MONITORING OF POND BREEDING AMPHIBIANS AT CAPE COD NATIONAL SEASHORE, 2005

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EXECUTIVE SUMMARY

Given the abundance and significance of freshwater wetlands at Cape Cod National Seashore (CACO), the important role amphibians play in them, and concerns that global, regional, and local factors (pollution, disease, road kill, development) may alter the abundance, distribution, and structure of amphibian communities, long term monitoring of pond breeding amphibians was initiated in 2003. It is part of the park's long term ecological monitoring program, and consists of two components. Vernal pond egg mass counts monitor the abundance and distribution of spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Rana sylvatica*). Anuran call counts monitor abundance, distribution, and habitat association of the park's anurans (frogs and toads). In addition, data on each pond's physical and chemical attributes and vegetation are collected.

In spring 2005 three counts of egg masses were conducted in 40 vernal ponds. Based on each pond's maximum count, a total of 6359 spotted salamander masses and 162 wood frog masses were present. Spotted salamanders occurred in 29 ponds, from Eastham to the limit of glacial deposits at High Head, Truro. Wood frog egg masses were recorded in 15 ponds in Eastham and South Wellfleet. There were no significant differences in spotted salamander egg mass counts from 2004 to 2005, no significant trend over the past four or five years, nor any relationship between egg mass counts and breeding season rainfall. Although increasing annually, there was no significant trend in wood frog egg mass counts. Given the lack of long term data, this lack of trends is not surprising.

Analysis of landscape and within-pond factors found spotted salamander abundance to be correlated positively with water depth, which is correlated with hydroperiod (time water is present), suggesting that the largest populations of spotted salamanders occur at vernal ponds that hold water longest. This is consistent with research conducted elsewhere. Abundance of wood frogs was also positively correlated with pH and emergent vegetation. Compared to other areas of the Eastern United States, the CACO landscape, particularly Eastham, supports a widespread and very abundant population of spotted salamanders, but a limited and small population of wood frogs. Lack of forested wetlands, a critical habitat for wood frogs but not spotted salamanders, appears to be responsible for this difference.

Anuran call counts were conducted weekly at 30 freshwater sites for 15 consecutive weeks, from mid-April to late July. Counts consisted of visiting ponds after dark, listening for five minutes, and recording the abundance of species heard as an index value ranging from 0 to 3. Six species of frogs and toads, all the species known to occur at CACO except for eastern spadefoot toads (*Scaphiopus holbrookii*) and wood frogs (*Rana sylvatica*), were recorded at least once. In descending order, the most widespread species were spring peepers (*Pseudacris crucifer*), green frogs (*Rana clamitans*), Fowler's toads (*Bufo fowleri*), bullfrogs (*Rana catesbiana*), grey treefrogs (*Hyla versicolor*) and pickerel frogs (*Rana palustris*). Analysis of species occurrence and site features, and seasonal patterns indicate that habitat use and breeding season chronology of species here are similar to other anuran communities in the Northeastern U.S

INTRODUCTION

Cape Cod National Seashore (CACO) supports a great abundance and diversity of freshwater wetlands. Few landscapes in the region contain such a wealth of wetlands, which in turn support many regionally uncommon species of wetland-dependent flora and fauna. Among these, amphibians play a significant role in the energy flow, biomass, and community structure of freshwater wetlands, and contribute significantly to terrestrial ecosystems as well. Consequently, monitoring of pond breeding amphibians was initiated in 2003 as a component of freshwater wetland monitoring in the Cape Cod National Seashore prototype monitoring program (Roman and Barrett 1999). Specific rationale for the program includes concerns for individual habitats and species, as well as questions related to changes in abundance, distribution, and structure of the park’s amphibian communities in the face of potential impacts from acid deposition, road mortality, groundwater borne and air borne contaminants, habitat changes, and groundwater withdrawal (Paton et al. 2003).

Pond breeding amphibian monitoring at CACO consists of two components; monitoring occurrence and abundance of the vernal pond breeding species spotted salamander (*Ambystoma maculatum*) and wood frog (*Rana sylvatica*) through egg mass counts, and monitoring occurrence and relative abundance of the breeding anuran community park wide, in a range of wetland types, through the use of anuran call counts. Since these components entail distinct methods, target organisms, and sample sites, each will be reported on separately.

VERNAL POND EGG MASS COUNTS

Introduction

Monitoring of egg masses in vernal ponds in 2005 was a combination of activities called for in the CACO Amphibian Monitoring Protocol (Paton et al. 2003), plus a collaboration with the United States Geological Survey (USGS) Amphibian Research and Monitoring Initiative (ARMI). The USGS ARMI work in 2005 employed a proportion of area occupied (PAO) approach to determine the proportion of available vernal ponds occupied by spotted salamanders and wood frogs and the role of within-pond and adjacent landscape variables in determining occupancy. USGS randomly selected 40 known vernal ponds at CACO, and randomly assigned them a priority for inclusion in the sampling effort (Grant et al. 2004). A total of 40 ponds were sampled. These included the 20 called for in CACO’s Pond Breeding Amphibian Monitoring Protocol (Paton et al. 2003) and 30 of the 40 called for by the USGS ARMI protocol. Ten ponds sampled belonged to both groups (Appendix 1).

Methods

Counts of spotted salamander and wood frog egg masses were conducted at 40 vernal ponds in 2005. Ponds ranged geographically from Eastham to Provincetown and include most of the Eastham vernal pool complex (figs. 1-3). Three counts were conducted between 29 March 2005 and 6 May 2005. At each count, the entire pond was searched carefully and methodically, and all egg masses found were enumerated. For each species at a given pond, the highest of the three counts or maximum count was used as the measure of abundance (Cook and Boland 2005). At each count, maximum water depth (at a marked point determined to be the deepest point in the pond), air and water temperature were recorded (Paton et al. 2003). Maximum pond length and width (Jung 2002) were also measured at each count, and the maximum values used to calculate pond size. Analysis of a suite of water quality parameters was conducted, based on water samples collected in April. Analysis was conducted at the North Atlantic Coastal Lab, North Truro, using methods described in Boland and Cook (2004).

Analysis of between year (2004 *vs* 2005) differences in maximum egg mass counts was conducted by a paired t-test. Trends in egg mass counts were analyzed using linear regression, as recommended by Paton et al. (2003). Spotted salamander trend analysis was conducted for the period 2001 through 2005 based on seven ponds, using data for spotted salamanders from 2001 from Paton et al. (2003) to augment our own, and from 2002 through 2005, based on 14 ponds. Trends in wood frog egg mass counts from 2002 to 2005 were based on 12 ponds.

In addition, since there is a significant positive correlation between annual breeding effort in *Ambystoma* salamanders and rainfall during the breeding migration season (Semlitsch 1987), the effects of rainfall-related variation in total egg mass counts were removed using partial correlation (Pechmann et al. 1991). Since wood frogs and spotted salamanders in Massachusetts migrate to breeding ponds in March and April, the total rainfall for these two months, as recorded at a Cape Cod National Seashore rain gauge in Eastham, was used to estimate migration season rainfall.

Data from 2005 were analyzed to explore relationships between egg mass counts and physical, chemical, and ecological attributes of ponds and their adjacent areas. Many water quality parameters (Appendix 2) were highly significantly correlated (e.g. pH and alkalinity ($r=0.6999$, $p<0.0001$), conductivity and chloride ($r=0.9981$, $p<0.0001$). As was done in 2004, to remove these redundant variables and simplify analysis, only pH, conductivity, and color (Absorbance Coefficient at 440 nanometers (AbsCo440)) were retained for use in analysis. Methods for measuring the ecological attributes of ponds and adjacent areas are based on the ARMI protocol (Jung 2002). The adjacent landscape parameters measured were distance to nearest paved road, number of vernal ponds within 250 meters, and percent of woodland, paved road, field, wetland, and residential development within 50 meters. Within-pond parameters were area, maximum depth, pH, conductivity, absorbance, and percent of pond occupied by submerged aquatic vegetation (SAV), emergent, water lily, shrubs, trees, open water, and deadfalls (Appendix 3).

Figure 1. Vernal pond egg mass count sites in Eastham.

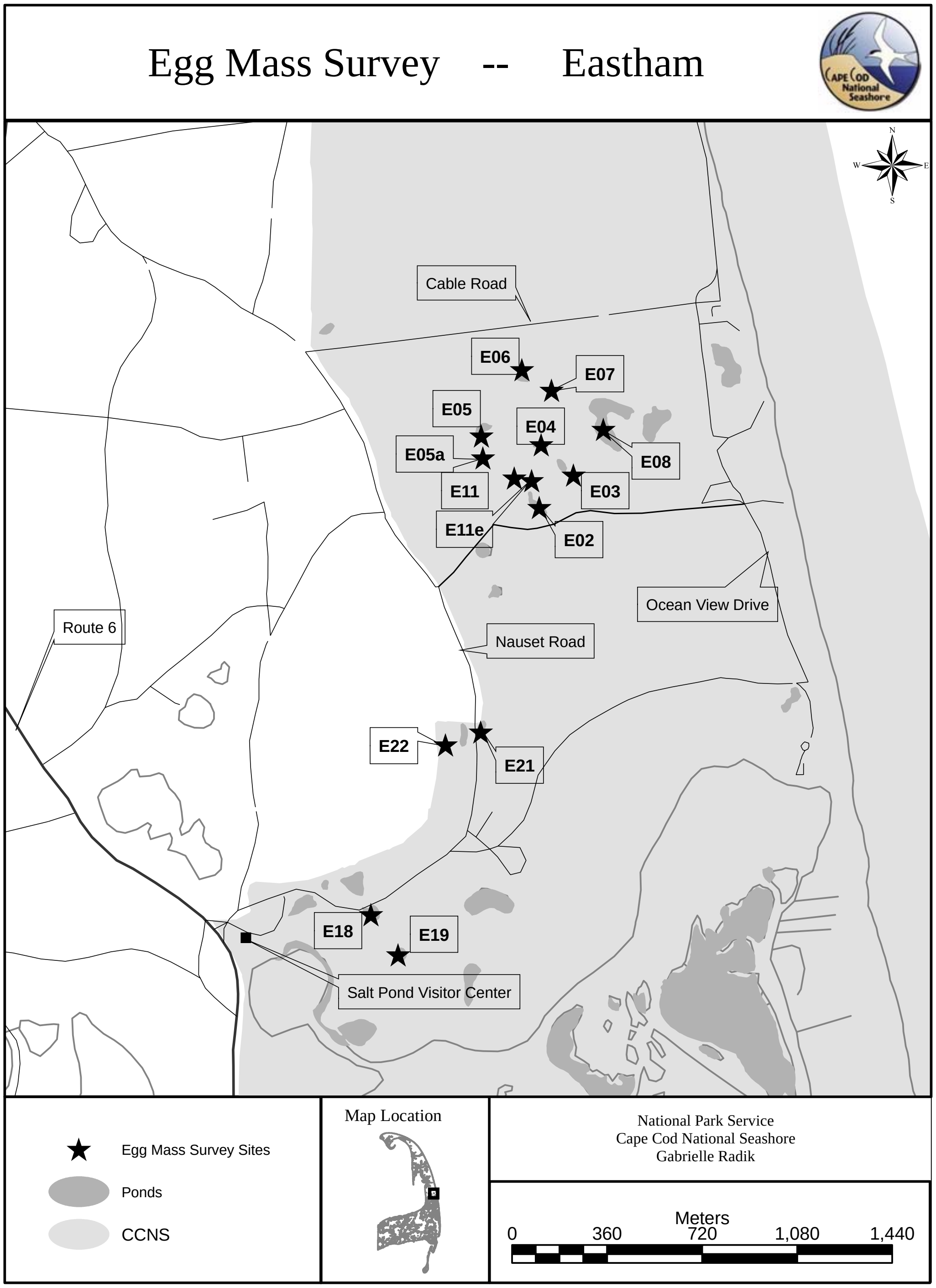


Figure 2. Vernal pond egg mass count sites in Truro and Wellfleet.

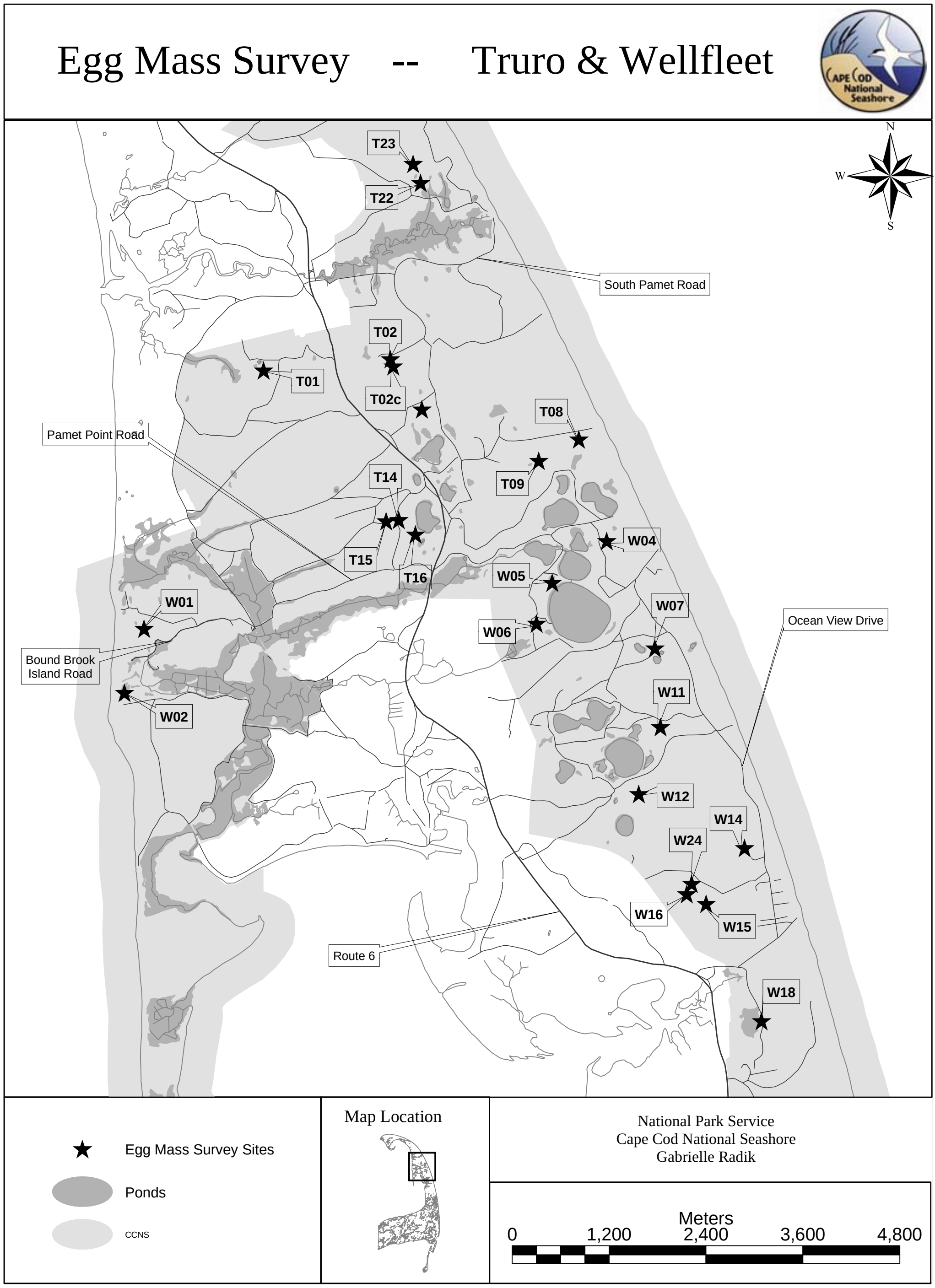
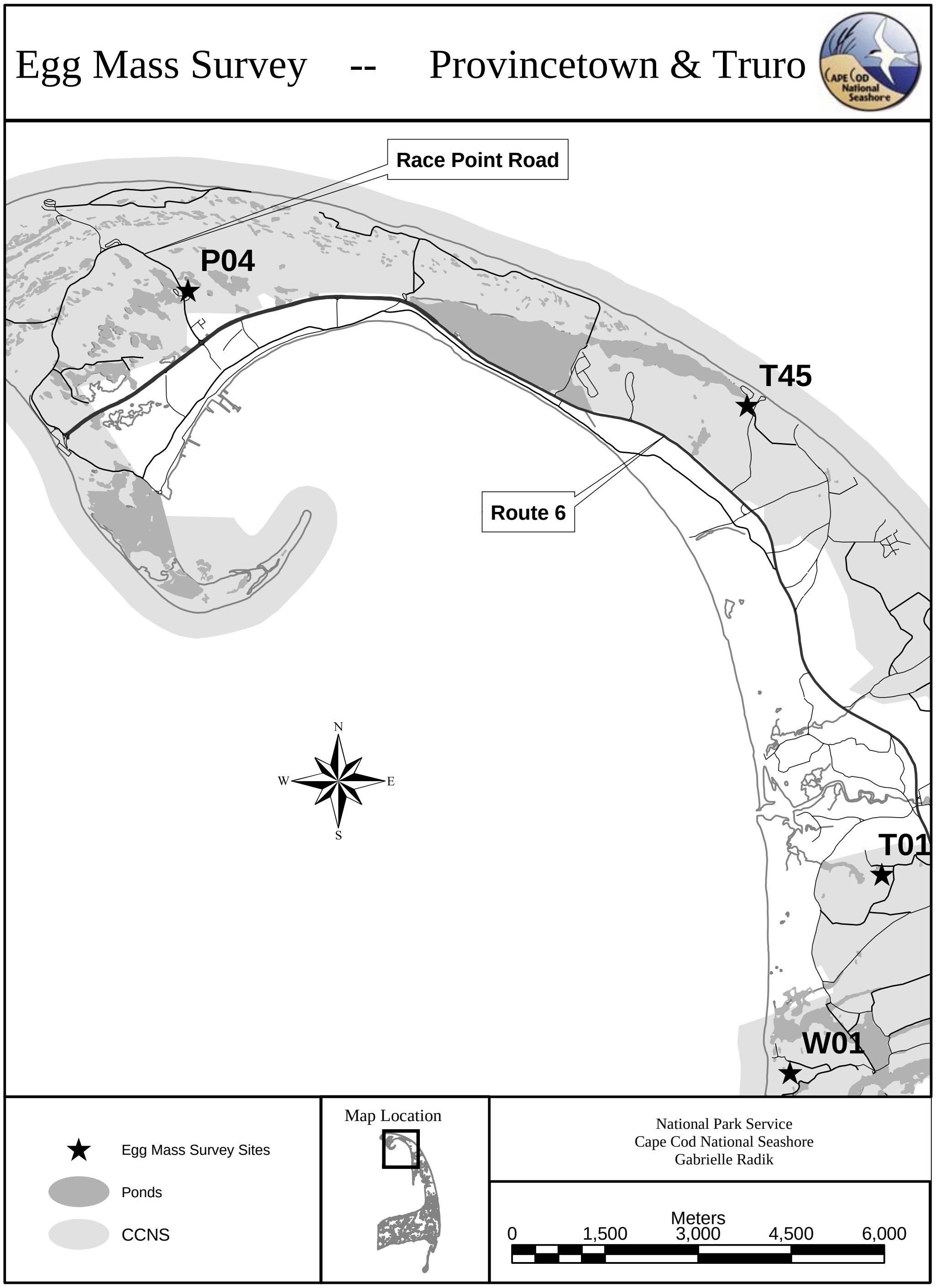


Figure 3. Vernal pond egg mass count sites in North Truro and Provincetown.



The relationship between egg mass counts and habitat parameters was analyzed using forward stepwise multiple regression, with variables entered and removed at critical values of p = 0.05 and p = 0.10, respectively (Egan 2001). Percentage data were arcsine transformed prior to analysis. Remaining habitat variables (Appendix 3) were tested for normality using the Shapiro-Wilks test of program STATISTICA (Statsoft 2000). Those not meeting assumptions of normality were transformed to best meet assumptions of normality using either the square root or log transformation procedures detailed in Zar (1996). Analysis was performed separately on within-pond and adjacent landscape variables. Since the known range of spotted salamanders at CACO only extends to High Head, pond P04 was excluded from the spotted salamander analysis. Similarly, since wood frogs are only known to occur in Eastham and into Wellfleet as far as W07, only the 22 ponds within this known range were included in the wood frog analysis.

Results

Spotted Salamander Egg Mass Counts

Of the 40 ponds sampled, a total of 6359 spotted salamander egg masses were detected in 29 (73%). Within its known range at CACO (i.e. omitting P04) the naïve occupancy rate (percentage of sampled ponds at which it was recorded) is 74% (29/39). Mean (± SE) number of egg masses per pond were 159 ± 45 for all 40 ponds, 163 ± 46 for all 39 ponds within the known range of spotted salamanders at CACO, and 219 ± 58 for the 29 ponds where egg masses were detected (range 1 to 1277). Maximum counts occurred predominantly in replicate two (table 1) whereas in 2004, maxima were more evenly distributed between replicates two and three (Cook et al. 2006).

Maximum egg mass counts were generally higher in 2005 than 2004. For 40 ponds with two year's data, the total number of egg masses increased from 5322 to 6359. However, 11 of these 40 ponds did not have egg masses in either year. Based only on the 29 ponds where egg masses were recorded, counts increased at 15 ponds, decreased at 13 and remained the same at 1 (table 2). Mean increase per pond was 96 egg masses, whereas mean decline was 31. Differences in egg mass counts between 2004 and 2005 were not significant (t= -1.3738, df=39, p=0.177). For the seven ponds with data from 2001 to 2005, the trend in combined egg mass counts was slightly positive (slope=0.080) and did not differ significantly from zero (p=0.90). Three of the seven ponds had positive slopes and four negative. None deviated significantly from zero (table 3). For the 14 ponds with data from 2002 to 2005, the trend in combined egg masses was negative (slope =-0.76), but not significantly different from zero (p=0.24) (table 4). Four of the 14 ponds had positive slopes and ten were negative. Only E11 deviated significantly from zero (slope= -0.97, p=0.03) (table 4). Yet, for the period from 2001 to 2005, there was no deviation from zero at E11 (slope=-0.33, p=0.59) (table 3).

After correcting for rainfall, the trend in combined egg mass count from 2001 through 2005 was not significant (r= -0.5049, p=0.495), nor was the correlation between egg mass count and migration season rainfall (r = -.725, p=0.166).

Table 1. Spotted salamander egg mass counts by replicate for 2005 at Cape Cod National Seashore. Bold indicates maximum count.

Pond	Replicate 1	Replicate 2	Replicate 3	Maximum Count
	3/29-4/08	4/11-4/20	4/25-5/06	
E02	0	**34**	32	34
E03	0	**44**	13	44
E04	0	**523**	388	523
E05	11	**613**	403	613
E05a	0	**276**	227	276
E06	0	**414**	344	414
E07	0	**130**	57	130
E08	0	**94**	76	94
E11	0	**99**	92	99
E11east	0	**4**	2	4
E18	0	1	**6**	6
E19	0	**111**	97	111
E21	0	**308**	271	308
E22	656	**1277**	757	1277
P04	0	0	0	0
T01	312	**446**	214	446
T02	37	**64**	27	64
T02C	0	**1**	0	1
T04	0	0	0	0
T08	0	0	0	0
T09	0	0	0	0
T14	0	**17**	7	17
T15	11	**31**	10	31
T16	0	0	0	0
T22	0	0	0	0
T23	4	**17**	9	17
T45	0	0	0	0
W01	276	**396**	215	396
W02	89	**151**	20	151
W04	0	0	0	0
W05	5	9	**11**	11
W06	14	**22**	7	22
W07	801	**1021**	247	1021
W11	0	0	0	0
W12	0	0	0	0
W14	0	**6**	3	6
W15	0	112	**117**	117
W16	0	**42**	41	42
W18	0	**84**	78	84
W24	0	**0**	0	0
Total	2216	6347	3771	6359

Table 2. Maximum count (MC) of spotted salamander egg masses in ponds with data from 2004 and 2005.

Pond	2004 MC	2005 MC	Change	%Change
E02	12	34	22	183%
E03	21	44	23	110%
E04	532	523	-9	-2%
E05	687	613	-74	-11%
E05a	297	276	-21	-7%
E06	396	414	18	5%
E07	193	130	-63	-33%
E08	93	94	1	1%
E11	124	99	-25	-20%
E11east	4	4	0	0%
E18	5	6	1	20%
E19	52	111	59	113%
E21	179	308	129	72%
E22	778	1277	499	64%
P04	0	0	0	0%
T01	541	446	-95	-18%
T02	95	64	-31	-33%
T02C	8	1	-7	-88%
T04	0	0	0	0%
T08	0	0	0	0%
T09	0	0	0	0%
T14	16	17	1	6%
T15	27	31	4	15%
T16	0	0	0	0%
T22	0	0	0	0%
T23	63	17	-46	-73%
T45	0	0	0	0%
W01	362	396	34	9%
W02	28	151	123	439%
W04	0	0	0	0%
W05	9	11	2	22%
W06	25	22	-3	-12%
W07	499	1021	522	105%
W11	0	0	0	0%
W12	0	0	0	0%
W14	12	6	-6	-50%
W15	114	117	3	3%
W16	48	42	-6	-13%
W18	102	84	-18	-18%
W24	0	0	0	0%
Total	5322	6359	1037	19%

Table 3. Trend analysis of spotted salamander egg mass maximum counts at seven CACO vernal ponds from 2001 through 2005.

Pond	2001 MC	2002 MC	2003 MC	2004 MC	2005 MC	Slope	R^2	*p*
E03	48	25	38	21	44	-0.1611	0.0260	0.7958
E04	503	1227	633	532	523	-0.3363	0.1131	0.5800
E05	174	596	767	687	613	0.6658	0.4433	0.2199
E06	168	599	575	396	414	0.2642	0.0698	0.6675
E07	92	226	269	193	130	0.0951	0.0090	0.8791
E11	101	359	254	124	99	-0.3277	0.1074	0.5903
E11east	0	29	24	4	4	-0.2025	0.0410	0.7439
All	1086	3061	2560	1957	1827	0.0795	0.0063	0.8988

Table 4. Trend analysis of spotted salamander egg mass maximum counts at 14 CACO vernal ponds from 2002 through 2005.

Pond	2002 MC	2003 MC	2004 MC	2005 MC	Slope	R^2	*p*
E02	30	50	12	34	-0.2150	0.0462	0.7850
E03	25	38	21	44	0.4781	0.2286	0.5219
E04	1227	633	532	523	-0.8506	0.7235	0.1494
E05	596	767	687	613	-0.0479	0.0023	0.9521
E05a	677	315	297	276	-0.8246	0.6799	0.1754
E06	599	575	396	414	-0.8957	0.8023	0.1043
E07	226	269	193	130	-0.8018	0.6429	0.1982
E08	243	250	93	94	-0.8823	0.7784	0.1177
E11	359	254	124	99	-0.9717	0.9442	0.0283
E11east	29	24	4	4	-0.9327	0.8699	0.0673
E21	434	261	179	308	-0.5570	0.3103	0.4430
E22	910	486	778	1277	0.5481	0.3004	0.4519
W06	8	27	25	22	0.6017	0.3620	0.3983
W15	81	64	114	117	0.7904	0.6247	0.2096
All	5444	4013	3455	3955	-0.7582	0.5748	0.2418

Wood Frog Egg Mass Counts

A total of 162 egg masses were recorded from 15 of 40 ponds sampled (38%). Within its known range at CACO the naïve occupancy rate was 68% (15/22). Mean (± SE) number of egg masses per pond were 4.05± 1.55 for all 40 ponds, 7.3604± 2.64 for all 22 ponds within the known range of wood frogs at CACO, and 10.8 ± 3.56 for the 15 ponds where egg masses were detected in 2005(range 1 to 56). Maximum counts occurred in replicate two (table 5).

Table 5. Summary of wood frog egg mass counts for 2005 season at Cape Cod National Seashore. Bold indicates maximum count.

Pond	Replicate 1	Replicate 2	Replicate 3	Maximum
	3/29-4/08	4/11-4/20	4/25-5/06	Count
E02	0	**1**	0	1
E03	0	**10**	0	10
E04	0	**22**	1	22
E05	39	**56**	0	56
E05a	0	**9**	0	9
E06	3	**8**	0	8
E07	0	**14**	0	14
E08	0	**1**	0	1
E11	0	**6**	2	6
E11east	0	**2**	1	2
E18	0	**8**	0	8
E19	0	**13**	0	13
E21	0	**8**	0	8
E22	0	**3**	0	3
P04	0	0	0	0
T01	0	0	0	0
T02	0	0	0	0
T02C	0	0	0	0
T04	0	0	0	0
T08	0	0	0	0
T09	0	0	0	0
T14	0	0	0	0
T15	0	0	0	0
T16	0	0	0	0
T22	0	0	0	0
T23	0	0	0	0
T45	0	0	0	0
W01	0	0	0	0
W02	0	0	0	0
W04	0	0	0	0
W05	0	0	0	0
W06	0	0	0	0
W07	0	0	0	0
W11	0	0	0	0
W12	0	0	0	0
W14	0	0	0	0
W15	0	0	0	0
W16	0	0	0	0
W18	0	**1**	0	1
W24	0	0	0	0
Sum	42	162	4	162

Of 22 ponds within the known range of RASY and with data from 2004 and 2005, eleven contained a total of 86 egg masses in 2004 and fifteen ponds contained 162 egg masses in 2005 (table 6). Differences in egg mass counts between years were not significant (t= -1.577, df=21, p=0.13). For twelve ponds with data from 2002 to 2005, the trend in combined egg masses was positive, but did not differ significantly from zero (slope=0.88, *p*=0.12). Nine ponds had a positive slope and three were negative. E07 was the only pond that deviated significantly from zero (slope= 0.97, *p*=0.03) (Table 7).

After correcting for rainfall, the trend in combined egg mass count from 2002 through 2004 was positive but not significant (r=0.96, *p*=0.18) nor was the correlation between egg mass count and migration season rainfall (r = .74, *p*=0.26).

Table 6. Maximum count in 2004 and 2005 of wood frog egg masses in ponds within the known range of the species as of 2005.

Pond	2004 MC	2005 MC	Change	%Change
E02	0	1	1	first verified occurrence
E03	1	10	9	900%
E04	4	22	18	450%
E05	16	56	40	250%
E05a	6	9	3	50%
E06	2	8	6	300%
E07	8	14	6	75%
E08	0	1	1	first verified occurrence
E11	2	6	4	200%
E11east	0	2	2	first verified occurrence
E18	2	8	6	300%
E19	9	13	4	44%
E21	22	8	-14	-64%
E22	14	3	-11	-79%
W07	0	0	0	0%
W11	0	0	0	0%
W12	0	0	0	0%
W14	0	0	0	0%
W15	0	0	0	0%
W16	0	0	0	0%
W18	0	1	1	first verified occurrence
W24	0	0	0	0%
Sum	86	162	76	88%

Table 7. Trend analysis of wood frog egg mass counts at twelve CACO vernal ponds from 2002 through 2005.

Pond	2002 MC	2003 MC	2004 MC	2005 MC	Slope	R^2	*p*
All	52	61	75	162	0.8780	0.7715	0.1216
E02	0	0	0	1	0.7750	0.6000	0.2254
E03	0	1	1	10	0.8260	0.6818	0.1743
E04	2	1	4	22	0.8210	0.6733	0.1795
E05	0	16	16	56	0.9080	0.8243	0.0921
E05a	9	15	6	9	-0.3100	0.0947	0.6922
E06	8	16	2	8	-0.3146	0.0990	0.6854
E07	3	7	8	14	0.9660	0.9323	0.0345
E08	0	0	0	1	0.7750	0.6000	0.2254
E11	0	1	2	6	0.9327	0.8699	0.0673
E11east	0	0	0	2	0.7750	0.6000	0.2254
E21	11	2	22	8	0.1690	0.0287	0.8306
E22	19	2	14	3	-0.5557	0.3100	0.4433

Environmental Conditions

Pond water temperatures in 2005 averaged 9.10, 9.10, and 11.30°C for replicates one, two, and three respectively (table 8). For 39 ponds with complete water temperature data in 2005, the mean water temperature was 9.90 °C. For 34 ponds with complete data from 2004 and 2005, the mean temperature was 10.01 in 2004 and 9.92 in 2005. Differences in water temperature were not significant between ponds ($F_{33,136}$=1.504, p=0.055) nor between years ($F_{1,136}$=0.033, p=0.86).

Maximum water depth in 2005 (table 9) ranged from 5 to 129 centimeters (cm), with a mean of 58.95 cm and a standard deviation of 26.80. For 40 ponds measured in 2004 and 2005, the mean maximum depth in 2004 (39.75 cm) was significantly less than in 2005 (58.95 cm) (t= -7.315, df=39, p=0.00000001). Total rainfall during the breeding migration season was 32.8 cm in 2001, 26.5 cm in 2002, 26.7 cm in 2003, 24.9 cm in 2004 and 28.6 cm in 2005.

Table 8. Water temperature (°C) of the forty ponds where egg mass counts were conducted in 2005, for each of three sampling replicates.

Pond	Rep 1	Rep 2	Rep 3
E02	11.0	6.0	11.0
E03	7.5	9.5	12.0
E04	6.0	9.0	12.0
E05	11.5	7.5	11.5
E05a	9.0	7.0	10.0
E06	9.5	8.5	14.0
E07	7.0	6.0	10.0
E08	9.0	8.0	15.0
E11	8.5	6.5	10.0
E11east	7.0	5.5	9.5
E18	8.0	7.0	10.0
E19	8.0	10.0	12.0
E21	6.0	9.0	11.0
E22	8.0	8.5	11.0
P04	9.0	21.5	11.0
T01	10.0	16.0	13.5
T02	10.5	8.0	9.0
T02C	12.0	12.0	19.0
T04	13.0	*dry*	17.5
T08	11.0	10.0	13.5
T09	12.0	12.5	9.0
T14	9.0	10.0	11.5
T15	9.0	12.0	9.0
T16	7.0	6.5	13.0
T22	11.5	11.0	13.5
T23	10.5	11.0	14.0
T45	18.0	14.0	9.0
W01	8.0	8.0	11.5
W02	9.0	9.0	13.0
W04	7.0	5.5	9.5
W05	12.0	11.5	13.0
W06	9.0	7.5	13.0
W07	11.5	15.5	12.5
W11	9.5	7.5	11.0
W12	10.0	9.5	9.0
W14	8.0	5.0	10.0
W15	5.5	6.5	9.0
W16	5.0	5.5	9.0
W18	8.0	5.5	8.0
W24	8.5	6.5	9.0
Mean*	9.1	9.1	11.3

*Mean based only on ponds with data from all three replicates (i.e. does not include T04).

Table 9. Maximum and mean water depth (cm) recorded during egg mass counts from 2003 through 2005. Mean represents the mean of the maximum depth recorded during three replicates in each of these three years.

Pond	Max 2003	Max 2004	Max 2005	Mean 2003	Mean 2004	Mean 2005
E02	59	30	45	51.75	26.67	41.33
E03	60.5	21	56	52.63	17.33	52.00
E04	71	32	64	63.00	27.00	60.33
E05	80	43	68	69.00	37.00	65.00
E05a	78	35	65	66.50	28.33	61.33
E06	87	51	91	79.00	44.00	87.67
E07	50	20	55	46.25	28.67	49.00
E08	65	43	61	61.50	37.67	55.33
E11	67	37	52	57.00	34.67	50.00
E11east	58	18	53	49.50	10.67	48.33
E18	***	60	86	***	50.00	81.67
E19	***	82	129	***	70.00	126.00
E21	106	53	103	100.50	52.00	99.00
E22	102	60	118	96.25	58.33	112.67
P04	77	40	71	75.00	37.67	69.00
T01	82	52	63	74.00	49.00	57.00
T02	***	26	36	***	20.67	29.33
T02C	***	27	27	***	22.67	24.33
T04	***	4	5	***	2.00	4.00
T08	***	5	22	***	1.67	15.33
T09	***	17	25	***	5.67	20.67
T14	***	79	74	***	74.67	69.33
T15	90	75	82	82.00	69.67	76.00
T16	***	20	21	***	18.67	17.67
T22	***	83	82	***	79.67	80.33
T23	***	49	52	***	45.33	46.67
T45	***	40	35	***	35.67	33.00
W01	74	56	73	62.50	51.67	60.00
W02	***	50	49	***	46.00	47.33
W04	***	41	50	***	31.00	47.67
W05	***	50	43	***	44.67	41.00
W06	56	36	45	53.00	31.33	39.67
W07	102	70	98	94.00	64.67	88.67
W11	***	16	30	***	15.00	24.00
W12	***	30	39	***	21.33	30.33
W14	***	24	40	***	18.50	37.33
W15	86	27	65	70.75	21.00	56.33
W16	***	40	80	***	37.67	68.33
W18	74	37	68	66.00	26.67	61.00
W24	***	11	37	***	6.33	32.33

***denotes sites that were not sampled in specified year

Pond area ranged from 0.25 to 23040 meter^2, with a mean of 2319 and a standard deviation of 4314. All ponds were acidic: pH ranged from 4.06 to 5.95, with a mean of 4.706 and a standard deviation of 0.497. Conductivity ranged from 31.9 to 126µS/cm with a mean of 60.89 and standard deviation of 17.12. Color, measured as the absorption coefficient at 440 nanometers (AbsCo440), ranged from 9.442 to 75.769, with a mean of 31.25 and standard deviation of 17.79. Physical parameters of individual ponds where egg mass counts were conducted are in Appendix 3.

Habitat Parameters and Spotted Salamander Egg Mass Counts

Woodland habitat comprised from 10 to 100% of pond adjacent habitat. Only a few ponds had any roads, field, wetland, or residential use within 50 m, and in these instances, those habitat and land use categories almost always accounted for only 5 to 10% of the adjacent zone (Appendix 3b). Of the adjacent landscape parameters, none were significant enough to be entered into the regression model. Within-pond vegetation tended to be a mix of both shrubby and emergent plants. Emergent vegetation comprised from 0 to 95% of a pond (mean 32%) and shrubby vegetation from 0 to 90% (mean 37%). Ponds heavily dominated by shrubs tended to lack emergent vegetation, and vice versa (Appendix 3). Of the within-pond parameters, maximum water depth was the only one that entered into the regression model (model adjusted $R^2 = 0.458$, $F\ 1_{,37} = 33.110$, $p < 0.000$) and had a significant standardized regression coefficient (*Beta*) of 0.687 ($p<0.000$).

Habitat Parameters and Wood Frog Egg Mass Counts

Of the landscape variables, number of adjacent vernal pools and road distance were entered into the model (model adjusted $R^2 = 0.509$, $F_{2,19} = 11.892$, $p < 0.000$). Number of adjacent pools and distance to paved road were significant variables, with standardized regression coefficients (*Beta*) of 0.784 ($p<0.000$) and -0.532 ($p=0.005$) respectively. Of the within-pond variables, pH and percent emergent vegetation were entered into the regression model (model adjusted $R^2 = 0.550$, $F_{2,19} = 13.808$, $p < 0.000$). pH and percent emergent vegetation were significant variables, with standardized regression coefficients (*Beta*) of 0.586 ($p=0.001$) and 0.424 ($p=0.010$) respectively.

Discussion

Temporal Trends in Spotted Salamander Egg Mass Counts

Annual variation in reproductive effort of *Ambystoma* salamanders is well documented. Numbers of egg masses deposited in a pond in a given year reflect both the size of the adult population and the proportion of that population that bred. Breeding populations vary more than adult populations, and long term data show orders of magnitude variation in breeding populations (reproductive effort) that is highly correlated with rainfall during the breeding migration season (Semlitsch 1987, Pechmann et al. 1991). Yet, data on spotted salamander collected by Shoop (1974) over a five year period in eastern Massachusetts do not show this correlation.

The data collected to date at CACO are short term and generally show variation in reproductive effort within the same order of magnitude (table 3, 4). A similar degree of annual variation over the short term has been found in spotted salamander populations elsewhere in Massachusetts (Shoop 1974, 5 years), Alabama (Blackwell et al. 2004, 6 years), Ohio (Brodman 2002, 12 years), and the Appalachia region (Petranka et al. 2004, 10 years). Given the limited data, several more years of monitoring will be necessary for meaningful trend analysis.

Spatial Variation in Spotted Salamander Egg Mass Counts

The influence of within-pond and adjacent landscape attributes on numbers of spotted salamander egg masses has been moderately well studied. In Pennsylvania, the number of eggs present in ponds was positively correlated with pH and pond size, and negatively correlated with total cations and silica (Rowe and Dunson 1993). In Ontario, number of eggs in ponds was positively correlated with alkalinity (Clark 1986, cited in Petranka 1998). In Rhode Island, spotted salamander occurrence was associated with presence of woodland habitat (Egan 2001) and number of eggs in ponds was negatively correlated with road density. Beyond those landscape features, large numbers of egg masses were more likely to be deposited in larger ponds with greater canopy closure, extensive shrub cover and persistent non-woody vegetation, and relatively longer hydroperiod (Egan and Paton 2004). Similarly, in eastern Massachusetts, viable populations of spotted salamanders were associated with relatively large (>1000 m^2), deep (>1 m), fishless, permanent or semi-permanent ponds with relatively open canopies in a well drained, topographically varied, unfragmented forested landscape (Windmiller 1996). In New Hampshire, numbers of spotted salamander egg masses were positively correlated with hydroperiod, amount of forest and agriculture, and distance to road (Mattfeldt 2004).

The ponds monitored at CACO are fewer than the numbers sampled in the some of the above works and were chosen for monitoring based, in part, on their known use by spotted salamanders. In addition, they are inside the park, in a relatively uniform forested landscape. Thus, the ponds monitored here at CACO represent a much narrower range of conditions than would be found in a random sample of vernal ponds from a larger geographic area. Consequently, the parameters that differentiate between ponds in a broad scale analysis may not be informative at the park scale. For example, whereas Windmiller (1996), Egan (2001), and Mattfeldt (2004) found that landscapes with low road density and high woodland habitat were positively correlated with occurrence and larger populations of spotted salamanders, all of the ponds monitored at CACO meet this description. The lack of any significant relationship between egg mass counts and adjacent habitat features is due to the fact that all ponds are essentially in woodlands with very low road density. With only one exception (W14), from 90 to 100% of their adjacent area is occupied by woodland and only 6 of 40 ponds have any paved roads within 50 meters (Appendix 3).

Water depth was the only significant within-pond variable, explaining 46% of the variability in numbers of egg masses in a pond. Since water depth is generally positively correlated with hydroperiod (Brooks and Hayashi 2002), a strong positive relationship between egg mass counts and water depth (hydroperiod) is consistent with findings from Rhode Island (Egan and Paton 2004), eastern Massachusetts (Windmiller 1996), New Hampshire (Mattfeldt 2004), and coastal Maine (Baldwin and Vasconcelos 2003). Also, given the positive relationship between hydroperiod and reproductive success in other *Ambystoma* species at a single pond over time (Semlitsch 1987, Pechmann et al. 1991), and the well established philopatry of spotted salamanders, it seems logical that among a group of vernal ponds, those with deeper water and longer hydroperiods would tend to support larger populations.

Landscape analysis throughout the Northeast U.S. has shown that the ideal landscape for spotted salamanders is a non-urbanized, non-fragmented, roadless, forested landscape with well drained soils and moderately hilly topography, containing long hydroperiod vernal ponds (Windmiller 1996, Gibbs 1998, Egan 2001, Guerry and Hunter 2002, Egan and Paton 2004, Mattfeldt 2004, Rubbo and Kiesecker 2005). This describes much of the CACO landscape, particularly the Eastham vernal pools area. This complex of ponds in close proximity, with varied hydroperiods and with many supporting large numbers of spotted salamanders appears exceptional. For example, whereas Windmiller (1996) found only 12 of 94 (13%) ponds occupied by spotted salamanders in the largely urbanized landscape in eastern Massachusetts had more than 104 egg masses (indicative of a viable population of 500 adults) eight of 14 (57%) ponds sampled in Eastham in 2004 did.

Further evidence that CACO provides an optimal landscape for spotted salamanders is seen in comparisons of naive occupancy rates and mean numbers of egg masses per pond between CACO and other geographic areas. At CACO, the 39 vernal ponds within the known range of spotted salamanders had a naive occupancy rate of 74% (29 of 39) and a mean number of egg masses per pond of 163 (range 0 to 1277, SE=45, includes ponds not occupied). Naive occupancy rate and mean number of egg masses/pond reported from elsewhere include: 67% (33/49) and 25.9 (range 0-217, SE=7) from New Hampshire (Mattfeldt 2004); 78% (28/36) and 45.4 (range 0-747, SE=21.1) in Rhode Island (Egan 2001); 49% (94/193) and 21.0 (range 0-374) in Concord, Massachusetts (Windmiller 1996); 70% (7/10) and 31.5 (range 0-230, SE=22.4) in Maryland (Albers and Prouty 1987); and 90% and 124 (SE=24.4) in western Virginia (Petranka et al. 2003a). In Pennsylvania, Rowe and Dunson (1993) report median numbers of spotted salamander egg masses/pond in four different regions of the state as 65 (range 0-456), 12 (range 0-195), 48 (range 0-361), and 146 (3-1298). In northeast Maine, occupancy rate was 52% (Guerry and Hunter 2002) and in three regions of the state, it varied from 66.3% to 93.3 % (71% overall) (Calhoun et al. 2003). These comparisons indicate that there are few areas where spotted salamanders are as widespread and abundant as CACO.

While CACO is noteworthy in that it appears to be a high quality landscape for supporting robust populations of spotted salamanders, urbanization, road construction, increased traffic volume, groundwater withdrawal, and habitat fragmentation all have the potential to reduce spotted salamander abundance. These stressors will likely have their greatest impacts outside of CACO, suggesting that CACO will become increasingly more important regionally for maintaining viable populations. However, considering that the negative effects of forest habitat alteration and road impacts can extend up to 300 meters (Windmiller 1996), there is also potential for these impacts to extend into the park.

Temporal Trends in Wood Frog Egg Mass Counts

Annual variation in reproductive effort in wood frogs is also well documented. Berven (1990) noted that breeding population size in Maryland varied by a factor of 10 over a seven year period and that breeding effort (number of egg masses) sometimes varied by a factor of 20 between consecutive years. Crouch and Paton (2000) found that numbers of egg masses in a pond varied by a factor of two to three from one year to the next, and in a group of Virginia ponds, numbers of breeding females sometimes varied annually by a factor of 10 to 20 (Berven and Grudzien 1990). Such variation primarily reflects a time-lagged response to variation in juvenile recruitment (Berven 1990, Petranka et al. 2003a) which in turn is a function of larval density and hydroperiod. A Maryland population was regulated by density-dependant factors affecting larval survival (i.e. survival was negatively correlated with number of eggs deposited) and hydroperiod. Larval survival at short hydroperiod ponds could vary dramatically between years due to pond drying whereas at the opposite extreme, more permanent ponds had lower larval survival, presumably due to presence of more predators (Berven 1990). Variation in numbers of breeding females (each wood frog egg mass represents one female, Crouch and Paton 2000) at CACO (tables 6 and 7) falls within this range of variation. The lack of significant trends is not surprising, given the short term nature of the data.

Spatial Variation in Wood Frog Egg Mass Counts

Similar to spotted salamanders, wood frog occurrence and abundance is generally associated with an unfragmented, roadless, forested landscape (Gibbs 1998, Egan 2001, Guerry and Hunter 2002, Egan and Paton 2004, Mattfeldt 2004, Porej et al. 2004, Rubbo and Kiesecker 2005). However, some subtle landscape level differences between these two species appear to exist, such as adjacent forested wetlands being a critical habitat component for wood frogs (Egan 2001). Though both wood frogs and spotted salamanders typically breed in fishless vernal ponds, there is a growing body of literature demonstrating that wood frog abundance is greatest in vernal ponds with short and intermediate hydroperiods and spotted salamander abundance is greatest in long hydroperiod vernal and semi-permanent ponds (Berven 1990, Rowe and Dunson 1993, Paton et al. 2000, Babbitt et al. 2003, Calhoun et al. 2003, Mattfeldt 2004, Egan and Paton 2004). While pond hydroperiod seems to be the most important within-pond factor, egg mass abundance of both species was also positively linked to ponds with extensive woody and non-woody emergent vegetation in Rhode Island (Egan and Paton 2004) and to pond volume, dissolved organic carbon in Pennsylvania (Rowe and Dunson 1993).

The significant positive relationship between wood frog abundance and number of adjacent pools at CACO contrasts with the results of Mattfeldt (2004) who found an inverse relationship between wood frog abundance and numbers of adjacent ponds. Mattfeldt (2004) speculated that when many ponds are in close proximity, there are several small populations rather than one large one. Similarly, Calhoun et al. (2003)

found that numbers of wood frog egg masses were greatest in isolated wetlands. The significant negative relationship between wood frog abundance and distance to paved roads is also inconsistent with studies demonstrating negative impacts of roads on amphibian breeding abundance (Egan and Paton 2004, Mattfeldt 2004).

These contrasting results at CACO are likely due to the expanding range of wood frogs at CACO. When this monitoring program began in 2002, the known range of wood frogs at CACO was limited to Eastham. By 2004, wood frogs had been recorded calling at W18 in South Wellfleet, and a 2005 calling record at W07 indicated they had leap-frogged over several suitable breeding ponds into northern Wellfeet. Thus, while Eastham remains the core of wood frog occurrence and abundance at CACO, their expansion into Wellfleet, typical of most range extensions, has been limited to a few scattered records. Analysis based on known range includes ponds from Wellfleet where wood frogs appear to have recently colonized and are still few and far between. Since the ponds in Wellfleet are more isolated from each other and paved roads than those in Eastham, it drives the analysis towards finding a positive relationship between wood frog egg mass numbers and numbers of adjacent ponds and proximity to paved roads. In contrast, analysis of abundance based only on ponds occupied by wood frogs found no significant adjacent landscape variables.

Wood frogs at CACO present a number of paradoxes. Their known distribution is limited to Eastham and Wellfleet . Within this distribution they appear widespread, yet uncommon. The naive occupancy rate at CACO, within its known range, is fairly high (68%), and compares favorably with other regions: e.g.17% in southwest Ontario (Hecnar and M'Closkey 1996); from 78% to 100% in Virginia (Petranka et al 2003a,b); 86%, 11%, and 8% in rural, urban, and suburban Pennsylvania (Rubbo and Kiesecker 2005); 43% in Ohio (Porej et al. 2004); 88% (Mattfeldt 2004) and 48% (Babbitt et al. 2003) in New Hampshire; 75% (Egan 2001) and 69% (Egan and Paton 2004) in Rhode Island; 82% in northeast Maine (Guerry and Hunter 2002), and in three regions of Maine, 39%, 51%, and 23% (Calhoun et al. 2003). In contrast, wood frog abundance at CACO is comparatively very low. Within its known range at CACO, the mean number of egg masses per pond (including ponds not occupied) is only 7.36. Similar studies, sampling multiple sites across a landscape, report a much greater abundance (mean number of egg masses/pond): e.g. 47.7 in New Hampshire (Mattfeldt 2004); 169 (Egan 2001) and 131 (Crouch and Paton 2000) in Rhode Island; 86.5 (Berven and Grudzien 1990) and 124 (Petranka et al. 2003b) in Virginia. Comparison with these and other studies (e.g. Rowe and Dunson 1993, Calhoun et al. 2003) indicates that wood frogs are not abundant at CACO.

The contrasting widespread distribution and abundance of spotted salamanders versus the localized rarity of wood frogs at CACO presents a puzzling situation for which several explanations were considered. Lazell (1976) describes a model of post-glacial colonization of Cape Cod by amphibians and reptiles in which more "northern" or cold adapted species are the first to arrive. Since wood frogs are the most northerly amphibian in North America they would be expected to precede, not follow spotted salamanders, which do not range as far north (Conant and Collins 1998). While the wood frog appears to be expanding its range onto the outer Cape and has recently been recorded as far out as South Wellfleet, spotted salamanders extend out much farther, to High Head in Truro.

Since most landscape level analyses find occurrence and abundance of these two species to be linked to the same factors, the forested and relatively unfragmented, roadless landscape full of vernal ponds at CACO, which appears ideal for spotted salamanders, should seemingly be so for wood frogs as well. While these two species appear to be highly correlated at a coarse landscape level, there is some evidence suggesting subtle differences at a finer scale. For example, Porej et al. (2004) found that while both spotted salamander and wood frog presence at breeding ponds were positively associated with a forested "core", wood frog presence also was correlated with the larger landscape being forested. Similarly, Egan (2001) found that the amount of forested upland within 1000 m of breeding ponds had a greater effect on wood frog abundance than on spotted salamanders. These findings suggest that wood frogs, which emigrate greater distances from their breeding ponds than spotted salamanders (Berven and Grudzien 1990, Madison 1997), extend their use of the landscape much further away from breeding ponds than do spotted salamanders, and hence require a more extensively forested landscape. Given that forest habitat at CACO is still in the process of recovering from colonial era deforestation (Eberhardt et al. 2003), if wood frogs were more sensitive to the extent of forest than spotted salamanders, they would be expected to be less common. While they are in fact less common, since wood frogs at CACO occur primarily in Eastham, where deforestation was more extensive than in Wellfleet or Truro (Eberhardt et al. 2003), it seems unlikely that the extent of woodland habitat is limiting the range and abundance of wood frogs at CACO.

Another subtle difference between wood frogs and spotted salamanders is the length of their larval period and consequent pond hydroperiod requirements. In Rhode Island, wood frogs required a minimum hydroperiod of 16.4 weeks, whereas for spotted salamanders it was 20 weeks (Paton et al. 2000). As noted above, wood frogs are most abundant and dominant in intermediate-duration vernal ponds whereas spotted salamanders are most abundant and dominant in long-duration vernal and semi-permanent ponds. In two of three regions studied in Maine, numbers of wood frog egg masses were negatively correlated with numbers of spotted salamander egg masses, and spotted salamander abundance was greatest in semi-permanent ponds (Calhoun et al. 2003). Similarly, in Pennsylvania, wood frogs dominated in areas where ponds tended to be low volume and spotted salamanders dominated in an area where pond volume was greater (Rowe and Dunson 1993). These studies suggest that landscape level abundance of wood frogs relative to spotted salamanders may be a function of which hydroperiod types dominate the landscape. While detailed hydroperiod data are not yet available to include in analysis of CACO's egg mass data, pond maximum depth data (Appendix 3) were normally distributed, suggesting that a broad range of hydroperiods with many intermediate depth ponds are present within our study area. The low numbers of wood frog egg masses, even at intermediate depth ponds, suggests that their rarity at CACO is not related to pond hydroperiod.

Another factor potentially determining the number of wood frog egg masses in a pond is the negative correlation between egg mass abundance and number of adjacent vernal ponds (Mattfeldt 2004). Isolated ponds contain greater numbers of egg masses (Calhoun et al. 2003), suggesting that when many ponds are in close proximity, reproductive effort is spread among them (Mattfeldt 2004). This seems plausible and likely very adaptive, and the ponds used by wood frogs at CACO are in fact in close proximity to other vernal ponds. Yet, the total number of wood frog egg masses at CACO (162 found in 15 ponds) barely exceeds most of the pond means detailed above. Clearly, wood frogs are uncommon at CACO, and neither extent of forested upland, hydroperiod, nor proximity to other vernal ponds seems to be a factor.

One other subtle difference between spotted salamanders and wood frogs is that wood frogs appear to require a more complex landscape to support seasonal shifts in habitat use. Whereas non-breeding spotted salamanders are primarily fossorial, spending most of their time underground in mammal burrows (Faccio 2003, Regosin et al. 2003a), wood frogs appear to move from breeding ponds in the spring to moist lowland forests in the summer and back to forested uplands adjacent to breeding ponds for hibernation (Regosin et al. 2003b). Wood frog occurrence and abundance at ponds in Rhode Island was positively linked to amount of nearby forested wetlands (Egan 2001). Given the positive relationship between survival of adult wood frogs and rainfall (Berven 1990), it would appear that wood frogs are more sensitive to dessication pressures and forested wetlands provide an important summer micro-habitat. CACO has few forested wetlands, with the largest, “Red Maple Swamp” in Eastham. Eastham is also the primary range of wood frogs here, suggesting that the rarity of wood frogs at CACO is due to a lack of forested woodlands.

ANURAN CALL COUNTS

Methods

Anuran call counts were conducted at a total of 30 sites (figs. 4-6), selected in a stratified random design to sample across the range of freshwater wetlands present at CACO, as well as along the length of the park’s long axis from Eastham to Provincetown (Paton et al. 2003). Each site was sampled weekly, for 15 consecutive weeks, beginning on April 12 and extending until July 21. The thirty sites were divided into three groups of 10 (survey routes one, two, and three). Within a given week, one survey route was sampled each night, such that a complete sampling of all 30 ponds occurred over the course of three nights, nearly always Tuesday, Wednesday, and Thursday.

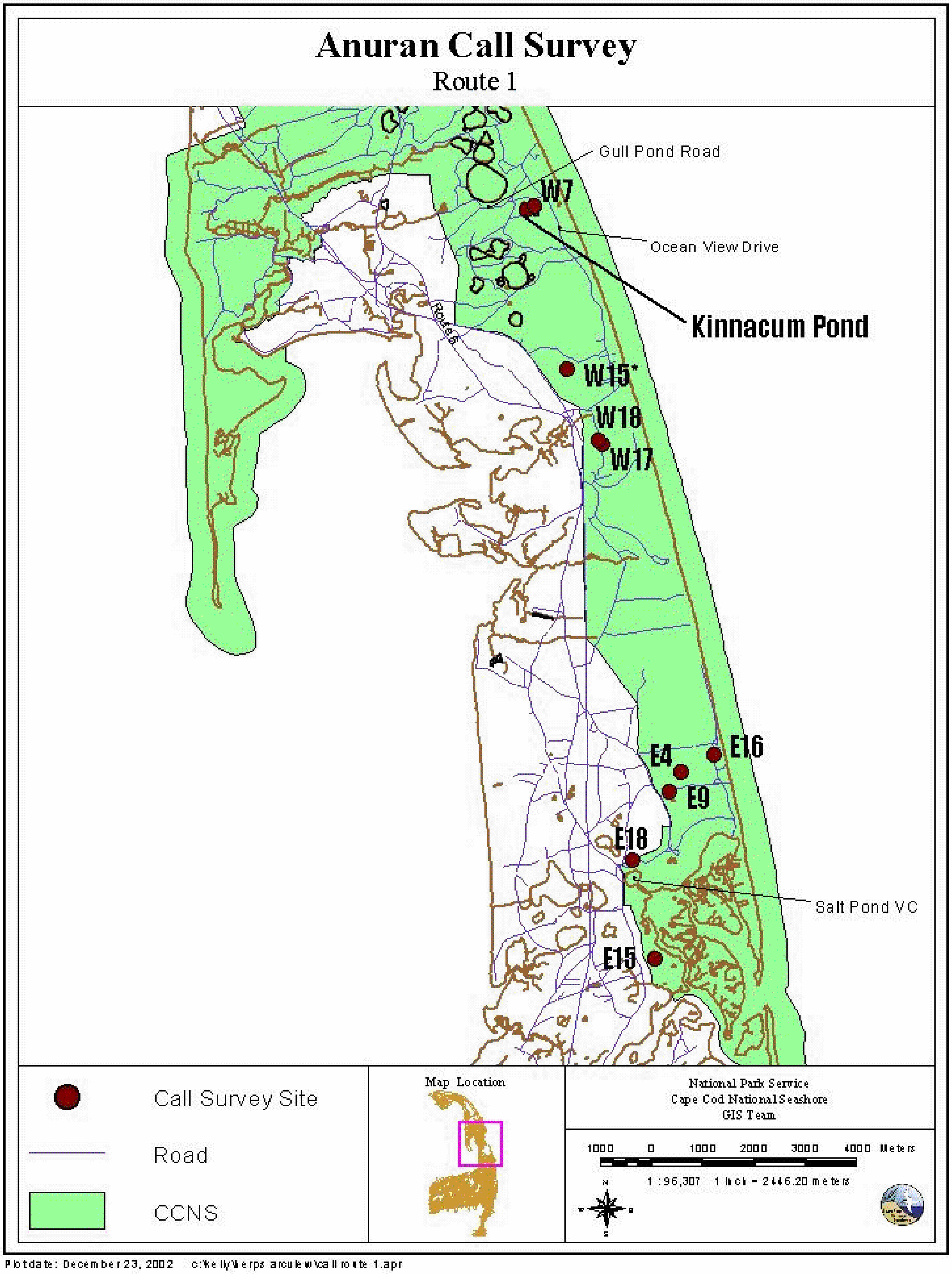
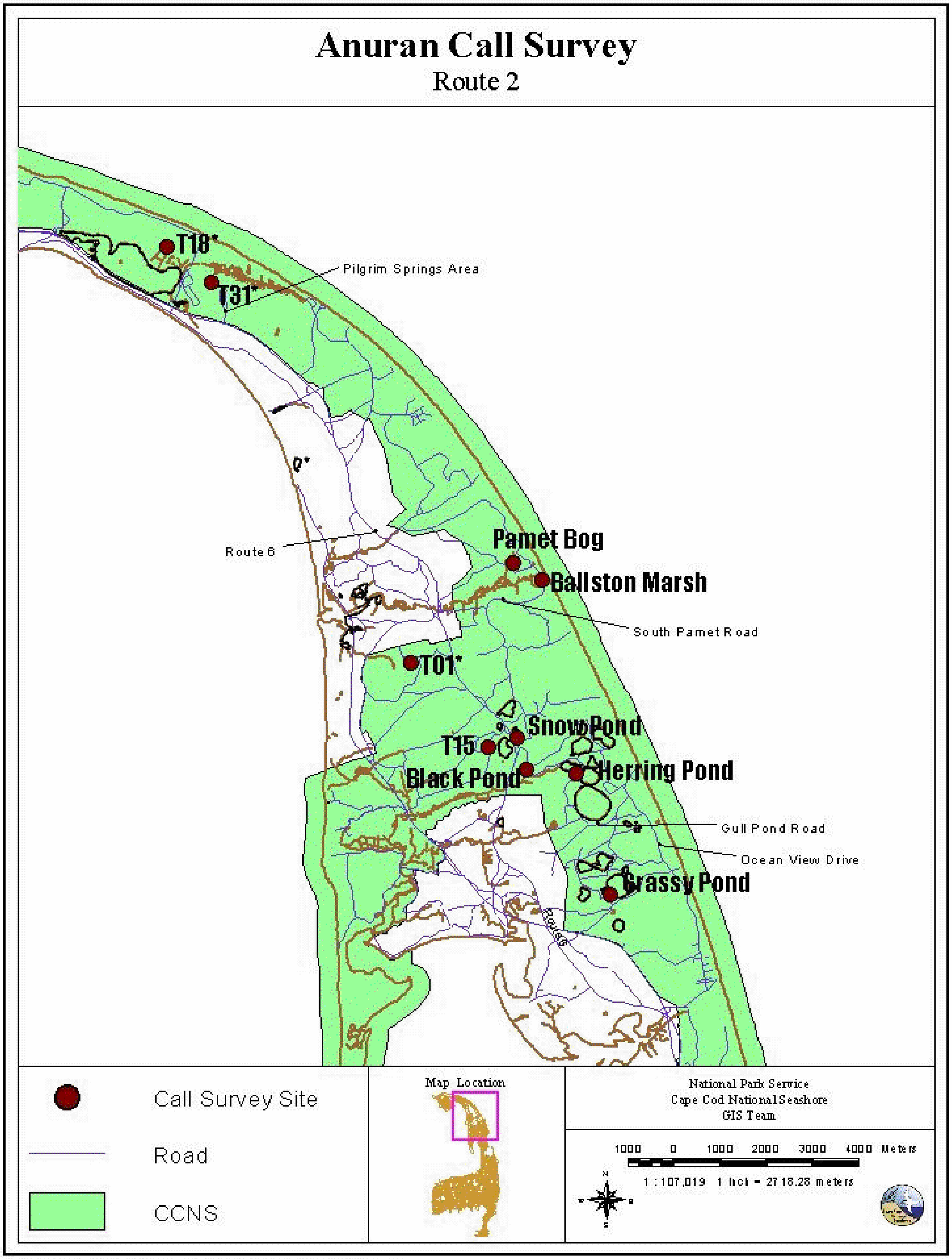


Figure 4. Anuran call survey Route 1.



Plotdate: December 23, 2002 c:\kelly\herps arcview\call route 1.apr

Figure 5. Anuran call survey Route 2.

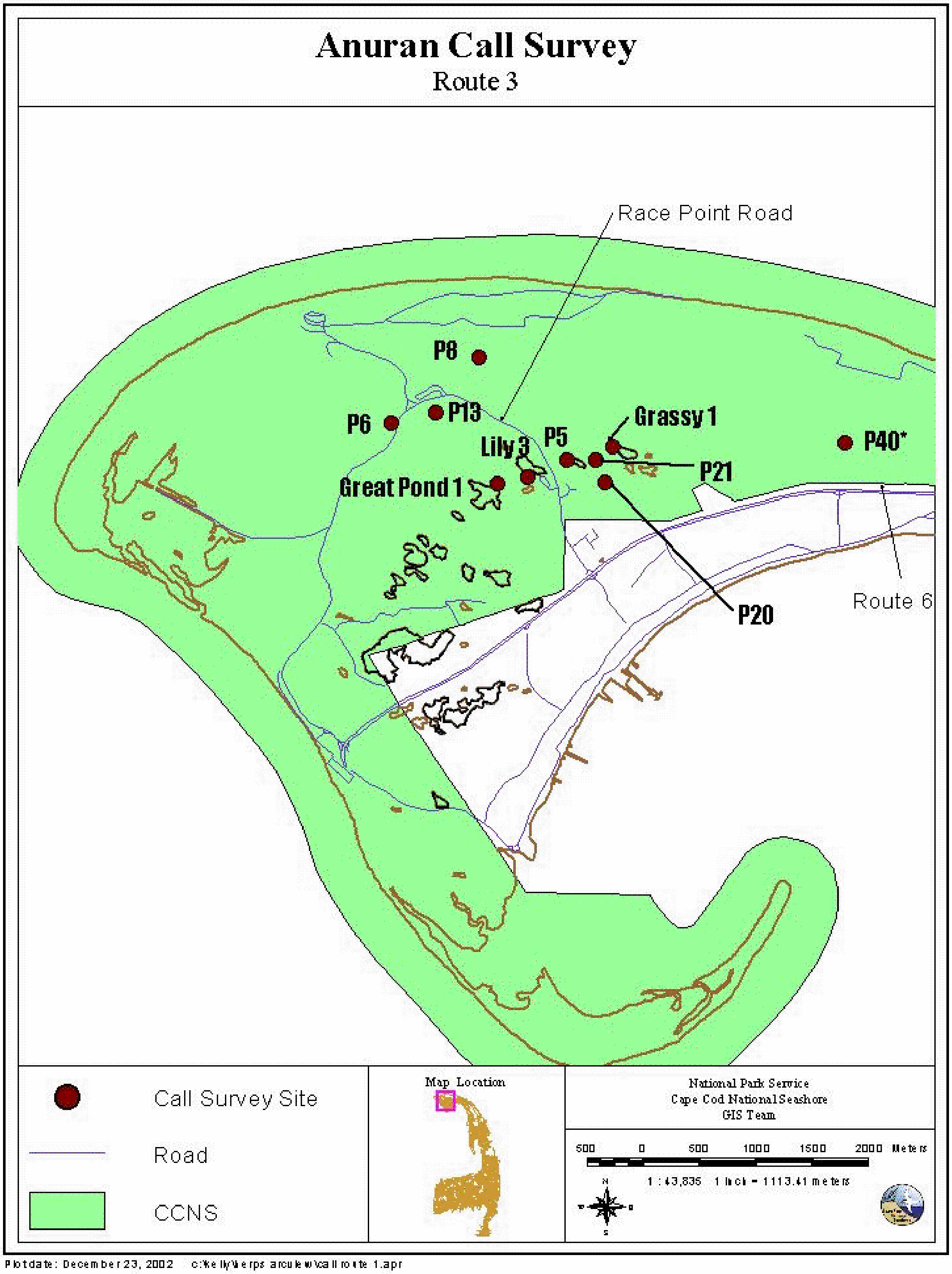


Figure 6. Anuran Call Survey Route 3.

Nightly sampling occurred from 30 minutes after sunset until ca. midnight – 0100 hours, and consisted of listening for and identifying anuran vocalizations. Vocalizations were scored according to an index value that ranged from zero to three (Mossman et al. 1998). In addition, data on air and water temperature, sky, wind, and precipitation conditions were recorded. See Paton et al. (2003) for further details of sampling procedure. Water samples from the 30 call count ponds were collected and analyzed in conjunction with those collected from ponds where egg mass counts were conducted.

Call count data were used as a measure of distribution based on sites recorded, and a measure of abundance based on the calling index. For each species, abundance at a particular site was based on the maximum index value recorded (Stevens et al. 2002). As a measure of a species' overall abundance at sites where it was present, the mean of these maxima was calculated (based only on sites where the species was present).

For each species recorded over the course of the season, program PRESENCE (MacKenzie et al. 2002) was used to estimate detection probability (probability of detecting a species at a site on a given sampling occasion, given it is actually present at the site) and determine the role of sampling covariates (air and water temperature) in detectability. The data set was reduced by only including data from the first to last week (inclusive) when a given species was recorded. PRESENCE was also used to estimate site occupancy rates (proportion of sites that species is estimated to occur at) for each species detected, and the relationship of each species occurrence to site covariates. One group of site covariates was based on hydroperiod (temporary, semi-permanent, or permanent) and a second group related to water chemistry (pH, conductivity, and color (AbsCo440)) (table 10). Temporary ponds were defined as ponds that dry out every or nearly every year. Conversely, semi-permanent ponds were defined as ponds that retain water in most years but dry out infrequently. Permanent ponds retain standing water even during droughts.

The process of constructing and selecting models to explain detectability and occurrence with PRESENCE involved first determining the best model for detectability. Pre-defined models for constant ($p(.)$) and time dependent ($p(\mathrm{t})$) probability of detection were run, and compared to custom models of detectability based on air and water temperatures and wind code recorded during sampling events. PRESENCE calculated the Akaike Information Criterion (AIC) for each model and, based on differences in AIC and a model weighting procedure detailed in Cooch and White (2001), the best model for explaining detectability was selected. Additional models testing the role of hydroperiod and water chemistry in explaining occurrence (ψ) were built upon the best detectability model. AIC weighting was used to determine the most informative hydroperiod and water chemistry covariates and a final model, containing both of these two covariates (and the detectability covariate) was constructed. These four models, plus a null model (constant occurrence, constant detectability) were compared based on AIC weighting, and the best overall model determined.

Between-year differences in each species' abundance (based on maximum index values) were analyzed using Friedman's ANOVA, which treated each year as a repeated measure of a subject (pond) (Statsoft 2000, Zar 1996). Between year differences in occupancy rates and mean abundance for the entire community were also analyzed with Friedman's ANOVA.

Results

A total of six species were recorded. Spring peepers (*Pseudacris crucifer*, PSCR) were the most widespread. They were detected at 28 sites and, at those sites, had a mean maximum index value of 2.57. Grey treefrogs (*Hyla versicolor*, HYVE) and pickerel frogs (*Rana palustris*, RAPA) were least widespread, detected at five sites, and pickerel frog was least abundant, with a mean maximum index value of 1.4 (table 10). Site occupancy rates estimated by PRESENCE ranged from 0.0.1667 for pickerel frogs to 0.9333 for spring peepers, and generally were very similar if not identical to a species' naive rate. Pickerel frogs were the most detectable (probability of detection=0.60) and Fowler's toads the least detectable (p=0.29) (table 11). There was a highly significant correlation between occupancy rate and abundance (Spearman's R=0.94, *p*=0.005).

In terms of seasonal chronology, spring peepers and pickerel frogs began calling earliest, at week one (4/12/05), and Fowler's toads (*Bufo fowleri*, BUFO) in week two (4/21/05). Green frogs (*Rana clamitans*, RACL) were first recorded in week four (5/4/04) and Grey treefrogs and bullfrogs (*Rana catesbiana*, RACA*)* in week nine (6/8/04). Breeding season duration (number of weeks from first to last records, inclusive) was shortest for gray treefrogs and bullfrogs (7 weeks) and longest for Fowler's toads and spring peepers (13weeks) (fig. 7).

The best models for explaining detection and occurrence varied by species. Grey treefrog detectability was positively correlated with water temperature and for bullfrog there was a negative correlation with wind. Pickerel frog detectability was constant, and for the remaining three species, detectability varied by sampling occasion but was not related to either temperature parameter (table 11, 12).

Table 10. Anuran call count maximum index values and site covariates for 2005. Mean maximum represents the mean of maximum values for a species based only on sites where the species was recorded. Hydro=hydroperiod and Cond=conductivity.

Route	SiteID	RACL	RACA	PSCR	RAPA	BUFO	HYVE	# Species	Wetland Type	Hydro	pH	Cond	AbsCo 440
1	E04	3	0	3	0	0	1	2	Vernal Pool	Temp	5.03	61.1	11.9756
1	E09	3	1	3	0	0	3	4	Vernal Pool	Temp	4.80	66.6	9.6726
1	E15	1	0	1	0	0	0	2	Swamp-red maple	Temp	3.99	130.0	53.1993
1	E16	2	0	3	0	0	0	3	Vernal Pool	Temp	4.34	230.0	44.6782
1	E18	1	0	3	0	0	0	3	Vernal Pool	Temp	5.84	53.2	14.0483
1	Kinnacum	2	2	2	1	2	0	4	Kettle Pond	Perm	4.80	72.9	0.9212
1	W07	2	0	3	1	0	0	4	Vernal Pool	Temp	4.99	60.3	38.6904
1	W15	1	0	3	0	0	0	1	Vernal Pool	Temp	4.30	56.4	18.4240
1	W17	0	0	0	0	0	0	1	Swamp-white cedar	Temp	3.83	143.0	35.2359
1	W18	1	0	3	0	0	0	1	Vernal Pool	Temp	4.69	71.0	74.6172
2	Ballston Marsh	0	2	1	0	3	0	4	Riparian Marsh	Perm	7.34	4320.0	1.6121
2	Black Pond	1	0	1	0	0	0	1	Riparian Marsh	Perm	6.27	87.1	1.8424
2	Grassy Pond	2	0	3	0	0	0	3	Kettle-shallow	Semi	4.50	53.7	27.1754
2	Herring Pond	1	2	2	2	0	0	5	Kettle Pond	Perm	6.88	97.7	0.4606
2	Pamet Bog	1	2	2	1	0	0	5	Bog	Perm	4.93	268.0	37.7692
2	Snow Pond	1	1	3	1	2	0	4	Kettle Pond	Perm	5.76	67.2	0.9212
2	T01	2	0	3	0	0	0	2	Vernal Pool	Semi	5.12	31.9	9.4423
2	T15	1	0	1	0	0	0	0	Vernal Pool	Temp	4.71	53.3	49.0539
2	T18	0	0	3	0	2	0	2	Dune Slack	Temp	4.99	83.4	7.1393
2	T31	2	1	3	0	0	0	2	Vernal Pool	Temp	4.18	82.8	21.1876
3	Grassy1	3	0	3	0	3	1	3	Interdune pond	Perm	4.54	83.6	15.4301
3	Great Pond 1	3	1	3	0	3	1	4	Interdune pond	Perm	5.95	61.8	10.1332
3	Lily3	2	0	3	0	2	0	3	Interdune pond	Semi	4.93	68.7	17.7331
3	P05	1	0	3	0	2	0	3	Dune Slack	Semi	4.42	85.9	20.7270
3	P06	1	0	3	0	3	0	2	Dune Slack	Temp	5.04	72.9	4.6060
3	P08	0	0	3	0	3	0	1	Dune Slack	Temp	4.74	88.8	7.1393
3	P13	0	0	3	0	2	0	3	Dune Slack	Temp	4.73	70.2	5.0666
3	P20	2	0	3	0	1	1	2	Interdune pond	Perm	4.43	81.1	16.3513
3	P21	0	0	0	0	0	0	0	Vernal Pool	Temp	4.15	88.6	39.6116
3	P40	0	0	2	0	3	0	2	Dune Slack	Temp	5.84	63.9	2.5333
Mean Max Index		1.696	1.500	2.571	1.200	2.385	1.400						
Total # Ponds		23	8	28	5	13	5						

Table 11. Results of analysis of anuran call count data by program PRESENCE. Best model explaining detectability (*p*) and occurrence (Ψ), naive occupancy rate (frequency of occurrence), estimated site occupancy rate (Ψ), and average probability of detection (*p*) for each species. Average probability of detection was obtained from the constant probability of detection model (p(.)).

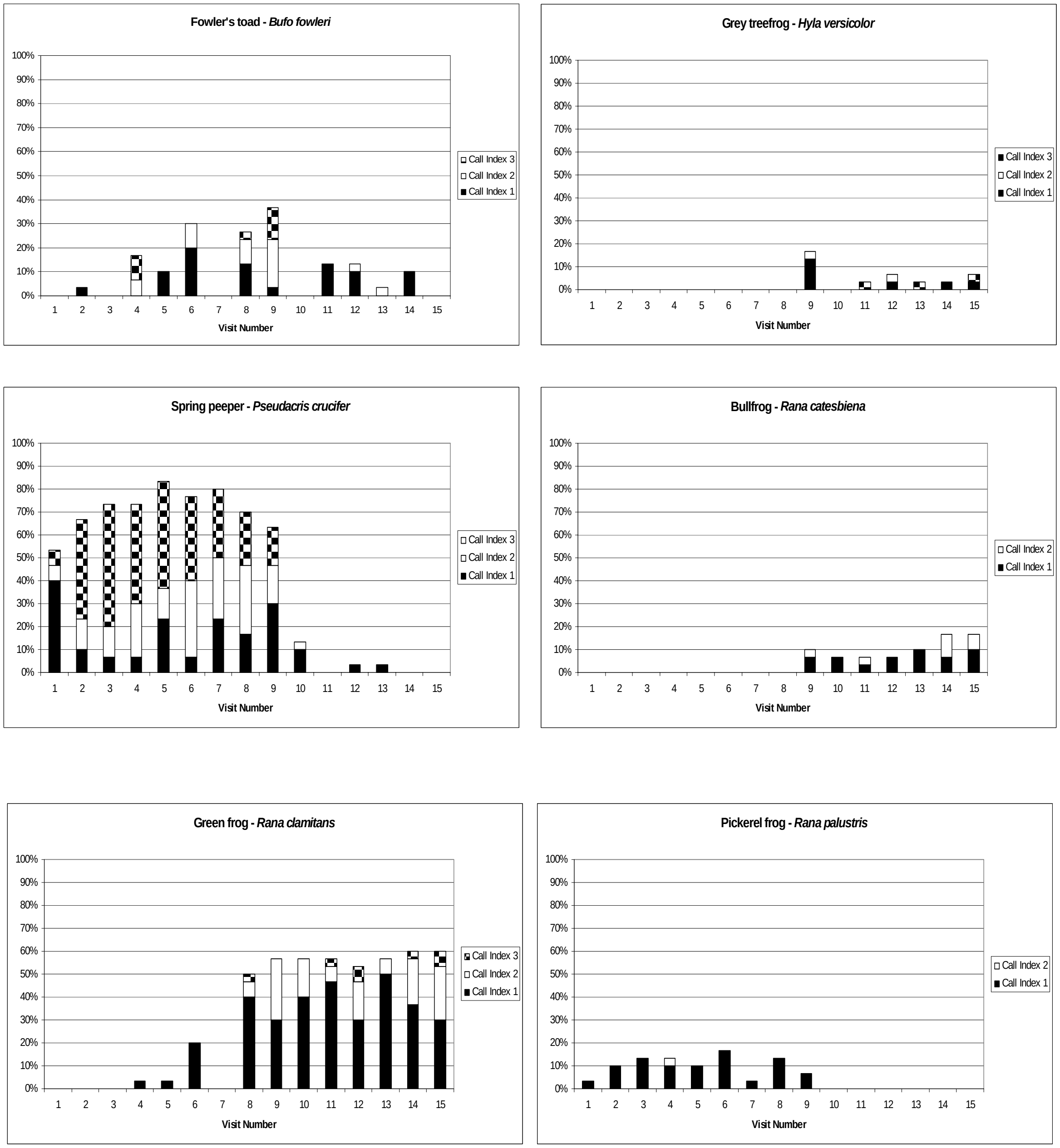
Species	Best Model	naïve	Ψ	*p*
BUFO	ψ(AbsCo) p(t)	0.4333	0.4345	0.29
HYVE	ψ(perm) p(water)	0.1667	0.2247	0.32
PSCR	ψ(pH) p(t)	0.9333	0.9333	0.54
RACA	ψ(perm) p(wind)	0.2667	0.2733	0.38
RACL	ψ(cond) p(t)	0.7667	0.7667	0.52
RAPA	ψ(perm) p(.)	0.1667	0.1667	0.60

Table 12. Coefficients for parameters included in “best” model for each species by Program PRESENCE.

Species	Parameter	Coefficients
BUFO	AbsCo440	-0.1114
HYVE	Permanent	1.6217
	Water	0.5327
PSCR	pH	28.4421
RACA	Permanent	2.9906
	Wind	-0.5359
RACL	Conductivity	-0.0018
RAPA	Permanent	2.7728

The most important parameter influencing species occurrence was hydroperiod, which affected three of six species, green frogs, pickerel frogs and grey treefrogs (table 11, 12). All had positive coefficients for permanent water. Fowler’s toads were negatively associated with water color, indicating an avoidance of highly colored waters. Green frogs had a weak negative association with conductivity and spring peepers a strong positive association with pH. In actuality, spring peepers occurred in ponds with pH ranging from 3.99 to 7.34, but the two sites it was absent from had pH of 3.83 and 4.15.

Figure 7. Seasonal variation in calling index values over course of sampling in 2005 for each encountered species. Black bars = Call Index 1, white bars = Call Index 2, checkered bars = Call Index 3.



Species site occupancy rates and mean maximum index values in 2005 were generally similar to those of 2003 and 2004, although there were significant between-year differences in abundance for HYVE, SCHO, and RACL (table 13). Community-level patterns of site occupancy and abundance did not differ significantly between years (Friedman's ANOVA χ^2 =0.60, p=0.74 for mean maximum abundance; χ^2 =1.45, p=0.48 for naïve occupancy rate; and χ^2 =3.27, p=0.20 for estimated occupancy rate).

Table 13. Comparison of naive and estimated site occupancy rates and mean maximum calling index for anuran species detected in 2003, 2004 and 2005. χ^2 and p obtained from Friedman's ANOVA, testing each species' between–year abundance.

Species	2003 naive	2004 naive	2005 naive	2003 Ψ	2004 Ψ	2005 Ψ	2003 Mean	2004 Mean	2005 Mean	X^2	p
BUFO	0.500	0.400	0.433	0.502	0.417	0.44	1.87	1.75	2.385	3.16	0.206
HYVE	0.100	0.033	0.1667	0.333	0.033	0.22	1.00	1.00	1.400	**6.33**	**0.042**
PSCR	0.900	0.900	0.933	0.900	0.900	0.93	2.56	2.81	2.571	1.54	0.462
RACA	0.267	0.267	0.2667	0.272	0.268	0.27	1.33	1.38	1.500	2	0.368
RACL	0.700	0.733	0.7667	0.700	0.733	0.77	1.43	1.48	1.696	**6.24**	**0.044**
RAPA	0.170	0.133	0.1667	0.170	0.133	0.17	1.80	1.50	1.200	1.33	0.513
RASY	0.067	0.100	0	0.067	0.175	0	1.00	1.67	0.000	3.85	0.146
SCHO	0.100	0.000	0	0.100	0.000	0	3.00	0.00	0.000	**6**	**0.049**

Discussion

Although too soon to detect trends, the first three year's data suggest that CACO's anuran community may be fairly stable in terms of distribution and abundance. Occupancy rates and abundance varied little between years (table 13) and there was no difference in community level patterns. The few differences in abundance generally involved species that are difficult to detect or with limited distributions, such as spadefoot toads, wood frogs, and gray treefrogs. Spadefoot toads and wood frogs are explosive breeders with short breeding seasons, and are not well suited for monitoring by nighttime calling surveys (Crouch and Paton 2002, Paton et al. 2003). These species are detected on such few occasions that small year to year differences may appear large. For example, spadefoots were detected in full chorus at three sites in 2003 and none in 2004 or 2005. Gray treefrogs were detected at three sites in 2003, one in 2004, and five in 2005. In contrast, green frogs are widespread and highly detectable (tables 11 and 13), and the significant difference in abundance suggests they are becoming more abundant.

Of the eight anurans known to occur at CACO, six were recorded in 2005. Only spadefoot toads and wood frogs, noted as difficult to monitor using this protocol, were missed. However, spadefoot eggs were observed at other CACO sites, indicating it bred in 2005. For the six species recorded, patterns of habitat use were similar to those observed in 2003 and 2004, and conform to known habitat affinities for these species (Lazell 1976, Klemens 1993). Distributions of some species, however, continue to be puzzling. Gray treefrogs were recorded in Provincetown in 2003 and 2005, but were only recorded in Eastham in 2004. This species, first recorded at CACO in Eastham in 2001, has never been recorded in Wellfleet or Truro, despite apparently suitable breeding habitat. While wood frogs were only recorded during surveys in Eastham, one was heard calling at W07 in Wellfleet on April 7, 2005 during an egg mass count. As discussed above, the distribution and abundance of wood frogs seems to be limited by a lack of summer habitat (forested wetlands) rather than a lack of vernal pond breeding sites. Pickerel frogs were only recorded at a small number of sites from northern Wellfleet and Truro and seemingly correspond to the distribution of their suitable habitat, permanent clearwater ponds. Similarly, the remaining species are fairly widespread and have a distribution that essentially reflects the distribution of their preferred habitats.

Site occupancy rates of CACO anurans show both similarities and differences compared to other areas sampled with anuran call counts. Spring peepers were most widespread at CACO (occurring at 93% of sites) as well as in Southern Rhode Island (68% of sites) (Crouch and Paton 2002) and Prince Edward Island, Canada (90%)(Stevens et al. 2002). However, while both Crouch and Paton (2002) and Stevens et al. (2002) found wood frogs to be the second most widespread species (occurring at 65% and 83% of sites, respectively), wood frogs are the most geographically restricted CACO anuran, occurring only in Eastham and Wellfleet. They were not even recorded in 2005. This difference is likely due to two factors. While woodland vernal pond habitat is widespread at CACO, wood frogs have only been recorded during calling surveys from vernal ponds in Eastham. As discussed previously, this limited range and abundance seems to be the result of limited forested wetland at CACO. In addition, since wood frogs typically breed in small vernal ponds, some of this disparity is due to sampling bias. Ponds sampled by Crouch and Paton (2002) and Stevens et al. (2002) tended to be smaller than those sampled at CACO, and thus more likely to be used by wood frogs.

Green frogs, the second most widespread species at CACO and a species of permanent water bodies, had a 77% naive occupancy rate here, but only 32% in Rhode Island. This difference is also likely due to differences in the size and permanence of sample sites. For the remaining species, occupancy rates were similar to those reported by Crouch and Paton (2002). In addition, patterns of seasonal chronology and breeding season duration were also similar to those reported from southern Rhode Island (Crouch and Paton 2002), though the breeding season on Cape Cod is generally a few weeks later in the year.

RECOMMENDATIONS

While we have attempted some trends analysis with these limited data, a more in-depth analysis should be conducted after five years. In addition to trends, this analysis should look at annual variability, power, and sampling frequency to determine if protocol modifications are called for. Until then, we plan to continue annual monitoring.

For both egg mass counts and anuran call counts, further research and consideration should be given to identifying, defining, measuring, and analyzing pond and landscape parameters and their relationship to the distribution and abundance of target species. In particular, the relationship of wood frog presence and abundance to extent of forested upland and wetlands should be examined. Additional monitoring of pond water depth is also needed to better characterize pond hydroperiod.

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Appendix 1. Ponds sampled for egg masses in 2005 at Cape Cod National Seashore.

Name	Town	Easting	Northing	Protocol
E02	E	420291	4633806	Both
E03	E	420420	4633929	Both
E04	E	420298	4634044	CACO
E05	E	420071	4634077	Both
E05A	E	420077	4633994	Both
E06	E	420225	4634328	Both
E07	E	420337	4634250	CACO
E08	E	420533	4634102	Both
E11	E	420196	4633918	CACO
E11east	E	420262	4633908	CACO
E18	E	419653	4632264	PAO
E19	E	419756	4632112	PAO
E21	E	420069	4632956	CACO
E22	E	419936	4632907	CACO
P04	P	401405	4657852	Both
T01	T	412586	4648436	CACO
T02	T	414157	4648575	PAO
T02C	T	414190	4648487	PAO
T04	T	414546	4647955	PAO
T08	T	416490	4647582	PAO
T09	T	415993	4647319	PAO
T14	T	414260	4646585	PAO
T15	T	414104	4646568	CACO
T16	T	414467	4646406	PAO
T22	T	414530	4650759	PAO
T23	T	414436	4650994	PAO
T45	T	410416	4655998	PAO
W01	W	411106	4645239	PAO
W02	W	410864	4644444	PAO
W04	W	416834	4646324	PAO
W05	W	416160	4645808	PAO
W06	W	415966	4645301	Both
W07	W	417431	4644996	CACO
W11	W	417499	4644021	PAO
W12	W	417231	4643191	PAO
W14	W	418540	4642523	PAO
W15	W	418064	4641832	Both
W16	W	417823	4641952	PAO
W18	W	418750	4640381	CACO
W24	W	417886	4642081	PAO

Both=ARMI PAO and CACO protocol pond
PAO=ARMI PAO protocol only pond
CACO=CACO protocol pond, not on PAO list

Appendix 2. Water quality data collected from all amphibian monitoring sites in 2005.

Pond	Date	pH	Alkalinity	Conductivity	Cl$^-$ (mg/L)	Cl$^-$ mM)	SO$_4^{2-}$ (mg/L)	SO$_4^{2-}$ (mM)	Cl:SO$_4$	AbsCo440
Ballston Marsh	5/4/2005	7.34	58.10	4320.0	10560.0	297.862	1440.0	14.990	19.871	1.612
Black Pond	5/3/2005	6.27	4.75	87.1	28.7	0.810	6.9	0.072	11.271	1.842
E02	4/27/2005	4.55	-1.80	50.4	12.7	0.358	0.2	0.002	172.062	11.976
E03	4/25/2005	4.84	-0.40	59.6	17.8	0.502	0.8	0.008	60.289	19.576
E04	4/25/2005	5.03	0.00	61.1	19.1	0.539	1.0	0.010	51.754	11.976
E05 main	4/26/2005	4.70	-1.10	62.9	19.5	0.550	1.6	0.017	33.024	18.654
E05a	4/27/2005	5.45	1.90	57.9	16.9	0.477	0.6	0.006	76.321	16.582
E06	4/26/2005	5.03	0.10	56.8	16.9	0.477	0.9	0.009	50.881	16.351
E07	4/27/2005	4.77	-1.00	56.1	16.3	0.460	0.5	0.005	88.334	17.042
E08	4/26/2005	4.46	-2.10	56.9	16.2	0.457	0.6	0.006	73.160	11.745
E09	4/25/2005	4.80	-0.70	66.6	21.3	0.601	1.9	0.020	30.376	9.673
E11	4/27/2005	4.80	-0.75	59.6	16.8	0.474	0.5	0.005	91.044	14.048
E11east	4/27/2005	4.79	-0.70	69.3	19.9	0.561	1.5	0.016	35.948	31.551
E15	4/27/2005	3.99	-6.40	130.0	38.5	1.086	1.7	0.018	61.365	53.199
E16	4/26/2005	4.34	-3.40	230.0	43.8	1.200	1.3	0.014	183.500	44.678
E18	4/25/2005	5.84	4.10	53.2	12.7	0.358	0.9	0.009	38.236	14.048
E19	4/25/2005	5.87	3.30	56.2	16.9	0.477	0.8	0.008	57.241	13.357
E21	4/25/2005	5.58	2.60	56.9	15.8	0.446	1.4	0.015	30.580	13.588
E22	5/2/2005	4.83	-0.60	56.8	15.6	0.440	0.9	0.009	46.967	17.273
Grassy_W	5/9/2005	4.50	-1.80	53.7	14.5	0.409	1.5	0.016	26.193	27.175
Grassy1_P	5/10/2005	4.54	-1.35	83.6	27.7	0.781	4.0	0.042	18.764	15.430
Great1_P	5/10/2005	5.95	1.50	61.8	20.1	0.567	2.6	0.027	20.948	10.133
Herring Pond	4/26/2005	6.88	5.20	97.7	34.1	0.962	5.9	0.061	15.661	0.461
Kinnacum Pond	8/4/2005	4.80	-0.45	72.9	20.5	0.578	2.6	0.027	21.364	0.921
Lily Pond 3	5/10/2005	4.93	-0.30	68.7	23.7	0.668	2.3	0.024	27.921	17.733
P04	5/4/2005	4.29	-0.85	76.7	20.7	0.584	1.7	0.018	32.994	50.436
P05	5/10/2005	4.42	-1.40	85.9	29.5	0.832	1.7	0.018	47.020	20.727
P06	5/9/2005	5.04	-0.25	72.9	26.5	0.747	2.5	0.026	28.722	4.606
P08	5/9/2005	4.74	-0.70	88.8	32.5	0.917	3.6	0.037	24.462	7.139
P13	5/9/2005	4.73	-0.65	70.2	25.0	0.705	1.8	0.019	37.634	5.067
P20	5/10/2005	4.43	-1.45	81.1	26.4	0.745	3.4	0.035	21.040	16.351
P21	5/10/2005	4.15	-4.20	88.6	26.4	0.745	2.3	0.024	31.102	39.612

Pond	Date	pH	Alkalinity	Conductivity	Cl^- (mg/L)	Cl^-(mM)	SO_4^{2-} (mg/L)	SO_4^{2-} (mM)	$Cl:SO_4$	AbsCo440
P40	5/10/2005	5.84	1.00	63.9	23.1	0.652	2.3	0.024	27.214	2.533
Pamet Bog	5/6/2005	4.93	-0.05	268.0	101.7	2.900	7.7	0.080	36.300	37.769
Snow Pond	4/20/2005	5.76	0.40	67.2	20.0	0.564	3.7	0.039	14.647	0.921
T01	5/4/2005	5.12	-0.05	31.9	7.8	0.220	0.6	0.006	35.225	9.442
T02	5/5/2005	4.99	0.50	41.7	7.3	0.206	1.3	0.014	15.216	51.127
T02C	5/5/2005	4.39	-1.90	50.6	8.2	0.231	1.5	0.016	14.813	60.108
T04	5/5/2005	4.06	-4.95	52.6	7.7	0.217	1.1	0.011	18.967	34.084
T08	5/5/2005	4.37	-1.85	66.8	16.7	0.471	1.3	0.014	34.808	56.654
T09	5/5/2005	4.28	-0.60	59.6	13.3	0.375	1.0	0.010	36.038	39.842
T14	5/6/2005	4.33	-3.45	55.6	12.2	0.344	0.9	0.009	36.731	33.854
T15	5/6/2005	4.71	-1.25	53.3	12.8	0.361	1.6	0.017	21.677	49.054
T16	5/6/2005	4.68	-1.55	42.2	6.2	0.175	1.0	0.010	16.800	48.363
T18	5/10/2005	4.99	-0.20	83.4	32.7	0.922	2.5	0.026	35.442	7.139
T22	5/6/2005	4.33	-3.50	62.5	17.4	0.491	0.5	0.005	94.295	43.987
T23	5/5/2005	4.39	-1.20	63.9	19.0	0.536	1.1	0.011	46.803	41.684
T31	5/9/2005	4.18	-3.15	82.8	40.0	1.128	20.0	0.208	5.419	21.188
T45	5/5/2005	4.41	-1.95	109.0	39.3	1.109	1.1	0.011	96.808	36.848
W01	5/3/2005	5.09	0.50	52.4	14.7	0.415	1.0	0.010	39.832	21.418
W02	5/3/2005	5.95	5.00	126.0	46.5	1.312	1.6	0.017	78.749	43.987
W04	5/4/2005	4.63	-1.65	63.2	17.4	0.491	2.2	0.023	21.431	32.472
W05	4/28/2005	4.09	-6.15	81.8	20.4	0.575	0.8	0.008	69.096	75.769
W06	5/2/2005	4.33	-3.85	59.8	12.6	0.355	1.7	0.018	20.083	45.139
W07	5/4/2005	4.99	0.15	60.3	18.2	0.513	1.2	0.012	41.096	38.690
W11	5/9/2005	4.10	-3.90	47.2	9.9	0.279	0.8	0.008	33.532	19.806
W12	5/4/2005	4.41	-1.80	50.2	12.1	0.341	0.9	0.009	36.430	19.345
W14	5/9/2005	4.50	-2.25	93.3	32.1	0.905	2.3	0.024	37.817	37.309
W15	5/9/2005	4.30	-0.75	56.4	14.3	0.403	1.5	0.016	25.832	18.424
W16	5/9/2005	4.11	-3.70	49.8	10.8	0.305	0.9	0.009	32.516	15.430
W17	4/27/2005	3.83	-8.50	143.0	37.1	1.046	3.4	0.035	29.567	35.236
W18	4/27/2005	4.69	-1.55	71.0	20.0	0.564	1.7	0.018	31.878	74.617
W24	5/9/2005	4.17	-3.35	44.0	6.9	0.195	1.3	0.014	14.382	24.412

Appendix 3a. Maximum counts of spotted salamander (AMMA) and wood frog (RASY) egg masses and within-pond variables used in habitat analysis. Columns 9-15 are % cover.

Pond	AMMA	RASY	Depth	Area	pH	Cond	AbsCo	SAV	Emerg	Lily	Shrub	Tree	Water	Deadfall
E02	34	1	45	3296	4.55	50.4	11.98	0	15	0	85	0	0	0
E03	44	10	56	960	4.84	59.6	19.58	0	75	0	15	5	5	0
E04	523	22	64	1760	5.03	61.1	11.98	0	75	0	10	5	10	0
E05a	276	9	65	648	5.45	57.9	18.65	0	95	0	5	0	0	0
E05	613	56	68	2232	4.70	62.9	16.58	0	90	0	5	0	5	0
E06	414	8	91	1700	5.03	56.8	16.35	0	90	0	5	0	5	0
E07	130	14	55	990	4.77	56.1	17.04	0	85	0	5	5	5	0
E08	94	1	61	6432	4.46	56.9	11.75	5	55	5	35	0	0	0
E11	99	6	52	1025	4.80	59.6	14.05	0	80	0	15	0	0	5
E11e	4	2	53	297	4.79	69.3	31.55	0	15	0	35	0	40	10
E18	6	8	86	1768	5.84	53.2	14.05	5	15	0	75	5	0	0
E19	111	13	129	2501	5.87	56.2	13.36	0	0	0	60	0	40	0
E21	308	8	103	957	5.58	56.9	13.59	0	45	0	5	0	50	0
E22	1277	3	118	23040	4.83	56.8	17.27	10	15	0	50	10	15	0
P04	0	0	71	384	4.29	76.7	50.44	0	0	0	20	10	55	15
T01	446	0	63	2691	5.12	31.9	9.44	15	45	15	5	0	20	0
T02	64	0	36	65	4.99	41.7	51.13	0	15	0	5	5	65	10
T02C	1	0	27	360	4.39	50.6	60.11	0	75	0	0	5	5	15
T04	0	0	5	0	4.06	52.6	34.08	nd	nd	0	nd	nd	0	0
T08	0	0	22	640	4.37	66.8	56.65	0	5	0	80	10	5	0
T09	0	0	25	1064	4.28	59.6	39.84	0	0	0	55	15	30	0
T14	17	0	74	608	4.33	55.6	33.85	0	0	0	10	10	60	20
T15	31	0	82	672	4.71	53.3	49.05	0	0	0	50	10	40	0
T16	0	0	21	239	4.68	42.2	48.36	0	0	0	10	5	70	15
T22	0	0	82	1008	4.33	62.5	43.99	0	0	0	85	0	15	0
T23	17	0	52	1750	4.39	63.9	41.68	0	10	0	80	10	0	0
T45	0	0	35	630	4.41	109.0	36.85	0	60	0	20	10	0	0
W01	396	0	73	1708	5.09	52.4	21.42	0	0	0	90	5	0	0
W02	151	0	49	13770	5.95	126.0	43.99	0	45	0	45	0	10	0
W04	0	0	50	1272	4.63	63.2	32.47	0	0	0	20	25	25	30
W05	11	0	43	10530	4.09	81.8	75.77	0	0	0	70	10	5	15
W06	22	0	45	1696	4.33	59.8	45.14	0	0	0	20	30	20	30

Pond	AMMA	RASY	Depth	Area	pH	Cond	AbsCo	SAV	Emerg	Lily	Shrub	Tree	Water	Deadfall
W07	1021	0	98	2304	4.99	60.3	38.69	0	40	0	25	5	5	25
W11	0	0	30	510	4.10	47.2	19.81	0	5	0	89	2	4	0
W12	0	0	39	480	4.41	50.2	19.35	0	65	0	30	0	5	0
W14	6	0	40	114	4.50	93.3	37.31	0	60	0	15	20	5	0
W15	117	0	65	160	4.30	56.4	18.42	0	0	0	15	0	65	20
W16	42	0	80	2250	4.11	49.8	15.43	0	25	0	70	0	5	0
W18	84	1	68	154	4.69	71.0	74.62	0	5	0	60	0	35	0
W24	0	0	37	108	4.17	44.0	24.41	0	10	0	40	0	40	10

Appendix 3b. Adjacent habitat variables used in habitat analysis. Columns 2 – 6 are % cover.

Pond	Woods	Road	Paved	Field	Resid	Adjpool	RdDist
E02	97	3	0	0	0	6	530
E03	97	3	0	0	0	6	565
E04	100	0	0	0	0	10	454
E05a	100	0	0	0	0	4	414
E05	100	0	0	0	0	6	355
E06	100	0	0	0	0	3	185
E07	100	0	0	0	0	5	258
E08	100	0	0	0	0	5	397
E11	100	0	0	0	0	6	506
E11e	100	0	0	0	0	6	569
E18	90	5	5	5	0	3	31
E19	100	0	0	0	0	3	206
E21	85	5	5	10	0	1	19
E22	94	1	1	0	5	1	35
P04	98	0	0	0	0	6	88
T01	97	3	0	0	0	1	277
T02	100	0	0	0	0	5	492
T02C	100	0	0	0	0	5	453
T04	100	0	0	0	0	4	157
T08	100	0	0	0	0	1	1483
T09	100	0	0	0	0	1	945
T14	97	3	0	0	0	2	558
T15	95	5	0	0	0	1	557
T16	97	3	0	0	0	3	359
T22	100	0	0	0	0	1	120
T23	100	0	0	0	0	1	402
T45	97	3	3	0	0	1	35
W01	100	0	0	0	0	1	1262
W02	10	3	3	57	0	0	42
W04	96	2	0	0	2	2	572
W05	89	5	0	0	4	0	1004
W06	97	3	3	0	0	0	48
W07	100	0	0	0	0	0	247
W11	100	0	0	0	0	0	84
W12	100	0	0	0	0	2	65
W14	10	0	0	0	0	0	246
W15	100	0	0	0	0	3	827
W16	100	0	0	0	0	4	925
W18	95	5	0	0	0	1	729
W24	100	0	0	0	0	2	954

Appendix 4. Program PRESENCE model comparison, by species. AIC is the Akaike Information Criterion, w_i is the model weight, ψ is the site occupancy rate, “naïve” is the naive detection rate, and *p* detection is the average probability of detection.

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
BUFO	ψ(AbsCo440) p(t)	15	195.181	0.000	0.693	0.435	0.433	
BUFO	ψ(perm,AbsCo) p(t)	16	196.894	1.713	0.294	0.435	0.433	
BUFO	ψ(perm) p(t)	15	204.265	9.085	0.007	0.435	0.433	
BUFO	ψ(.) p(t)	14	205.129	9.948	0.005	0.435	0.433	
BUFO	ψ(.) p(.)	2	248.248	53.067	0.000	0.439	0.433	0.2863

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
HYVE	ψ(perm) p(water)	4	65.149	0.000	0.419	0.225	0.167	
HYVE	ψ(perm, cond) p(water)	5	65.274	0.125	0.394	0.204	0.167	
HYVE	ψ(.) p(water)	3	65.344	0.194	0.381	0.236	0.167	
HYVE	ψ(cond) p(water)	4	66.413	1.264	0.223	0.224	0.167	
HYVE	ψ(.) p(.)	2	75.425	10.275	0.002	0.179	0.167	0.3197

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
PSCR	ψ(pH) p(t)	15	340.863	0.000	0.771	0.933	0.933	
PSCR	ψ(perm,pH) p(t)	16	342.083	1.220	0.228	0.933	0.933	
PSCR	ψ(.) p(t)	14	347.824	6.961	0.001	0.933	0.933	
PSCR	ψ(perm) p(t)	15	348.337	7.474	0.000	0.933	0.933	
PSCR	ψ(.) p(.)	2	520.488	179.625	0.000	0.933	0.933	0.5439

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
RACA	ψ(perm) p(wind)	5	103.485	0.000	0.414	0.273	0.267	
RACA	ψ(perm, pH) p(wind)	4	103.655	0.170	0.380	0.271	0.267	
RACA	ψ(pH) p(wind)	4	104.979	1.495	0.196	0.271	0.267	
RACA	ψ(.) p(wind)	3	111.602	8.117	0.007	0.274	0.267	
RACA	ψ(.) p(.)	2	113.301	9.816	0.003	0.277	0.267	0.3788

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
RACL	ψ(cond) p(t)	14	312.186	0.000	0.307	0.767	0.767	
RACL	ψ(semi, cond) p(t)	15	312.253	0.067	0.297	0.767	0.767	
RACL	ψ(semi) p(t)	14	312.912	0.726	0.213	0.767	0.767	
RACL	ψ(.) p(t)	13	313.219	1.033	0.183	0.767	0.767	
RACL	ψ(.) p(.)	2	418.844	106.658	0.000	0.767	0.767	0.518

Species	Model	# param	AIC	Δ AIC	w_i	ψ	naive	p detection
RAPA	ψ(perm) p(.)	3	86.974	0.000	0.614	0.167	0.167	
RAPA	ψ(perm, pH) p(.)	4	88.974	2.000	0.226	0.167	0.167	
RAPA	ψ(.) p(.)	2	91.602	4.628	0.061	0.167	0.167	0.5998
RAPA	ψ(pH) p(.)	3	91.805	4.831	0.055	0.167	0.167	
RAPA	ψ(.) p(t)	10	92.244	5.270	0.044	0.167	0.167	