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TEN YEARS OF THE SOUTHWEST FLORIDA FROG MONITORING NETWORK: NATURAL VARIATION AND HUMAN-DRIVEN CHANGES

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Abstract: *The Southwest Florida Frog Monitoring Network was established in 2000 to collect long-term data on frog communities of the region. Routes of 10-12 stops were monitored monthly during the rainy season (June–September). Data on all frog calls during a three minute period were recorded using a three-level intensity code. We report results from the first ten years of monitoring to examine broad trends in the frog populations of southwest Florida. We explored the abundance of all frog species, as reflected by calling intensity, to elucidate potential factors that may influence long-term changes in frog populations and communities. These factors may include: natural variations of frog populations, disappearing and altered habitats through local and global human actions, landscape context, and the impacts of invasive species. At a regional scale, it appears that most frog species are maintaining natural variations in calling levels among years, suggesting that frogs are responding to annual variation and not regional or global changes. Use of behavioral indicators, such as calling intensity of frogs, may provide understanding of the environmental implications of altered hydroperiods and other landscape perturbations in our watershed and possibly some positive responses to restoration efforts.*

Key Words: Amphibians, frog calling, frog communities, citizen science, declining amphibian populations, behavioral conservation

Amphibians have been an indicator of environmental changes beginning with the realization of declining amphibian populations in the 1980s (Collins and Storfer, 2003; Beebee and Griffiths, 2005; McCallum, 2007; Lips et al., 2008). Causes of global decreases are multifactorial and include habitat loss, human exploitation, land use change, global climate change, environmental contaminants, the introduction of non-native species, and emerging infectious diseases as well as interactions among these factors (Collins et al., 2003; Lannoo, 2005; McMenamin et al., 2008). Discovery of this global decline in amphibian populations resulted in the development of long-term monitoring initiatives to document the fate of species and communities (Dodd et al., 2007).

To ensure that as many amphibians were tracked as possible, volunteer networks were established around the country to monitor different locations, using similar protocols that would enable temporal and spatial comparisons (NAAMP, 2011; DAPTF, 2011; Frog Watch, 2011). Many of these volunteer monitoring programs have collected data on frog calls as an indicator of population trends. Frog calls are a particularly valuable gauge of population and community dynamics because the behavior is associated with reproduction. As a consequence, the presence of frog calls in an area illustrates individuals of sufficient quality to engage in reproductive displays.

Southwest Florida has experienced dramatic environmental changes over the past decades that could be expected to affect local amphibian populations. Explosive growth and development have led to habitat destruction, altered hydrology, and declining water quality, all of which might affect amphibians adversely. In addition, estimates of land use change predict an increase in urbanization by 62% between 2000 and 2025. This is expected to be accompanied by a 26.5% decrease in rangeland/upland forest and an 11.5% reduction in wetlands (SFWMD, 2008). Many of southwest Florida's waters are also listed as impaired for a variety of nutrient criteria (FDEP, 2011). Since the 1990s development regulations and best management practices have driven the construction of stormwater management ponds to retain more water across the developed landscape. However, this has still resulted in the replacement of shallow, seasonal wetlands with deeper more permanent water bodies.

In response to these potential threats to local amphibian populations, the Southwest Florida Amphibian Monitoring Network (SWF Frog Watch) was established in 2000 to document the status and population trends of local anuran species over time (Pieterson et al., 2006). To date, the network maintains a database of 10645 observations from 23 routes in Charlotte, Lee, and Collier Counties. Pieterson et al. (2006) analyzed this database after five years. They reported an increased occurrence of the exotic Cuban treefrog (*Osteopilus septentrionalis*) and an apparent shift in the anuran community toward species such as pig frogs (*Lithobates grylio*) and green treefrogs (*Hyla cinerea*). They attributed these changes to human modifications of the landscape, including the trend away from shallow, seasonal wetlands to deeper permanent stormwater retention ponds. Herein, we extend that work by analyzing more data that have accumulated, including ten total years of data. The major goal of this analysis is to explore possible changes in populations of individual frog species over our ten year study period. Specifically, we asked whether frog populations are declining in southwest Florida, and if so, which species are most concerning.

METHODS—SWF Frog Watch uses a data collection protocol similar to that used in the North American Amphibian Monitoring Program (NAAMP). Routes were established with at least ten stops, separated by at least 1 km. Stop locations along each route were established in a non-random manner to include, initially, suitable anuran habitat. All stop locations are georeferenced. Sampling occurs in the rainy season only, one night a month every June-September, and begins 15 minutes after sundown. Sampling nights are chosen arbitrarily as the third Wednesday of each month,

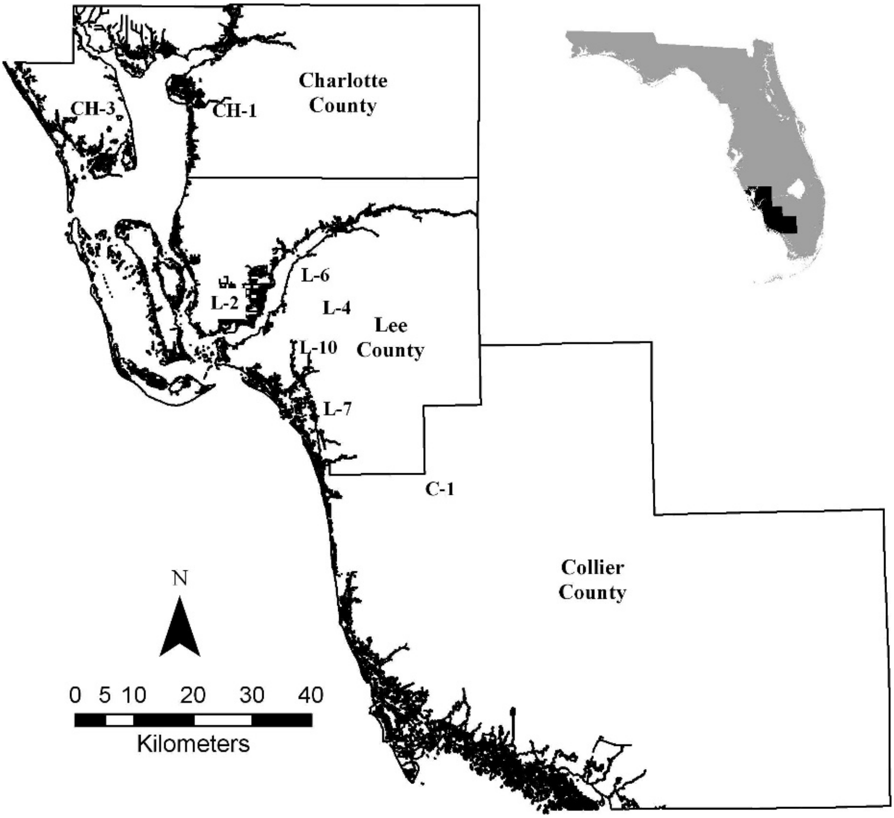

FIG. 1. Eight frog monitoring routes used in the analysis of trends over ten years, with "CH" for Charlotte County routes, "C" for Collier County routes, and "L" for Lee County routes.

which occurs randomly with respect to local weather and precipitation at each route. Volunteers listen for three minutes then record the intensity for each species' calls. Call intensities are quantified using a scale of 0–3 (0: no frogs calling; 1: individuals can be distinguished; 2: some overlap of individual calls; and 3: a chorus where individuals cannot be detected and calls are constant, continuous and overlapping).

Each route was established by a route leader, so routes and stops are not placed randomly across the landscape. In addition, sampling effort on routes varied over the ten years, with several routes 'orphaned' by leaders. For the purposes of this study, we limited the analysis to the eight most consistently monitored routes (FIG. 1), for a total of 6512 observations, including routes in all three counties within the network (Charlotte, Collier and Lee).

Calling data are summarized using *mean calling intensity*, calculated by averaging calling intensity for each species by stop or route. The percent change in mean calling intensity was compared between 2000 and 2004 and 2000 and 2009 to reexamine trends reported by Pieterson et al. (2006). Significant differences through time were tested using ANOVA on the annual mean calling intensity for each species.

RESULTS—Examination of mean calling intensity data over five year intervals (2000–2004 and 2005–2009) suggests dramatic changes in the community of anurans in southwest Florida (FIG. 2). Although most species

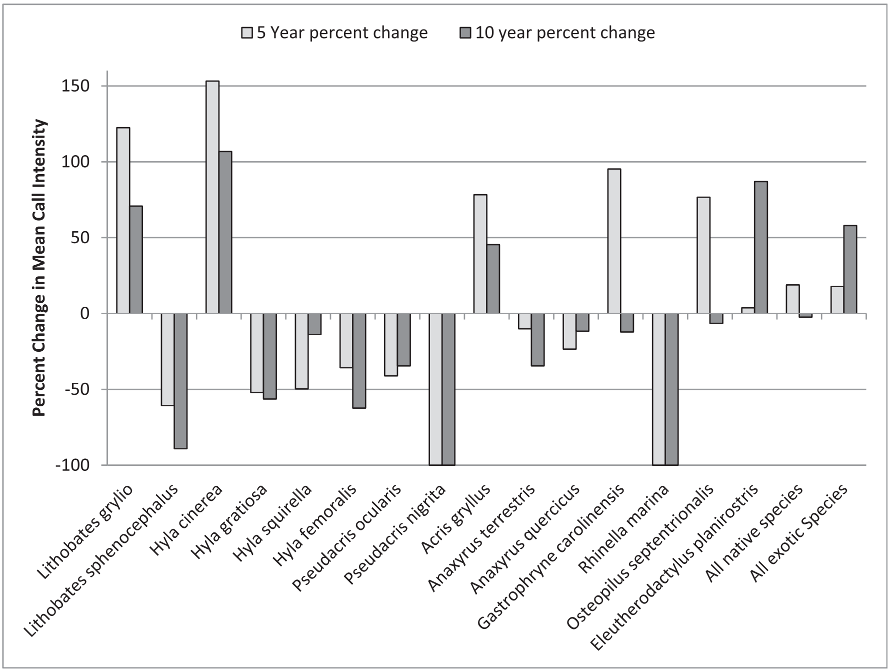

FIG. 2. Percent change in frog species mean calling intensity for the first five years, and for the total ten years, calculated by comparing mean calling intensities from year 2000 to 2004 and 2009. Nomenclature follows Collins and Taggart (2009).

exhibited a similar change in the five-year and ten-year calling intensity trends, several clear patterns exist. No native species with a positive increase after five years showed an even greater increase over the full ten years. The only species that showed consecutive increases in mean calling intensity over both the five- and ten-year intervals was the exotic greenhouse frog (*Eleutherodactylus planirostris*). When data for all native species were combined, there was an overall slight decrease over the ten years, reversing the slight increase that was observed after five years. The overall mean calling intensity for exotics increased after both five years, driven principally by the increase in Cuban treefrogs (*O. septentrionalis*), and after ten years because of the increase for *E. planirostris*. In contrast, the giant toad (*Rhinella marina*) showed a dramatic reduction in both the five- and ten-year interval. *Osteopilus septentrionalis* was one of two species that reversed its percent change from five years (positive) to ten years (negative). The other was the native eastern narrowmouth toad (*Gastrophryne carolinensis*), which showed the same trend.

While examination of mean call intensity data after five- and ten-year intervals is compelling, the dramatic negative changes in anuran populations and communities are no longer evident when annual mean calling intensity data are tracked among consecutive years. Southern cricket frog (*Acris gryllus*), pinewoods treefrog (*Hyla femoralis*), green treefrog (*H. cinerea*), and pig frog

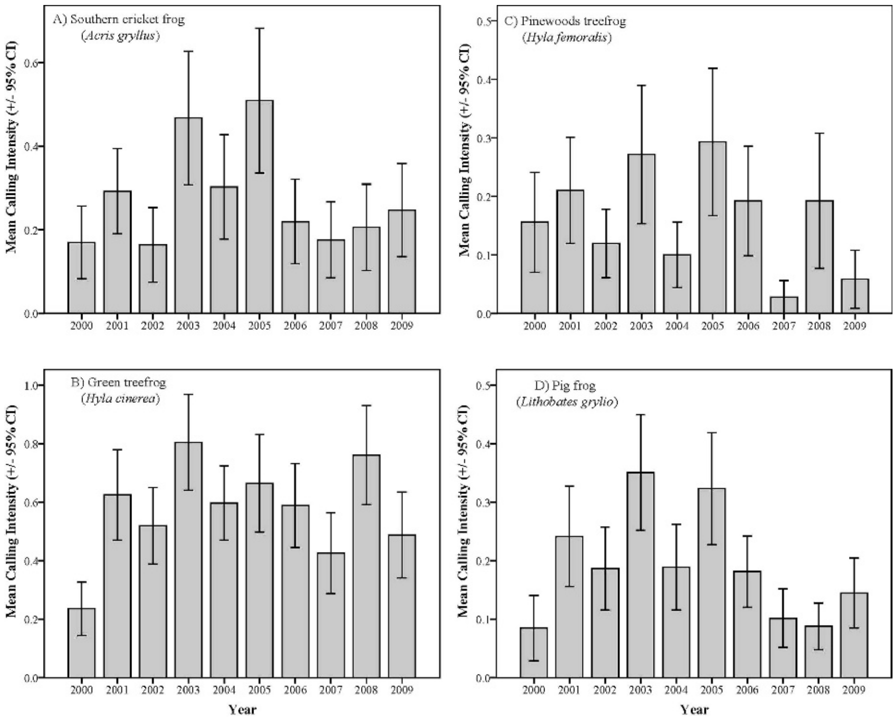

FIG. 3. Annual mean calling intensities for: A. Southern cricket frog; B. Pinewoods treefrog; C. Green treefrog; D. Pig frog. Error bars represent the 95% confidence interval.

(*L. grylio*) all showed similar trends in calling intensity among years (FIG. 3). These four species have high mean calling intensities around 2003 and 2005. In addition, these four species all showed lower mean calling intensity in 2000, 2002, 2004, and again in 2007. In particular, *H. femoralis* was one of the species to show an apparent dramatic decline after both five- and ten-year intervals but had high calling intensity in 2005, 2006, and 2008. Mean calling intensity values varied significantly among years, which is consistent with the underlying variation of amphibian populations (*A. gryllus*: $F_{9,839} = 4.1$, $p < 0.001$; *H. femoralis*: $F_{9,839} = 1.9$, $p = 0.046$; *H. cinerea*: $F_{9,839} = 4.2$, $p < 0.001$; *L. grylio*: $F_{9,839} = 6.3$, $p < 0.001$). The mean calling intensity scale (y-axis) was adjusted for each species to better emphasize annual variation (FIGS. 3–6). Among all species, the natives *A. gryllus*, *H. cinerea*, and *Anaxyrus quercicus* had the highest mean calling intensities and were all greater than any of the exotic species.

The annual mean calling intensities for eastern narrowmouth toad (*G. carolinensis*), squirrel treefrog (*Hyla squirella*), oak toad (*A. quercicus*), and southern toad (*Anaxyrus terrestris*) also showed similar patterns of annual change (FIG. 4). All species exhibited peaks in mean calling intensity in 2002 and 2008 (though *G. carolinensis* also had high mean calling intensities in 2004

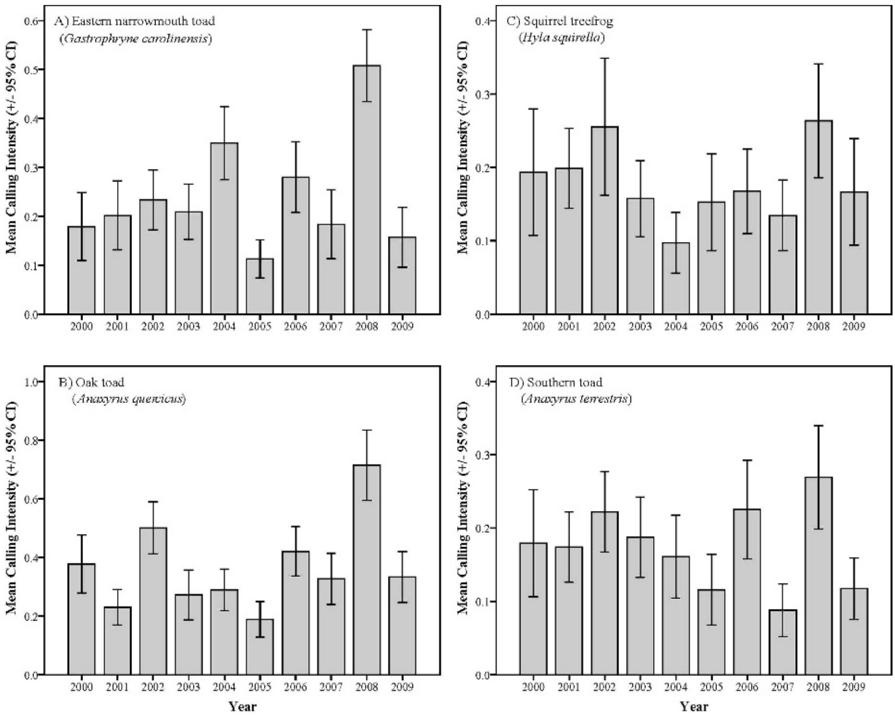

FIG. 4. Annual mean calling intensity for: A. Eastern narrowmouth toad; B. Squirrel treefrog; C. Oak toad; D. Southern toad. Error bars represent the 95% confidence interval.

and 2006). In addition, all four species showed a decline in mean calling intensity in either 2004 or 2005 and 2007. Of particular interest, *H. squirella* and *A. quercicus* both showed dramatic declines when data were examined after five- and ten-year intervals, but showed comparable increases in 2002, 2006, 2008. All four species have significantly different mean calling intensities among years (*G. carolinensis*: $F_{9,839} = 12.1$, $p < 0.001$; *H. squirella*: $F_{9,839} = 3.9$, $p < 0.001$; *A. quercicus*: $F_{9,839} = 13.0$, $p < 0.001$; and *A. terrestris*: $F_{9,839} = 4.2$, $p < 0.001$).

Some frogs were either observed rarely or showed unique patterns of call intensity data among years that were not comparable to other species (FIG. 5). The little grass frog (*Pseudacris ocularis*) showed peaks in 2001 and 2008, but apparent disappearance in 2005–2006. Both the southern leopard frog (*L. sphenocephalus*) and southern chorus frog (*Pseudacris nigrita*) may have shown declines as indicated by mean calling intensity. In fact, *P. nigrita* disappeared for 4 years from 2003–2006 as well as 2008–2009, while *L. sphenocephalus* was not heard from 2005 before returning in low activity in 2006. In each case, these three species were rarely observed over the 10 years of sampling. *Pseudacris ocularis* was documented only 29 times, *L. sphenocephalus* only 25 times, and

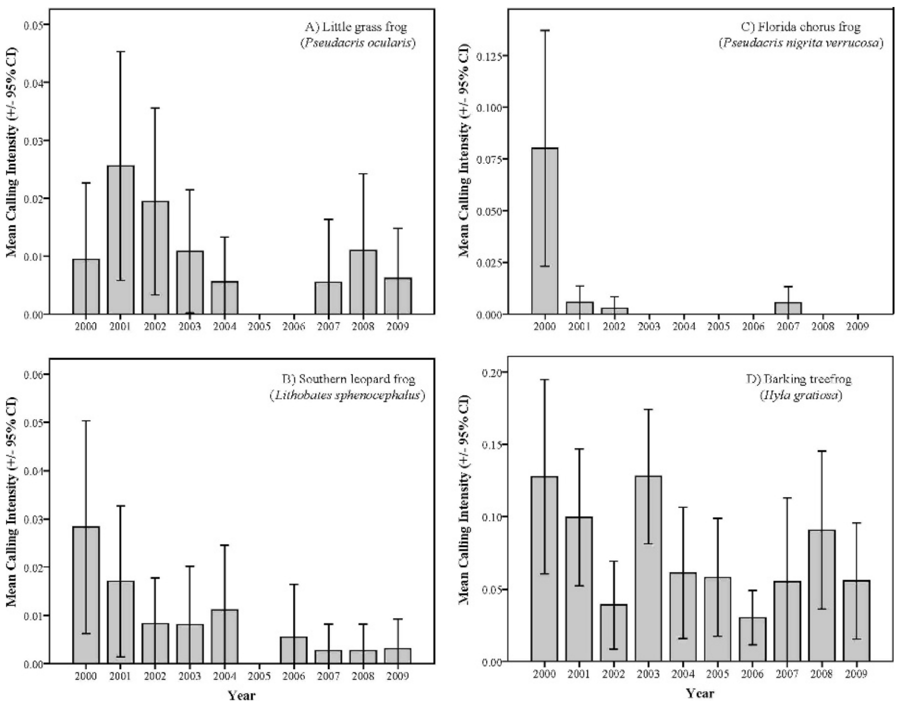

FIG. 5. Annual mean calling intensity for four of the rarer frog species: A. Little grass frog; B. Southern leopard frog; C. Florida chorus frog; D. Barking treefrog. Error bars represent the 95% confidence interval.

P. nigrita only 14 times. Barking treefrogs (*Hyla gratiosa*) showed a unique pattern of mean calling intensity over the ten-year study. *Hyla gratiosa* showed higher calling intensity in 2000, 2001, 2004, 2008 and lower calling intensity in 2002 and 2006. In addition, the overall mean calling intensity was particularly low even though these animals were heard 151 times over the study. All four species had significantly different mean calling intensities among years (*P. ocularis*: $F_{9,839} = 1.9$, $p = 0.046$; *L. sphenocephalus*: $F_{9,839} = 1.9$, $p = 0.048$; *P. nigrita*: $F_{9,839} = 11.5$, $p < 0.001$; *H. gratiosa*: $F_{9,839} = 2.2$, $p = 0.02$).

Mean calling intensity data for the exotic frog species, greenhouse frog (*E. planirostris*), cane toad (*R. marina*), and Cuban treefrog (*O. septentrionalis*) all show distinct differences in annual patterns (FIG. 6). *Eleutherodactylus planirostris* does not follow either of the annual patterns exhibited by native frogs in FIGS. 3 and 4. In addition, *E. planirostris* was the one species that did not show significant differences in mean calling intensity among years ($F_{9,989}=1.2$, $p = 0.1$). *Rhinella marina* was rarely heard (only 11 times over 10 years) and showed a spotty record of presence in some years but not in others. The sample size was too small to analyze in depth. Annual mean calling intensity for *O. septentrionalis* was significantly different ($F_{9,989}=1.3$,

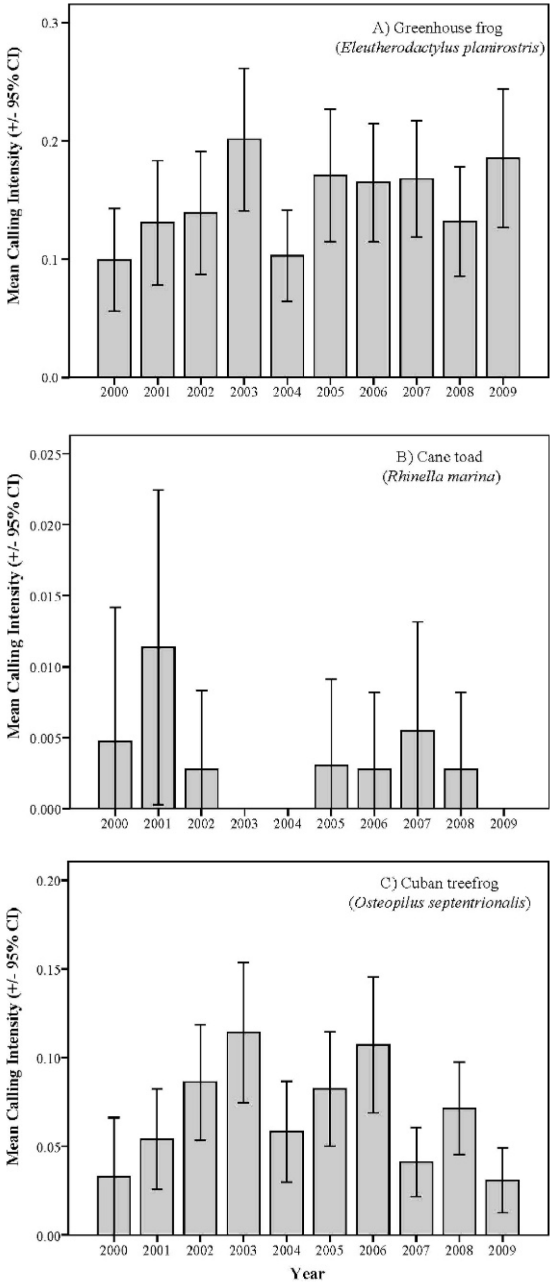

FIG. 6. Annual mean calling intensity for exotic species: A. Greenhouse frog; B. Cane toad; C. Cuban treefrog. Error bars represent the 95% confidence interval.

$p < 0.001$) among years and followed an overall pattern similar to native species in FIG. 4, with peaks in 2003, 2006, and 2008 and drops in 2004 and 2007.

DISCUSSION—The five- and ten-year percent changes in mean calling intensity documented a slight overall decline in native frog species mean calling intensity and an increase in calling of exotics. In addition, all but three native species had a negative percent change in mean calling intensity from the first to last year in the sample. The three that showed a positive percent change all had a lower percent increase after ten years compared to five years. Both the native *P. nigrita* and the exotic *R. marina* were not heard at all in the last year of sampling. In addition, the gopher frog (*Lithobates capito aesopus*) was never heard on the eight routes analyzed in this study, though they have been heard sporadically (<10 records) in the monitoring program. All three may have been extirpated from the landscape, but they may exist in areas not sampled in the monitoring network or at times outside the sampling procedure. The more resolved annual mean calling data showed an apparent downward trend for *P. nigrita* and three additional native species (*P. ocularis*, *L. sphenocephalus*, and *H. gratiosa*). With this preliminary analysis, focusing on changes in five-year periods, there appeared to be sufficient data to conclude an overall reduction of natives in the frog communities. Although some native frog species may indeed be in decline, this interpretation would be premature, or inappropriate, without more detailed study of annual call variation, habitat changes along routes, and effects of extreme environmental events (see below).

The punctuated analysis of percent change from first to fifth, and first to tenth years sampled, misrepresents trends for many of the species. For example, if we had reported on the nine-year trends (2000–2008) nine of the twelve native species would have had a *positive* percent change in mean calling intensity. Interpreting long-term anuran calling data must consider: 1) the underlying variation of anuran populations; 2) the probability of missing calling events when calling is sampled once per month; and 3) that maintenance of a population may only require one successful reproductive event in a year. The clearest signal from these data is the need to continue monitoring to differentiate background variations from long-term trends and to incorporate all annual data, instead of punctuated analyses which might misrepresent trends (Pechmann et al., 1991).

The annual variations in FIGS. 3 and 4 (and for *O. septentrionalis,* FIG. 6) may be driven by extreme wet and dry years, and particularly in the case of *O. septentrionalis* extreme cold spells, possibly leading to mortality of this tropical species. It is important to recognize that these monitoring data are not direct measures of abundance, but of calling. Changes in calling frequency and intensity are behavioral changes. During dry years, calling is expected to be reduced, even if there is no mortality associated with the drought. Wet years may stimulate reproduction, raising mean calling intensity, and this effect may carry over to the following year, with increased reproduction leading to population increases and continued high calling intensity.

Additionally, the altered hydrology associated with human development has increased the detrimental effects of drought. Development has also decreased and fragmented native habitats, and exotic plant invasions have decreased the quality of the remaining undeveloped lands. Development in southwest Florida is typically related to construction of new roads that eventually bring higher traffic levels, which has an important impact on this monitoring program limiting our ability to detect calling frogs in noisy environments. Moreover, global climate change scenarios suggest increased frequency of extreme weather events, potentially increasing the likelihood of extirpation of already reduced and stressed populations. However, some regional changes may be maintaining, or facilitating the recovery, of native frog populations. Changes in stormwater best management practices, wetland restoration, public land acquisition programs, and increased efforts to manage and control invasive exotics may all be decreasing rates of habitat loss and improving habitat in some areas.

Extreme weather events, (tropical storms and other intense rainfalls, drought, cold fronts) varied across the region over the decade of study. The impact of individual events may be obscured by our regional analyses that combined all eight routes. To better determine environmental factors that may lead to a decline, or facilitate an increase, in native frog populations, there is a need to examine changes in calling at a site-specific scale and to tie these changes to habitat characteristics. The habitat surrounding stop locations has changed in complex, site-specific ways over the period of monitoring. The behavioral response (calling) of each individual species must be interpreted in light of its unique life history requirements, in relation to these habitat changes. It is also warranted to examine biotic community interactions, particularly the role of exotics, in maintaining, or reducing, frog biodiversity. We see the opportunity to identify and categorize specific stops in terms of the degree of habitat modification through time and analyze the differential impacts on varying species.

Our citizen science monitoring effort is providing long-term data to examine overall regional trends. There is the potential for additional analyses, outside the scope of this paper, to examine more species- or site-specific patterns. The limitations of this type of monitoring effort include the tradeoff between covering larger areas, but with less intense sampling that is not tied to optimal calling conditions. Inevitably, this requires longer time periods to confirm population changes. In addition, many of the sampling locations are adjacent to private lands, with no ability to control habitat changes through time. The establishment of new routes, or networks, might include an effort to sample public conservation areas, which presumably can provide reference sites for detecting change in the anuran populations in areas undergoing habitat modification. Additionally, a citizen science monitoring network can serve as a heuristic, with the preliminary trends serving to focus additional research effort to target areas, habitats, or species within the region.

Ultimately, the frog community is a sentinel for determining the effectiveness of our efforts to maintain wetland function and water quality.

Their loss would be a measure of our failure. Implementation and continued support of citizen-science programs such as the Southwest Florida Amphibian Monitoring Network will be critical to prevent this failure.

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LITERATURE CITED

BEEBEE, T. J. C. AND R. A. GRIFFITHS. 2005. The amphibian decline crisis: A watershed for conservation biology? Biological Conservation 125:271–285.

COLLINS, J. P. AND A. STORFER. 2003. Global amphibian declines: Sorting the hypotheses. Diversity and Distributions 9:89–98.

COLLINS, J. T. AND T. W. TAGGART. 2009. Standard common and current scientific names for North American amphibians, turtles, reptiles, and crocodilians. The Center for North American Herpetology. Lawrence.

DECLINING AMPHIBIAN POPULATIONS TASK FORCE (DAPTF). 2011. http://ice.ucdavis.edu/project/daptf.

DODD, C. K. JR, W. J. BARICHIVICH, S. A. JOHNSON, AND J. S. STAIGER. 2007. Changes in a Northwestern Florida Gulf Coast herpetofaunal community over a 28-y period. American Midland Naturalist 158:29–48.

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION (FDEP). 2011. http://www.dep.state.fl.us/water/wqssp/nutrients/.

SOUTHWEST FLORIDA AMPHIBIAN MONITORING NETWORK (SWF Frog Watch). 2011. Southwest Florida Amphibian Monitoring Network. http://www.frogwatch.net/.

KAISER, K. 2008. Evaluation of a long-term amphibian monitoring protocol in Central America. Journal of Herpetology 42:104–110.

LANNOO, M. 2005. Amphibian Declines: The Conservation Status of United States Species. University of California Press, Berkeley.

LIPS, K. R., J. DIFFENDORFER, J. R. MENDELSON, AND M. W. SEARS. 2008. Riding the wave: Reconciling the roles of disease and climate change in amphibian declines. PLoS Biology 6:e72.

MATTFELDT, S. D., L. L. BAILEY, AND E. H. CAMPBELL GRANT. 2009. Monitoring multiple species: Estimating the state variables and exploring the efficacy of a monitoring program. Biological Conservation 142:720–737.

MCCALLUM, M. L. 2007. Amphibian decline or extinction? current declines dwarf background extinction rate. Journal of Herpetology 41:483–491.

MCMENAMIN, S. K., E. A. HADLEY, AND C. K. WRIGHT. 2008. Climate change and wetland desiccation cause amphibian decline in Yellowstone National Park. Proceedings of the National Academy of Sciences 105:16988–16993.

NORTH AMERICAN AMPHIBIAN MONITORING PROGRAM (NAAMP). 2011. http://www.pwrc.usgs.gov/naamp/.

PECHMANN, J. H. K., D. E. SCOTT, R. D. SEMLITSCH, J. P. CALDWELL, L. J. VITT, AND J. W. GIBBONS. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science 253(5022):892–895.

PIETERSON, E. C., L. M. ADDISON, J. N. AGOBIAN, B. BROOKS-SOLVESON, J. CASSANI, AND E. M. EVERHAM III. 2006. Five years of the Southwest Florida frog monitoring network: Changes in frog communities as an indicator of landscape change. Florida Scientist 69:117–126.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT (SFWMD). 2008. Lower Charlotte Harbor surface water improvement and management plan. West Palm Beach, FL: South Florida Water Management District.

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