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Changes in the first spawning dates of common frogs and common toads in western Poland in 1978–2002

Piotr Tryjanowski[1], Mariusz Rybacki[2] & Tim Sparks[3]

[1)] *Department of Avian Biology and Ecology, Adam Mickiewicz University, Fredry 10, PL-61-701 Poznań, Poland (e-mail: ptasiek@amu.edu.pl)*
[2)] *Research Centre for Agricultural and Forest Environment, PAS, Bukowska 19, PL-60-809 Poznań, Poland*
[3)] *NERC Centre for Ecology and Hydrology, Monks Wood, Abbots Ripton, Huntingdon, Cambridgeshire PE28 2LS, UK*

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We analysed longitudinal data of observations of the first spawning dates of two anuran species (*Rana temporaria* and *Bufo bufo*) from western Poland (1978–2002). For both species, a trend towards earlier breeding was found, corresponding to an eight to nine day shift over the 25-year period. These shifts appear to be associated with increased temperatures in the winter and early spring in our study area.

Introduction

One major requirement to identify changes in phenology of organisms is access to good long-term data. Biological data sets sufficient to identify phenological shifts include observations of birds, of insects, and of vegetation. Mason (1977, 1995), and Lundberg and Edholm (1982) suggested that in the 1970s some bird species arrived later in breeding areas than in earlier years. More recent work has suggested a shift towards earlier arrival (e.g. Sokolov *et al*. 1998, Sparks *et al*. 1999, Tryjanowski *et al*. 2002) and breeding (Crick & Sparks 1999, Koike & Higuchi 2002) dates. Profound changes towards earlier activity have been detected in a range of insect species, including moths and butterflies (Ellis *et al*. 1997, Roy & Sparks 2000). Furthermore, advances in leafing and flowering have been reported from across Europe and North America (e.g. Menzel & Fabian 1999, Abu-Asab *et al*. 2001, Fitter & Fitter 2002).

In many countries initiation of amphibian breeding activity is seen as a traditional indication of spring. Because amphibians are sedentary poikilothermic animals and because they are sensitive to changes in local ambient temperature, subtle changes in climate may be reflected in changes in timing and duration of their hibernation and breeding activity. However, data on changes in amphibian phenology are relatively scarce, in comparison with data on bird migration and plant phenology (*see* reviews in Walther *et al*. 2002, Parmesan & Yohe 2003). To date, appropriate data are only available from the British Isles, Finland and some places in North America. In Britain, Beebee (1995) showed that spawning in two anurans and three urodeles occurred earlier towards the end of the 17-year (1978–1994) study period, and that these changes were correlated with changes in spring temperatures. A long-term study in Finland demonstrated the relationship between spawn dates and temperature and a trend towards earlier spawning in a period of climate warming (Terhivuo 1988). In Ithaca, New York, Gibbs and Breisch (2001) found that the calling of four out of six frog species advanced 10–13 days during the 20th century.

However, data from mainland Europe are still lacking. Based on experience from other organisms, we anticipate differential changes by amphibians in different geographical areas within Europe. We suspect this because amphibians are highly sensitive to ambient temperature, and local temperature patterns and even large scale phenomena (e.g. North Atlantic Oscillation, Ottersen *et al*. 2001) have not changed uniformly across Europe. Even for bird migration patterns, i.e. for species affected by large scale weather phenomena, differences in advanced arrival were apparent between Britain and Central Europe (Tryjanowski *et al*. 2002, Hüppop & Hüppop 2003).

In this paper, we report the spawning times of two early breeding amphibian species (common frog *Rana temporaria* and common toad *Bufo bufo*) in the Wielkopolska region of western Poland during the years 1978–2002. To examine how local climate changes affect endemic fauna, we must study animals like these that complete their entire life cycles in that area. In contrast, migrant birds, for example, may be influenced by environmental conditions over a very large area. The main aim of this paper is to describe the changes in spawning times during the 25-year period and identify possible relationships between spawning dates and ambient temperatures and precipitation.

Methods

Study area and data sources

Observations on the first spawning dates of common frog and common toad in 1978–2002 were recorded within a 5-km radius of the village of Turew in the General Dezydery Chłapowski Landscape Park, Wielkopolska region, western Poland (52°04´N, 16°48´E). This is a typical farmland region, where arable fields occupy nearly 70% of the area. The climate of the region is typical for central Europe where two climate types, oceanic and continental, meet. The mean annual temperature is ca. 8 °C (sub-zero mean monthly temperatures occur in December–February) with mean annual precipitation ca. 550 mm (Ryszkowski *et al*. 1996).

The two study species are the most common and most numerous amphibian species both in the study area (ponds often contain hundreds of individuals), and in western Poland in general (Rybacki & Berger 1997).

From mid-February onwards, 50–100 possible breeding sites of anurans (small ponds, canals, puddles, ditches etc.) were searched 1–2 times per week. The number of searched sites varied across time because not all contained water each year. If amphibian spawn was detected, we noted the developmental stage of the eggs (Berger 1967, Kowalewski 1974) and based on the stage, back-calculated the date of spawning.

Monthly air temperature and precipitation data for the period 1978–2002 were obtained from the Turew meteorological station, located in the centre of the study area.

Statistical analysis

Trends over time were determined by linear regression of response variables against year, and relationships with temperature by correlation and regression analyses, respectively. Neither of the spawn records differed significantly from a Normal distribution. Regression coefficients are presented as means ± SE and all tests are two-tailed.

Results

Trends in first spawning dates

Information on first spawning dates is given in Table 1. When subjected to ANOVA (factors species and year), the data suggested that years with missing dates did not greatly distort mean first spawning dates as the least square means did not differ by more than one day from the simple means given in Table 1. Mean first spawning date of common frog was significantly earlier (paired *t*-test, $t_{16} = -7.90$, $p < 0.001$) than that for common toads.

Regressions against year (Table 2) suggest that common toad ($F_{1,16} = 6.93$, $p = 0.018$) first spawning has advanced by nine days over the 25 year period (Fig. 1). The equivalent test for common frog just fails to achieve the 5% significance level ($F_{1,17} = 3.85$, $p = 0.066$) but would estimate an eight day advance (Fig. 1). The year 2002 was the earliest first spawn year for both species. First spawn dates of the two species were significantly positively correlated ($r = 0.66$, $p < 0.01$). Of the meteorological variables examined, there had been a significant reduction of December rainfall of 35 mm and a significant increase in February temperature of 5 °C, over the period (Table 2).

The influence of temperature and precipitation

Precipitation does not appear to be associated with first spawn dates (Table 2). However, first spawn dates are correlated with temperature; for common frog significant correlations exist for several months, whilst common toad first spawn dates were significantly correlated with March temperature only. Regression of common frog first spawn dates on mean January–March temperatures suggested a response of 1.46 ± 0.38 days earlier for every 1 °C increase in mean ambient temperature ($F_{1,17} = 14.34$, $R^2 = 45.8\%$, $p < 0.001$). Regressing common toad first spawn date on March mean temperature suggested a response of 1.17 ± 0.49 days earlier for every 1 °C warmer ($F_{1,16} = 5.70$, $R^2 = 26.3\%$, $p < 0.05$). However there was some suggestion that the common toad model could be improved by including precipitation, for example in January; in this model the coefficient for precipitation was positive (higher precipitation delaying spawning) and almost significant ($p = 0.056$). To investigate this aspect further, we checked if the first spawning dates of common frog and common toad could have been modified

Table 1. Information on first spawning dates of the common frog and the common toad in Turew, Poland 1978–2002. *n* = number of years, SD = standard deviation.

Species	*n*	Mean	SD	Median	Earliest	Latest
Common frog	19	31 March	5.6	1 April	17 March	8 April
Common toad	18	9 April	4.8	10 April	30 March	17 April

Table 2. Trends (per annum changes) in first spawning dates, precipitation and temperature at Turew, 1978–2002. Results were determined by regression of spawning dates and meteorological variables against year and correlations between first spawning dates and meteorological variables.

	Regression			Correlation with			
	Coefficient	SE	*p*	Common frog	*p*	Common toad	*p*
Common frog	–0.32	0.16	0.066				
Common toad	–0.35	0.13	0.018				
Precipitation							
December	–1.39	0.63	0.038	0.15	0.553	0.36	0.143
January	–1.05	0.61	0.097	–0.06	0.820	0.33	0.182
February	0.34	0.34	0.332	–0.08	0.736	0.21	0.404
March	–0.58	0.75	0.446	0.22	0.376	–0.06	0.802
Temperature							
December	0.000	0.058	0.999	–0.43	0.068	–0.07	0.796
January	0.125	0.096	0.203	–0.64	0.003	–0.34	0.166
February	0.202	0.090	0.035	–0.52	0.023	–0.34	0.164
March	–0.010	0.056	0.856	–0.48	0.036	–0.51	0.030

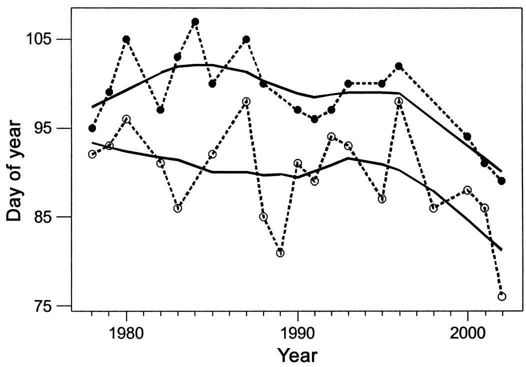

Fig. 1. Changes in the first spawn dates of common frog (open circles) and common toad (solid circles) shown as days after 31 December (e.g. day 95 = 5 April). Distance weighted smoothed (LOWESS) lines have been superimposed to indicate the underlying trend.

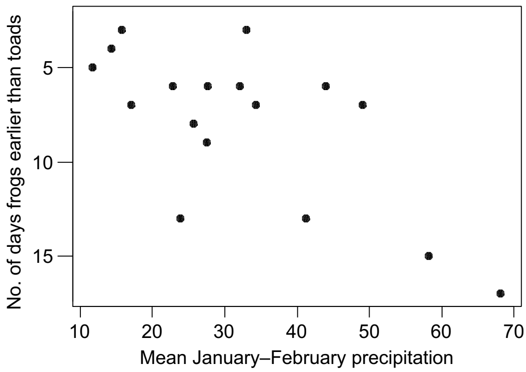

Fig. 2. The relationship between winter precipitation (mm) and the spawn date advantage of common frogs over common toads (r = –0.69, p < 0.01).

by precipitation. Increased winter precipitation increased the time advantage of common frog first spawning over that of common toads (r = –0.69, p < 0.01; Fig. 2).

Discussion

This study revealed an advance in first spawn dates of both common frogs and common toads, both of which seem to be driven, at least partly, by temperature. However, both the advance in spawning and the response to temperature are modest relative to other studies (*see* Parmesan & Yohe 2003 for a review). If phenological activity is controlled by day length and temperature, does this suggest that the relative contribution of temperature to spawning is less in continental Europe than in the margin of the continent? Beebee (1995) showed that, over a 17-year period (1978–1994) in S. England, earlier activity and correlations with spring temperatures occurred for five species, but no such trend was found for common frog. However, such a trend in common frog was detected in Finland by Terhivuo (1988). Reading (1998) reported no significant trend towards earliness for *Bufo bufo* in 1980–1998 but suggested that the temperature during the 40 days prior to spawning was critical, with earlier spawning following warmer weather. The results of Cooke (1977) suggest that timing of common frog spawning is more variable than that of common toads, and that, in early springs, common frogs breed much earlier than common toads. Gibbs and Breisch (2001) reported an advancement of calling in frog species in eastern U.S.A. Temperature increases may also advance the appearance of the prey items of amphibians (e.g. amphibians, earthworms, flies, beetles; Kminiak 1987).

Interspecific competition between common frogs and common toads may occur at the tadpole stage as well as via indiscriminate pairing of mixed species. The balance between the species may be disrupted by climate change if temperature and precipitation differentially affect the migration, spawning and duration of larval development of either species.

Potential effect of population size

It must be remembered that we are dealing with first spawning dates, which may, or may not, imply a shift in the whole breeding time distribution. For some bird species population size has been shown to influence first dates (e.g. Tryjanowski & Sparks 2001) through increased probability of early observation when the population size is greater and vice versa. We are thus cautious in interpreting these results but the large size of these amphibian populations suggests that this will not be a major issue in this instance, and the results are in contrast to those expected in declining populations. Indeed, declining populations of common toad, as reported by Carrier and Beebee (2003), may partially mask changes in phenology.

Mechanism

Natural selection should favour rapid changes in spawning date, because early breeding is considered advantageous allowing longer development time for juveniles, and more time to accumulate energy reserves before hibernation (*see* also Morbey & Ydenberg 2001). Moreover, earlier arrival at breeding ponds will allow males to maximise mating opportunities, especially if female arrival time is unpredictable (Semlitsch *et al*. 1993).

In this paper, we have shown a strong relationship between temperature (particularly that in March) and spawning dates for both common frogs and common toads, and a suggestion that both species have advanced their spawning in recent years. Common frog spawning appears to be correlated with temperature over a longer period than that of common toads, and this may explain the greater variability in common frog spawning dates as compared with those of the common toad. Other studies have reported temperature response in migration timing (e.g. Cooke 2000), calling (e.g. Sparks & Carey 1995), spawning date (e.g. Reading 1998) and larval development rates (e.g. Reading & Clarke 1999). Climate change is likely to affect many aspects of the life cycles of these amphibians and in effect the resulting potential conflicts between them need to be investigated.

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