When Do Peepers Peep? Climate and the Date of First Calling in the Spring Peeper (*Pseudacris crucifer)* in Southeastern New York State

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Abstract - The date of first calling (DFC) of *Pseudacris crucifer* (Spring Peeper) was recorded over 15 years between 1997 and 2012 in a small vernal pond in southeastern New York State. There was no statistically significant trend in temperature or in the DFC over this period. To determine what temperature cues best predicted DFC, 20 potential temperature indices (daily mean, minimum and maximum temperatures averaged over several different time periods, and thermal sums using several different base temperatures) and five precipitation indices (precipitation on the DFC and for four time windows prior to the DFC) were calculated, and predicted DFCs were compared to observed DFCs. The thermal sum with a base of 3 °C (TS3) was the best predictor but overestimated DFC slightly at high values of DFC. In evaluating impacts of climate change on the calling of this frog, the TS3 index may provide a more accurate metric than the daily temperature statistics that have been used in previous studies. In a 63-year record from a nearby weather station, the TS3 index declined significantly, suggesting that Spring Peepers may be calling earlier now than they were in the mid-20th century.

Introduction

It is important to understand the climatic cues for amphibian breeding behavior to improve the knowledge of the basic natural history of the animals and also to provide better predictions of how climate change will affect amphibian behavior and survival. Climate change is likely to affect many different environmental cues that could influence the timing of reproduction, including temperature, rainfall, drought frequency, and snowpack (Beebe 1995, 2002; Blaustein et al. 2001; Rodenhouse et al. 2009).

Pseudacris crucifer (Wied-Neuweid) (Spring Peeper) is a common frog that breeds in the early spring in semi-permanent pools throughout eastern North America. The adults overwinter in crevices, logs, and leaf litter in terrestrial habitats, and they move to ponds to mate in early spring. Males situated on vegetation overhanging water produce a loud "peep" call, repeated typically 15–25 times per minute, to attract mates (Gibbs et al. 2007). The call of the Spring Peeper is a familiar sound throughout its range, and as it typically begins in March or early April, is often considered one of the first harbingers of spring. Though only weighing a few grams, the Spring Peeper can produce a call as loud as songbirds that weigh 10–100 times as much (Wells and Schwartz 2006). With hundreds of individuals calling simultaneously in a small pond, the resulting chorus is a loud and unmistakable din.

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In some areas, the initiation of calling by Spring Peepers is occurring earlier in the spring, presumably in response to climate warming. In Ithaca, NY, Gibbs and Breisch (2001) found that the mean date of first calling (DFC) by the Spring Peeper was approximately 13 days earlier in 1990–1999 than in 1900–1912. A warming of daily maximum temperatures occurred over the same period. In Michigan, Spring Peepers showed no significant change in DFC between 1967 and 1994, but there was a relationship between DFC and daily maximum air temperature from February through April (Blaustein et al. 2001). Both studies assumed that daily maximum temperature was the appropriate temperature cue for the calling behavior, but did not test other temperature indices. In general, the climatic cues for the initiation of calling have not been well studied.

Todd et al. (2011) studied the arrival date of Spring Peepers at a pond in South Carolina from 1979–2003 and found no significant relationship between the mean arrival date and average minimum daily temperatures either for the breeding season or for the 90-day period prior to the breeding season. Likewise, there was no significant relationship between arrival date and precipitation amount for either period. However, a congeneric species, *Pseudacris ornata* (Holbrook) (Ornate Chorus Frog), did show a significant relationship between arrival date and precipitation in the pre-breeding season and daily minimum temperature during the breeding season (Todd et al. 2011). Both relationships were negative, indicating that greater precipitation and higher temperature were associated with earlier arrival dates for *P. ornata*.

I used a record of DFC by Spring Peepers collected over a 16-year period (1997–2012) at a site in southeastern New York to determine whether there is a trend in the DFC over this period, and what temperature and precipitation cues are most closely associated with the onset of calling in the spring.

Methods

I recorded the DFC of the Spring Peeper in a vernal pond about 50 m from my residence in a rural area near Clinton Corners, NY (41°51.01'N, 73°44.90'W). The roughly 0.1-ha pond is at an elevation of 95 m and is bordered by deciduous woods, shrubs, and meadows. The pond contains water most winters and springs, and it typically dries out in the summer and refills after leaf fall in the autumn. Once peepers begin to call on a particular date, they call continuously throughout the evening and into the night. The DFC was determined by listening for the calling of peepers for at least 10 minutes every evening during March and April in all weather conditions. The Spring Peeper data record began in 1997 and is ongoing; the data in this paper cover the period from 1997–2012. Data were not collected in 2007; thus, there were 15 years of DFC records across the 16-year period. I obtained air temperature and precipitation data for the 1997–2012 period from the weather station of the Cary Institute of Ecosystem Studies (http://www.caryinstitute.org/emp_data.html), 7.2 km from the pond. Over the period of record at this station (1988–2011), the mean annual temperature was 9.7 °C and the mean annual precipitation was 1150 mm. I also examined the longer-term temperature data for this area using data from the National Weather Service station in Poughkeepsie, NY (Dutchess County Airport), which is 27.5 km from the pond and has continuous data starting in 1949.

Data were analyzed in the SAS statistical package (SAS, Inc. 2004) using univariate analyses and linear regression (Proc REG). To determine which weather cues best predicted the calling date, I first identified a suite of temperature and precipitation indices that could potentially serve as cues (Table 1). These included the mean, maximum, and minimum temperatures and precipitation amount for five time periods: the day of first calling itself, averages over periods of 5, 10, and 20 days prior to the DFC, and the average over the window from Julian day 32 (1 February) to the DFC. I also calculated five thermal sum (degree day) variables, using a base temperature of 0, 3, 5, 7, or 10 °C, and summing from Julian day 32 to the DFC every year. Thermal sums are calculated by taking the difference between the base temperature and the mean daily temperature for each day, and then summing these differences across all the days in a specified period, in this case from February 1 to the DFC. Altogether there were 15 temperature averages, 5 thermal sums, and 5 precipitation sums for a total of 25 indices (Table 1). I first calculated the mean value of each index across the 15 years of data (Table 1). I then stepped through the daily temperature data for each year until the mean value of the index was reached. For example, the mean value of thermal sum with a 0 °C base (TS0) at the DFC was 102.7 degree-days. Using the daily temperature data for each year, I calculated the day of the year where the TS0 first exceeded 102.7, and that day was the predicted DFC in that year for that index. I repeated this procedure for all indices in all years. I then used a stepwise linear regression to determine which of the 25 indices provided the best prediction of the observed DFC data across years, and I performed linear regressions on predicted vs. observed DFC for all 25 variables individually. With only 15 years of data, I limited the analysis to single-variable regressions. Because of the large numbers of regressions in this procedure, I considered significance to be at the $P < 0.01$ level to avoid assigning statistical significance to relationships which may be due to chance. For the long-term weather record from Poughkeepsie, only one regression was performed, therefore significance was taken to be at the $P < 0.05$ level.

This procedure of comparing predicted to observed DFC values for potential indices is preferable to a simple regression of DFC vs. temperature variables. For example, Blaustein et al. (2001) regressed DFC against the mean daily maximum air temperature for the period February–April, but that approach requires arbitrarily setting a fixed time window over which to calculate the index. That window may include irrelevant data if, for instance, the DFC is in March but the temperatures in April are included, or it may exclude relevant data if the window ends before the DFC.

Results

Over the 15 years of record, the DFC varied over almost a month from 9 March to 4 April. The mean DFC was Julian day 81, which equates to 22 March

Table 1. Temperature and precipitation indices evaluated for prediction of DFC of Spring Peepers. Thermal sum (TS) variables are in degree-days (see Methods for description of calculation), temperature averages are in °C, and precipitation is in mm. Adjusted R^2 and P values are shown for regressions of actual DFC vs. predicted DFC, using each variable as a predictor in a simple linear regression.

					Regressions w/2002		Regressions w/o 2002	
Index	Average or sum	Variable	Period	15-y mean value	Adj. R^2	P	Adj. R^2	P
TS0	Sum	Degree days, 0 °C base	Feb 1 - DFC	102.7	0.349	0.0199	0.795	<0.0001
TS3	Sum	Degree days, 3 °C base	Feb 1 - DFC	44.3	0.513	0.0016	0.932	<0.0001
TS5	Sum	Degree days, 5 °C base	Feb 1 - DFC	23.0	0.222	0.0434	0.416	0.0076
TS7	Sum	Degree days, 7 °C base	Feb 1 - DFC	10.7	0.084	0.1552	0.274	0.0318
TS10	Sum	Degree days, 10 °C base	Feb 1 - DFC	2.9	0.125	0.1072	0.261	0.0359
DFCave	Average	Mean daily temp	1d on DFC	8.6	0.261	0.0298	0.366	0.0130
DFCmin	Average	Min daily temp	1d on DFC	0.7	0.137	0.0961	0.127	0.1151
DFCmax	Average	Max daily temp	1d on DFC	16.5	0.235	0.0386	0.429	0.0066
5dayave	Average	Mean daily temp	5d prior to DFC	5.0	0.204	0.019	0.256	0.0374
5daymin	Average	Min daily temp	5d prior to DFC	-1.7	0.146	0.0884	0.166	0.0826
5daymax	Average	Max daily temp	5d prior to DFC	11.8	0.077	0.1642	0.065	0.1934
10dayave	Average	Mean daily temp	10d prior to DFC	3.9	0.106	0.1267	0.271	0.0325
10daymin	Average	Min daily temp	10d prior to DFC	-2.6	0.252	0.0325	0.230	0.0474
10daymax	Average	Max daily temp	10d prior to DFC	10.4	0.084	0.1540	0.261	0.0357
20dayave	Average	Mean daily temp	20d prior to DFC	2.1	0.064	0.1856	0.192	0.0662
20daymin	Average	Min daily temp	20d prior to DFC	-4.0	0.098	0.1362	0.164	0.0838
20daymax	Average	Max daily temp	20d prior to DFC	8.2	0.030	0.2521	0.224	0.0499
Mndailyave	Average	Mean daily temp	Feb 1 - DFC	0.1	0.026	0.2634	-0.003	0.3456
Mndailymin	Average	Min daily temp	Feb 1 - DFC	-5.9	-0.017	0.3969	-0.047	0.5278
Mndailymax	Average	Max daily temp	Feb 1 - DFC	6.1	-0.017	0.3963	-0.029	0.4402
DFCprecip	Sum	Precip. amount	1d on DFC	1.1	-0.014	0.3845	-0.076	0.7044
5dayprecip	Sum	Precip. amount	5d prior to DFC	16.3	-0.053	0.5956	0.095	0.1605
10dayprecip	Sum	Precip. amount	10d prior to DFC	28.7	-0.076	0.9256	-0.059	0.5739
20dayprecip	Sum	Precip. amount	20d prior to DFC	58.1	-0.076	0.7018	-0.080	0.7465
Totalprecip	Sum	Precip. amount	Feb 1 - DFC	141.8	-0.057	0.5957	-0.004	0.3491

(or 21 March in leap years). The regression of DFC on year had a negative slope (-0.6 days year $^{-1}$) but was not statistically significant ($P = 0.15$), indicating that there was no significant trend in calling date over this period (Fig. 1). There was also no significant trend in February–March daily mean temperature, minimum temperature, or maximum temperature for the period 1997–2012 (data not shown).

In the 15-year data set, the thermal sum with a 3 °C base (TS3), which had a mean value of 44.3 degree-days, was the best predictor, explaining 51% of the variance in observed DFC in this data set (Table 1). No other variable had a regression with $P < 0.01$, although several other temperature variables had regressions with $P < 0.05$ (Table 1). TS3 was also the first variable entered when all 25 climate variables were used together in a stepwise linear regression. Precipitation variables explained very little of the variance in observed DFC, and the adjusted R^2 values were negative (Table 1).

The year 2002 was clearly an unusual case (Fig. 2) and represents an interesting illustration of how precipitation may influence DFC. The winter of 2001–2002 was quite dry, and there was no water in the pond in the early spring. The spring of 2002 was warm, and the TS3 index variable predicts that the peepers should have begun calling on 8 March of that year, which would have been the earliest date in the record. However, because there was no water in the pond, there was no peeper calling on that date. A significant rainstorm finally occurred and the

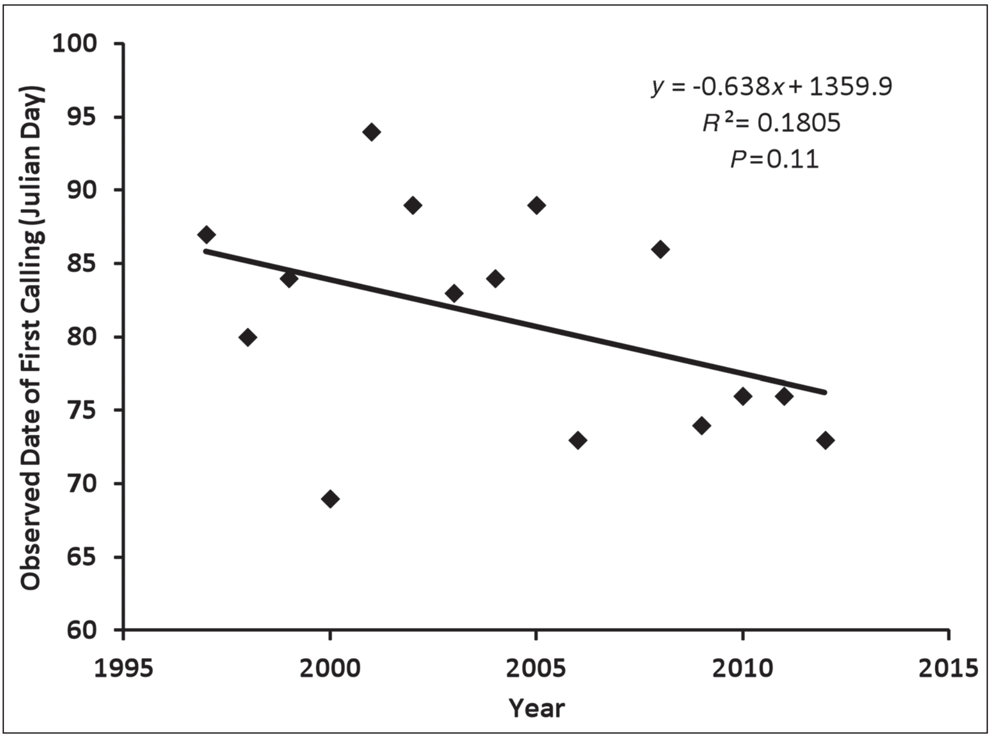

Figure 1. Observed dates of first calling by Spring Peepers from 1997–2012. The data show a downward trend, but the regression slope is not statistically significant.

pond began to fill on 28 March, and there was a full chorus of Spring Peepers by 30 March. When the regressions were run excluding 2002, TS3 became a much better predictor of DFC, explaining 93% of the variance (Table 1, Fig. 2). Other temperature indices also yielded highly significant regressions, including TS0 and TS5 and the maximum temperature on the DFC; however, TS3 explained 14% more of the variation than the next best variable (TS0; Table 1). There was a slight bias relative to a 1:1 prediction, such that for years when the DFC was later, the observed DFC was somewhat less than the predicted values (Fig. 2).

Discussion

The TS3 index is a very good predictor of DFC of *P. crucifer* at this location, explaining 51% of the variance when all years were considered and 93% of the variance when one year in which the pond was dry (2002) was excluded from the data set. In evaluating impacts of climate change on the calling of this frog, the TS3 index may provide a more accurate metric than the daily temperature statistics that have been used by others (Blaustein et al. 2001, Gibbs and Breisch 2001, Todd et al. 2011). The slight bias in which the DFC is earlier than predicted when the DFC is late in the season may indicate that other cues (e.g., photoperiod or another temperature variable) come into play in years when cooler temperatures delay the DFC.

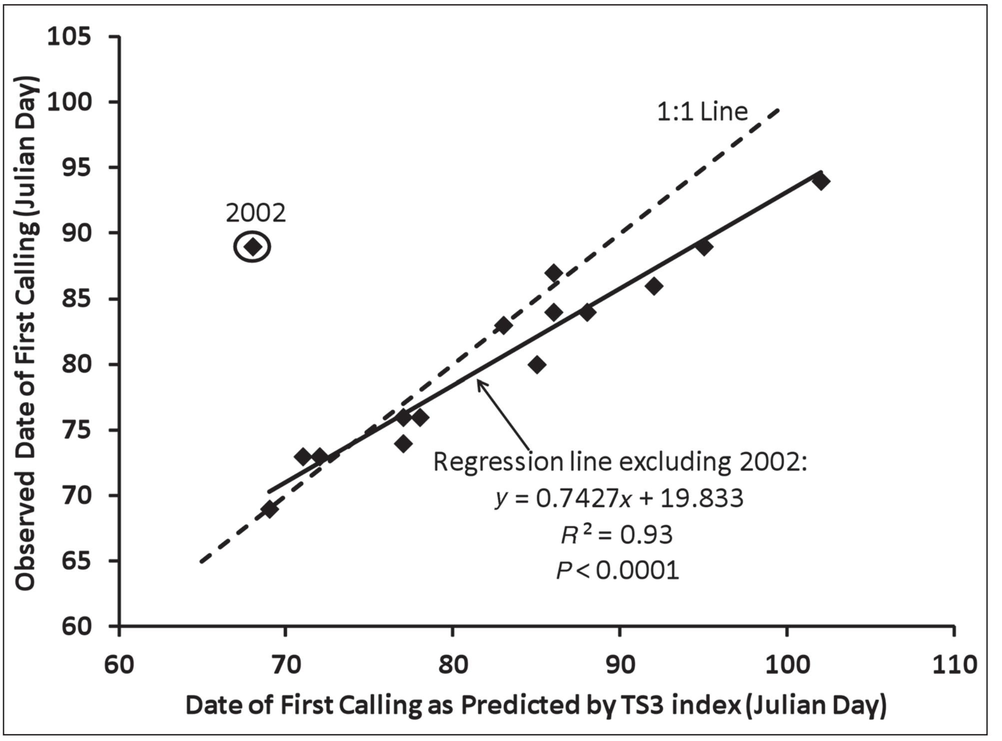

Figure 2. Observed date of first calling (DFC) plotted against the DFC predicted by the TS3 index (thermal sum with 3 °C base). The circled point is for 2002, when the pond was initially dry. The solid line is the regression line (excluding 2002) and the dashed line is the 1:1 line.

The comparison of analyses including and excluding 2002 suggests that the hydrology of the system acts as a binary control on the calling system, i.e., if there is water in the pond, then TS3 is an excellent predictor of DFC, but if there is no water in the pond, then calling will not occur. Predictions of future climate for this region call for increased winter temperatures, increased rainfall in winter, and smaller snowpack (Hayhoe et al. 2008). This combination of variables makes the impact of climate change on peeper calling difficult to predict. Increased temperatures should advance the DFC earlier in the season, and increased winter precipitation may increase the likelihood of there being water in the pond. However, the water in the pond in March often results from a melting snowpack, so that the pond usually contains some water in the spring, even during relatively dry seasons. If the water storage in the snowpack declines in the future, the filling of the pond may become more sensitive to the vagaries of precipitation in any given year.

As noted above, the 15-year data set shows no significant trend in DFC or temperature because there is much year-to-year variation and the record is short. However, the longer temperature data record (63 years, 1949–2011) available from the nearby National Weather Service station in Poughkeepsie can be used to look for longer-term trends in the TS3 index. Simple regression of predicted DFC (based on the date when TS3 > 44.3 degree-days) vs. year for the Poughkeepsie data shows a significant downward trend (P = 0.046) with a slope of -0.18 days year $^{-1}$ (Fig. 3). There is much scatter in the data, as would be expected given

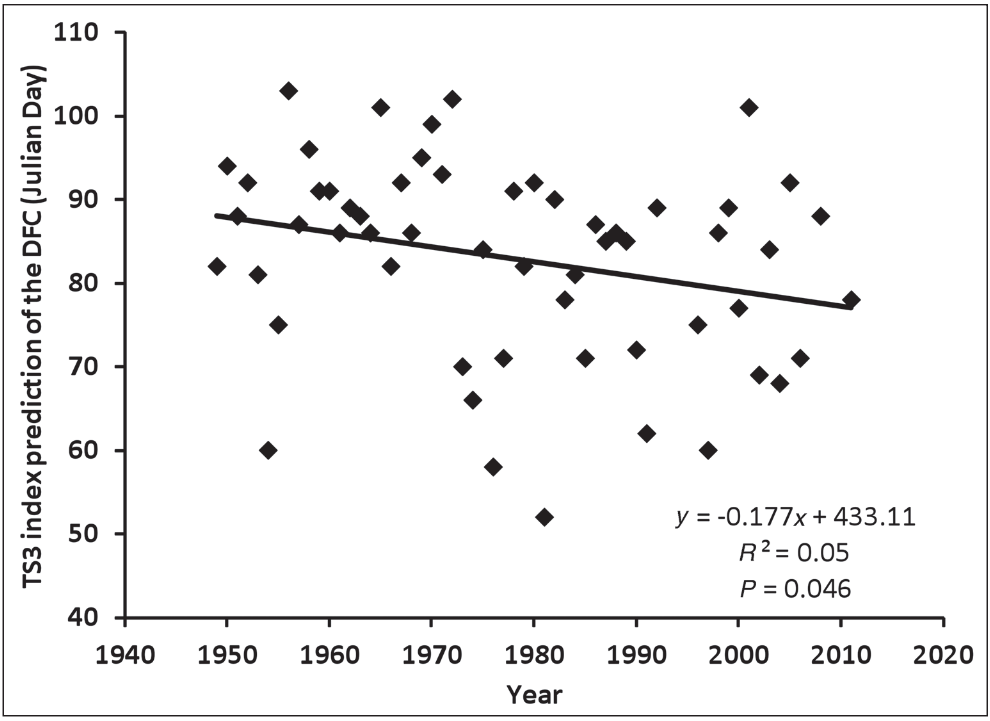

Figure 3. Trend in the TS3 index prediction of date of first calling, using the temperature records of the Poughkeepsie weather station.

year-to-year variation in weather. However, if we assume that TS3 is a good predictor throughout this 63-year period, these data suggest that the Spring Peepers are currently calling approximately 11 days earlier than they were in 1949. This finding is roughly consistent with the 13.6-day advancement of DFC over the 20th century reported by Gibbs and Breisch (2001) for ponds near Ithaca, NY.

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Literature Cited

Beebee, T.J.C. 1995. Amphibian breeding and climate. Nature 374:219–220.

Beebee, T.J.C. 2002. Amphibian phenology and climate change. Conservation Biology 16:1454–1454.

Blaustein, A.R., L.K. Belden, D.H. Olson, D.M. Green, T.L. Root, and J.M. Kiesecker. 2001. Amphibian breeding and climate change. Conservation Biology 15:1804–1809.

Blaustein, A.R., T.L. Root, J.M. Kiesecker, L.K. Belden, D.H. Olson, and D.M. Green. 2002. Amphibian phenology and climate change. Conservation Biology 16:1454–1455.

Gibbs, J.P., and A.R. Breisch. 2001. Climate warming and calling phenology of frogs near Ithaca, New York, 1900–1999. Conservation Biology 15:1175–1178.

Gibbs, J.P., A.R. Breisch, P.K. Ducey, G. Johnson, J.L. Behler, and R.C. Bothner. 2007. The Amphibians and Reptiles of New York State. Oxford University Press, New York, NY.

Hayhoe, K., C. Wake, B. Anderson, X.Z. Liang, E. Maurer, J.H. Zhu, J. Bradbury, A. DeGaetano, A.M. Stoner, and D. Wuebbles. 2008. Regional climate change projections for the Northeast USA. Mitigation and Adaptation Strategies for Global Change 13:425–436.

Rodenhouse, N.L., L.M. Christenson, D. Parry, and L.E. Green. 2009. Climate change effects on native fauna of northeastern forests. Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere 39:249–263.

SAS Institute. 2004. SAS/STAT 9.1 User's Guide. Cary, NC. 5180 pp.

Todd, B.D., D.E. Scott, J.H.K. Pechmann, and J.W. Gibbons. 2011. Climate change correlates with rapid delays and advancements in reproductive timing in an amphibian community. Proceedings of the Royal Society B-Biological Sciences 278:2191–2197.

Wells, K., and J. Schwartz. 2006. The behavioral ecology of anuran communication. Pp. 44–86, *In* P.M. Narins, A.S. Feng, R.R. Fay, and A.N. Popper (Eds.). Hearing and Sound Communication in Amphibians. Springer, New York, NY.