especially from introduced fish (Hayes and Jennings 1986). A current study on the introduced bullfrog on lower Vancouver Island and its effects on native species will hopefully indicate whether or not *R. aurora* is threatened by this species.

Rana aurora also could suffer heavy predation from introduced fish species. Native ranids may be more susceptible to predation by exotic fish than by native fish, and bullfrogs appear to have an advantage over native frogs under conditions of predation by fish (Hayes and Jennings 1986). In California, native ranids were rarely found at sites where introduced fish were abundant, while locations with bullfrogs tended to have the fish fauna dominated by introduced fish (Hayes and Jennings 1986).

SPECIAL SIGNIFICANCE OF THE SPECIES

This species occurs in Canada and the United States; it is considered to be "not rare, of long-term concern" throughout its range by The Nature Conservancy in the U.S. and "frequent to common, of restricted distribution, with perceived future threats" throughout its range by the B.C. Conservation Data Centre (Corkran and Thoms 1996). Amphibians as a whole are a significant part of an ecosystem; they act as primary or secondary consumers at different life stages, and are important prey items to many other species (Shirose and Brooks 1997). *Rana aurora* is the only native ranid on Vancouver Island and through its range on the mainland outside the Fraser Valley, where it is sympatric with *R. pretiosa*. In western North America, ranid frogs appear to be undergoing the most severe declines (Drost and Fellers 1996), and should be examined more closely. There is no special public interest in this species, although the survival of amphibians overall has become of more public concern lately. This species is not commercially exploited in any way, either for food or for the pet trade, and is not economically important, although it might be considered a form of insect control. There is no adverse public opinion against this species; frogs actually appear to be popular with the general public.

EVALUATION AND PROPOSED STATUS

The most likely reason for any population decline in B.C. is loss of habitat, especially loss of vegetative cover in and around water, possibly coupled with the introduction of exotic predators. Bullfrogs have not yet spread throughout the entire range of *R. aurora*, so urbanization and forestry activities are probably the cause of most local population extinctions. The loss of local populations could be avoided by more sensitive development practices and the maintenance of wetland and pond habitats within suburban and urban areas. These measures would have to be combined with water quality controls and efforts to reduce pollution and other human impacts. In areas where logging and other forestry activity occur, regulations in the Forest Practices Code controlling impact on water bodies and riparian habitats should be more strictly enforced and extended to frog-supporting non-fish-bearing water bodies (as the current regulations only apply to fish-bearing streams). The loss of habitat to urbanization is probably more important, as it is occurring where most of the historic sites are (or were), and the habitat is lost forever. As this species does not appear to be close to extinction at this time, actions such as these will ensure that it is not severely threatened in the future. A series of intensive monitoring projects, surveying populations at historic sites over several years and searching for *R. aurora* at locations where it has not yet been recorded, will further clarify the status of this species.

The status of *R. aurora* in Canada is **Special Concern** mainly because of the rate of human development leading to decline of habitat throughout its range.

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