Supplemental Tables and Figures

Terrell, V., J. C. Maerz, N. J. Engbrecht, R. M. Stiles, B. A. Crawford, and M. J. Lannoo. 22 September 2022. Breeding Population Dynamics of Threatened Crawfish Frogs Informs Targets for Habitat Management. Ichthyology and Herpetology.

Table S1. Age at first known reproduction for male and female Crawfish Frogs that metamorphosed between 2009–2011 from Nate's Pond, and estimated annual juvenile survival (Φ), probability of first breeding at age 2 (p), and probability of breeding at age 3 (q) if an individual did not breed at age 2 ($1–p$) based on adjusted observed numbers. "Adjusted observed numbers" are observed numbers multiplied by 1.359 to account for temporary emigration.

		Observed			Adjusted observed						
Females	No. metamorphs	2yrs	3yrs	4+yrs	2yrs	3yrs	4+yrs	p	q	Φ	Mean diff SS
2009	143	3	0	0	4	0	0	0.947	0.000	0.135	0.0000
2010	1051	1	27	7	1	37	10	0.008	0.582	0.361	0.0000
2011	1561	15	9	5	20	12	7	0.129	0.328	0.271	0.0000
weighted mean								0.125	0.408	0.298	
SD								±0.276	±0.212	±0.114	
Males											
2009	143	2	0	3	3	0	4	0.095	0.000	0.398	0.0000
2010	1051	16	21	5	22	29	7	0.134	0.591	0.344	0.0000
2011	1561	25	15	3	34	20	4	0.209	0.578	0.274	0.0000
weighted mean								0.175	0.553	0.307	
SD								±0.058	±0.338	±0.062	

Table S2. Numbers of breeding adult Crawfish Frogs and estimated mean reproductive effort and tadpole survival for two proximate wetlands in southwest Indiana, USA, 2009–2013.

Pond/ Year	Total # males	Total # females	# spent females	Mean female body length (mm; ± 95% CI)	Mean clutch size[a] (± 95% CI)	# eggs deposited	# embryos hatched [b]	Total # metamorphs	Larval survival
Nate's 2009	38	31	30	100.3 ± 2.2	6,303 ± 381	189,079	185,297	286	0.15%
2010	20	22	20	102.8 ± 2.8	6,724 ± 491	114,316	112,029	2,103	1.88%
2011	33	32	31	99.4 ± 3.7	6,144 ± 645	116,743	114,408	3,122	2.73%
2012	22	9	6	102.3 ± 1.7	6,650 ± 300	39,898	39,100	0	0%
2013	69	51	−	88.4 ± 2.3	4,238 ± 403	159,538	156,347	8	0.005%
Cattail 2009	14	14	11	104.4 ± 3.4	7,002 ± 598	77,020	75,480	11	0.01%
2010	14	7	7	108.0 ± 6.9	7,633 ± 1,194	45,796	44,880	0	0%
2011	7	11	11	103.6 ± 2.9	6,722 ± 497	53,775	52,700	30	0.06%
2012	12	11	11	92.2 ± 4.7	4,892 ± 822	24,458	23,969	0	0%
2013	18	21	−	95.7 ± 3.3	5,505 ± 576	77,211	75,667	16	0.02%

[a] estimated from snout-vent lengths (SVL) of spent females at each wetland each year and the regression: Clutch size = −10,974.3 + 172.4 × SVL.

[b] Accounts for mean number of unhatched eggs per egg mass of 135 ± 101 (mean ± 95% CI; range = 55–339, n = 5).

Table S3. Top model survival estimates (and 95% confidence intervals) of Crawfish frogs in Greene County, Indiana for the year following a breeding season during 2009–2013. Estimates are pooled for males and females and were generated from robust design candidate models. Survival varied by breeding status (1 = previously caught as a breeding adult, 0 = otherwise) and year of study.

	Known [or presumed] first time breeders		Known second time or greater breeders	
Year	Estimate	95% CI	Estimate	95% CI
2009[a]	0.52	0.38−0.66	–	–
2010	0.30	0.14−0.53	0.61	0.38−0.80
2011	0.18	0.06−0.44	0.44	0.18−0.74
2012	0.59	0.20−0.95	0.86	0.41−0.98

[a] Survival rate was estimated across all individuals because we could not identify breeding status during the first year of study.

Table S4. AICc, ΔAIC_c, and Akaike weights for robust design candidate models of temporary emigration rates (γ' and γ'') for a population of Crawfish Frogs in Greene County, Indiana, USA. Temporary emigration parameters were varied while all other parameters were specified using the effects supported by prior model assessment and fixed across candidate models. Fixed parameters included a year + known breeding status effect for survival (S), a time+session effect for capture (p), capture = recapture (c), and constant annual abundance (N).

Model[a]	K[b]	AIC_c[b]	ΔAIC_c[b]	w_i[b]
γ''=γ'(.)	17	-1470.8	0.0	0.420
γ''=γ'(t)	20	-1470.0	0.8	0.276
γ''(.)γ'(.)	18	-1469.8	1.0	0.257
γ''(t)γ'(t)	23	-1466.4	4.4	0.046

[a] Model effect codes: emigration out of the study area after being available (γ'') or unavailable (γ') in the previous occasion, . = constant, and t = year (primary period).
[b] K = no. of parameters, AIC_c = Akaike's Information Criterion, ΔAIC_c = difference in AIC_c from the best model, and w_i = Akaike wt.

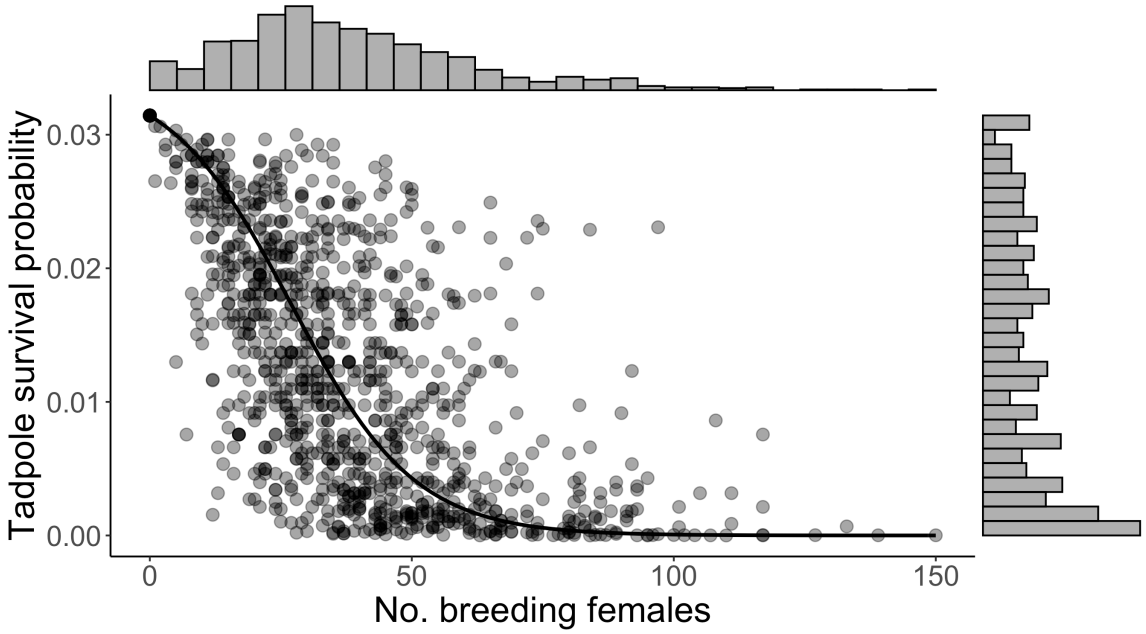

Figure S1. Stochastic tadpole survival rates sampled from 1000 simulations of Nate's Pond using a negative density dependent relationship between the number of breeding female Crawfish Frogs and tadpole survival for Nate's Pond. The black line shows a best fit sigmoidal curve of mean tadpole survival for four data points for which the number of adult breeding females and subsequent tadpole survival rate was known when the wetland held water sufficiently long for complete tadpole development. Stochastic tadpole survival rate for Nate's Pond ($S_{t\,Nate's}$) for each year absent drought was generated using the function: $S_{t\,Nate's} = 0.0346 \,/\, (1+e^{(0.085*(N-27)} + \varepsilon)$ where ε was modeled as a Guassian function with $a = 0.008$, $b = 25$ and $c = 9$ and survival was bounded between 0.00 and 0.35. This created a highly variable yet negative density dependent tadpole survival mechanism for the population viability model of Nate's Pond.

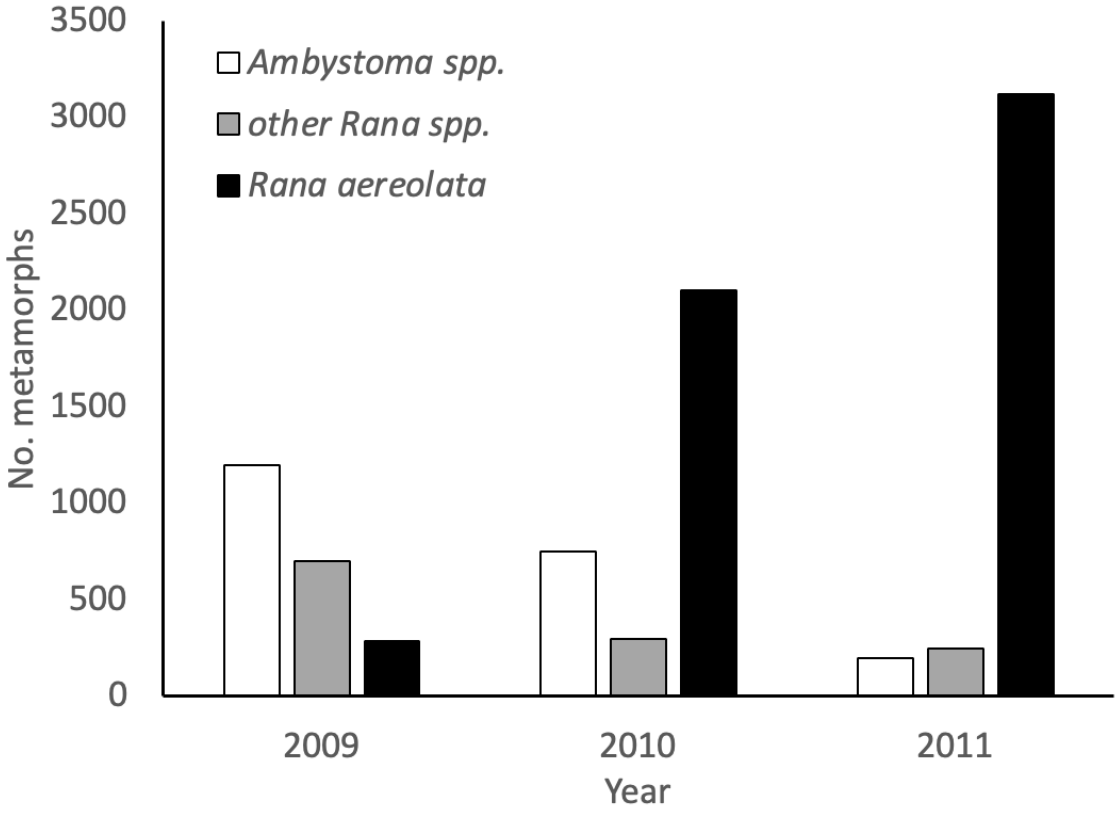

Figure S2. Total number of recently metamorphosed Crawfish Frogs (*Rana areolatus*) and other selected amphibian species at Nate's Pond a breeding site located in southwest Indiana, USA, between 2009–2011. *Rana* spp. consisted of Green Frog (*R. clamitans*) and Southern Leopard Frog (*R. sphenocephala*) tadpoles, which are known competitors with Crawfish Frog tadpoles. Larval *Ambystoma* are predators on tadpoles.

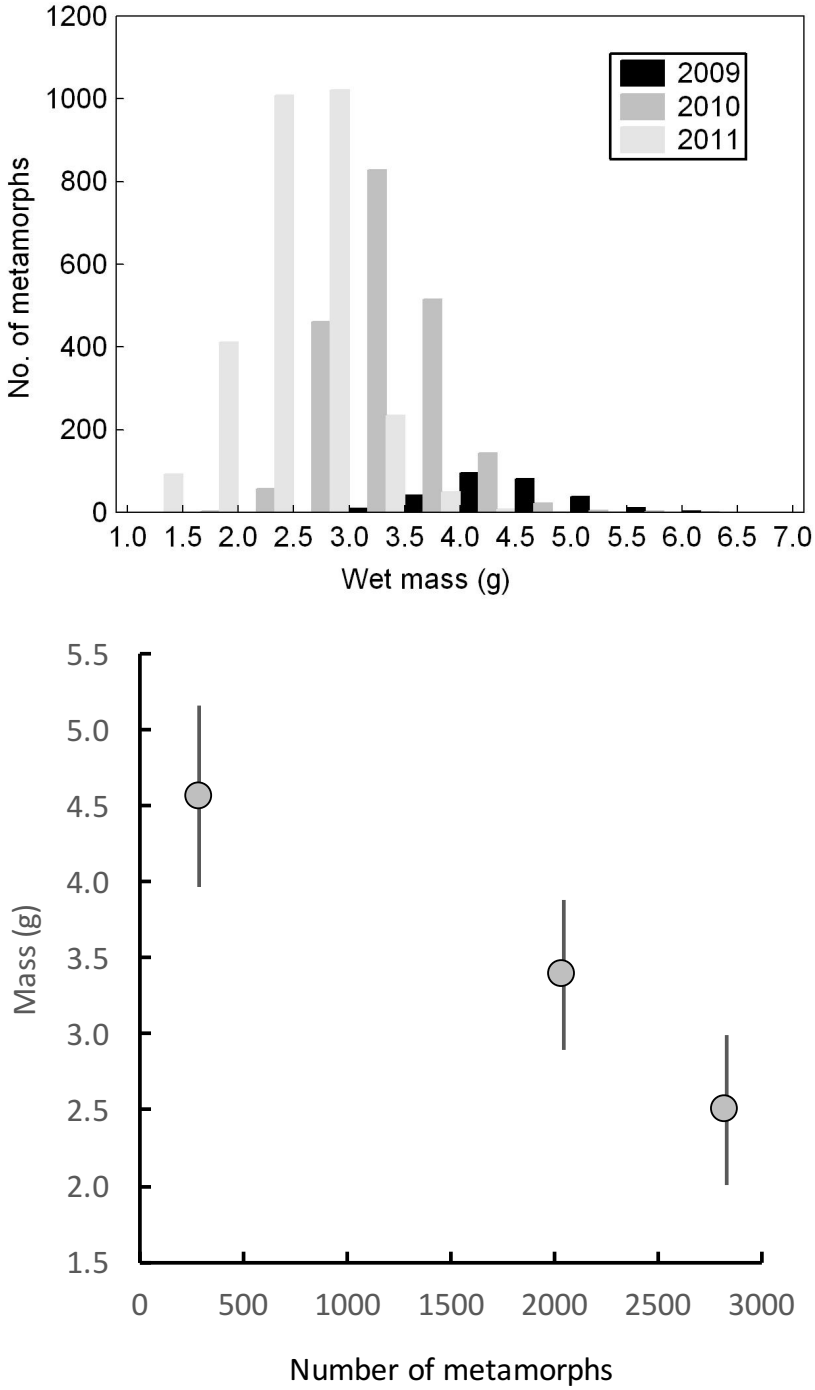

Figure S3. (upper) Distribution of wet mass (grams) among newly metamorphosed Crawfish Frogs in 2009, 2010, and 2011 at Nate's Pond, a breeding site located in southwest Indiana, USA. (lower) Mean (±1 SD) wet mass of newly metamorphosed Crawfish Frogs as a function of the number of metamorphs produced that year.

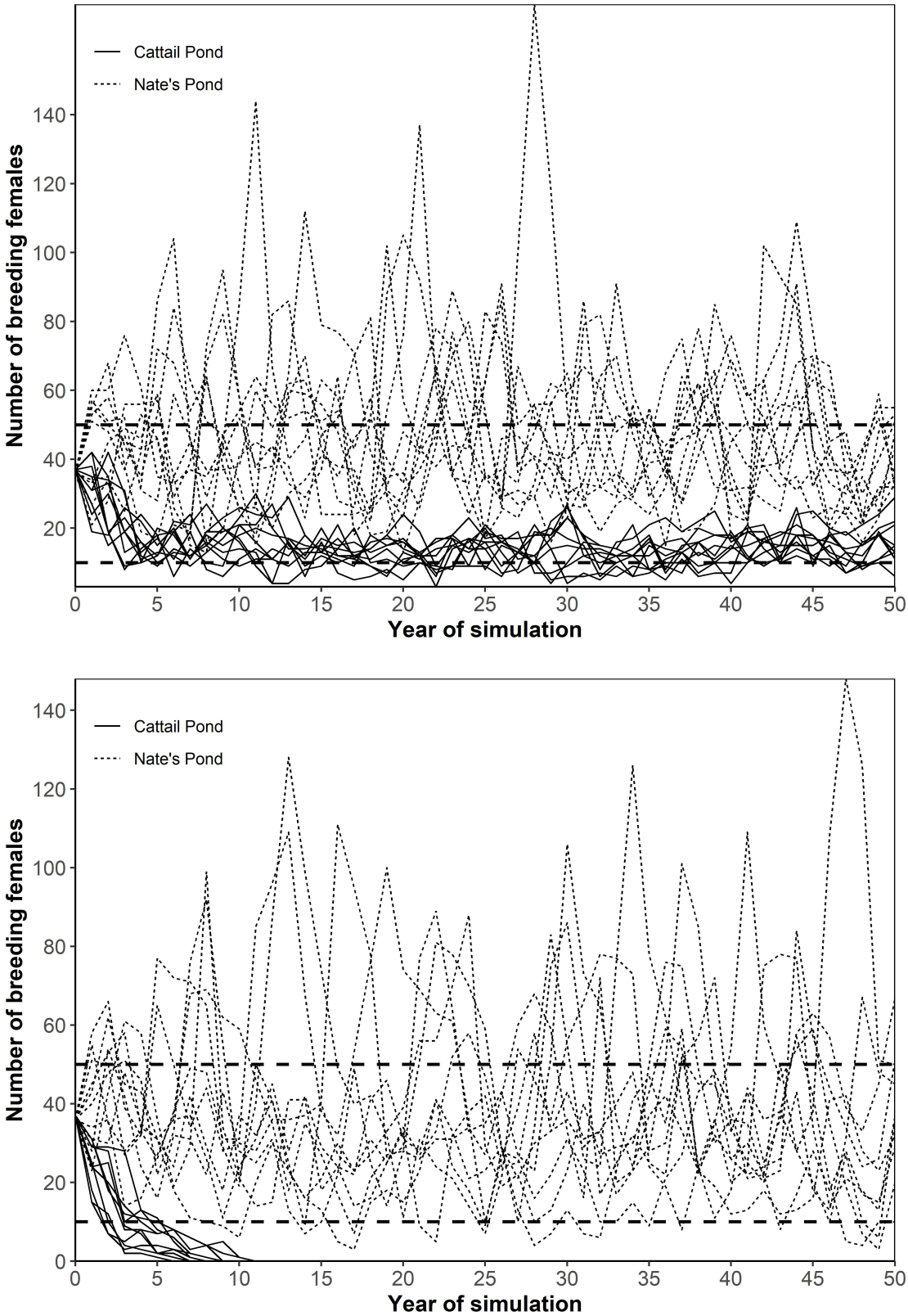

Figure S4. (A) Number of breeding females from ten, randomly selected simulations

among 1,000 simulations of stochastic population dynamics at Nate's Pond and Cattail Pond with (upper panel) and without (lower panel) immigration included in the simulation model. The bold, black, dashed lines mark the observed range of the total number of adult breeding females observed at Nate's Pond between 2009 and 2016. The number of breeding females at Cattail Pond ranged between 7 and 21 individuals between 2009-2013, which was consistent with simulated breeding population sizes with immigration but not when immigration was absent. The lines of breeding female abundance over time at Nate's Pond demonstrate that the larval density-dependence mechanism in the model was sufficient to prevent populations from expanding "out of control" or to unrealistic abundances, and the majority of time over the fifty year simulations, the number of breeding females was within the observed range of breeding female abundance observed at Nate's Pond over an 8 year period.