
Amphibian Breeding and Climate Change

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Abstract: *Climate changes may be influencing the breeding patterns of certain organisms. Effects on breeding activities could eventually lead to significant changes in population structure that may be reflected in population declines of species that are especially sensitive, such as some amphibians. Thus, climate changes may have affected the timing of breeding in some European amphibian species. To further test whether amphibian reproductive cycles in temperate countries are responding to climate changes, we conducted an analysis of the breeding phenology of four species of North American anurans for which we have long-term data sets. Populations of at least two of these species have been declining, and it has been suggested that they and other amphibians may be especially sensitive to climate change. Our results suggest that climate change has not influenced the timing of breeding in amphibians in North America. At one site, in Oregon, a trend (non-significant) for western toads (*Bufo boreas*) to breed increasingly early was associated with increasing temperature. At four other sites, however, neither western toads nor Cascades frogs (*Rana cascadae*) showed statistically significant positive trends toward earlier breeding. At three of four of these sites, breeding time was associated with warmer temperatures. The spring peeper (*Pseudacris crucifer*) in Michigan did not show a statistically significant trend toward breeding earlier but did show a significant positive relationship between breeding time and temperature. Fowler's toad (*Bufo fowleri*) in eastern Canada did not show a trend toward breeding earlier, and there was no positive relationship between breeding time and temperature. It did however, show a strong but statistically insignificant trend toward breeding later. The broad pattern emerging from available studies is that some temperate-zone anuran populations show a trend toward breeding earlier, whereas others do not. It is important to track the breeding patterns of amphibians with long-term data sets to more fully understand how we can manage threatened populations.*

Reproducción de Anfibios y Cambio Climático

Resumen: *Los cambios climáticos pueden estar influyendo los patrones reproductivos de ciertos organismos. Los efectos sobre actividades reproductivas eventualmente podrían provocar cambios significativos en la estructura poblacional que pueden reflejarse en declinaciones en especies muy sensibles, como algunos anfibios. Así, los cambios climáticos pueden haber afectado el tiempo de reproducción de algunas especies de anfibios europeos. Para probar si los ciclos reproductivos de anfibios en países templados responden a cambios climáticos, realizamos un análisis de la fenología reproductiva de cuatro especies de anuros de Norte América para las que se tiene información de largo plazo. Las poblaciones de por lo menos dos de estas especies han estado declinando y se ha sugerido que estos y otros anfibios son especialmente sensibles al cambio climático. Nuestro resultados sugieren que el cambio climático no ha influido el tiempo de reproducción de anfibios de Norte América. En un sitio, en Oregon, hubo la tendencia (no significativa) en sapos (*Bufo boreas*) de reproducción temprana asociada al incremento de temperatura. Sin embargo, en otros cuatro sitios, ni los sapos ni ranas (*Rana cascadae*) mostraron tendencias positivas estadísticamente significativas hacia la reproducción temprana. En tres de los cuatro sitios el tiempo de reproducción estuvo asociado con tem-*

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peraturas más cálidas. El anuro (*Pseudacris crucifer*) en Michigan no mostró una tendencia estadísticamente significativa de reproducción temprana, pero sí mostró una relación positiva significativa entre el tiempo de reproducción y la temperatura. Los sapos (*Bufo fowleri*) en Canadá oriental no mostraron una tendencia a la reproducción temprana y no hubo relación positiva entre el tiempo de reproducción y la temperatura. Sin embargo, hubo una tendencia fuerte, pero estadísticamente no significativa, a la reproducción tardía. El amplio patrón que emerge de los estudios disponibles es que algunas poblaciones de anuros de zonas templadas muestran una tendencia a la reproducción temprana, mientras otras no. Es importante seguir los patrones reproductivos de anfibios con datos de largo plazo para entender cómo se pueden manejar poblaciones amenazadas.

Introduction

Global climate changes, especially those concerning global warming, have received a great deal of attention because of their potential effects on the distribution and abundance of plants, animals, and microorganisms. For example, global climate changes seem to be influencing the distribution and abundance of butterflies, amphibians, and reptiles, (Parmesan 1996; Pounds et al. 1999). Warming trends may have led to the extinction of some populations (Parmesan 1996; Parmesan et al. 1999; Pounds et al. 1999) and may be influencing the breeding patterns of others (Beebee 1995; Forchhammer et al. 1998; Crick & Sparks 1999; Hoegh-Guldberg 1999). The effects of climate change on breeding activities could eventually lead to profound changes in population structure. This may be reflected in population declines of species, such as amphibians, that are especially sensitive to climate changes because of their behavioral, physiological, and ecological attributes (Blaustein et al. 1994a; Stebbins & Cohen 1995).

Beebee (1995), plotting the start of breeding activities for six amphibian species in southern England over 16 years, concluded that amphibian reproductive cycles in temperate countries are responding to climate change by breeding earlier. Furthermore, he found that the breeding dates of two species of April–June breeding anurans were negatively correlated with average minimum temperatures in March and April and maximum temperatures in March. The spawning date of one early-breeding anuran species whose breeding date did not change from 1978 to 1994 was strongly negatively correlated with overall winter maximum temperatures since 1978. An analysis of the most abundant newt species showed a strong negative correlation between lateness of pond arrival time and average maximum temperature in the month before arrival.

To further test whether amphibian reproductive cycles in temperate countries are responding to climate changes, we conducted an analysis of the breeding phenology of four species of North American anurans for which we have long-term data sets. Populations of at least two of these species have been declining, and it has been suggested that they and other amphibians may be especially sensitive to climate change (Blaustein et al. 1994b).

Methods

We used methods similar to those of Beebee (1995). In Oregon we assessed the breeding phenology of the Cascades frog (*Rana cascadae*) at two sites and of the western toad (*Bufo boreas*) at three sites from 1982 to 1999. Populations of these species have been declining in certain parts of their ranges (Blaustein et al. 1994b; Drost & Fellers 1996). From one site each we also analyzed breeding patterns of the spring peeper (*Pseudacris crucifer*) in Michigan from 1967 to 1994 (excluding 1988) and Fowler's toad (*Bufo fowleri*) from 1980 to 1981 and from 1988 to 1998 in Ontario, Canada. *Bufo fowleri* is considered a threatened species in Canada (Green 1999). *Rana cascadae* and *B. boreas* are explosive breeders that synchronously deposit eggs in conspicuous masses that are easy to detect. We therefore used the presence of egg masses to indicate the first day of breeding for *R. cascadae* and *B. boreas*. We used first date of calling to assess the beginning of the breeding season for *P. crucifer* and *B. fowleri*.

For each species we obtained maximum daily air temperatures for the 3 months before breeding (see Beebee 1995). We averaged the mean maximum temperatures for regression analysis. The particular months of temperature data we selected for analysis depended upon the species, study site, and average dates of breeding for each species. For the species in Oregon (*R. cascadae* and

Table 1. Statistical values of regression analysis for breeding dates per year and breeding dates per temperature for four North American amphibian species.

Species and site	Year		Temperature	
	p	adjusted r ²	p	adjusted r ²
<i>Bufo boreas</i>				
Lost Lake, Oregon	0.35	0	0.39	0
Three Creeks, Oregon	0.72	0	<0.01	0.39
Todd Lake, Oregon	0.95	0	<0.01	0.38
<i>Rana cascadae</i>				
Site One, Oregon	0.67	0	0.64	0
Todd Lake, Oregon	0.75	0	<0.01	0.44
<i>Bufo fowleri</i>				
Long Point, Ontario	0.08	0.19	0.45	0
<i>Pseudacris crucifer</i>				
Germfask, Michigan	0.97	0	<0.01	0.57

B. boreas), we estimated average time of first breeding for each species and obtained temperature data from the Oregon State University weather station in Sisters, Oregon, for March through May. The weather station and all study sites are within 26 km of one another. For *B. fowleri* we obtained temperature data for February through April from a weather station at the breeding site (Long Point, Ontario, Canada). For *P. crucifer*, we obtained temperature data from February through April from Newberry State Hospital (about 37 km from the breeding site at Germfask, Michigan). For all species, estimated dates of first breeding were plotted against mean air temperatures and year.

Results

At one site in Oregon, there was a trend (not statistically significant) for *B. boreas* to breed increasingly early (Table 1; Fig. 1). At four other sites, neither *B. boreas* (two sites) nor *R. cascadae* (two sites) showed significant posi-

tive trends toward earlier breeding (Table 1; Fig. 1). At three of five of these sites (two for *B. boreas*, one for *R. cascadae*) breeding time was associated with warmer temperatures (Table 1; Fig. 1). *Pseudacris crucifer* did not show a statistically significant trend toward breeding earlier but did show a significant negative relationship between breeding time and temperature (Table 1; Fig. 2). *Bufo fowleri* did not show a trend toward breeding earlier, and there was no positive relationship between breeding time and temperature (Table 1; Fig. 2). There was, however, a strong but statistically nonsignificant trend toward breeding later from 1980 to 1998.

Discussion

Similar to Reading's (1998) finding for the common toad (*Bufo bufo*) in England, our data suggest that temperatures (1–2 months immediately before breeding) may be associated with timing of first breeding for some North American

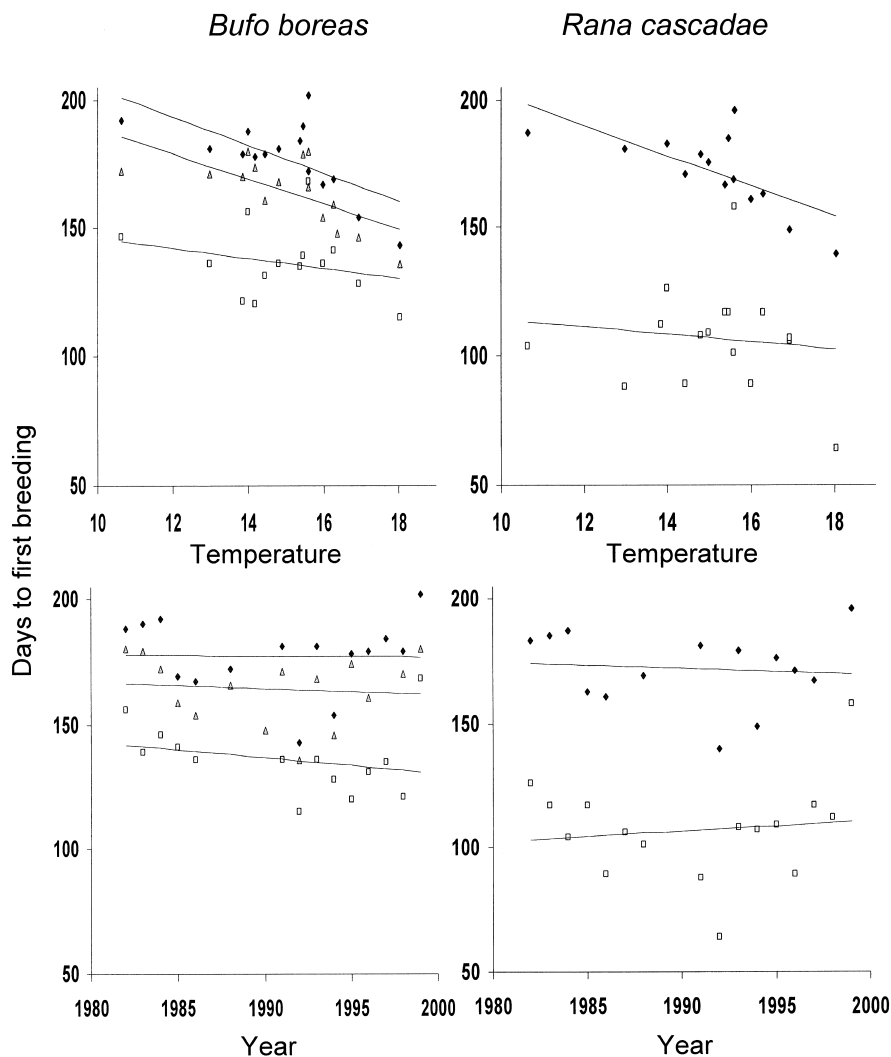


Figure 1. Estimated number of days to first breeding from 1 January as related to temperature and year for *Rana cascadae* (Todd Lake [◆] and Site One [□]) and *Bufo boreas* (Todd Lake [◆], Three Creeks Lake [▲], and Lost Lake [□]) in Oregon.

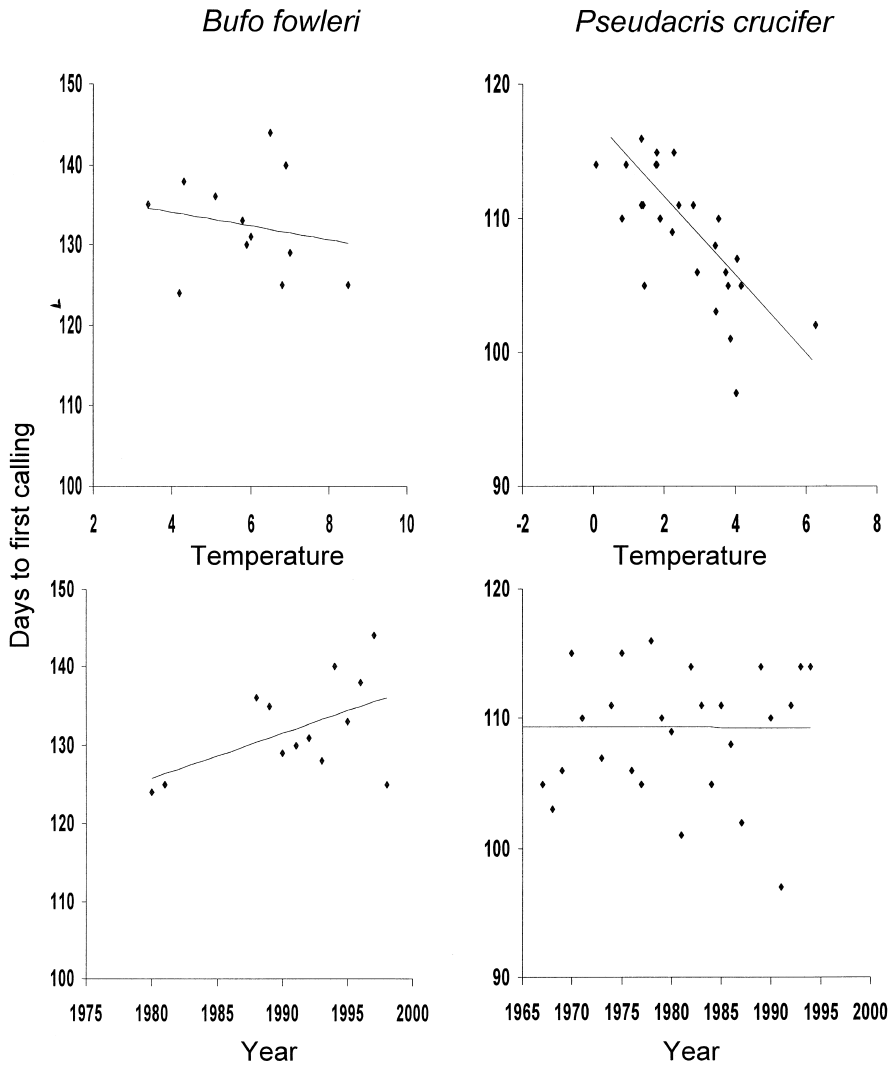


Figure 2. Estimated number of days to first calling for *Bufo fowleri* (Long Point, Ontario, Canada) and *Pseudacris crucifer* (Germfask, Michigan) from 1 January as related to temperature and year.

amphibians. We found, however, some variability in time to first breeding. In Oregon, sites separated by relatively short distances experienced differences in breeding regimes. Contrary to Beebee's findings, only one species at only one site showed a tendency to breed earlier during the past 18 years.

Our study showed that, at six sites, the four species failed to show statistically significant trends toward earlier breeding. In three of four sites in Oregon, toad and frog breeding was associated with warmer temperatures, as was breeding of the spring peeper in Michigan. This was not the case for Fowler's toad in Ontario, which showed a trend toward breeding later and no trend toward breeding during warmer temperature regimes. Thus, in both western and northeastern North America, anuran amphibians failed to show the statistically significant earlier breeding pattern described by Beebee (1995) for amphibians in southern England. There may, however, be some biologically meaningful information relevant to reproductive timing that was not fully accounted for in our statis-

tical tests. For example, western toads at Lost Lake began to lay eggs 12 days earlier in 1999 than they did in 1982. Unexpectedly, Fowler's toads began calling about 10 days later than 19 years ago. If time to first breeding is assumed to be linear, then western toads would be breeding about 0.66 days earlier per year over the years during which we assessed breeding. Similarly, Fowler's toads would be breeding about 0.53 days per year later. Because of the variability among years, however, such rates are difficult to calculate.

Reading's (1998) study of the common toad (*B. bufo*) in England from 1980 to 1998 showed that main arrival to breeding sites was highly correlated with mean daily temperatures over the 40 days immediately preceding main arrival. But a significant trend toward earlier breeding in recent years compared with previous years was not found.

The broad pattern that is emerging from the available studies is that some temperate-zone anuran populations show a trend toward earlier breeding (*Bufo calamita*, *Rana esculenta* [Beebee 1995]; *B. boreas* at one site in this study), whereas others do not (*Rana temporaria*

[Reading 1998]; *B. boreas* at the other Oregon sites, this study; *R. cascadae*, *Pseudacris crucifer*, *B. fowleri*, this study). It is not known why some populations show trends toward earlier breeding and others do not.

Amphibians may be especially sensitive to climatic change because they are ectotherms (Donnelly & Crump 1998). Changes in ambient temperature may influence amphibian behaviors, including those related to reproduction. Potentially, changes in ambient temperature on a global scale could disrupt timing of breeding, periods of hibernation, and ability to find food. Furthermore, global warming could potentially affect amphibians at the population level and could potentially contribute to widely reported population declines (e.g., Blaustein & Wake 1995; Stebbins & Cohen 1995; Ovaska 1997). Because amphibians are key components of many ecosystems (Burton & Likens 1975; Blaustein 1994), changes in amphibian populations could affect other species within their communities, such as their predators and prey, even if these species were unaffected directly by global warming (see discussion by Donnelly & Crump 1998).

Global warming could also have a number of indirect effects on amphibians. For example, one potential consequence of global warming is the increased spread of infectious disease (Cunningham et al. 1996; Epstein 1997). This may occur, for example, if rising temperatures affect the distribution of the vectors of a pathogen, making additional hosts susceptible, or if an environmental agent renders a host's immune system more susceptible. Changes in precipitation, acidification, pollutants, and increased UV radiation are some of the stressors that may affect the immune systems of amphibians. Immune-system damage from multiple stressors could make amphibians more susceptible to pathogens whose ranges may change due to global warming (Blaustein et al. 1994c). Thus, rising temperatures and changes in precipitation could be stressful and might be associated with disease outbreaks in amphibian populations in the tropics (Pounds et al. 1999). Moreover, recent evidence suggests that amphibians compromised by UV radiation are more susceptible to certain pathogens (Kiesecker & Blaustein 1995).

Amphibian populations may be significantly affected by global warming and other climate changes (Green 1997; Donnelly & Crump 1998; Kiesecker et al. 2001). Nevertheless, based on our data for North American species and the report by Reading (1998) on toads in Europe, we believe the suggestion that amphibians in temperate regions are breeding earlier due to climate change may be premature.

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