Biological Indicators of Wetland Health: Comparing Qualitative and Quantitative Vegetation Measures with Anuran Measures

by

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ABSTRACT

Understanding wetland responses to human perturbations is essential to the effective management of Florida's surface and ground water resources. Southwest Florida Water Management District (SWFWMD) Rules (Chapter 40D-2.301(c) FAC) prohibit adverse environmental effects to wetlands, fish and wildlife caused by groundwater withdrawal. Numerous studies have documented the responses of biological attributes across taxa and regions to human disturbance. Biological assessment can provide information about ecological condition. Based on long-term monitoring conducted by the SWFWMD, the anthropogenic changes observed on the Starkey Wellfield are attributed to groundwater withdrawal.

Biological indicators are species, species assemblages, or communities whose presence, abundance, and condition are indicative of a particular set of environmental conditions. Monitoring early indicators of ecosystem stress may shorten response time by shifting attention to the relatively quick response of sensitive species. Species used to assess biological condition should be abundant and tractable elements of the system that provide an early, diagnosis.

Regulatory requirements within 40D-2 F.A.C. dictate an extensive analysis be conducted twice yearly on wetlands within all wellfields. This quantitative analysis provides information on the wetland plant community through the collection of eighteen categorized vegetative and physical variables. Because of the size of the area in which monitoring is required and the large number of wetlands, a rapid qualitative monitoring method was developed using vegetation and physical variables to classify wetlands into one of three categories based on their perceived health.

Wetland plants have many characteristics suited to assessments of biological condition including their diversity, taxonomy, distribution, relative immobility, well developed sampling protocols, and, for herbaceous species, their moderate sensitivity to disturbance (U.S. EPA 2002, Doherty et al. 2000). Because amphibians occupy both aquatic and terrestrial habitats in their life history, have physiological adaptations and specific microhabitat requirements, they are considered to be extremely sensitive to environmental perturbations and excellent barometers of the health of the aquatic and terrestrial habitats in which they reside (Vitt et al. 1990, Wake 1998, Blaustein 1994, Blaustein et al. 1994).

The purpose of my study was to 1) compare a qualitative method of wetland vegetation monitoring to a quantitative method, 2) document the reproductive success of anurans, and 3) compare anuran reproductive success to the vegetation monitoring results on the J.B. Starkey Wellfield (SWF). The results are published in chapters, with each chapter addressing one of the topics stated above.

The results show a rapid, qualitative measure of wetland health is useful for the determination of severely affected wetlands. The anuran reproductive success reflected similar results. The results show that wetlands can be categorized based solely on amphibian reproductive success variables. The anuran categorization, qualitative vegetative categorization, and quantitative vegetative categorization overlap on the high and low success wetlands. The low degree of overlap observed in the intermediate category could be attributed to fish predation in a wetland otherwise suited for amphibian reproduction, natural variability in the two years of anuran data collected or lag time inherent in vegetative monitoring. Strong correlative evidence suggests hydroperiod regulates anuran reproductive success on the J. B. Starkey Wellfield. The average length of inundation was correlated with the number of tadpoles captured per unit effort and the number of tadpole species captured per year ($R=0.73$, $p<.01$; $R=0.70$, $p<.05$). The average Julian date of inundation was negatively correlated with the same two tadpole variables ($R=0.81$, $p<.01$, $R=0.78$, $p<.01$). The Julian date of inundation at which breeding attempts stopped and no tadpoles were observed was weeks within the published breeding season for many species. I detected a correlation between the number of species calling in each wetland and the number of tadpole species captured per year ($R=0.87$, $p<.001$) suggesting call censuses may be used at this site to estimate anuran reproductive success if enough well-timed observations are made. These findings will allow resource managers and regulators to evaluate and possibly refine land management practices, including existing monitoring methods, and water policy to meet the needs of resident amphibians at the J.B. Starkey Wellfield.

CHAPTER 1 – Vegetative Measures of Wetland Health: A Comparison of Two Methods

Introduction

Understanding wetland responses to human perturbations is essential to the effective management of Florida's surface and ground water resources (Doherty et. al. 2000, USEPA 1987, 1989). Southwest Florida Water Management District (SWFWMD) Rules (Chapter 40D-2.301(c) FAC) prohibit adverse environmental effects to wetlands, fish and wildlife caused by groundwater withdrawal. Measurement of environmental effects is currently conducted by SWFWMD and independent environmental consultants through numerous quantitative and qualitative assessments on over 2,900 square kilometers of land in the northern Tampa Bay Area (Rochow 1994). Because it is impractical to measure all aspects of the ecosystem to detect anthropogenic change or measure wetland function, recent focus has been on determining if certain attributes may reflect the overall biological integrity of certain systems (Doherty et al. 2000).

Biological assessment can provide information about ecological condition (Karr 1991). Numerous studies have documented the responses of biological attributes across taxa and regions to human disturbance (Doherty et al. 2000). Biological indicators are species, species assemblages, or communities whose presence, abundance, and condition are indicative of a particular set of environmental conditions (Adamus 1996). For instance, botanists and ecologists have been developing ways to use plants as indicators of local conditions for many years (Goslee et al. 1997). On a landscape scale, plant distribution is a function of climate, but on the local scale, distribution is primarily determined by local environmental factors (Billings 1952). Vegetation characteristics indicate the presence of wetlands and their boundaries and are used as a basis for many classification schemes (U.S. EPA 2002). Wetland plants have many characteristics suited to biological assessments of condition including their diversity, established taxonomy, distribution, relative immobility, well-developed sampling protocols, and, for herbaceous species, their sensitivity to disturbance (U.S. EPA 2002, Doherty et al. 2000). Because plant communities represent a diverse assemblage of species with differing requirements, adaptations, tolerances and life histories, community composition can reflect the biological integrity of a wetland.

Rapid and profound effects on forested wetland vegetation may be brought on by changes in hydroperiod (length of time that soils are saturated during a year) (Ewel 1990). Chronically reduced periods of inundation in North Florida cypress wetlands resulted in poor tree regeneration, an increase in shrubs and hardwood density and an increase in fire potential (Marois and Ewel 1983, Harris and Vickers 1984). Changes in hydroperiod can be a natural response to changing climate or response to an anthropogenic influence. Some anthropogenic activities, such as clearcutting wetland or adjacent upland vegetation, directly affect wetland hydroperiod (Riekerk and Korhnak 2000). Such is the case when agricultural features (i.e. ditches, ponds, etc.) are created to increase the agricultural potential of the landscape. Many anthropogenic changes are generally revealed through site reviews or interpretation of aerial photography. Other changes are induced more subtly and are initially more difficult to detect. For instance, drawdown effects on wetland plant community composition are well documented (Sonenshein and Hofstetter 1990, Edwards and Denton 1993, Rochow 1994, Ormiston et al. 1995), despite the lack of immediate or short-term physical evidence of alteration to the landscape. Wetland drawdown from high capacity groundwater withdrawals is realized by lowering the potentiometric surface of the Floridan aquifer, which in turn lowers the surficial aquifer level, and finally the level of inundation in wetlands (Brown 1984, also see Stewart 1968, Cherry et al. 1970, Parker 1975, Hutchinson 1984, SWFWMD 1996).

Regulatory requirements within 40D-2 F.A.C. dictate an extensive analysis be conducted twice yearly on wetlands within all groundwater supply wellfields. Because of the size of the area in which monitoring is required and the large number of wetlands, a rapid qualitative monitoring method was developed (SWFWMD 1996, 1999, Rochow 1998). This qualitative method, or Vegetative Health Rating (VHR), was a supplement to a quantitative analysis and provides a more rapid method to measure the health of a larger set of wetlands than could otherwise be monitored by more rigorous quantitative methods (SWFWMD 1999). The purpose of this study was to examine the quantitative monitoring method currently used and compare the results to the qualitative VHR method using multivariate analysis. This multivariate analysis was conducted using three years (2000, 2001 and 2002) of vegetative monitoring data in 12 wetlands that exhibit differing levels of groundwater withdrawal influence.

Methods

Study Sites

Starkey Wellfield (SWF) is located in Pasco County, Florida, approximately 28.20° North Latitude and 82.50° West Longitude (Figure 1.1). The site consists of approximately 3,237 hectares, portions of which were donated to or purchased by the Southwest Florida Water Management District (SWFWMD), since1975. The rectangular parcel is bounded by the Suncoast Parkway (toll highway) to the east, the Anclote River to the south, residential development to the west and a combination of residential development, the Pithlachascotee River, and another 3200-hectare state-owned preserve to the north (Figure 1.2). The habitat at SWF is a matrix of sand-pine dominated sandhill and lakes throughout the topographically higher western third of the site, while the topographically lower eastern two-thirds of the site are characterized by pine flatwoods and cypress wetlands.

Currently, SWF is maintained for multiple uses, including wildlife habitat, low-intensity recreation (i.e., hiking, biking and backpack camping) and groundwater pumping. The SWFWMD manages the land and assists with the monitoring of groundwater pumping effects. Groundwater withdrawal monitoring is reported according to water-years beginning October and ending the following September. During the two study water-years (October 1, 2001- September 30, 2002), groundwater pumping averaged 11.2 million gallons per day.

Cypress wetlands occur frequently in the southeastern coastal plain and are typically found scattered throughout the pine flatwoods of Florida (Ewel 1990). The typical hydrologic pattern for cypress wetlands in this area is inundation upon the onset of summer rains followed by a slow drying beginning in the fall (Mitsch 1984) and occasionally shorter periods of inundation in the winter (Berryman and Henigar 2000). Twelve cypress wetlands were chosen, in coordination with the SWFWMD. Each study wetland had similar surrounding habitat, and met criteria for minimum size (>0.2 hectare) and depth of historic inundation (>0.3 meter) (Table 1.1, Figure 1.2).

Figure 1.1 J.B. Starkey Wellfield Location Map

Figure 1.2 J.B. Starkey Wellfield Site Locations and Land Use Map

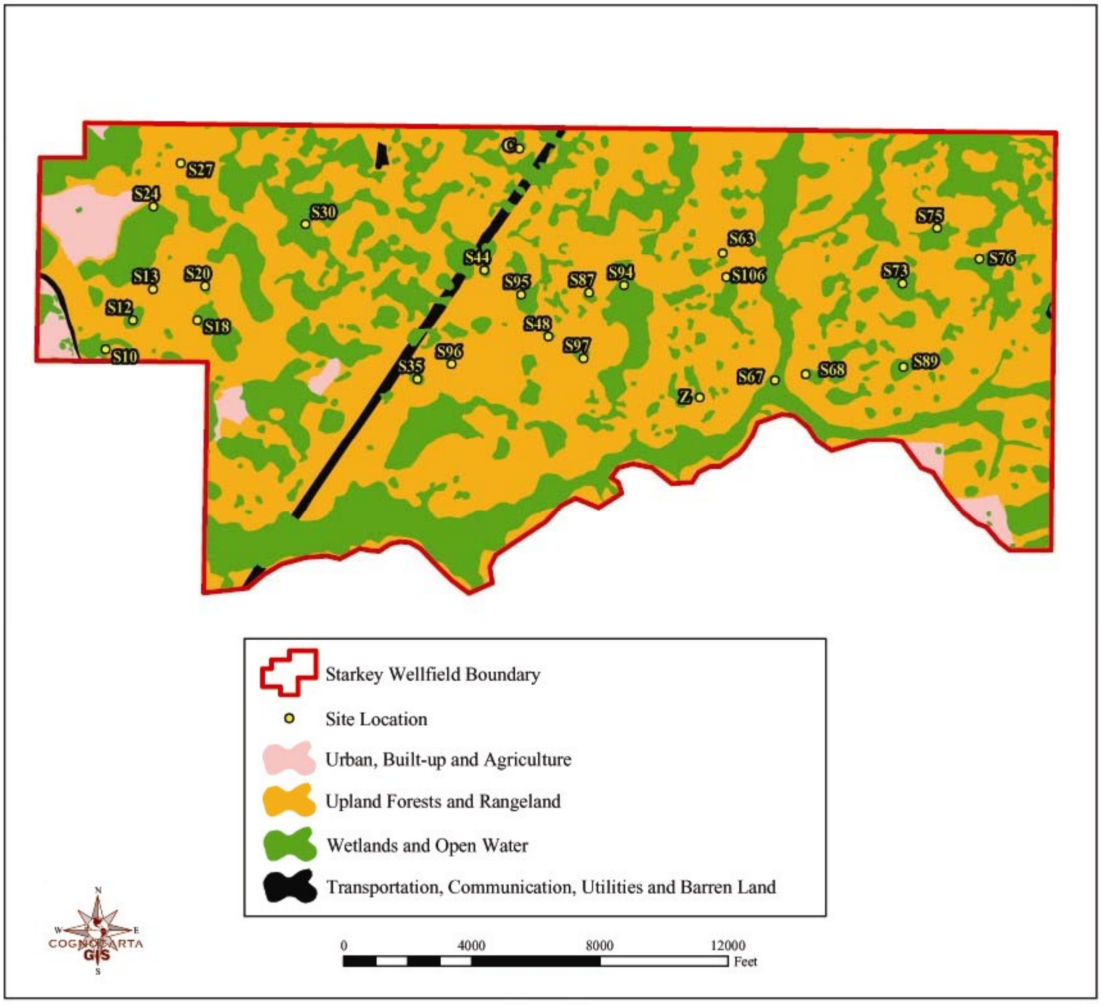


Table 1.1 Sampling Locations and Physical Characteristics

#	MONITORING ID	LATITUDE/ LONGITUDE	VEGETATIVE HEALTH RATING	SIZE (HECTARES)
1	S-87	28.24501N/82.59625W	Green	1.30
2	S-95	28.24473N/82.60283W	Blue	8.67
3	S-97	28.23936N/82.59667W	Blue	1.21
4	S-94	28.24566N/82.59286W	Green	36.90
5	S-68	28.23825N/82.57515W	Blue	2.17
6	S-106	28.24647N/82.58296W	Blue	8.06
7	S-10	28.23955N/82.64303W	Green	6.61
8	S-96	28.23871N/82.60947W	Blue	0.95
9	C	28.25725N/82.60318W	Green	1.67
10	Z	28.25561N/82.63597W	Green	2.74
11	S-44	28.24678N/82.60641W	Red	1.09
12	S-30	28.25055N/82.62383W	Red	92.26

*Wetlands S-87, C and Z were monitored by the SWFWMD. Wetlands S-95, S92, S-94, S-106, S-10, S-96 and S-44 were monitored by an independent consultant. Monitoring was conducted by both the SWFWMD and the independent consultant on Wetlands S-68 and S-30.

Qualitative Analysis

The original qualitative analysis method (SWFWMD 1999) included quantitative categorical variables that measured many of the same characters as the current quantitative method discussed below, and ultimately used three color-coded categories to describe each wetland by the level of anthropogenic change exhibited at the time of the monitoring event. After collecting several quantitative variables, the wetlands were rated on a 1-5 scale without a logarithm of any kind. This subjective decision rendered the evaluation qualitative, regardless of the quantitative data collected. Over time, the quantitative variables were replaced with reviewer comments and notes only; however, the three-color system remained.

A Vegetative Health Rating of blue was assigned to a wetland having vegetation, hydrology and soils indicative of natural, healthy cypress wetland. A VHR of green was assigned to a wetland in which moderate anthropogenic changes were observed. Anthropogenic changes were observed in vegetative composition and zonation, hydrologic indicators, soil subsidence or other abnormal characteristics noted by the researcher. A VHR of red was assigned to a wetland in which severe anthropogenic changes were observed. These changes include severe tree fall or death, upland species encroachment, changes in or elimination of zonation, severe soil oxidation or soil subsidence and biological evidence of hydroperiod reduction. The assignment of color categories was conducted one time in the Spring of 2001. The wetlands used in the analysis had not changed color category for at least one-year prior to or upon completion of the study (T. Rochow personal communication). The static Vegetative Health Rating allows for a comparison of the Vegetative Health Rating with the Quantitative Analysis during the three study years.

Quantitative Analysis

Because of the regulatory requirements of the SWFWMD Water Use Permit, an Environmental Management Plan (EMP) was developed for SWF and other Northern Tampa Bay regional wellfields (Tampa Bay Water 2000). One requirement of the EMP is a specific monitoring method known as the Wetland Assessment Procedure (WAP) be used twice yearly. The WAP consists of eighteen variables scored on a 1-3 scale (Table 1.2) measured on half-point increments. A score of one represents a wetland character that has been severely affected, while three represents an unaffected character or natural condition. Quantitative data from the spring and fall from three years were analyzed for the study.

Table 1.2 Wetland Assessment Procedure Variables

VARIABLE		**DESCRIPTION**
Groundcover		
	Deep Zone Composition	Percent cover of hydrophytic herbaceous vegetation
	Transitional Zone Composition	Percent cover of hydrophytic herbaceous vegetation in transitional zone
	Species Zonation	Current zonation vs. expected in an unaffected system
	Weedy Groundcover	Percent cover of weedy herbaceous vegetation in the entire wetland[1]
Shrub		
	Composition	Percent cover of hydrophytic woody species with a diameter at breast height (dbh) of < 4cm and < 1.0 m total height
	Species Zonation	Current zonation vs. expected in an unaffected system
	Weedy Shrubs	Percent cover of weedy woody species with a dbh of < 4cm and < 1.0 m total height[1]
Vines		
	Zonation	Current zonation vs. expected in an unaffected system
Canopy		
	Composition	Percent cover of appropriate woody species with a dbh of > 4cm and > 1.0 m total height
	Zonation	Current zonation vs. expected in an unaffected system
Tree Health		
	Stress	Percent of wetland-appropriate trees that exhibit signs of stress
	Leaning	Percent of wetland-appropriate trees that are leaning
	Dead	Percent of wetland-appropriate trees that are dead
Soils		
	D X 7/8	Presence and severity of soil subsidence at a fixed location near the edge of the wetland
	D X 1/2	Presence and severity of soil subsidence at a fixed location near the center of the wetland
	NP – 3	Presence and severity of soil subsidence at a fixed location where the ground elevation is approximately 3 inches below the Normal Pool elevation
	NP – 12	Presence and severity of soil subsidence at a fixed location where the ground elevation is approximately 12 inches below the Normal Pool elevation
Hydrology		
	Current water level indicators	Presence and level of biological indicators of hydrology (i.e. moss collars, lichens, stain lines, etc.)

* A list of potential “weedy” species is provided to the reviewer.

Hydrologic data were obtained from the SWFWMD or the environmental consultant that monitors wetlands at SWF on behalf of the wellfield operator, Tampa Bay Water. The Julian date of inundation was calculated using the first date of continuous inundation after the residual inundation from the previous year was no longer present. For instance, if a wetland was inundated continuously from July 2000 to January 2001, followed by a dry period that lasted until August 2001, the calculation of the 2001 Julian date of inundation used the August date even though it was not the first time that calendar year that inundation was present. In addition, when an anomalous rain event left a wetland inundated for a brief period (<2 weeks) in the dry season, this inundation was disregarded.

Statistics

Both R and Q-mode analyses were used. R-mode analysis was conducted to determine the relationships among variables. Spearman Rank Correlation was used to examine the relationships between each quantitative variable and the VHR, the average Julian date of inundation, and the average length of inundation for each wetland. In addition, simple descriptive statistics were used to examine the variability in scores between year and season. Q-mode analysis was conducted to illustrate the relationships among wetlands and compare the three VHR groups. I used descriptive statistics to compare the average score within each VHR category. I used hierarchical cluster analysis and nonmetric multidimensional scaling (an ordination technique) to elucidate patterns and categorize wetlands according to quantitative data.

Cluster analysis provides a dendrogram that illustrates the relationships of wetlands to each other in a nested fashion. I used Unweighted Pair-Group Average (UPGA) as the linkage method because, during the clustering, this linkage method preserves the original properties of the space in the dissimilarity matrix (Statistica for Windows 1995, McCune and Grace 2002). I used the Euclidean distance measure because of its compatibility with UPGA.

Ordination provides a graphical summary of complex relationships and extracts a dominant pattern from an infinite number of possible patterns (McCune and Grace 2002). Nonmetric multidimensional scaling (NMDS) is considered the most generally effective ordination technique for ecological community data and is recommended as the ordination method of choice unless a specific goal requires another method (McCune and Grace 2002). I used the dissimilarity matrix derived from the cluster analysis to conduct an NMDS. First, eighteen variables are used in the multivariate analysis, and in the second the average of the eighteen variables is used. In a third NMDS, the soil and hydrologic indicator variables are used in a separate analysis. Finally, descriptive statistics are used in a confirmatory manner to illustrate the difference between the qualitative vegetative categories and a proposed alternate grouping based on the NMDS results.

In some cases, data were not recorded on the soils and hydrologic indicators of each site, presumably because of the depth of inundation. Notes indicating the reviewer suggestion to use values from a previous event (i.e., use Spring 2001 score) were present for specific variables on some data sheets. In any case, when notes were taken referring to a past event, the instructions were followed. In a few cases, the reference was omitted, not legible, or referred to an event that had a reference to another previous (third) event. In these cases, the data were considered unreliable, and not included. All missing values were substituted by means for the multivariate analysis, but ignored when calculating the average score. For two wetlands, both the SWFWMD and an independent consultant collected data. In a preliminary analysis, the duplicate measurements were included. The duplicate wetlands fell into similar categories in the cluster and the NMDS analysis. Only the SWFWMD data were used for this analysis to avoid pseudoreplication.

Results

R-mode analysis

Table 1.3 presents the correlations among the average quantitative variables over the six events and the VHR, average length of inundation and average Julian date of inundation. The average score (average of all eighteen variables) is highly correlated (R-value 0.812, $p = <0.001$) with the VHR. In addition, eight other variables are significantly correlated ($p = <0.05$). If I increase p to 0.10, then 10 of the 18 parameters exhibit a significant correlation with the VHR. In contrast, only two variables (canopy zonation and biological indicators of hydrology) were significantly correlated ($p = <0.05$) with the average length of inundation. The number of significant correlations doubled when changing the acceptable p to 0.10 (canopy composition and canopy death), but none of the additional correlations were stronger than 0.55 ($p = <0.10$). Finally, each of the variables was examined for a relationship with the average Julian date of inundation. Two variables (canopy composition and biological indicators of hydrology) were negatively correlated ($p = <0.05$). Two others (average score and canopy composition) were significant at $p = 0.10$.

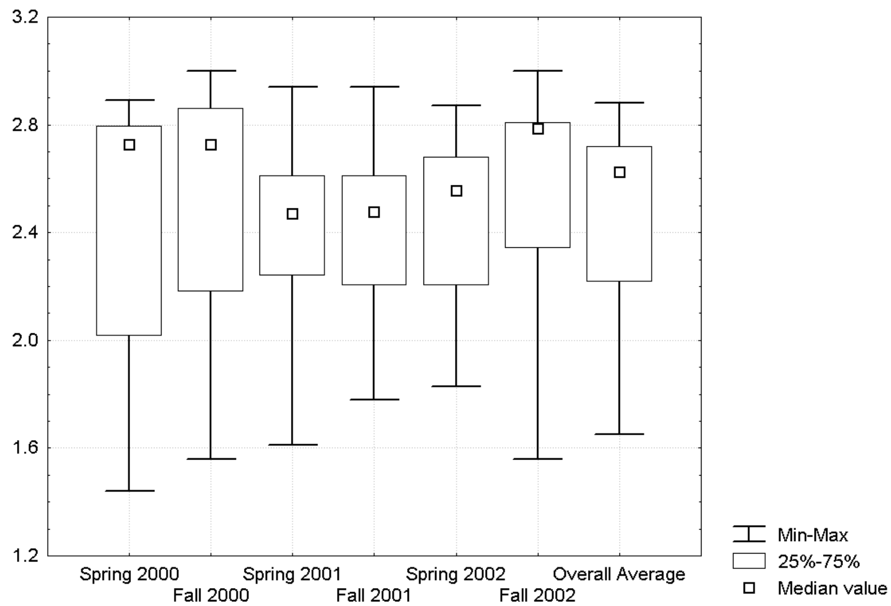
Table 1.3 Correlations between Wetland Assessment Procedure Variables and Vegetative Health Rating, Inundation Length, and Julian Date of Inundation

	Correlation with VHR		**Correlation with Inundation Length**		**Correlation with Julian date of inundation**	
	R	**p-level**	**R**	**p-level**	**R**	**p-level**
Average Score	**.812218**	**.001329**	.433566	.159106	-.524476	.080019
Groundcover						
Deep Composition	**.603720**	**.037648**	.187560	.559402	-.320415	.309922
Transitional Composition	.301370	.341130	.466712	.126123	-.123970	.701082
Species Zonation	**.671486**	**.016796**	.429588	.163399	-.471843	.121455
Weedy Groundcover	.682932	.014375	.244558	.443641	-.447729	.144408
Shrubs						
Composition	.074187	.818764	-.352121	.261243	.179582	.576520
Species Zonation	**.703824**	**.010634**	.411982	.183271	-.408461	.187417
Weedy Shrubs	-.034711	.914717	-.413053	.182022	.137684	.669587
Vines						
Species Zonation	.496711	.100438	.395244	.203498	-.116493	.718443
Canopy						
Composition	**.701239**	**.011052**	.5549181	.064405	-.520057	.083061
Zonation	**.756004**	**.004445**	**.709575**	**.0099745**	**-.748996**	**.005056**
Stress	.408528	.187338	-.014135	.965224	.056050	.861449
Leaning	.510740	.089729	.100968	.754870	-.055074	.865014
Death	**.775797**	**.003019**	.508611	.091303	-.463734	.128886
Soils						
Edge Subsidence	.383173	.218897	.354646	.258000	-.361739	.247922
Center Subsidence	.368509	.238521	.049740	.877996	-.284228	.370604
Subsidence at location 3” below NP	**.724131**	**.007743**	.486791	.108505	-.472682	.120702
Subsidence at location12” below NP	.521330	.082176	.168322	.602099	-.356643	.255138
Hydrology						
Current biological indicators	**.842279**	**.000586**	**.814847**	**.001244**	**-.772517**	**.003227**

* Bold numbers are significant to <.05.

The mean of all study wetland scores ranged from 2.38 to 2.58 over three years. The mean of the fall event (conducted at the end of the rainy season) was approximately 0.2 higher than the spring event each year. Figure 1.3 illustrates the similarities between the average scores of each event.

Figure 1.3 Box and Whisker Plot of Quantitative Vegetation Scores Categorized by Sampling Event



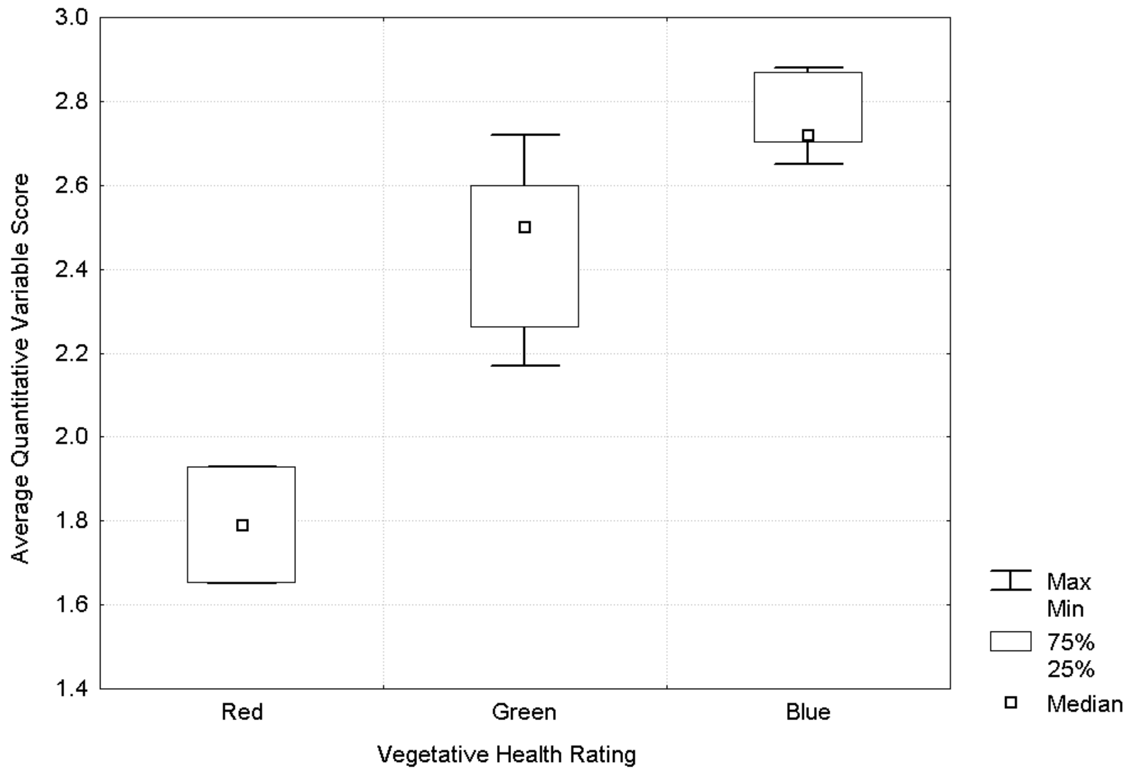
Q-mode analysis

Table 1.4 presents descriptive statistics for each of the three VHR categories using the average quantitative score for each wetland. All groups reached their maximum score over the study period in 2002. The mean score for all Red wetlands ranged from 1.63 to 1.98 reaching a peak in Spring 2002. Green wetlands had a mean score of 2.34 to 2.58. Blue wetlands mean score ranged from 2.70 to 2.83. Both Green and Blue wetlands reached their maximum score in Fall 2002.

Table 1.4 Descriptive Statistics of Wetland Assessment Procedure Variables Categorized by Vegetative Health Rating

		N	Mean	Confid. -95.000%	Confid. 95.000	Min	Max	Range	Variance	Std. Dev.	Std. Error	Skewness	Std.Err. Skewness	Kurtosis	Std.Err. Kurtosis
RED	Spring 2000	2	1.63	-0.726	3.976	1.44	1.81	0.37	0.068	0.262	0.185	--	--	--	--
	Fall 2000	2	1.67	0.272	3.068	1.56	1.78	0.22	0.024	0.156	0.110	--	--	--	--
	Spring 2001	2	1.71	0.439	2.981	1.61	1.81	0.20	0.020	0.141	0.100	--	--	--	--
	Fall 2001	2	1.84	1.136	2.534	1.78	1.89	0.11	0.006	0.078	0.055	--	--	--	--
	Spring 2002	2	1.98	0.074	3.886	1.83	2.13	0.30	0.045	0.212	0.150	--	--	--	--
	Fall 2002	2	1.93	-2.713	6.563	1.56	2.29	0.73	0.266	0.516	0.365	--	--	--	--
GREEN	Spring 2000	5	2.48	1.908	3.048	1.80	2.89	1.09	0.211	0.459	0.205	0.927	0.913	-0.739	2
	Fall 2000	5	2.46	1.992	2.932	2.17	2.92	0.75	0.143	0.379	0.169	0.637	0.913	-3.141	2
	Spring 2001	5	2.35	2.153	2.547	2.20	2.61	0.41	0.025	0.159	0.071	1.410	0.913	2.088	2
	Fall 2001	5	2.33	2.117	2.547	2.19	2.61	0.42	0.030	0.173	0.077	1.351	0.913	1.145	2
	Spring 2002	5	2.36	2.059	2.661	2.00	2.64	0.64	0.059	0.242	0.108	-0.660	0.913	0.506	2
	Fall 2002	5	2.58	2.248	2.920	2.21	2.83	0.62	0.073	0.270	0.121	-0.742	0.913	-1.828	2
BLUE	Spring 2000	5	2.76	2.651	2.861	2.61	2.83	0.22	0.007	0.084	0.038	-1.845	0.913	3.934	2
	Fall 2000	5	2.83	2.681	2.987	2.67	3.00	0.33	0.015	0.123	0.055	0.041	0.913	0.197	2
	Spring 2001	5	2.70	2.501	2.908	2.56	2.94	0.38	0.026	0.162	0.073	0.948	0.913	-0.986	2
	Fall 2001	5	2.70	2.488	2.916	2.56	2.94	0.38	0.030	0.173	0.077	0.782	0.913	-1.993	2
	Spring 2002	5	2.73	2.597	2.863	2.61	2.87	0.26	0.011	0.107	0.048	0.427	0.913	-1.767	2
	Fall 2002	5	2.84	2.727	2.953	2.79	3.00	0.21	0.008	0.0941	0.041	2.050	0.913	4.232	2

Figure 1.4 Box and Whisker Plot of Average Quantitative Variables Categorized by Vegetative Health Rating



The mean average score of Red wetlands over all events was significantly different from the Green wetlands and the Blue wetlands. The standard deviations of the mean scores of Green wetlands and Blue wetlands overlapped (Figure 1.4).

A visual representation of wetland dissimilarity is presented through a cluster analysis. Two alternative cluster analyses are offered. Both were constructed using Euclidean distance measures and Unweighted Pair-Group Averages linkage method. The first (Figure 1.5A) was constructed using all eighteen quantitative variables for each of the six monitoring events. The second alternative (Figure 1.5B) was constructed using only the average of the eighteen variables for each of the six events. The distance matrix derived from the cluster analyses were then used in constructing an NMDS plot.

Figure 1.5 Cluster Analysis Using Wetland Assessment Procedure Variables

Figure 1.5A Cluster analysis using all quantitative variables, unweighted pair-group average linkage method and Euclidean distance measures.

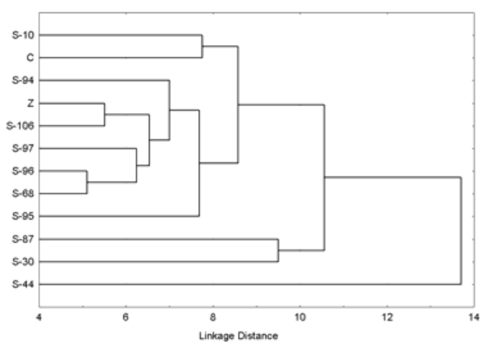


Figure 1.5B Cluster analysis using average quantitative variables, unweighted pair-group average linkage method and Euclidean distance measures.

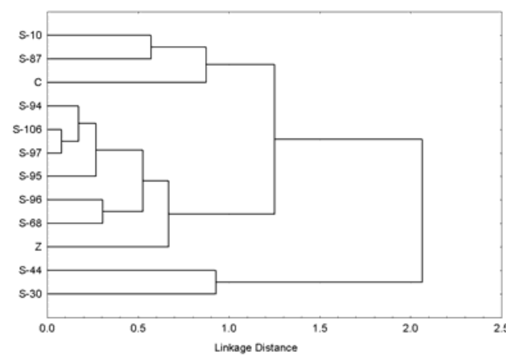


Figure 1.5A was created using all eighteen variables collected for each year and season. The figure illustrates the difference between S-44, S-30, S-87, and all other wetlands. All relationships are separated by a minimum of five distance units.

Figure 1.5B was created using the averages of all eighteen variables collected each season and year. The dendrogram provides evidence that S-44 and S-30 form a separate cluster, and S-87, C, and S-10 form a separate cluster; however, the relationship between these two groups and the remaining wetlands is because of the potential rotation of each axis. All relationships are separated by a maximum of one distance unit.

Figure 1.6 NMDS plot of all quantitative variables for spring and fall 2000, 2001 and 2002.

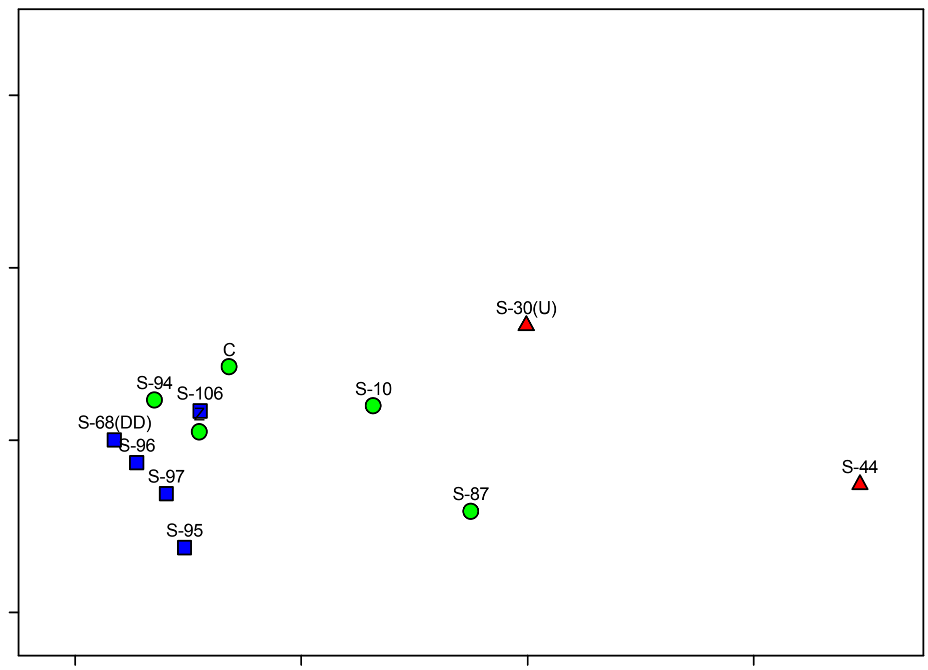


Figure 1.6 was constructed using the distance matrix derived from Figure 1.5A. Five-hundred twenty-five iterations were performed. The final configuration stress value was .052, alienation value was .074, D-Starr: Raw stress was .799 and D-Hat: Raw stress was .394. In general, the red wetlands fall to the left and the blue wetlands to the right. The green wetlands span the center.

Figure 1.7 NMDS plot of average quantitative variables for spring and fall 2000, 2001 and 2002.

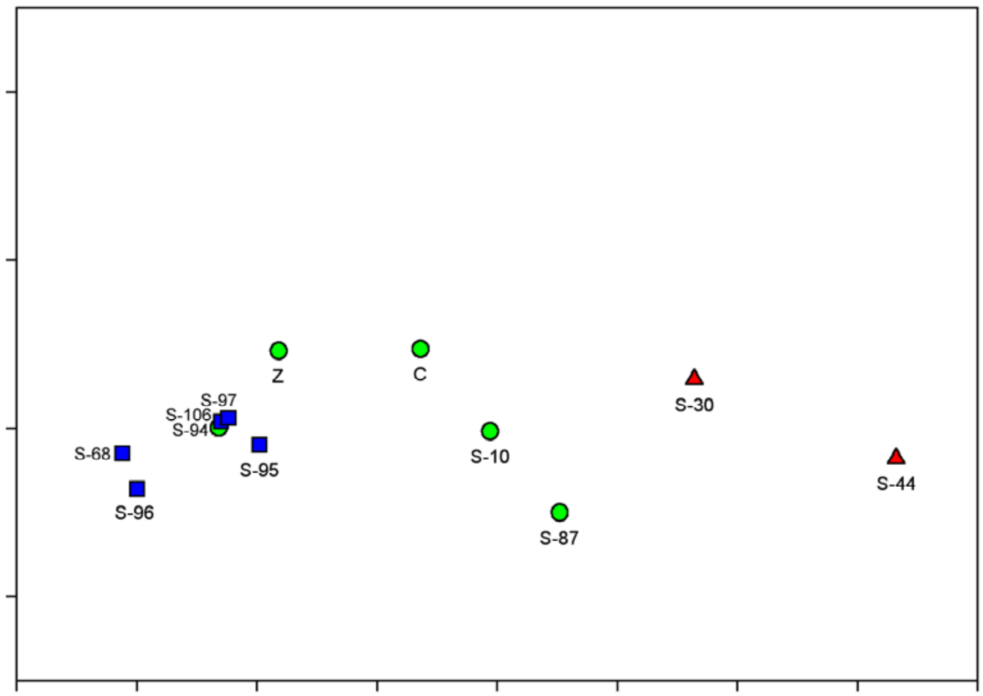


Figure 1.7 was created using the distance matrix derived from Figure 1.5B. Four-hundred forty iterations were performed. The final configuration stress value was .028, alienation value was .048, D-Star: Raw stress was .333 and D-Hat: Raw stress was .112. The red wetlands fall on the right of the NMDS plot and the blue wetlands fall on the left of the plot. Green wetlands are concentrated in the center except S-94 which is tightly clustered with the blue wetlands.

Figure 1.8 Cluster analysis using soils and hydrologic variables, unweighted pair-group average linkage method and Euclidean distance measures.

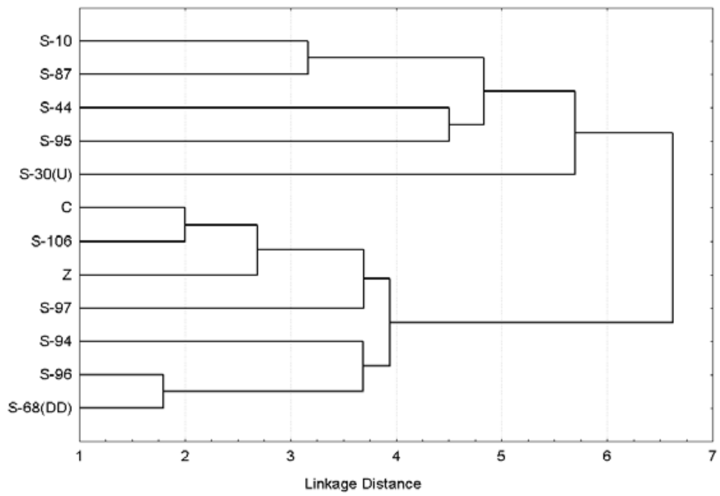


Figure 1.9 NMDS plot using soils and hydrologic variables for spring and fall 2000, 2001 and 2002.

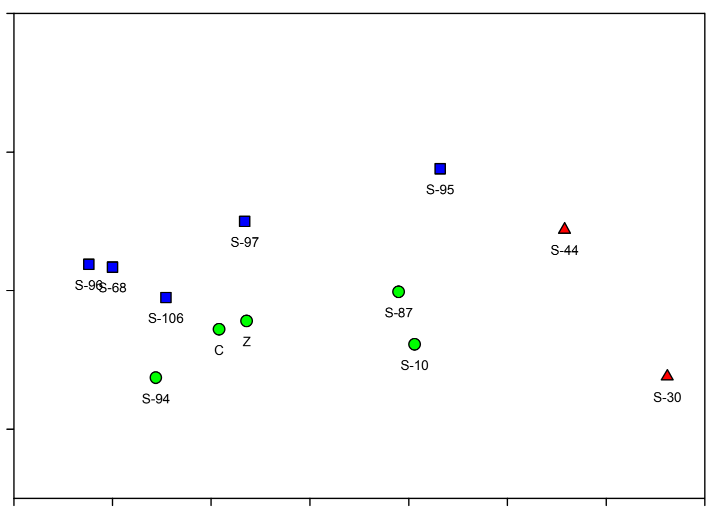


Figure 1.8 was created using the soils and hydrologic variables collected each season and year. Two clusters area apparent wetlands within the cluster containing five wetlands

(S-10, S-87, S-44, S-95, and S-30) are not as tightly associated as those within the other cluster.

Figure 1.9 was created from the distance matrix derived from Figure 1.8. Four-hundred forty-seven iterations were performed. The final configuration stress value was .073, alienation value was .104, D-Star: Raw stress was 1.58 and D-Hat: Raw stress was .757. The distribution of wetlands on this NMDS plot is more uniform relative to Figure 1.6 and 1.7. The red wetlands remain removed from other wetlands to the right. Blue and green wetlands are scattered on the left and S-95 is near the center with S-87 and S-10.

Table 1.4 and Figures 1.4-1.9 indicate the VHR assigned to the wetlands do not reflect the results of the multivariate analysis, but some overlap of the Green and Blue categories is evident. Although the VHR is used to indicate three categories of anthropogenic change, the evidence suggests that a two-color VHR would more accurately depict the quantitative data that were collected between 2000 and 2002, or perhaps a reshuffling of the wetlands to form three different categories. Based upon the evidence presented here and the statement of caution by Karr and Chu (1999) warning against the preoccupation with anthropogenic disturbance gradients, I propose an alternative to the original three-color categories. Tables 1.5 and 1.6 provide the revised version of the descriptive statistics presented in Table 1.4. The revision involved simply adjusting the VHR categories to match the multivariate analysis and reclassifying the wetlands based upon a two-color scheme (Table 1.5, Figure 1.10A) and a revised three-color scheme (Table 1.6, Figure 1.10B).

Table 1.5 Descriptive Statistics of Wetland Assessment Procedure Variables Categorized by Two-Category Alternate Vegetative Health Rating

		N	Mean	Confid. -95.000%	Confid. 95.000	Min	Max	Range	Variance	Std. Dev.	Std. Error	Skewness	Std.Err. Skewness	Kurtosis	Std.Err. Kurtosis
RED	Spring 2000	4	1.82	1.310	2.325	1.44	2.22	0.78	0.102	0.319	0.159	0.235	1.014	1.526	2.617
	Fall 2000	4	1.93	1.433	2.422	1.56	2.20	0.64	0.097	0.311	0.155	-0.407	1.014	-3.615	2.617
	Spring 2001	4	2.02	1.432	2.608	1.61	2.38	0.77	0.136	0.369	0.185	-0.184	1.014	-4.270	2.617
	Fall 2001	4	2.07	1.619	2.521	1.78	2.39	0.61	0.080	0.284	0.142	0.173	1.014	-3.660	2.617
	Spring 2002	4	2.06	1.756	2.364	1.83	2.28	0.45	0.037	0.191	0.096	-0.133	1.014	-0.615	2.617
	Fall 2002	4	2.11	1.515	2.710	1.56	2.39	0.83	0.141	0.376	0.188	-1.771	1.014	3.277	2.617
BLUE/GREEN	Spring 2000	8	2.77	2.694	2.843	2.61	2.89	0.28	0.008	0.089	0.031	-0.776	0.752	0.357	1.481
	Fall 2000	8	2.76	2.553	2.974	2.19	3.00	0.81	0.063	0.252	0.089	-2.034	0.752	4.718	1.481
	Spring 2001	8	2.58	2.371	2.779	2.20	2.94	0.74	0.059	0.243	0.086	-0.242	0.752	-0.246	1.481
	Fall 2001	8	2.57	2.357	2.783	2.19	2.94	0.75	0.065	0.255	0.090	-0.222	0.752	-0.457	1.481
	Spring 2002	8	2.65	2.515	2.778	2.38	2.87	0.49	0.025	0.157	0.056	-0.312	0.752	-0.008	1.481
	Fall 2002	8	2.82	2.745	2.885	2.71	3.00	0.29	0.007	0.083	0.030	1.666	0.752	4.240	1.481

Figure 1.10 Box and Whisker Plots of Alternate Wetland Classifications

Figure 1.10A Box and Whisker Plot of Average Quantitative Variables Categorized by Vegetative Health Rating.

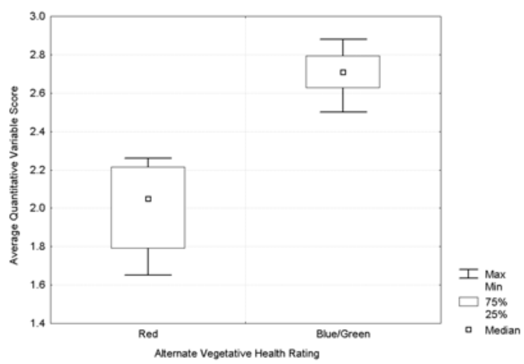


Figure 1.10B Box and Whisker Plot of Average Quantitative Variables Categorized by Vegetative Health Rating.

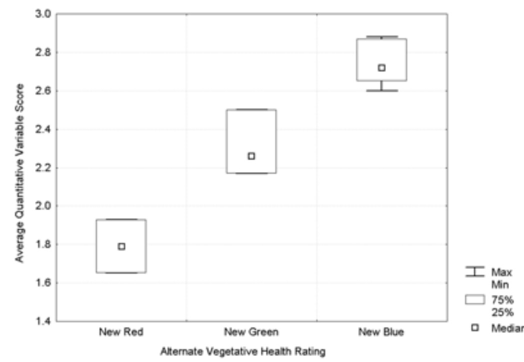


Figure 1.10A illustrates an alternative classification scheme based on two categories. The Red group includes wetlands S-10, S-30, S-44, and S-87; the Blue/Green group includes wetlands C, Z, S-68, S-94, S-95, S-96, S-97, and S-106. Upon reclassification, the mean of average scores for Red wetlands is 2.00 and the new Green/Blue wetland category is 2.69. The standard deviations no longer overlap, confirming that these groups are discrete.

The New Red group includes wetlands S-30, and S-44; the New Green group includes wetlands C, S-10, and S-87; the New Blue group includes Z, S-68, S-94, S-95, S-96, S-97, and S-106. Figure 1.12 illustrates a second alternative classification scheme. The mean score of the New Red class is 1.79; Green is 2.27, and Blue is 2.73. The standard deviations do not overlap, confirming that these three groups are discrete.

Table 1.6 Descriptive Statistics of Wetland Assessment Procedure Variables Categorized by Three-Category Alternate Vegetative Health Rating

		N	Mean	Confid. -95.000%	Confid. 95.000	Min	Max	Range	Variance	Std. Dev.	Std. Error	Skewness	Std.Err. Skewness	Kurtosis	Std.Err. Kurtosis
RED	Spring 2000	2	1.63	-0.726	3.976	1.44	1.81	0.370	0.068	0.262	0.185	--	--	--	--
	Fall 2000	2	1.67	0.272	3.068	1.56	1.78	0.220	0.024	0.156	0.110	--	--	--	--
	Spring 2001	2	1.71	0.439	2.981	1.61	1.81	0.200	0.020	0.141	0.100	--	--	--	--
	Fall 2001	2	1.84	1.136	2.534	1.78	1.89	0.110	0.006	0.078	0.055	--	--	--	--
	Spring 2002	2	1.98	0.074	3.886	1.83	2.13	0.300	0.045	0.212	0.150	--	--	--	--
	Fall 2002	2	1.93	-2.713	6.563	1.56	2.29	0.730	0.266	0.516	0.365	--	--	--	--
GREEN	Spring 2000	3	2.23	1.149	3.311	1.80	2.67	0.870	0.189	0.435	0.251	0.103	1.225	--	--
	Fall 2000	3	2.19	2.149	2.225	2.17	2.20	0.030	0.000	0.015	0.009	-0.935	1.225	--	--
	Spring 2001	3	2.29	2.063	2.511	2.20	2.38	0.180	0.008	0.090	0.052	0.331	1.225	--	--
	Fall 2001	3	2.27	1.999	2.535	2.19	2.39	0.200	0.012	0.108	0.062	1.583	1.225	--	--
	Spring 2002	3	2.22	1.731	2.709	2.00	2.38	0.380	0.039	0.197	0.114	-1.244	1.225	--	--
	Fall 2002	3	2.46	1.736	3.184	2.21	2.78	0.570	0.085	0.291	0.168	1.019	1.225	--	--
BLUE	Spring 2000	7	2.78	2.703	2.862	2.61	2.89	0.280	0.007	0.086	0.032	-1.399	0.794	3.401	1.587
	Fall 2000	7	2.85	2.748	2.943	2.67	3.00	0.330	0.011	0.106	0.040	-0.306	0.794	0.492	1.587
	Spring 2001	7	2.63	2.438	2.819	2.28	2.94	0.660	0.042	0.206	0.78	-0.200	0.794	1.120	1.587
	Fall 2001	7	2.62	2.421	2.827	2.25	2.94	0.690	0.048	0.220	0.083	-0.279	0.794	0.887	1.587
	Spring 2002	7	2.68	2.570	2.799	2.50	2.87	0.370	0.015	0.124	0.047	0.201	0.794	-0.182	1.587
	Fall 2002	7	2.82	2.738	2.902	2.71	3.00	0.290	0.008	0.089	0.034	0.149	0.794	3.563	1.587

Discussion

From 1995 – 2020, the public supply water demand within the Southwest Florida Water Management District is expected to increase thirty-nine percent from 459.4 million gallons per day (mgd) to 640.2 mgd. The agricultural demand during the same temporal and spatial scale is separate, and also is expected to increase from 587.8 to 710.7mgd. Much of the current water supply is provided through groundwater withdrawal. Because of “known resource impacts throughout much of the planning region caused by existing water withdrawals”, groundwater was not included as a potential source for the increased demand (Southwest Florida Water Management District 2001). Even at the current level of groundwater withdrawal, signs of ecosystem stress are present. Thus, it is imperative to have accurate and rapid means of monitoring and the ability to adjust management and policy to ensure habitat is available for the natural flora and fauna.

The purpose of this study was to examine the quantitative monitoring method currently used and compare the results to the qualitative VHR method using multivariate analysis. Although the data did not reflect the original three VHR color categories presented, they appeared to have correctly characterized the highest scoring and lowest scoring wetlands. Two of the Green wetlands (S-87 and S-10) sometimes fell into the Red category and three of the Green wetlands (C, Z, and S-94) sometimes fell into the Blue category, but when long-term results are considered, only S-94 and Z were mischaracterized. Mischaracterization of the wetlands in the moderately anthropogenically influenced green VHR category could reflect the small sample size, or the scale on which each of the variables was measured. A 1-3 scale with half-point increments (which were seldom used) offers a maximum of 7 possible scores for each variable. If the researcher were able to evaluate vegetation on the same scale in .1 increments, more variability could be expressed. It is also possible that because many of the variables are correlated with one another, expected variability is lost and scores tend toward a bimodal distribution.

The relatively rapid VHR assessment may be conducted on many more wetlands in a shorter time period than the more rigorous quantitative method. The increase in the number of wetlands that are monitored as a result of the VHR, coupled with the ability of the VHR to characterize the highest and lowest scoring wetlands make the VHR a useful tool. A more detailed analysis of wetlands that fall into the moderate or low VHR categories may be warranted, but if a wetland consistently maintains a high VHR, then further resources need not be unnecessarily expended on detailed monitoring.

The appropriate criteria for measuring wetland health must include physical/chemical as well as biological conditions because there are sampling limitations, including a lag in response time inherent in measuring biological conditions (U.S. EPA 2002, Tiner 1991). The quantitative method used in this study included five non-vegetative variables, but these variables were the most often overlooked or omitted by the researcher, presumably because the indicators were inundated at the time of the site visit. Soil indicators may also have a lag in response time to changes in hydrology. Although a pattern is evident in the groups of wetlands when examining only the vegetation and hydrologic information, it may be more informative to measure other variables as well. When the physical variables were partitioned and used in a multivariate analysis without vegetation, only wetlands that had evidence of long-term anthropogenic change (S-44 and S-30) were segregated from all others, but this pattern had similarities to the analysis measuring change in vegetation. The reason for the similarity was likely the variables included in the physical variable analysis measure long-term changes. Soil oxidation and subsidence in a seasonally-inundated wetland must be preceded by hydrologic changes, such as inundation timing or length, that would affect vegetation and wildlife habitat more immediately.

Wetland plants are unreliable as sole indicators of change in hydrologic regime or nutrient status (Tiner 1991). Rather, soil biogeochemistry and physical characteristics need to be used in concert with vegetation to avoid lag times in plant response to hydrologic alteration. The effort to collect additional soil variables would undoubtedly increase the sensitivity of the analysis, but could also prove cost prohibitive or difficult because of training costs or additional personnel. Also, many of the physical variables currently measured may have a greater lag time than the vegetation. I suggest a focus on more rapidly responding biological indicators. Cost aside, other factors such as invertebrate colonization, overall wildlife utilization or amphibian reproductive success could serve to further distinguish between groups of wetlands or provide a similar picture without the lag time inherent in vegetation monitoring.

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CHAPTER 2 – Amphibian Measures of Wetland Health: An Evaluation of Anuran Reproductive Success

Introduction

Wetlands provide many ecosystem functions including primary production, water attenuation, biochemical transfer and storage, decomposition, and wildlife habitat (Richardson 1994). The interactions of flora and fauna with the physical environment provide the functions that are important to the overall landscape (U.S. EPA 2002a). When the interaction of organisms and the environment is altered, the functions of the ecosystem may be disrupted (U.S. EPA 2002a). Because it is impractical to measure all aspects of the ecosystem to detect anthropogenic influence or measure wetland function, recent focus has been on determining if certain attributes may reflect the overall biological integrity of certain systems. Numerous studies have documented the responses of biological attributes across diverse taxa and regions to human disturbance (Doherty et al. 2000). Sensitive species are usually effected first during times of environmental stress (Odum 1992). Currently, much debate exists over which sensitive species, or species assemblages, are used appropriately as biological indicators. Biological indicators are species, species assemblages, or communities whose presence, abundance, and condition are indicative of a particular set of environmental conditions (Adamus 1996). Monitoring early indicators of ecosystem stress may shorten response time by shifting attention to the relatively quick response of sensitive species (Rapport 1992). Species used as indicators should be abundant and tractable elements of the system that provide an early diagnosis (Rapport 1992, Welsh and Ollivier 1998). Because of their biphasic life history, physiological adaptations and specific microhabitat requirements, amphibians are sensitive to environmental perturbations and excellent barometers of the health of the aquatic and terrestrial habitats in which they reside (Vitt et al. 1990, Wake 1998, Blaustein et al. 1994). Physical and chemical conditions in a wetland are known to influence amphibian assemblages (Lehtinen et al. 1999, Pierce 1985, Sadinski and Dunson 1992, and Skelly 1996); however, given their diversity and ecological requirements, no consensus exists on what conditions are “suitable” for survival and reproduction of amphibians.

Although much attention has been aimed at identifying large scale, even global, threats to anurans (Wake 1998), evidence exists that local populations are in decline because of changes in their habitats. Many detrimental habitat alterations are associated with increased human influence and urbanization (Delis et al. 1996). During the five-year period ending in 2000 the human population of Florida increased by approximately 1.7 million. Similar increases are projected for each of the next five-year periods until the year 2025 (U.S. Census Bureau 2000). Accordingly, the human population may increase from 14.2 million in 1995 to 20.7 million in 2025. Landscape-level land use practices can have both direct and indirect effects on wetland habitats and amphibian populations (Lehtinen et al. 1999). Some influences are large in scale and extremely visible such as habitat destruction in the form of conversion from native land-cover to agriculture or development, but others may occur without large-scale topographic or land cover changes

(Dodd 1997). A more subtle type of habitat destruction may affect the availability or suitability of amphibian breeding habitat. Breeding habitats may be modified to the extent that they become unsuitable for many species as a result of pollution, introduced species, vegetative composition changes, altered hydrologic regimes, or other anthropogenic alterations (Johnson et al. 2002). Hydrologic alterations such as ditching of wetlands to enhance drainage can have a large effect on anuran use of wetland sites because of alterations to hydroperiod or species interactions (Vickers et al. 1985).

Groundwater withdrawal is another type of hydrologic alteration that may have effects on amphibian breeding habitat. Wetland drawdown is realized by lowering the potentiometric surface of the aquifer, which in turn lowers the surficial aquifer level and finally the level of inundation in wetlands (Brown 1984, also see Stewart 1968, Cherry et al. 1970, Parker 1975, Hutchinson 1984, SWFWMD 1996). Draw down effects on wetland plant community composition are well documented (Sonenshein and Hofstetter 1990, Edwards and Denton 1993, Rochow 1994, Ormiston et al. 1995), but may leave no immediate physical evidence of alteration to the landscape. Groundwater withdrawal from the Edwards Aquifer in Texas did not alter land cover of the region, but it was determined, the withdrawal could lead to the loss of aquatic biota including amphibians (U.S. Fish and Wildlife Service 1984, Chippindale et al. 1993).

Alterations in the availability of breeding habitat even on a small scale may have long-term or large-scale effects on amphibian populations. Many authors have discussed pond-breeding amphibian populations in terms of metapopulations (Levins 1969, Gill

1978, Berven and Grudzien 1990, Sinsch 1992, Hecnar and M'Closkey 1996, Semlitsch and Bodie 1998, and Skelly et al. 1999) whose viability is dependent on a balance of sub-population colonization and extinction. Within the context of a metapopulation, local habitat perturbations that alter breeding habitat even on a relatively small scale could have long-term negative effects on the regional population (Johnson et al. 2002).

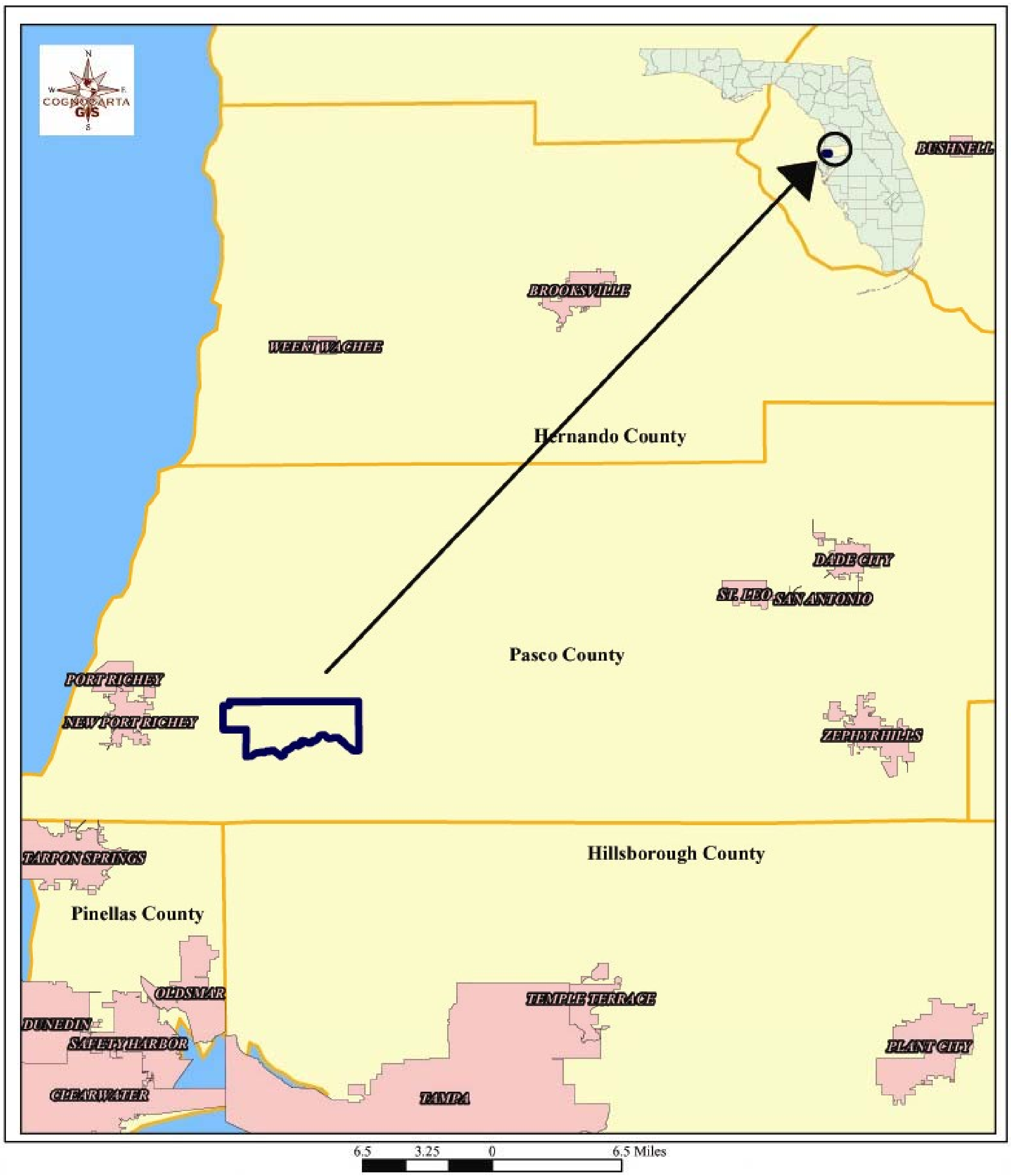
The purpose of this study was to (1) document amphibian reproductive success, and (2) identify potential causative factors in anuran reproductive success or failure among wetlands on the J.B. Starkey wellfield (SWF). I used multivariate analysis to describe the gradient of anthropogenic change in and categorize a selection of cypress wetlands. The goal of my study was to provide data for resource managers to evaluate and possibly refine land management practices, including existing monitoring methods.

Methods

Study Sites

Starkey Wellfield (SWF) is 3,237 hectares located in Pasco County, Florida, approximately 28.20° North Latitude and 82.50° West Longitude (Figure 2.1). The rectangular parcel is bounded by the Suncoast Parkway (toll highway) to the east, the Anclote River to the south, residential development to the west and a combination of residential development, the Pithlachascotee River, and another 3200-hectare state-owned preserve to the North (Figure 2.2). The habitat at SWF is a matrix of sand-pine dominated sandhill and lakes throughout the topographically higher western third of the site, while the topographically lower eastern two-thirds of the site are characterized by pine flatwoods and cypress wetlands.

Figure 2.1 J.B. Starkey Wellfield Location Map



Currently, SWF is maintained for multiple uses, including wildlife habitat, low-intensity recreation (i.e., hiking, biking and backpack camping) and groundwater pumping. The SWFWMD manages the land and assists with the monitoring of groundwater pumping effects. Groundwater withdrawal monitoring is reported according to water-years beginning October and ending the following September. During the two study water-years (October 1, 2001- September 30, 2002), groundwater pumping averaged 11.2 million gallons per day (mgd).

Cypress wetlands occur frequently in the southeastern coastal plain and are typically found scattered throughout the pine flatwoods of Florida (Ewel 1990). The typical hydrologic pattern for cypress wetlands in west-central Florida is inundation upon the onset of summer rains followed by a slow drying beginning in the fall (Mitsch 1984) and occasionally shorter periods of inundation in the winter (Berryman and Henigar 2000). Twelve cypress wetlands were chosen, in coordination with the SWFWMD, for the anuran reproductive success analysis. Each study wetland had similar surrounding habitat, and met criteria for minimum size (>0.2 hectare) and depth of historic inundation (>0.3 meter). An additional 14 wetlands were chosen for a breeding male census (Table 2.1, Figure 2.2).

Figure 2.2 J.B. Starkey Wellfield Site Locations and Land Use Map

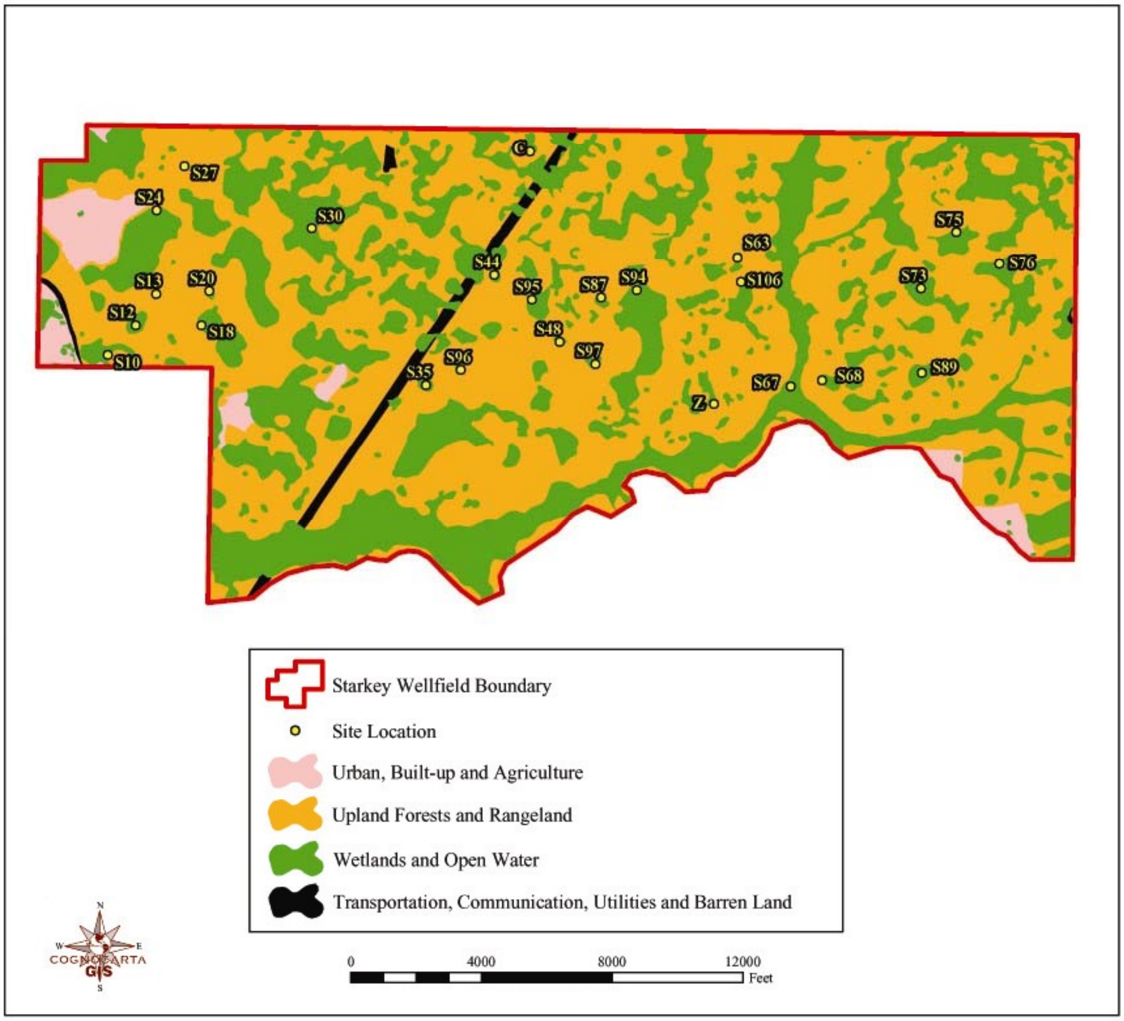


Table 2.1 Sampling Locations and Monitoring Methods

#	MONITORING ID	LATITUDE/ LONGITUDE	SAMPLING METHODS
1	S-87	28.24501N/82.59625W	Tadpole Monitoring Site, Traps and Net
2	S-95	28.24473N/82.60283W	Tadpole Monitoring Site, Traps and Net
3	S-97	28.23936N/82.59667W	Tadpole Monitoring Site, Traps and Net
4	S-94	28.24566N/82.59286W	Tadpole Monitoring Site, Net
5	S-68	28.23825N/82.57515W	Tadpole Monitoring Site, Traps and Net
6	S-106	28.24647N/82.58296W	Tadpole Monitoring Site, Net
7	S-10	28.23955N/82.64303W	Tadpole Monitoring Site, Net
8	S-96	28.23871N/82.60947W	Tadpole Monitoring Site, Traps and Net
9	C	28.25725N/82.60318W	Tadpole Monitoring Site, Net
10	Z	28.25561N/82.63597W	Tadpole Monitoring Site, Net
11	S-44	28.24678N/82.60641W	Tadpole Monitoring Site, Net
12	S-30	28.25055N/82.62383W	Tadpole Monitoring Site, Net
13	S-18	28.24219N/82.63418W	Call Census Only
14	S-12	28.24212N/82.64040W	Call Census Only
15	S-13	28.24480N/82.63851W	Call Census Only
16	S-63	28.24850N/82.58331W	Call Census Only
17	S-27	28.25561N/82.63597W	Call Census Only
18	S-24t	28.25187N/82.63857W	Call Census Only
19	S-20	28.24509N/82.63346W	Call Census Only
20	S-76	28.24829N/82.55843W	Call Census Only
21	S-73	28.24613N/82.56585W	Call Census Only
22	S-75	28.25091N/82.56259W	Call Census Only
23	S-67	28.23770N/82.57811W	Call Census Only
24	S-89	28.23898N/82.56568W	Call Census Only
25	S-35	28.23742N/82.61278W	Call Census Only
26	S-48	28.24117N/82.60011W	Call Census Only

In all, the two-year study included a frog call census of 26 wetlands on SWF and a more detailed tadpole census of 12 of the 26. The wetlands were sampled 12 times for breeding males and 13 times for larvae between July 2001 and December 2002. The number of wetlands chosen for the study represents the maximum number of wetlands possibly visited by one individual in one night (call-collection) or three sequential days (tadpole collection). Site selection was based on ecological habitat type, geographic position of the wetlands and specific requests of the SWFWMD. Sites were visited for tadpole census every three weeks during the peak-breeding season to reduce the possibility of missing an entire breeding cycle while reducing the potential disturbance to the community. The 15 September event 2001 was rescheduled for one week after a tropical storm.

Anuran Breeding Male Census

Anuran surveys at breeding ponds are particularly effective in estimating species richness or comparing breeding attempts across sites (Scott and Woodward 1994). Surveys were conducted in accordance with the North American Amphibian Monitoring Program (NAAMP) guidelines (http://www.mp2-pwrc.usgs.gov/naamp/protocol/). Surveys began immediately upon inundation of any of the 26 study wetlands. Because of quickly changing summer weather patterns in Florida, ideal conditions (warm ambient temperature with high humidity or light rain) were not present at each wetland on every evening. Surveys were conducted when these conditions were present in the late afternoon or forecast for the evening. If a survey was begun, all wetlands were visited unless weather conditions or lack of vehicular access prohibited data collection. Survey results were reported for evenings in which all wetlands were visited. In 2001, I chose a route that allowed all wetlands to be visited between 30 minutes after sunset and 0100 hours. This route was followed during all 12 surveys. Thus, each wetland was visited approximately the same time after sunset during each survey.

Data were collected during nine surveys in 2001 and eleven surveys in 2002. Each wetland was visited for 3 minutes and the number of calling males of each species was recorded. The size of the chorus recorded was the maximum number of individuals of each species heard during the 3-minute observation. Calling activity was measured in size categories. The categories were based on the NAAMP, but refined to reflect six categories as follows: 1-10 calling males, 11-25 calling males, 26-50 calling males, 51-100 calling males, 101-500 calling males and greater than 500 calling males. I also recorded the date, time, current weather conditions (ambient temperature and observations regarding clouds and precipitation) and weather conditions over the preceding 24 hours. If no water was present at the permanently marked center of the wetland, the observation was limited to 1 minute provided no calling males of any species were recorded. During four of the call events each year, sampling could not be completed because of impassible roads or intense thunderstorms. Thus, data from five nights in 2001 and seven in 2002 are reported herein.

Quantitative Larva Sampling

Collection and identification of larvae is difficult for many reasons. Thus, tadpole sampling efforts must be well planned to obtain meaningful data without affecting the population. Injury or death of individual tadpoles may occur as a result of excessive handling (P. Delis personal communication). Identification often requires magnification of mouthparts which is difficult or impossible with living specimens in the field. Even in the laboratory, many tadpole species have been incorrectly identified (McDairmid and Altig 2000). Under normal conditions, tadpole densities drop rapidly throughout the larval period and samples should be taken when the larvae are approximately the same age (McDairmid and Altig 2000). Tadpole census events were scheduled for three sequential days to minimize changes in densities during a single sampling event and each event was separated by three weeks to minimize disturbance to the site and population. Larva microhabitat is often species-specific (McDairmid and Altig 2000), and each microhabitat must be sampled with equal intensity (Heyer et al. 1994). Only one species expected on the SWF (*Scaphiophus holbrookii*) has a mean metamorphosis time of less than 30 days (Wright 1932) (Table 2.2). The three weeks between sampling was short enough to be confident that no species had completed the larval stage between sampling.

Twelve wetlands were monitored for larvae. All wetlands chosen were greater than 0.2 hectare and had biological indicators that demonstrated historic normal seasonal water levels of at least 0.3 meters in depth. Data were collected during six sampling periods in 2001 and seven in 2002.

A standardized sampling effort was applied at each site during the two years to estimate relative sizes of tadpole population as they advanced toward metamorphosis. Tadpoles were identified to species (Altig et al. 1999) during active and passive larval sampling methods, as described below.

The active sampling method was based on The Florida Department of Environmental Protection (DEP) Habitat Assessment Standard Operating Procedures (2001) commonly used for rapid bioassessment (macroinvertebrates and fish) of streams and rivers. The method required making a number of one-meter dip net sweeps in each microhabitat proportional to the fraction of the total area of the wetland that each microhabitat covers.

For instance, if there are two microhabitats present in a wetland (water column 25% and edge vegetation 75%) and 20 sweeps to be used in each wetland, then 5 water column sweeps and 15 edge-vegetation sweeps are required. The available microhabitat (acreage and percentage) changed with fluctuating water levels. Vegetation within each wetland was generally homogeneous, and microhabitat was based upon depth of water and presence/absence of vegetation.

Table 2.2 Frog Species known with a range that includes Pasco County, Florida.

Commom Name	Scientific Name	Larval Period*	Breeding Time*
oak toad	*Bufo quercicus*	33-44 days	April to October
southern toad	*Bufo terrestris*	35-55 days	March to October
Florida cricket frog	*Acris gryllus*	50-90 days	throughout the year
green treefrog	*Hyla cinerea*	55-63 days	March to October
pinewoods treefrog	*Hyla femoralis*	35-65 days	March to October
barking treefrog	*Hyla gratiosa*	41-65 days	March to August
squirrel treefrog	*Hyla squirella*	40-60 days	March to October
little grass frog	*Pseudacris ocularis*	45-70 days	throughout the year
Florida chorus frog	*Pseudacris nigrita*	40-60 days	throughout the year
eastern narrowmouth toad	*Gastrophryne carolinensis*	23-67 days	April to October
eastern spadefoot	*Scaphiopus holobrooki*	14-30 days	April to October
Florida gopher frog	*Rana capito*	85-106 days	February to October
bullfrog	*Rana catesbeiana*	365-730 days	February to October
pig frog	*Rana grylio*	365-730 days	April to October
southern leopard frog	*Rana utricularia*	67-86 days	throughout the year
giant toad	*Bufo marinus*	45-50 days	late spring to summer
greenhouse frog	*Eleutherodactylus planirostris*	no larval period	April to September
Cuban treefrog	*Osteopilus septentrionalis*	21-28 days	May to October

* Larval period and breeding time is listed as published in the references below.

1. Ashton, R.E. and P.S. Ashton. 1998. *Handbook of Reptiles and Amphibians of Florida*: *Part Three, The Amphibains.* Windward, Miami.

2. Conant, R. And J.T. Collins, 1998. *A Field Guide to Reptiles and Amphibians: Eastern and Central North America*. The Peterson Guide Services. Houghton Miflin, Boston.

3. Wright, A.H., 1932. *Life Histories of the Frogs of Okeifinokee Swamp, Georgia.* The Macmillan Company, New York.

A passive sampling effort was applied at selected sites by using two sizes of funnel traps that allowed sampling of different microhabitats within each wetland. Ten unbaited minnow traps (60X30X30 cm) were used for sampling relatively deep areas in the wetland. Traps were used in wetlands that had water over 0.3 meters in depth in 2001.

Wetlands that met the water depth criteria only after the passing of Tropical Storm Gabrielle (14 September 2001) were not sampled with large traps. Calling activity indicated that there were few calling males in the wetlands that did not have water until mid-September. Traps were used in the same wetlands both years regardless of water levels. A total of 10 traps were placed in each wetland scattered over approximately 2 hectares. The funnel traps are constructed of 3-mm black plastic Vexar netting (DuPont De Memours & Co., Model No. 5-59-V-360-BABK) stretched over welded frames with funnel entrances at each end (Godley et al. 1981). The funnel entrance was modified to maintain it at approximately 5 centimeters in diameter. Traps were placed in each wetland for approximately 24 hours. Sampling time of approximately 24 hours is recommended (U.S. EPA 2002e) because the allotted time is sufficient to allow for acclimation to disturbance caused by the trap placement and yet short enough to reduce mortality from the variety of vertebrate and invertebrate predators that coexist with the tadpoles. Tadpoles were removed from traps by hand and identified to species (Altig et al. 1999) before release. In cases where field identification was not possible, a sample of tadpoles were collected and preserved for later identification. All aquatic animals caught in the traps or dipnets were identified.

Twenty sweeps, using D-Frame dip nets (Wildco model number 486-E80; 12″X16″, 1/16″ mesh), were used on every wetland during each sampling event in 2002. If a small pool of water was the only inundation in a wetland, then the number of dip net sweeps was reduced to eliminate sampling the same area more than once.

Some of the collection methods were refined before the beginning of sampling in 2002 within the framework of the protocol used in 2001. Refinements include documenting each unit of sampling effort (trap or dipnet sweep) separately rather than pooling data by wetland. For those wetlands in which traps were not used, ten dipnet sweeps were added in 2002 to obtain consistency of units of sampling effort in each wetland.

In 2002, I classified tadpoles into one of three Gosner Stage Categories. The categories used were similar to those proposed McDairmid and Altig (2000) for use in developmental and ecological studies. The categories were adopted to allow measurement of tadpole development progress in the field with minimal harm to the individual. Category 1 is egg or larval maturation prior to hind limb bud development (Gosner Stages 1-25). Category 2 is subsequent to hind limb bud development, but prior to front limb bud development (Gosner Stages 26-40), and Category 3 is development beyond front limb development (Gosner Stages 41-46).

Measurement of Environmental Factors

During each sample period water surface temperature and pH were collected with a Corning Checkmate II pH meter at the edge (<3 meters from the waters edge) and the center. The minimum and maximum temperature between events and a current thermometer reading were collected at the wetland bottom adjacent the staff gauge (Sper Scientific, model number 736690, min/max thermometer) to provide a record of the fluctuation of water temperature between events and the difference between the surface and the bottom temperatures at the sampling time.

The staff gauge reading was taken during each sampling period during 2001. In two wetlands it was noted that the staff gauge placement was not in the deepest location of the wetland and consequently indicated the wetland was dry when water was actually present elsewhere in the wetland. To correct this problem, I installed a staff gauge at more appropriate locations in wetland S-87 and S-44. The new staff gauges were used for the 2002 events. Some gauges were installed to measure inundation in terms of a known vertical coordinate system (NGVD) and some were installed to measure the level of inundation above the wetland bottom. The measurements in NGVD were converted to depth of inundation measurements for all analyses. The size of each wetland was measured using the (GIS) Florida Land Use Cover and Forms Classification System (FLUCFCS) map obtained from SWFWMD.

Statistics

Each wetland was considered a Sampling Unit (SU). Data for each SU were analyzed each year of the study individually, and also pooled for a two-year analysis. Nonparametric statistics are sometimes suggested when sample sizes are small or the underlying distribution of the data is unknown (Potvin and Roff 1999). Although there is debate about the reason to use nonparametric statistics (validity vs. efficiency) or the situations that warrant their use (non-normal distribution, small sample size, high kurtosis) nonparametric statistics were used throughout this analysis because of their wide acceptance in ecological literature, and their simplicity and efficiency in revealing patterns within the data (Stewart-Oaten 1995).

Three types of data analysis were conducted. The first was an R-mode analysis using Spearman Rank Correlation Coefficient was conducted to determine the relationship between tadpole variables (capture rate per unit effort and average number of species per year) and timing of inundation, length of inundation and size of wetland. Temperature and pH were not used in this analysis because of their consistency among sites, given the dates and times of the measurements. Simple descriptive statistics were used to examine the variability between year and event. I used Spearman Rank Correlation index to explore the relationship between the number of species heard calling and the number of tadpole species captured in each wetland.

Second, a Q-mode analysis was conducted to illustrate the relationship between wetlands based on anuran and predator variables. The analysis consisted of a cluster analysis and a non-metric multidimensional scaling (NMDS) analysis that provided a visual illustration of the dissimilarity among wetlands. I used hierarchical cluster analysis and ordination to elucidate patterns and categorize wetlands using quantitative data.

The cluster analysis provided a dendrogram that illustrated the relationships of wetlands to each other in a nested fashion. I used Unweighted Pair-Group Average (UPGA) as the linkage method because, during the clustering, this linkage method preserves the original properties of the space in the dissimilarity matrix (Statistica for Windows 1995, McCune and Grace 2002). I used Euclidean distance measure because of its compatibility with UPGA.

Ordination is a way of graphically summarizing complex relationships and extracting a dominant pattern from an infinite number of possible patterns (McCune and Grace 2002). Nonmetric multidimensional scaling (NMDS) is considered the most generally effective ordination technique for ecological community data and is recommended as the ordination method of choice unless a specific goal requires another method (McCune and Grace 2002). I used the dissimilarity matrix derived from the cluster analysis to conduct an NMDS.

The third type of data analysis was box and whisker plots used to confirm patterns observed throughout the Q and R-mode analyses. Average number of tadpoles captured per unit effort and average number of tadpole species captured per year were used to confirm one distinct group of wetlands had successful anuran reproduction and a separate group of wetlands did not have successful anuran reproduction.

Results

The numbers of species calling in each wetland per event and the average size category for the choruses detected are presented in Tables 2.3 and 2.4. Peak calling activity was observed on 21 July 2001 during the first year of the study and 13 July 2002 during the second year of the study. The number of individuals per unit effort and the number of taxa captured during each sampling event for tadpoles and all predators are presented in Tables 2.5 and 2.6. Tadpole abundances generally peaked two to four weeks after calling activity. Invertebrate abundances fluctuated throughout the year. Fish presence and abundance increased steadily in 2001 until the wetlands began to dry, and throughout sampling in 2002 when most wetlands remained inundated.

Table 2.3 2001 Calling Male Summary Table.

Wetland	Sampling Event #1		Sampling Event #2		Sampling Event #3		Sampling Event #4		Sampling Event #5	
	11 July 2001		14 July 2001		21 July 2001		15 August 2001		04 September 2001	
	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category
C	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-10	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-12	6	1.33	1	4.00	1	4.50	2	1.50	1	1.00
S-13	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-18	2	3.00	1	4.00	2	3.00	2	3.50	2	1.50
S-20	2	2.5	0	N/A	0	N/A	3	1.50	0	N/A
S-24	5	2.60	0	N/A	2	1.00	1	3.00	3	1.33
S-27	0	N/A	0	N/A	1	1.00	0	N/A	0	N/A
S-30	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-35	1	5.00	0	N/A	0	N/A	3	2.67	1	2.00
S-44	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-48	7	2.57	4	2.75	6	2.17	1	1.00	0	N/A
S-63	2	5.00	1	2.00	0	N/A	1	1.00	1	1.00
S-67	2	1.50	1	6.00	0	N/A	1	5.00	0	N/A
S-68	4	3.00	4	2.00	3	1.67	1	3.00	2	1.50
S-73	2	3.00	0	N/A	6	2.83	3	2.00	0	N/A
S-75	0	N/A	0	N/A	3	2.00	4	1.50	2	1.50
S-76	4	2.00	4	2.00	4	2.75	3	1.33	2	1.50
S-87	6	2.67	0	N/A	5	1.60	1	1.00	3	1.33
S-89	5	2.60	5	1.60	4	3.00	1	3.00	2	2.00
S-94	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-95	2	2.50	2	1.00	3	2.67	2	1.50	0	N/A
S-96	6	2.17	4	2.00	6	1.50	2	2.00	2	1.50
S-97	5	3.80	4	3.00	4	1.50	3	2.00	1	2.00
S-106	0	N/A	0	0.00	1	1.00	1	1.00	0	N/A
Z	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A

Total number of species calling and the average size category of each chorus illustrated by date and wetland number. Size categories are as follows: 1 (1-10 calling males), 2 (11-25 calling males), 3 (26-50 calling males), 4 (51-100 calling males), 5 (100-500 calling males), and 6 (greater than 500 calling males).

Table 2.4 2002 Calling Male Summary Table.

Wetland	Sampling Event #1		Sampling Event #2		Sampling Event #3		Sampling Event #4		Sampling Event #5		Sampling Event #6		Sampling Event #7	
	25 June 2002		01 July 2002		09 July 2002		13 July 2002		30 July 2002		15 August 2002		25 August 2002	
	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category
C	0	N/A	0	N/A	0	N/A	4	4.75	3	4.33	2	1.00	3	1.00
S-10	0	N/A	0	N/A	0	N/A	2	3.50	0	N/A	0	N/A	1	1.00
S-12	5	3.60	2	4.50	2	3.50	4	3.00	3	1.67	2	1.00	0	N/A
S-13	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-18	5	4.20	2	3.50	3	3.33	4	3.00	3	2.67	3	2.67	2	1.50
S-20	0	N/A	0	N/A	0	N/A	6	2.00	2	2.00	3	1.33	3	1.33
S-24	0	N/A	0	N/A	0	N/A	7	4.43	4	2.75	2	1.00	2	1.00
S-27	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-30	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-35	0	N/A	0	N/A	1	3.00	4	4.50	6	3.67	3	2.33	3	1.33
S-44	0	N/A	0	N/A	0	N/A	0	N/A	1	2.00	1	1.00	0	N/A
S-48	0	N/A	4	4.50	4	2.00	5	2.60	3	5.33	3	1.33	2	1.50
S-63	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
S-67	0	N/A	8	1.63	0	N/A	0	N/A	1	3.00	2	1.50	2	2.50
S-68	0	N/A	8	2.63	4	4.25	5	3.60	3	4.67	2	1.50	3	1.33
S-73	1	1.00	4	1.75	2	4.00	4	3.50	*	N/A	*	N/A	*	N/A
S-75	0	N/A	4	4.00	2	1.50	4	1.50	4	2.00	2	1.00	2	1.00
S-76	0	N/A	5	1.60	5	2.40	5	1.80	4	1.25	4	1.25	4	1.50
S-87	0	N/A	3	1.67	2	1.00	5	3.40	4	3.50	3	1.67	2	2.00
S-89	0	N/A	2	1.00	5	3.60	5	3.40	4	3.50	2	1.50	1	2.00
S-94	0	N/A	0	N/A	0	N/A	0	N/A	6	3.00	1	6.00	2	2.00
S-95	0	N/A	0	N/A	0	N/A	6	4.67	4	5.25	4	1.75	2	1.50
S-96	0	N/A	7	3.29	0	N/A	3	3.00	3	4.33	4	1.75	4	1.00
S-97	0	N/A	4	3.25	1	1.00	5	3.60	3	5.00	2	2.00	2	2.00
S-106	0	N/A	0	N/A	0	N/A	6	3.67	5	4.20	4	2.00	1	1.00
Z	0	N/A	0	N/A	0	N/A	0	N/A	4	2.25	3	1.67	2	2.00

Total number of species calling and the average size category of each chorus is illustrated by date and wetland number. Size categories are as follows: 1 (1-10 calling males), 2 (11-25 calling males), 3 (26-50 calling males), 4 (51-100 calling males), 5 (100-500 calling males), and 6 (greater than 500 calling males).

Table 2.5 2001 Quantitative Sampling Summary.

Wetland	Sampling Event #1 04 August 2001				Sampling Event #2 25 August 2001				Sampling Event #3 22 September 2001				Sampling Event #4 13 October 2001			
	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
C	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.05(1)	1.05(4)	0(0)	0(0)	.30(2)	1.7(4)	0(0)	0(0)
S-10	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.60(3)	0(0)	0(0)	0(0)	.75(4)	0(0)	0(0)
S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.70	0(0)	0(0)	0(0)	.90	0(0)	0(0)
S-44	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.70	0(0)	0(0)	0(0)	1.55	0(0)	0(0)
S-68	2.46(2)	3.23(7)	.10(1)	0(0)	.60(3)	.67(3)	1.23(3)	0(0)	23.00(2)	1.17(6)	.70(2)	0(0)	0(0)	.77(4)	1.13(2)	0(0)
S-87	.80(2)	1.67(5)	0	.07(1)	2.50(3)	.87(6)	0(0)	.03(1)	.33(3)	1.90(5)	0(0)	0(0)	.23(2)	1.63(4)	0(0)	0(0)
S-94	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.90(3)	0(0)	0(0)	0(0)	.55(4)	0(0)	0(0)
S-95	1.53(2)	1.17(6)	0(0)	0(0)	9.37(5)	.80(5)	0(0)	0(0)	1.10(2)	2.00(1)	0(0)	0(0)	.23(2)	1.70(5)	2.37(1)	0(0)
S-96	2.33(3)	.90(5)	0(0)	0(0)	4.60(4)	1.47(5)	0(0)	0(0)	1.20(4)	.97(6)	0(0)	0(0)	.37(3)	1.70(5)	0(0)	.07(1)
S-97	6.90(5)	.80(4)	0(0)	0(0)	10.13(4)	1.77(5)	0(0)	0(0)	.90(4)	1.53(5)	0(0)	0(0)	.26(2)	1.60(5)	0(0)	0(0)
S-106	15.5(2)	.80(1)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.60(1)	3.55(5)	0(0)	0(0)	1.10(1)	.65(4)	0(0)	0(0)
Z	4.45(3)	.75(2)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.50(1)	3.15(4)	0(0)	0(0)	.05(1)	2.00(3)	0(0)	0(0)

Wetland	Sampling Event #5 10 November 2001				Sampling Event #6 14 December 2001			
	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
C	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
S-10	0(0)	3.60(4)	0(0)	0(0)	0(0)	23.00(1)	0(0)	0(0)
S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
S-44	0(0)	2.70(4)	0(0)	0(0)	0(0)	30.00(2)	0(0)	0(0)
S-68	.20(1)	1.2(6)	4.10(2)	0(0)	0(0)	0(0)	0(0)	0(0)
S-87	0.1(3)	1.80(5)	0(0)	0.03(1)	.37(2)	1.47(6)	0(0)	.03(1)
S-94	0(0)	3.50(3)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
S-95	.30(1)	2.10(6)	0.87(1)	0(0)	.55(1)	2.05(4)	.55(1)	0(0)
S-96	.25(2)	2.4(5)	0(0)	0(0)	4.55(2)	3.10(4)	0(0)	0(0)
S-97	.93(1)	4.10(5)	0(0)	0.07(1)	20.20(1)	11.20(5)	0(0)	0(0)
S-106	1.10(3)	4.95(6)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Z	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)

Each cell represents the total number of individuals captured per unit effort followed by the number of groups (tadpole species, predator family) captured in each wetland sampled during each event.

Table 2.6 2002 Quantitative Tadpole Sampling Summary.

Wetland	Sampling Event #1				Sampling Event #2				Sampling Event #3				Sampling Event #4			
	20 July 2002				10 August 2002				30 August 2002				19 September 2002			
	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
C	.10(2)	1.40(3)	0(0)	0(0)	1.93(7)	3.63(5)	.43(1)	0(0)	1.60(6)	2.80(7)	1.87(3)	0(0)	.70(2)	1.17(5)	1.53(2)	0(0)
S-10	0(0)	0(0)	0(0)	0(0)	.03(1)	3.10(7)	0(0)	0(0)	.20(1)	2.67(7)	0(0)	0(0)	.47(3)	1.80(4)	0(0)	0(0)
S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.70(3)	0(0)	0(0)	0(0)	2.07(5)	0(0)	0(0)
S-44	0(0)	0(0)	0(0)	0(0)	0(0)	2.33(5)	0(0)	0(0)	.40(2)	7.2(6)	0(0)	0(0)	0(0)	8.43(7)	0(0)	0(0)
S-68	1.27(3)	2.73(5)	.03(1)	0(0)	.47(1)	4.07(6)	.53(3)	0(0)	.27(2)	1.07(3)	.40(2)	0(0)	.07(2)	1.93(5)	.60(2)	0(0)
S-87	5.37(3)	5.20(7)	0(0)	0(0)	2.77(3)	3.83(7)	0(0)	0(0)	1.07(1)	3.87(7)	0(0)	0(0)	.20(1)	2.13(7)	0(0)	0(0)
S-94	0(0)	0(0)	0(0)	0(0)	.23(1)	3.70(7)	0(0)	0(0)	.60(2)	2.23(6)	0(0)	0(0)	.27(2)	3.67(7)	1.50(1)	0(0)
S-95	3.70(2)	3.43(5)	0(0)	0(0)	2.77(3)	7.93(8)	0(0)	0(0)	1.00(3)	4.30(6)	.70(1)	0(0)	.83(4)	2.73(5)	2.16(1)	0(0)
S-96	1.97(4)	5.33(6)	0(0)	0(0)	3.63(4)	4.70(7)	0(0)	0(0)	2.77(5)	5.87(8)	0(0)	0(0)	.83(3)	2.83(6)	0(0)	.03(1)
S-97	1.67(3)	3.83(7)	0(0)	0(0)	2.70(4)	5.60(8)	0(0)	.03(1)	1.97(5)	4.70(7)	0(0)	0(0)	.43(3)	2.40(8)	.06(1)	.03(1)
S-106	.93(2)	1.97(5)	0(0)	0(0)	2.67(4)	1.40(4)	0(0)	0(0)	2.00(4)	2.70(7)	0(0)	0(0)	.77(3)	3.9(8)	.17(1)	0(0)
Z	0(0)	0(0)	0(0)	0(0)	7.00(6)	3.23(6)	0(0)	0(0)	5.17(4)	2.23(5)	0(0)	0(0)	2.43(5)	2.10(6)	.07(1)	0(0)

Wetland	Sampling Event #5				Sampling Event #6				Sampling Event #7			
	11 October 2002				01 November 2002				27 November 2002			
	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
C	.07(2)	1.07(5)	3.03(2)	0(0)	.03(1)	1.17(6)	2.10(2)	0(0)	.03(1)	.77(4)	10.50(2)	0(0)
S-10	0(0)	1.00(4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
S-30	0(0)	1.20(5)	0(0)	0(0)	0(0)	8.30(7)	0(0)	0(0)	0(0)	5.53(6)	0(0)	0(0)
S-44	.07(2)	5.33(6)	0(0)	0(0)	0(0)	2.33(6)	0(0)	0(0)	0(0)	4.73(4)	0(0)	0(0)
S-68	0(0)	1.2(4)	1.36(3)	0(0)	0(0)	.67(4)	1.53(3)	0(0)	0(0)	.63(4)	1.93(2)	0(0)
S-87	.37(1)	2.87(8)	0(0)	0(0)	.67(1)	3.10(8)	0(0)	0(0)	1.56(2)	3.93(5)	0(0)	0(0)
S-94	0(0)	3.30(7)	1.70(1)	0(0)	.23(1)	3.97(7)	3.73(1)	0(0)	.07(1)	3.17(5)	2.93(1)	0(0)
S-95	.10(2)	3.60(8)	5.03(1)	0(0)	.13(1)	2.00(6)	3.70(1)	0(0)	0(0)	2.50(6)	17.97(1)	0(0)
S-96	.33(4)	3.37(9)	0(0)	0(0)	.17(3)	2.8(6)	0(0)	0(0)	.17(1)	2.5(5)	0(0)	0(0)
S-97	.10(2)	3.27(7)	.03(1)	0(0)	.43(2)	2.77(7)	1.13(1)	0(0)	.43(1)	1.3(5)	2.27(1)	0(0)
S-106	0(0)	2.8(5)	2.03(1)	0(0)	0(0)	1.93(6)	4.23(1)	0(0)	.03(1)	3.00(7)	4.20(1)	0(0)
Z	.37(4)	2.97(6)	2.77(2)	0(0)	.13(1)	2.77(5)	4.87(2)	0(0)	.13(1)	1.93(6)	.07(1)	0(0)

Each cell represents the total number of individuals captured per unit effort followed by the number of groups (tadpole species, predator family) captured in each wetland sampled during each event.

Figure 2.3 provides four alternate dendrograms that illustrate clusters based on various tadpole and predator species and individual abundances.

Variables used in the creation of Figure 2.3A include the average number of tadpoles captured per unit effort (Year 1, Year 2, and Overall Average), the number of species of tadpoles captured per event (Year 1, Year 2, and Overall Average), and the average number of species captured per year. The cluster analysis illustrates that there are at least two distinct groups.

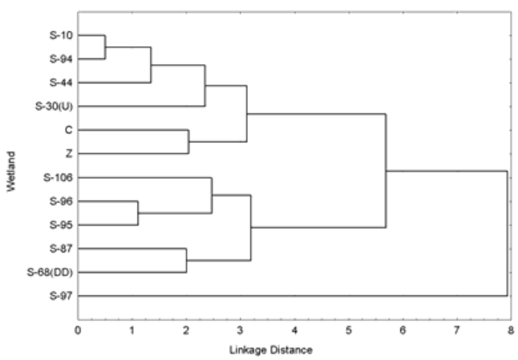
Figure 2.3B was created using 25 variables. The variables were individuals per unit effort and taxa per event for tadpoles, invertebrate predators, fish and other vertebrate predators (Year 1, Year 2 and Overall Average), and the average number of tadpole taxa in each wetland per year. This analysis does not clearly illustrate discrete clusters. Two wetlands were separated very early in the process (S-97 and S-30), followed by a group of two (S-44 and S-10). It is not clear what the relative similarity is between these early departures or their relative proximity to the remaining group. Although the NMDS was sufficient to reduce ambiguity among clusters, Ward's Linkage Method was used in a cluster analysis to illustrate the differences in cluster analyses given different linkage methods. The resultant matrix for the two cluster analyses was identical and thus, only one NMDS was provided.

Figure 2.3C was created using the same data as Figure 2.3B, but the Linkage Method was changed from Unweighted Pair Group Average to Ward's. Although the dissimilarity matrices were identical, and thus the NMDS plots were identical, the presentation of the clusters in the dendrogram is much different. The differences in Figures 2.3B and 2.3C illustrate the problem with using a single cluster analysis to categorize sampling units. Multiple cluster analyses or ordination should be used to clarify clusters.

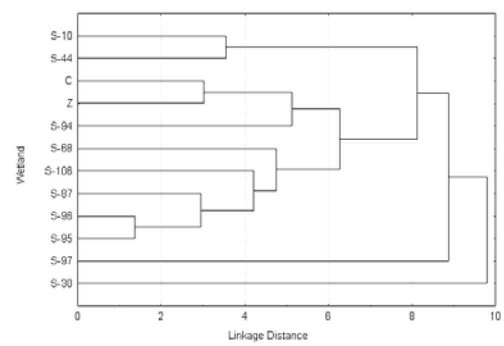
Nine variables were used to create the cluster analysis in Figure 2.3D. The figure was created using the average number of individuals per unit effort and species per event over two years and the number of tadpole species per year. This cluster analysis provides a comprehensive illustration of the data that were collected over the two-year study. Similar to previous cluster analyses, the four wetlands with the fewest numbers and species of tadpoles fall into a group while the remaining wetlands fall into a separate group. The separation based solely on tadpole variables in Figure 2.3A and the similarity to the separation illustrated in Figure 2.3D is notable because tadpole variables comprise only three of nine variables used in Figure 2.3D and seven of the 25 variables in Figures 2.3B and 2.3C.

Figure 2.3 Cluster analysis using a variety of anuran and predator variables.

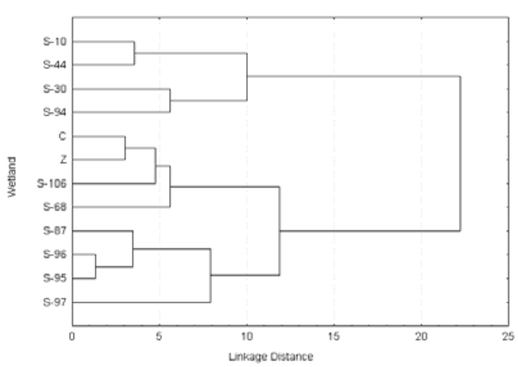
2.3A. Cluster analysis created using seven anuran variables, Unweighted Pair Group Average Linkage Method, and Euclidean distance measure.



2.3B. Cluster analysis created using twenty-five anuran and anuran predator variables, Unweighted Pair Group Average Linkage Method, and a Euclidean distance dissimilarity matrix.



2.3C. Cluster analysis created using twenty-five anuran and anuran predator variables, Wards Linkage Method, and a Euclidean distance dissimilarity matrix.



2.3D. Cluster analysis created using nine anuran and anuran predator variables, Unweighted Pair Group Average Linkage Method, and a Euclidean distance dissimilarity matrix.

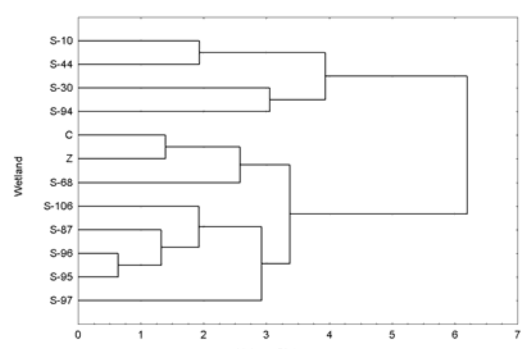


Figure 2.4 NMDS plot created using seven anuran variables and a Euclidean distance dissimilarity matrix. (Stress .0166, Alienation .0287, D-Hat Raw Stress .0396, D-Star Raw Stress .1188).

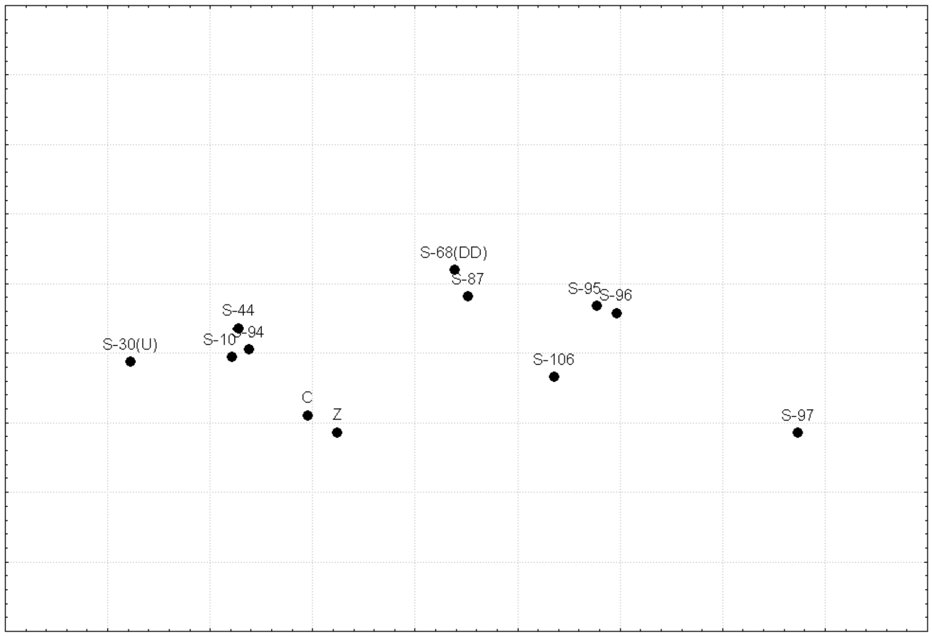
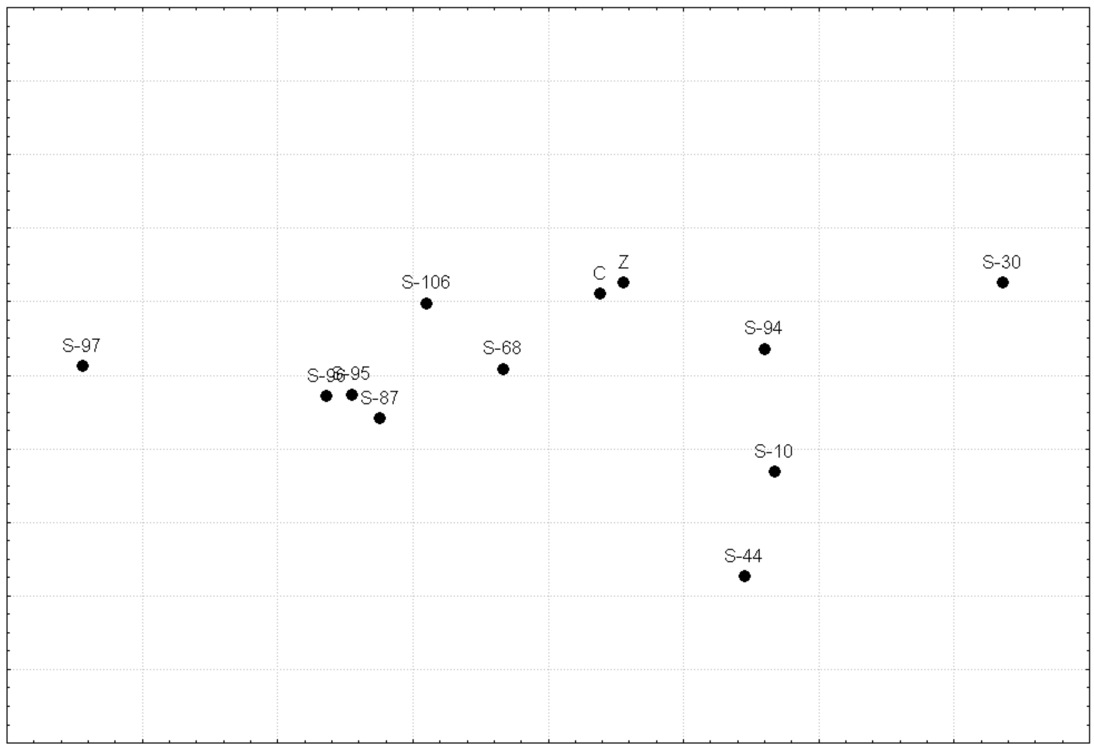


Figure 2.4 plot clears up the ambiguity from the cluster analyses presented in Figure 2.3. Variables used in the creation of Figure 2.4 include the average number of tadpoles captured per unit effort (year 1, year 2 and overall average), the number of species of tadpoles captured per event (year 1, year 2 and overall number average), and the number of species captured per year. It is evident that four wetlands (S-10, S-30, S-44, and S-94) are separate from the remaining wetlands. Examination of the tadpole summary tables (Tables 2.5 and 2.6) show that the separation of these four wetlands is because of their lack of tadpole numbers and diversity. Wetlands C and Z appear tightly grouped and separate from the remaining wetlands. Examination of the tadpole summary tables

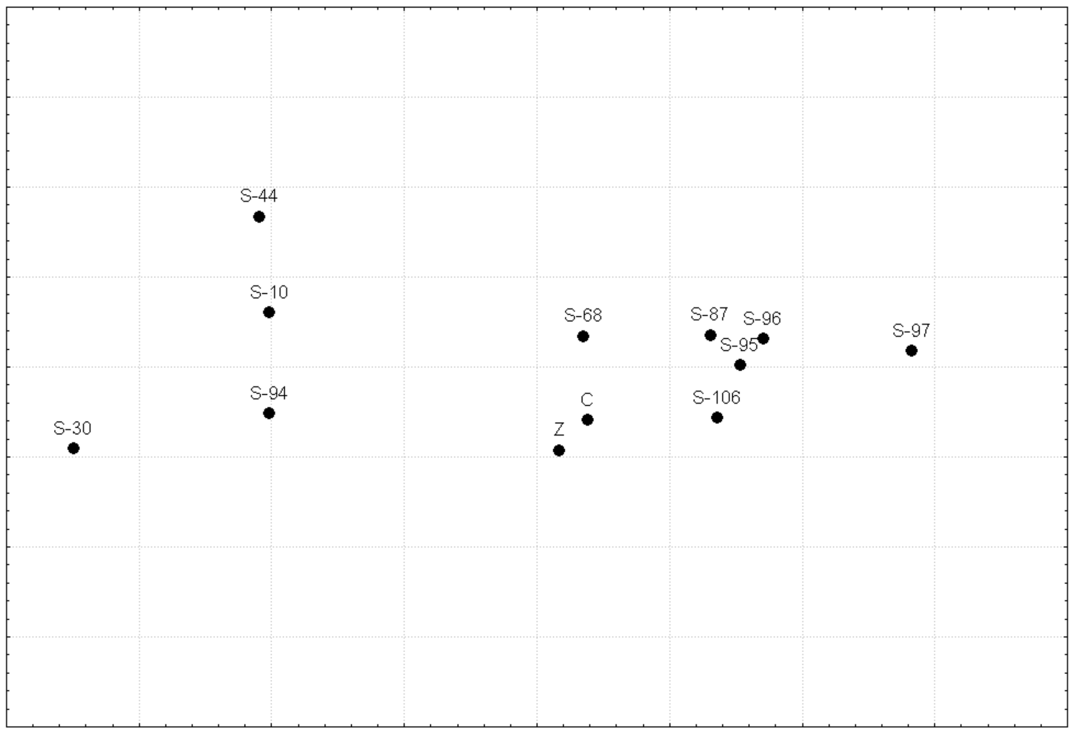
suggests that these wetlands are separate because of fluctuation between low tadpole number and diversity in Year 1 and high tadpole numbers and diversity in Year 2.

Figure 2.5 NMDS plot created using twenty-five anuran and predator variables and a Euclidean distance dissimilarity matrix. (Stress .0382, Alienation .0574, D-Hat Raw Stress .2098, D-Star Raw Stress .4746).



The NMDS using 25 anuran and anuran predator variables (Figure 2.5) provides a two-dimensional view of the relative similarity of wetlands based upon tadpole and predator variables. The groups are similar to those presented in the NMDS plot using only tadpole variables (Figure 2.4); however, an intermediate group appears to be distinct in Figure 2.5.

Figure 2.6 NMDS plot using nine anuran and predator variables and a Euclidean distance dissimilarity matrix. (329 iterations, Stress .0199, Alienation .0321, D-Hat Raw Stress .0576, D-Star Raw Stress .1476).



Clear separation of four wetlands is apparent in Figure 2.6, which was created using a Euclidean Distance dissimilarity matrix that was constructed using nine variables. Overall individuals per unit effort and overall taxa per wetland for tadpoles, invertebrate predators, fish and other vertebrate predators, and average number of tadpole species per year. The four wetlands that lie on the left in Figure 2.6 had low tadpole abundances in both years. All other wetlands had variable species presence and abundances considerably higher than S-10, S-30, S-44 and S-94. Figures 2.7A through 2.7D provide correlative evidence that the species richness and abundances captured are non-random. There are strong positive correlations between the average length of inundation and the number of individual tadpoles captured per unit effort and the number of species of tadpoles captured per year ($R = .73$ $p < .01$; $R = .70$, $p < .05$). There is also a strong negative correlation between the Julian date of inundation and the number of individual tadpoles captured per unit effort and the number of species of tadpoles captured per year ($R = -.81$, $p < .01$; $R = -.78$, $p < .01$). Wetland size was not significantly correlated with any tadpole variable tested. The number of anuran species heard calling was highly correlated with the number of tadpole species captured (Figure 2.8)

Figure 2.7 Spearman Rank Correlations between hydroperiod variables and tadpole variables in 2001 and 2002.

Figure 2.7A Spearman Rank Correlation between average length of inundation and number of tadpoles captured per unit effort (Spearman R= .73, p < .01).

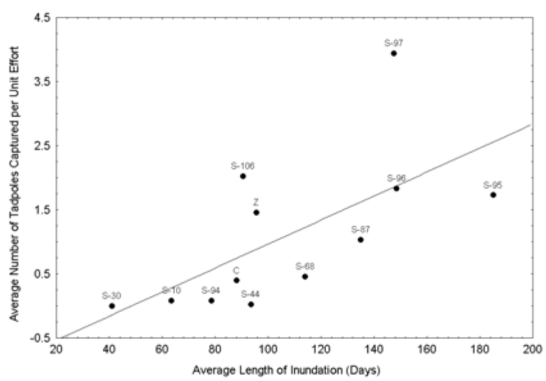


Figure 2.7C. Spearman Rank Correlation between average Julian Date of inundation and number of tadpoles captured per unit effort (Spearman R= -.81, p < .01).

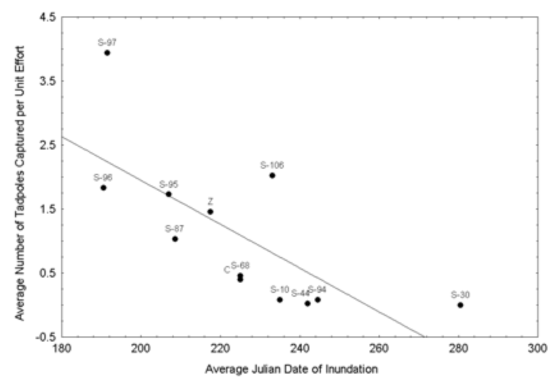


Figure 2.7B Spearman Rank Correlation between average length of inundation and number of tadpole species captured each year (Spearman R= .70, p < .05).

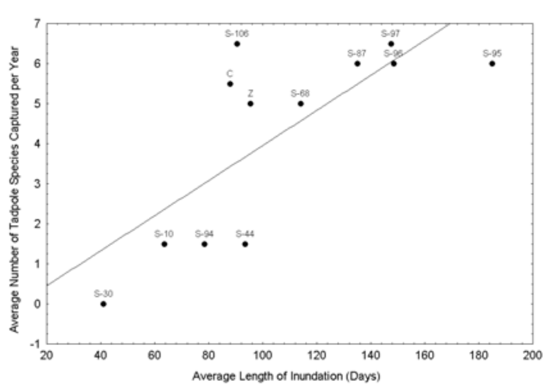


Figure 2.7D Spearman Rank Correlation between average Julian Date of inundation and number of tadpole species captured each (Spearman R= -.78, p < .01).

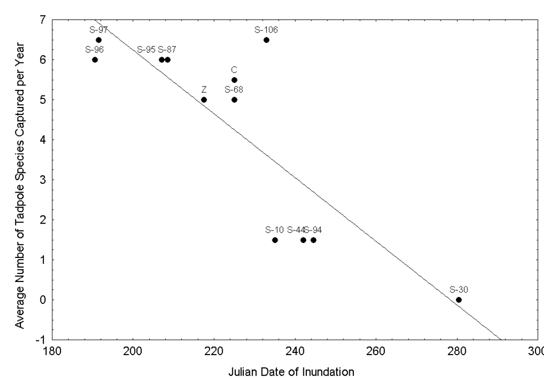
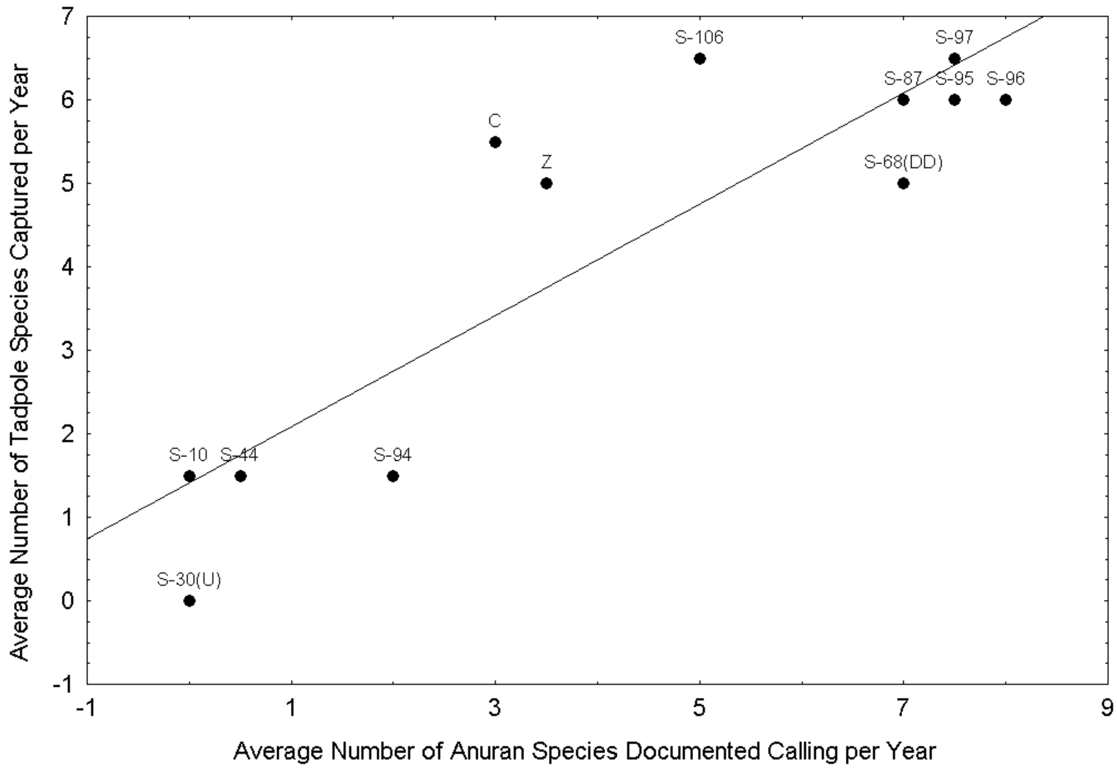


Figure 2.8 Spearman Rank Correlation between average number of species heard calling and the average number of tadpole species captured in 2001 and 2002 (Spearman R= .87, p < .001).



Based on the evidence provided in the cluster and NMDS analysis and the correlative evidence, the wetlands were separated into a successful reproduction group (S-10, S-30, S-44, and S-94) and an unsuccessful reproduction group (C, Z, S-68, S-87, S-95, S-97, and S-106). Box and whisker plots were created for the average number of tadpoles captured per unit effort (Figure 2.9) and the average number of tadpole species captured per year (Figure 2.10) separated by success group.

Figure 2.9 Box and Whisker plot using average number of tadpoles captured per unit effort for unsuccessful vs. successful anuran reproductive success categories.

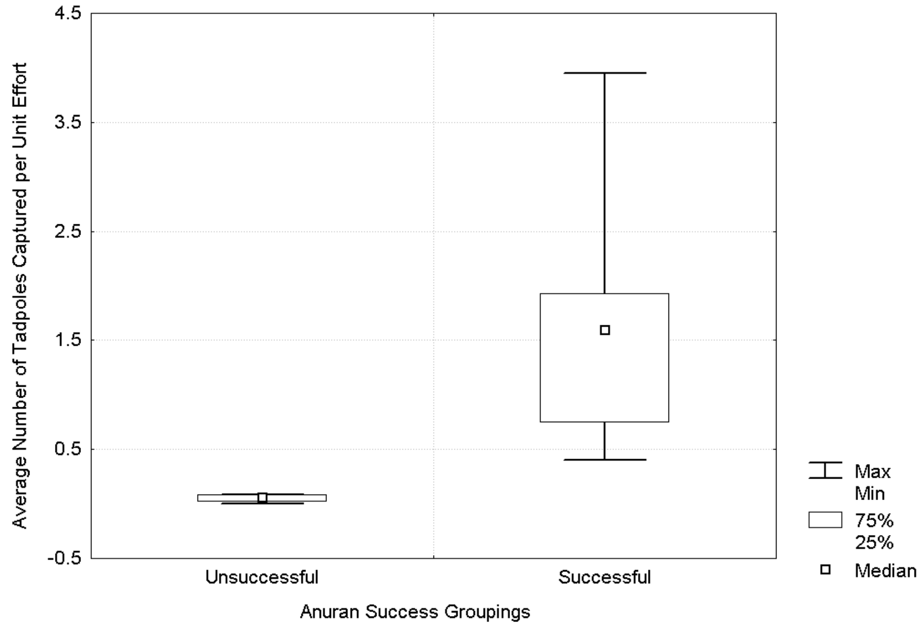
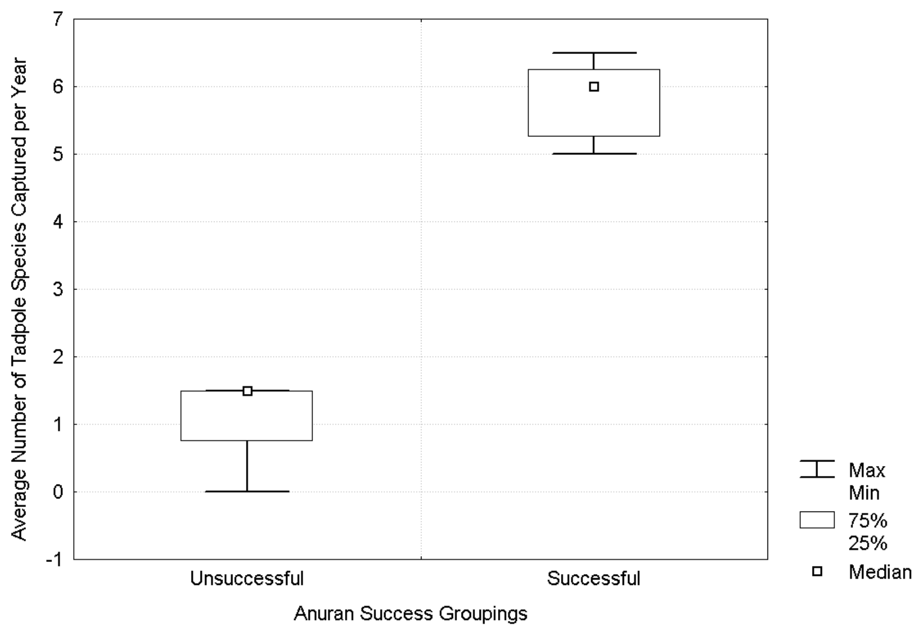


Figure 2.10 Box and Whisker plot using average number of tadpoles species captured per unit effort for unsuccessful vs. successful anuran reproductive success categories.



Discussion

Amphibians have characteristics of a good indicator taxon. They are sensitive to perturbations in aquatic and terrestrial environments because of their biphasic life-cycle, physiological adaptations, and specific microhabitat (Vitt et al. 1990, Wake 1991, Blaustien et al. 1994, Welsh and Ollivier 1998). Despite these characteristics, it is difficult to separate natural population variability from true population decline. For a variety of reasons, especially extreme variability in population sizes (e.g., Berven 1990, Dodd 1992), anuran studies need to be planned as long-term efforts at multiple locations. Using anurans as a surrogate for wetland health may be misleading without some knowledge about what is happening in nearby wetlands (U.S. EPA 2002).

This study provides data on 12 wetlands over two years and evidence that there are two groups of wetlands based on amphibian reproductive success. The first group includes wetlands S-10, S-30, S-44 and S-94). This group had no calling activity in 2001 and little activity in 2002. No tadpoles were captured in any of the four wetlands in 2001 and few were captured in 2002. The average capture rate for each wetland within this group over two years was less than 0.10 individual per unit effort and less than 2 species per year. The second group consists of wetlands C, Z, S-68, S-87, S-95, S-96, S-97 and S-106. This group had relatively large breeding choruses, a capture rate of over 0.39 individual per unit effort (6 of 8 wetlands had a capture rate of over 1.03) and over 4 species per year. These two groupings were confirmed using box and whisker plots for average number of tadpoles captured per unit effort and number of tadpole species captured per year. Various alternate groupings were tested, including adding an intermediate success group and moving C, Z, and S-68 individually or in combination from the successful group to the unsuccessful group. All variations other than those presented in Figures 2.9 and 2.10 diminished the significance of the separation. The clear separation of wetlands based solely on larval amphibian capture rates provides evidence for amphibian reproduction as an indicator of wetland health on the SWF.

The differences in categorization between wetlands can be attributed to the variability in abundance and richness for tadpoles, invertebrate predators, fish, and other vertebrate predators each year. Although no other statistically significant success groupings were observed in the two study years, some patterns began to merge that could be significant over a longer study period.

A group of four wetlands (S-10, S-30, S-44, and S-94) remained a distinct group regardless of separation or combination of study years.   These four wetlands had relatively low individual capture rates and species richness for tadpoles, invertebrates, fish and other vertebrate predators. No changes in categorization of these wetlands would be expected unless the hydroperiod improved. A group of four wetlands (S-95, S-96, S-97, and S-106) were distinct and distant from the low success group in all cluster and NMDS analysis. These three wetlands had relatively high individual tadpole capture rates, tadpole species richness, invertebrate predator capture rates, and relatively low individual fish capture rates and fish richness in both years. No changes in categorization of these wetlands would be expected unless the hydroperiod length or timing was altered.

The remaining four wetlands (C, Z, S-68, and S-87) fluctuated between high and low tadpole numbers and species depending on year or sampling event. Wetlands C and Z had a relatively low capture rate and tadpole species richness in one year and a relatively high capture rate and species richness in the other year resulting in intermediate results overall. Wetlands S-68 and S-87 actually had capture rates and species richness intermediate to the high and low success categories in both years. Wetland S-68 had relatively high capture rates during the first sampling event each year, but the number decreased sharply during subsequent events resulting in overall intermediate numbers each year. Wetland S-68 was relatively near the Cross Cypress branch of the Anclote River and flooding of the river routinely contributed to the water level in the wetland. Fish capture rates and richness in wetland S-68 increased sharply after the first event of both years and included regular captures of known voracious tadpole predators in the family Centrarchidae. River overflow may not affect vegetation composition, but could have detrimental effects on the anurans by supplying a constant source of fish predators. Wetland S-87 also had intermediate capture rate and tadpole richness; however, no fish were captured either year. The same method of sampling Wetlands S-68 and S-87 produced an average of 1.31 individual fish per unit effort in wetland S-68 and none in S-87. Water depth over 1 meter and fallen trees made sampling Wetland S-87 difficult and could have reduced the capture rate. Two species of salamander, of *Amphiuma means* and *Siren lacertian*, were captured in low numbers in wetland S-87 and nowhere else on the site. The presence of these predators could have also reduced the tadpole capture rate.

Strong correlative evidence suggests the hydroperiod of wetlands contributed to capture rates and species richness within wetlands on the SWF and confirms the conclusions of Paton and Crouch III (2002). Figure 2.7 shows wetlands with an average inundation length of less than 90 days had a tadpole capture rate of less than 0.10 individuals per unit effort; Wetlands with an average inundation length of less than 80 days had an average of less than 2 species per year captured. Also, in wetlands not inundated before day 235 (August 23), individual capture rates were less than 0.10 and an average of less than less than 2 species were captured over the study. The average hydroperiod of the high success wetlands was relatively long (>120 days) and began early in the year (before 26 July). The timing of the inundation in relation to reproduction is especially notable because the published breeding season for most of the frogs in central Florida extends to October and the maximum larval period for 14 of the 17 species is 90 days or less (Table 2.2). One explanation for the correlation between anuran success and length of inundation is that a longer period of inundation allows for a suite of asynchronous individuals and species to call, breed, and go through metamorphosis. That is, several large breeding events over several weeks could all produce new metamorphs. A shorter inundation period would allow fewer successful breeding events throughout the season because some tadpoles may not have time to complete metamorphosis. No significant correlation existed between wetland size, water depth, water temperature, or water pH and tadpole capture rate or species richness.

Human activities are known to be detrimental to the natural amphibian biota (Duellman and Trueb 1986). The two most dramatic ecological trends of the past century are anthropogenic changes in biotic diversity and alterations to the structure and function of natural systems (Vitousek 1997). To preserve the functions of the natural systems on the SWF, and extensive monitoring protocol is followed. Monitoring efforts on the J. B. Starkey Wellfield produce valuable data that may be used to predict the occurrence and reproductive success of the natural amphibian community. Maintenance and protection of biological diversity are best accomplished when ecologists and natural resource managers coordinate their efforts (Semlitsch 2000). The monitoring data should be evaluated in a timely manner to allow land managers to make necessary management adjustments.

The primary challenge with an indicator species is to separate natural population fluctuations from fluctuations occurring because of anthropogenic change (Welsh and Ollivier 1998, Penchman and Wilbur 1994). In this study, I illustrate changes in the categorization of wetlands based upon variation in tadpole abundance and richness over two years. If results from only one year were examined as opposed to both years individually and the average of both, different conclusions could be reached. Intermediate anuran reproductive success in wetlands C and Z was, in part, because of differential success over two years. Whether the differential success is part of a natural fluctuation or anthropogenic change is unknown.

Categorization of wetlands into two groups would provide a statistically strong result. Such a limited categorization strategy, however, could usher in unforeseen problems. If management decisions are made on the basis of the two-category system, then the wetlands are deemed either successful or unsuccessful at providing amphibian-breeding habitat. The danger in this strategy is that rehabilitation of an unsuccessful wetland may be perceived to be much more difficult and/or costly than rehabilitation of an intermediate wetland, when in reality, such is not the case. A limited categorization strategy would likely result in neglect and further deterioration of unsuccessful wetlands. Furthermore, because amphibian populations exist as metapopulations, a change in the success of a small number of seemingly isolated ponds for a short time period could have far-reaching detrimental effects on the amphibians across the landscape. Changes in management strategies should account for natural variability and focus on prevention of long-term reductions in hydroperiod.

Adding an intermediate category, even if it is statistically insignificant, may assist land managers in identifying potential problems before they become reproductively unsuccessful. However, categorization of wetlands into three groups and allowing potentially natural fluctuations in reproductive success to be deemed overall intermediate success could lead to erroneous conclusions. Actions taken as a result of such erroneous conclusions to correct perceived problems in reproductive success could be costly, unnecessary, or even detrimental to the long-term success of amphibian assemblage.

Determining the value of seasonal wetlands to anuran and other vertebrate populations is the focus of much contemporary research (Gibbs 1993 and 2000, Johnston 1994). For example, Gibbs (1993) reported that small wetlands play a greater role in the metapopulation dynamics of certain taxa of wetland animals than the modest area covered by such small wetlands might imply. In South Carolina, wetlands that retain water for about eight to ten months each year tended to have more anuran species than wetlands with longer or shorter hydroperiods (Snodgrass et al. 2000a). In general, wetlands that retain water for long periods of time tend to support fish, which, in turn, tend to reduce the number of amphibian species breeding in them (Moler 1992). Factors other than wetland size and length of inundation may influence amphibian populations as well. In Montana, amphibian species richness declined as wetland isolation and road density increased, regardless of the spatial scale used for the evaluation (Lehtinen et al. 1999). Habitat fragmentation, road density, habitat quality, or other landscape-scale urbanization affects are not relevant to the SWF at this time on the scale this study was conducted. The habitat is well managed and generally characterized by native land cover. Wetland size, depth, water temperature and pH had no significant relationship with anuran reproductive success. It is likely that the anurans are responding to the length and timing of inundation. Thus, hydroperiod may be used to predict the anuran success on the SWF. Source of inundation could also be important in determining amphibian success because of different predator contributions or water chemistry from the contributing water source.

Using amphibian success to supplement the ongoing vegetative and hydroperiod monitoring would provide the greatest protection from discounting important anthropogenic changes and provide a basis for understanding their natural population fluctuations. Comparing the results of vegetative monitoring with anuran reproductive success may provide the sensitivity to measure small changes that could indicate negative anthropogenic influence or recovery from such negative influences.

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Chapter 3 – Biological Measures of Wetland Health: Comparing Vegetation and Anurans as Indicators

Introduction

Wetlands provide many ecosystem functions including primary production, water attenuation, biochemical transfer and storage, decomposition, and wildlife habitat (Richardson 1994). The interactions of flora and fauna with the physical environment provide the functions that are important to the overall landscape (U.S. EPA 2002a). When the interaction of organisms and the environment is disrupted, the functions of the ecosystem may be diminished (U.S. EPA 2002a). Because it is impractical to measure all aspects of the ecosystem to detect anthropogenic change or measure wetland function, recent focus has been on determining if certain attributes may reflect the overall biological integrity of certain systems. Numerous studies have documented the responses of biological attributes across diverse taxa and regions to human disturbance (Doherty et al. 2000). Sensitive species are usually affected first during times of environmental stress (Odum 1992). Currently, much debate exists over which sensitive species, or species assemblages, are used appropriately as biological indicators. Biological indicators are species, species assemblages, or communities whose presence, abundance, and condition are indicative of a particular set of environmental conditions (Adamus 1996). Monitoring early indicators of ecosystem stress may shorten response time by shifting attention to the relatively quick response of sensitive species (Rapport 1992). Species used as indicators should be abundant and tractable elements of the system that provide an early, holistic diagnosis (Rapport 1992, Welsh and Ollivier 1998).

Because of their biphasic life history, physiological adaptations and specific microhabitat requirements, amphibians are considered to be extremely sensitive to environmental perturbations and excellent barometers of the health of the aquatic and terrestrial habitats in which they reside (Vitt et al. 1990, Wake 1998, Blaustein et al. 1994). Physical and chemical conditions in a wetland are known to exert great influence on amphibian assemblages (Lehtinen et al. 1999, Pierce 1985, Sadinski and Dunson 1992, and Skelly 1996); however, given the diverse taxa and often-specific requirements and responses of amphibians, no consensus exists on what conditions are "suitable" for survival and reproduction.

While much attention has been aimed at identifying large scale, or even global, threats to anurans (Wake 1998), evidence exists that local populations are in decline because of changes in their habitats. Many detrimental habitat alterations are associated with increased human influence and urbanization (Delis et al. 1996). During the five-year period ending in 2000 the human population of Florida increased by approximately 1.7 million. Similar increases are projected for each of the next five-year periods until the year 2025 (U.S. Census Bureau 2000). Accordingly, the human population may increase from 14.2 million in 1995 to 20.7 million in 2025. Landscape-level land use practices can have both direct and indirect effects on wetland habitats and amphibian populations (Lehtinen et al. 1999). Some influences are large in scale and extremely visible such as habitat destruction in the form of conversion from native land-cover to agriculture or development, but others may occur without large-scale topographic or land cover changes (Dodd 1997). A more subtle type of habitat destruction may affect the availability or suitability of amphibian breeding habitat. Breeding habitats may be modified to the extent that they become unsuitable for many species as a result of pollution, introduced species, vegetative composition changes, altered hydrologic regimes, or other anthropogenic alterations (Johnson et al. 2002). Hydrologic alterations such as ditching of wetlands to enhance drainage can have a large effect on anuran use of wetland sites because of alterations to hydroperiod or species interactions (Vickers et al. 1985).

Other forms of hydrologic alteration also may have effects on amphibian breeding habitat. Wetland drawdown is realized by lowering the potentiometric surface of the floridan aquifer, which in turn lowers the surficial aquifer level and finally the level of inundation in wetlands (Brown 1984, also see Stewart 1968, Cherry et al. 1970, Parker 1975, Hutchinson 1984, SWFWMD 1996). Draw down effects on wetland plant community composition are well documented (Sonenshein and Hofstetter 1990, Edwards and Denton 1993, Rochow 1994, Ormiston et al. 1995), but leave no immediate physical evidence of alteration to the landscape. Groundwater withdrawal from the Edwards Aquifer in Texas did not alter land cover of the region, but it was determined, the withdrawal could lead to the loss of aquatic biota including amphibians (U.S. Fish and Wildlife Service 1984, Chippindale et al. 1993).

Alterations in the availability of breeding habitat even on a small scale may have long-term or large-scale effects on amphibian populations. Many authors have discussed pond-breeding amphibian populations in terms of metapopulations (Levins 1969, Gill 1978, Berven and Grudzien 1990, Sinsch 1992, Hecnar and M'Closkey 1996, Semlitsch and Bodie 1998, and Skelly et al. 1999) whose viability is dependent on a balance of sub-population colonization and extinction. Within the parameters of a metapopulation, local habitat perturbations that alter breeding habitat on a relatively small scale could have long-term negative effects on the regional population (Johnson et al. 2002).

My study was designed to (1) compare anuran reproductive success to a vegetative method of wetland monitoring, and (2) identify differences in wetland health classification among wetlands on the J.B. Starkey Wellfield (SWF). The results will allow land resource managers and regulators to evaluate and possibly refine land management practices, including existing monitoring methods, and water policy to suit the natural fauna of the SWF.

Methods

Study Sites

J.B. Starkey Wellfield (SWF) is located in Pasco County, Florida, approximately 28.20° North Latitude and 82.50° West Longitude (Figure 3.1). The site consists of approximately 3,237 hectares, portions of which were donated to or purchased by the Southwest Florida Water Management District (SWFWMD), since 1975. The rectangular parcel is bounded by the Suncoast Parkway (toll highway) to the east, the Anclote River to the south, residential development to the west and a combination of residential development, the Pithlachascotee River, and another 3200-hectare state-owned preserve to the north (Figure 3.2). The habitat at SWF is a matrix of sand-pine dominated sandhill and lakes throughout the topographically higher western third of the site, while the topographically lower eastern two-thirds of the site are characterized by pine flatwoods and cypress wetlands.

Currently, SWF is maintained for multiple uses, including wildlife habitat, low-intensity recreation (i.e., hiking, biking and backpack camping) and groundwater pumping. The SWFWMD manages the land and assists with the monitoring of groundwater pumping effects. Groundwater withdrawal monitoring is reported according to water-years beginning October and ending the following September. During the two study water-years (October 1, 2001- September 30, 2002), groundwater pumping averaged 11.2 million gallons per day.

Cypress wetlands occur frequently in the southeastern coastal plain and are typically found scattered throughout the pine flatwoods of Florida (Ewel 1990). The typical hydrologic pattern for cypress wetlands in this area is inundation upon the onset of summer rains followed by a slow drying beginning in the fall (Mitsch 1984) and occasionally shorter periods of inundation in the winter (Berryman and Henigar 2000). Twelve cypress wetlands were chosen, in coordination with the SWFWMD, for the vegetative analysis and the anuran reproductive success analysis. Each study wetland had similar surrounding habitat, and met criteria for minimum size (>0.2 hectare) and depth of historic inundation (>0.3 meter). An additional 14 wetlands were chosen for a breeding male census (Table 3.1, Figure 3.2).

Figure 3.1 J.B. Starkey Wellfield Location Map

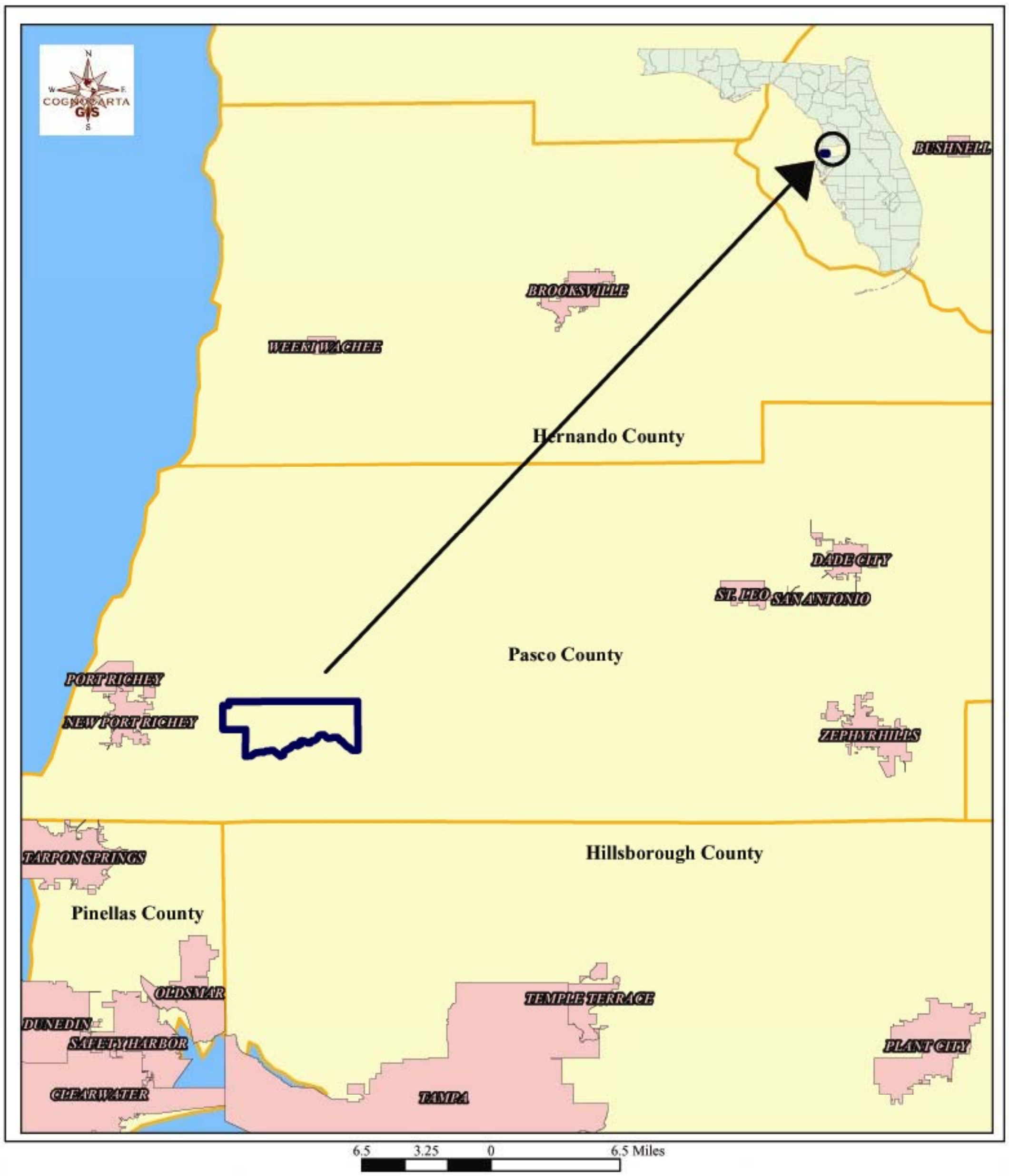


Figure 3.2 J.B. Starkey Wellfield Site Locations and Land Use Map

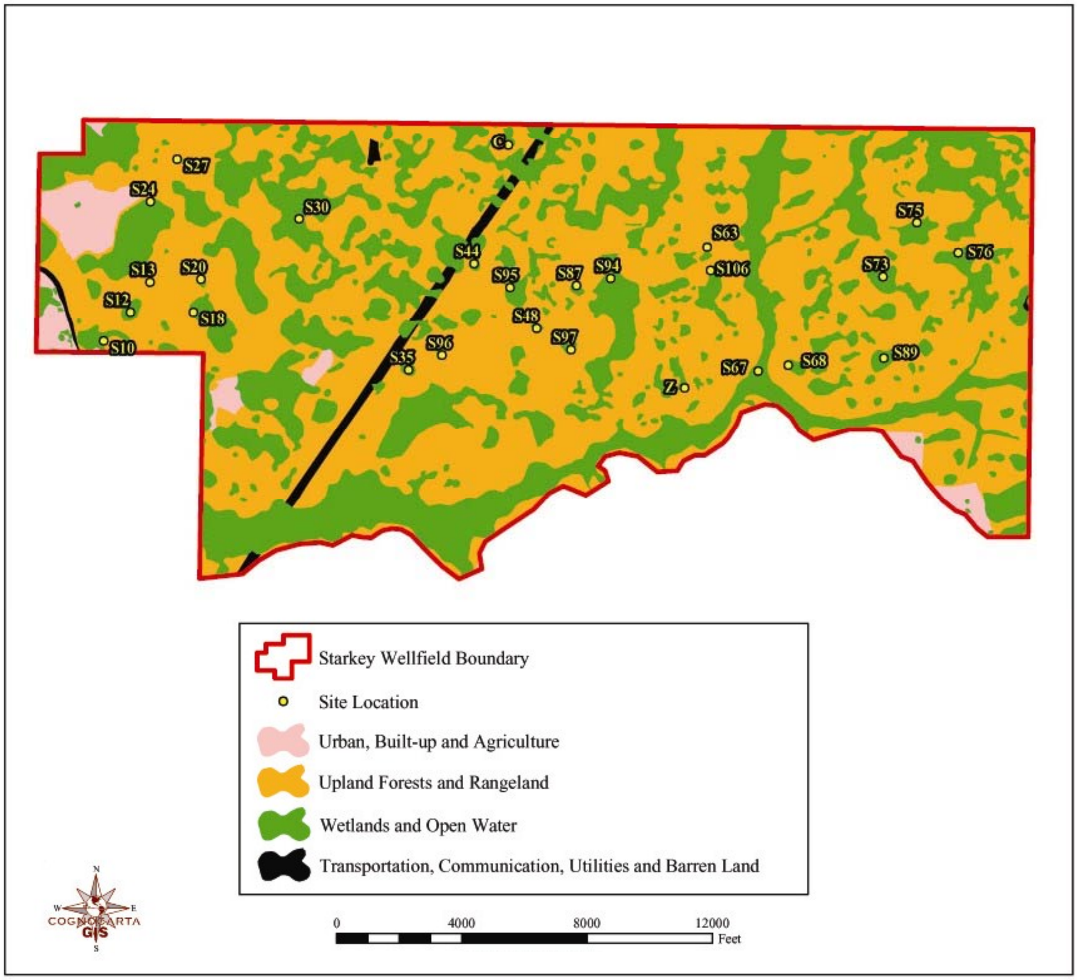


Table 3.1 Sampling Locations and Monitoring Methods

#	MONITORING ID	LATITUDE/ LONGITUDE	SAMPLING METHODS
1	S-87	28.24501N/82.59625W	Tadpole Monitoring Site, Traps and Net
2	S-95	28.24473N/82.60283W	Tadpole Monitoring Site, Traps and Net
3	S-97	28.23936N/82.59667W	Tadpole Monitoring Site, Traps and Net
4	S-94	28.24566N/82.59286W	Tadpole Monitoring Site, Net
5	S-68	28.23825N/82.57515W	Tadpole Monitoring Site, Traps and Net
6	S-106	28.24647N/82.58296W	Tadpole Monitoring Site, Net
7	S-10	28.23955N/82.64303W	Tadpole Monitoring Site, Net
8	S-96	28.23871N/82.60947W	Tadpole Monitoring Site, Traps and Net
9	C	28.25725N/82.60318W	Tadpole Monitoring Site, Net
10	Z	28.25561N/82.63597W	Tadpole Monitoring Site, Net
11	S-44	28.24678N/82.60641W	Tadpole Monitoring Site, Net
12	S-30	28.25055N/82.62383W	Tadpole Monitoring Site, Net
13	S-18	28.24219N/82.63418W	Call Census Only
14	S-12	28.24212N/82.64040W	Call Census Only
15	S-13	28.24480N/82.63851W	Call Census Only
16	S-63	28.24850N/82.58331W	Call Census Only
17	S-27	28.25561N/82.63597W	Call Census Only
18	S-24t	28.25187N/82.63857W	Call Census Only
19	S-20	28.24509N/82.63346W	Call Census Only
20	S-76	28.24829N/82.55843W	Call Census Only
21	S-73	28.24613N/82.56585W	Call Census Only
22	S-75	28.25091N/82.56259W	Call Census Only
23	S-67	28.23770N/82.57811W	Call Census Only
24	S-89	28.23898N/82.56568W	Call Census Only
25	S-35	28.23742N/82.61278W	Call Census Only
26	S-48	28.24117N/82.60011W	Call Census Only

In all, the two-year study included a frog call census of 26 wetlands on SWF and a periodic tadpole census of 12 of the 26. The wetlands were sampled for breeding males 12 times and 13 times for larvae between July 2001 and December 2002. The number of wetlands chosen for the study represents the maximum number of wetlands possibly visited by one individual in one night (call-collection) or three sequential days (tadpole collection). Site selection was based on habitat type, geographic location of the wetlands, exhibited level of anthropogenic degradation and specific requests of the SWFWMD (see

SWFWMD, 1996, Hancock et al. 1999, and Rochow 1998). Land managers estimated the level of anthropogenic change exhibited in each wetland and wetlands were placed in one of three categories described below. Sites were visited for tadpole census every three weeks during the peak-breeding season to eliminate the possibility of missing an entire breeding cycle and, at the same time, minimize the potential disturbance to the community. The 15 September event 2001 was rescheduled for one week after a tropical storm.

Analysis of Vegetation

Prior to this study, land managers categorized each of the study wetlands qualitatively using the Vegetative Health Rating (VHR). The VHR method (See Wetland Evaluation Method in Rochow 1998) includes quantitative categorical variables that measure vegetative composition and physical variables to ultimately produce three color-coded categories that reflect the level of anthropogenic change. Based on scores for several quantitative variables, the researcher rated the wetland on a 1-5 scale without a logarithm of any kind. Over time, the quantitative variables were replaced with reviewer comments and notes only.

Each of the twelve study wetlands was assigned a color representing the VHR of the wetland by a long-term land manager. A VHR of blue was assigned to a wetland having vegetation, hydrology and soils indicative of a natural, healthy cypress wetland. A VHR of green was assigned to a wetland in which moderate anthropogenic changes were observed. Anthropogenic changes were observed in vegetative composition and zonation, hydrologic indicators, soil subsidence or other abnormal characteristics noted by the researcher. A VHR of red was assigned to a wetland in which severe anthropogenic changes were observed. Such changes include severe tree fall or death, upland species encroachment, changes in or elimination of zonation, severe soil oxidation or soil subsidence and biological evidence of hydroperiod reduction. The assignment of color categories was most recently conducted in the spring of 2001. The wetlands used in this study had not changed color category for at least one-year prior to, or upon completion of the study (T. Rochow personal communication). The stable Vegetative Health Rating allows for a comparison of the Vegetative Health Rating with the results of our study.

Because of the regulatory requirements of the SWFWMD Water Use Permit, an Environmental Management Plan (EMP) was developed for SWF and other Northern Tampa Bay regional wellfields. One requirement of the EMP is a specific monitoring method known as the Wetland Assessment Procedure (WAP) be used twice yearly. The WAP consists of eighteen variables scored on a 1-3 scale (Table 3.2) measured on half-point increments, although fractions were rarely used. A score of one represents a wetland character that has been severely affected, while three represents an unaffected character or natural condition. Quantitative data from the spring and fall from 2001 and 2002 years were analyzed for our study.

Hydrologic data were obtained from the SWFWMD or the environmental consultant that monitors wetlands at SWF on behalf of the wellfield operator, Tampa Bay Water. The Julian date of inundation was calculated using the first date of continuous inundation after the residual inundation from the previous year was no longer present. For instance, if a wetland was inundated continuously from July 2000 to January 2001, followed by a dry period that lasted until August 2001, the calculation of the 2001 Julian date of inundation used the August date even though it was not the first time that year that inundation was present. In addition, when an anomalous rain event left a wetland inundated for a brief period (<2 weeks) in the dry season, this inundation was disregarded.

Table 3.2 Wetland Assessment Procedure Variables

VARIABLE		DESCRIPTION
Groundcover		
	Deep Zone Composition	Percent cover of hydrophytic herbaceous vegetation
	Transitional Zone Composition	Percent cover of hydrophytic herbaceous vegetation in transitional zone
	Species Zonation	Current zonation vs. expected in an unaffected system
	Weedy Groundcover	Percent cover of weedy herbaceous vegetation in the entire wetland[1]
Shrub		
	Composition	Percent cover of hydrophytic woody species with a diameter at breast height (dbh) of < 4cm and > 1.0 m total height
	Species Zonation	Current zonation vs. expected in an unaffected system
	Weedy Shrubs	Percent cover of weedy woody species with a dbh of < 4cm and >1.0 m total height[1]
Vines		
	Zonation	Current zonation vs. expected in an unaffected system
Canopy		
	Composition	Percent cover of appropriate woody species with a dbh of > 4cm and > 1.0 m total height
	Zonation	Current zonation vs. expected in an unaffected system
Tree Health		
	Stress	Percent of wetland-appropriate trees that exhibit signs of stress
	Leaning	Percent of wetland-appropriate trees that are leaning
	Dead	Percent of wetland-appropriate trees that are dead
Soils		
	D X 7/8	Presence and severity of soil subsidence at a fixed location near the edge of the wetland
	D X 1/2	Presence and severity of soil subsidence at a fixed location near the center of the wetland
	NP – 3	Presence and severity of soil subsidence at a fixed location where the ground elevation is approximately 3 inches below the Normal Pool elevation
	NP – 12	Presence and severity of soil subsidence at a fixed location where the ground elevation is approximately 12 inches below the Normal Pool elevation
Hydrology		
	Current water level indicators	Presence and level of biological indicators of hydrology (i.e. moss collars, lichens, stain lines, etc.)

1 – A list of potential “weedy” species is provided to the reviewer.

Anuran Breeding Male Census

Anuran surveys at breeding ponds are particularly effective in estimating species richness or comparing breeding attempts across sites (Scott and Woodward 1994). Surveys were conducted in accordance with the North American Amphibian Monitoring Program (NAAMP) guidelines (http://www.mp2-pwrc.usgs.gov/naamp/protocol/). Surveys began immediately upon inundation of any of the 26 study wetlands. Because of quickly changing summer weather patterns in Florida, ideal conditions (warm ambient temperature with high humidity or light rain) were not present at each wetland on every evening. Surveys were conducted when these conditions were present in the late afternoon or forecast for the evening. If a survey was begun, all wetlands were visited unless weather conditions or lack of vehicular access prohibited data collection. Survey results were reported for evenings in which all wetlands were visited. In 2001, I chose a route that allowed all wetlands to be visited between 30 minutes after sunset and 0100 hours. This route was followed during all 12 surveys. Thus, each wetland was visited approximately the same time after sunset during each survey.

Data were collected during nine surveys in 2001 and eleven surveys in 2002. Each wetland was visited for 3 minutes and the number of calling males of each species was recorded. The size of the chorus recorded was the maximum number of individuals of each species heard during the 3-minute observation. Calling activity was measured in size categories. The categories were based on the NAAMP, but refined to reflect six categories as follows: 1-10 calling males, 11-25 calling males, 26-50 calling males, 51-100 calling males, 101-500 calling males and greater than 500 calling males. I also recorded the date, time, current weather conditions (ambient temperature and observations regarding clouds and precipitation) and weather conditions over the preceding 24 hours. If no water was present at the permanently marked center of the wetland, the observation was limited to 1 minute provided no calling males of any species were recorded. During four of the call events each year, sampling could not be completed because of impassible roads or intense thunderstorms. Thus, data from five nights in 2001 and seven in 2002 are reported herein.

Quantitative Larva Sampling

Collection and identification of larvae is difficult for many reasons. Thus, tadpole sampling efforts must be well planned to obtain meaningful data without affecting the population. Injury or death of individual tadpoles may occur as a result of excessive handling (P. Delis personal communication). Identification often requires magnification of mouthparts which is difficult or impossible with living specimens in the field. Even in the laboratory, many tadpole species have been incorrectly identified (McDairmid and Altig 2000). Under normal conditions, tadpole densities drop rapidly throughout the larval period and samples should be taken when the larvae are approximately the same age (McDairmid and Altig 2000). Tadpole census events were scheduled for three sequential days to minimize changes in densities during a single sampling event and each event was separated by three weeks to minimize disturbance to the site and population. Larva microhabitat is often species-specific (McDairmid and Altig 2000), and each microhabitat must be sampled with equal intensity (Heyer et al. 1994). Only one species expected on the SWF (*Scaphiophus holbrookii*) has a mean metamorphosis time of less than 30 days (Wright 1932) (Table 3.3). The three weeks between sampling was short enough to be confident that no species had completed the larval stage between sampling.

Twelve wetlands were monitored for larvae. All wetlands chosen were greater than 0.2 hectare and had biological indicators that demonstrated historic normal seasonal water levels of at least 0.3 meters in depth. Data were collected during six sampling periods in 2001 and seven in 2002.

A standardized sampling effort was applied at each site during the two years to estimate relative sizes of tadpole population as they advanced toward metamorphosis. Tadpoles were identified to species (Altig et al. 1999) during active and passive larval sampling methods, as described below.

The active sampling method was based on The Florida Department of Environmental Protection (DEP) Habitat Assessment Standard Operating Procedures (2001) commonly used for rapid bioassessment (macroinvertebrates and fish) of streams and rivers. The method required making a number of one-meter dip net sweeps in each microhabitat proportional to the fraction of the total area of the wetland that each microhabitat covers. For instance, if there are two microhabitats present in a wetland (water column 25% and edge vegetation 75%) and 20 sweeps to be used in each wetland, then 5 water column sweeps and 15 edge-vegetation sweeps are required. The available microhabitat (acreage and percentage) changed with fluctuating water levels. Vegetation within each wetland was generally homogeneous, and microhabitat was based upon depth of water and presence/absence of vegetation

Table 3.3 Frog Species known with a range that includes Pasco County, Florida.

Commom Name	Scientific Name	Larval Period*	Breeding Time*
oak toad	*Bufo quercicus*	33-44 days	April to October
southern toad	*Bufo terrestris*	35-55 days	March to October
Florida cricket frog	*Acris gryllus*	50-90 days	throughout the year
green treefrog	*Hyla cinerea*	55-63 days	March to October
pinewoods treefrog	*Hyla femoralis*	35-65 days	March to October
barking treefrog	*Hyla gratiosa*	41-65 days	March to August
squirrel treefrog	*Hyla squirella*	40-60 days	March to October
little grass frog	*Pseudacris ocularis*	45-70 days	throughout the year
Florida chorus frog	*Pseudacris nigrita*	40-60 days	throughout the year
eastern narrowmouth toad	*Gastrophryne carolinensis*	23-67 days	April to October
eastern spadefoot	*Scaphiopus holobrooki*	14-30 days	April to October
Florida gopher frog	*Rana capito*	85-106 days	February to October
bullfrog	*Rana catesbeiana*	365-730 days	February to October
pig frog	*Rana grylio*	365-730 days	April to October
southern leopard frog	*Rana utricularia*	67-86 days	throughout the year
giant toad	*Bufo marinus*	45-50 days	late spring to summer
greenhouse frog	*Eleutherodactylus planirostris*	no larval period	April to September
Cuban treefrog	*Osteopilus septentrionalis*	21-28 days	May to October

*Larval period and breeding time is listed as publsihed in the references below.

1. Ashton, R.E. and P.S. Ashton. 1998. *Handbook of Reptiles and Amphibians of Florida*: *Part Three, The Amphibains.* Windward, Miami.

2. Conant, R. And J.T. Collins, 1998. *A Field Guide to Reptiles and Amphibians: Eastern and Central North America*. The Peterson Guide Services. Houghton Miflin, Boston.

3. Wright, A.H., 1932. *Life Histories of the Frogs of Okeifinokee Swamp, Georgia.* The Macmillan Company, New Yor

A passive sampling effort was applied at selected sites by using two sizes of funnel traps that allowed sampling of different microhabitats within each wetland. Ten large (60X30X30 cm) unbaited minnow traps were used for sampling relatively deep areas in the wetland. Large traps were used in wetlands that consistently had water over 0.3 meters in depth. Wetlands that met the water depth criteria only after the passing of Tropical Storm Gabrielle (14 September 2001) were not sampled with large traps. Calling activity indicated that there were few calling males in the wetlands that did not have water until mid-September. Traps were used in the same wetlands both years regardless of water levels.   A total of 10 traps were placed in each wetland scattered over approximately 2 hectares. The funnel traps are constructed of 3-mm black plastic Vexar netting (DuPont De Memours & Co., Model No. 5-59-V-360-BABK) stretched over welded frames with funnel entrances at each end (Godley et al. 1981). The funnel entrance was approximately 5 centimeters in diameter. Traps were placed in each wetland for approximately 24 hours (EPA 2002e) because the allotted time is sufficient to allow for acclimation to disturbance caused by the trap placement and yet short enough to reduce mortality from the variety of vertebrate and invertebrate predators that coexist with the tadpoles. Tadpoles were removed from traps by hand and identified to species (Altig et al. 1999) before release. In cases where field identification was not possible, a sample of tadpoles was collected and preserved for later identification. All aquatic animals caught in the traps or dipnets were identified.

Twenty sweeps, using D-Frame dip nets (Wildco model number 486-E80; 12″X16″, 1/16″ mesh), were used on every wetland during each sampling event in 2002, provided sufficient water was present. When a small pool of water was the only inundation in a wetland, the number of dip net sweeps was reduced to eliminate sampling the same area more than once. Ten dipnet sweeps were added in 2002 to the wetlands that were not trapped to standardize the effort to sample each wetland.

Some of the collection methods used in 2001 were refined in 2002. Refinements include documenting each unit of sampling effort (trap or dipnet sweep) separately rather than pooling data by wetland. For those wetlands in which large funnel traps were not used, ten dipnet sweeps were added in 2002. In 2002, I classified tadpoles into one of three Gosner Stage Categories. The categories used were similar to those proposed McDairmid and Altig (2000) for use in developmental and ecological studies. The categories were adopted to allow measurement of tadpole development progress in the field with minimal harm to the individual. Gosner Stage Category 1 is egg or larval maturation prior to hind limb bud development (Gosner Stages 1-25). Gosner Stage Category 2 is subsequent to hind limb bud development, but prior to front limb bud development (Gosner Stages 26-40), and Gosner Stage Category 3 is development beyond front limb development (Gosner Stages 41-46).

Measurement of Environmental Factors

Water surface temperature and pH were measured with a Corning Checkmate II pH meter with temperature capabilities at the time of sampling at the edge (<3 meters from the waters edge) and the center of each wetland. The minimum and maximum temperature between sampling events and a current temperature reading was collected at the wetland bottom adjacent the staff gauge (Sper Scientific, model number 736690, min/max thermometer) to provide a record of the fluctuation of water temperature between events and the difference between the surface and the bottom temperatures at the sampling time.

The staff gauge reading was taken during each sampling period during 2001. In two wetlands it was noted that the staff gauge placement was not in the deepest location of the wetland and consequently indicated the wetland was dry when water was actually present elsewhere in the wetland. To correct this problem, I installed a staff gauge at more appropriate locations in wetland S-87 and S-44. The new staff gauges were used for the 2002 events. Some gauges were installed to measure inundation in terms of a known vertical coordinate system (NGVD) and some were installed to measure the level of inundation above the wetland bottom. The measurements in NGVD were converted to depth of inundation measurements for all analyses.

Statistics

Each wetland was considered a Sampling Unit (SU). Data for each SU were analyzed each year of the study individually, and also pooled for a two-year analysis. Nonparametric statistics are sometimes suggested when sample sizes are small or the underlying distributions of the data are unknown (Potvin and Roff 1999). Although debate exists about the proper use of nonparametric statistics (validity vs. efficiency) and/or the situations that warrant their use (non-normal distribution, small sample size, high kurtosis) nonparametric statistics were used throughout this analysis because of their wide acceptance in ecological literature, and their simplicity and efficiency in revealing patterns within the data (Stewart-Oaten 1995).

Three types of data analysis were conducted. The first was an R-mode analysis using Spearman Rank Correlation Coefficient was conducted to determine the relationship between tadpole variables (capture rate per unit effort and average species per year) and WAP, timing of inundation, length of inundation and size of wetland. Temperature and pH were not used in this analysis because of their consistency among sites, given the dates and times of the measurements. Simple descriptive statistics were used to examine the variability between year and event. We used Spearman Rank Correlation index to explore the relationship between the number of species heard calling and the number of tadpole species captured in each wetland.

Second, a Q-mode analysis was conducted to illustrate the relationship between wetlands and compare the three VHR groups. The analysis consisted of descriptive statistics comparing each VHR category, followed by a cluster analysis and a non-metric multidimensional scaling (NMDS) analysis that provided a visual illustration of the dissimilarity among wetlands. We used hierarchical cluster analysis and ordination to elucidate patterns and categorize wetlands using quantitative data.

The cluster analysis provided a dendrogram that illustrated the relationships of wetlands to each other in a nested fashion. We used Unweighted Pair-Group Average (UPGA) as the linkage method because, during the clustering, this linkage method preserves the original properties of the space in the dissimilarity matrix (Statistica for Windows 1995, McCune and Grace 2002). We used Euclidean distance measure because of its compatibility with UPGA.

Ordination is a way of graphically summarizing complex relationships and extracting a dominant pattern from an infinite number of possible patterns (McCune and Grace 2002). Nonmetric multidimensional scaling (NMDS) is considered the most generally effective ordination technique for ecological community data and is recommended as the ordination method of choice unless a specific goal requires another method (McCune and Grace 2002). We used the dissimilarity matrix derived from the cluster analysis to conduct an NMDS.

Third, box and whisker plots were used to confirm patterns observed throughout the Q and R-mode analyses. Average number of tadpoles captured per unit effort and average number of tadpole species captured per year were used to confirm one distinct group of wetlands had successful anuran reproduction and a separate group of wetlands did not have successful anuran reproduction.

Results

The numbers of species calling in each wetland per event and the average size category for the choruses detected are presented in Tables 3.4 and 3.5. The mean of all average size categories in each VHR category excludes the wetlands that had no calling frogs, whereas the average number of species per VHR category includes the wetlands with no calling frogs. A consistent difference in the number of calling species and chorus size is evident between VHR categories in most events over both years. Blue wetlands consistently had more species and larger choruses and Red wetlands consistently had fewest species and smallest choruses.

Table 3.4 2001 Calling Male Summary Table.

Wetland		Sampling Event #1		Sampling Event #2		Sampling Event #3		Sampling Event #4		Sampling Event #5	
		11 July 2001		14 July 2001		21 July 2001		15 August 2001		04 September 2001	
		# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category
Blue	S-27	0	N/A	0	N/A	1	1.00	0	N/A	0	N/A
	S-68	4	3.00	4	2.00	3	1.67	1	3.00	2	1.50
	S-73	2	3.00	0	N/A	6	2.83	3	2.00	0	N/A
	S-75	0	N/A	0	N/A	3	2.00	4	1.50	2	1.50
	S-76	4	2.00	4	2.00	4	2.75	3	1.33	2	1.50
	S-89	5	2.60	5	1.60	4	3.00	1	3.00	2	2.00
	S-95	2	2.50	2	1.00	3	2.67	2	1.50	0	N/A
	S-96	6	2.17	4	2.00	6	1.50	2	2.00	2	1.50
	S-97	5	3.80	4	3.00	4	1.50	3	2.00	1	2.00
	S-106	0	N/A	0	0.00	1	1.00	1	1.00	0	N/A
Average		**2.80**	**2.72**	**2.30**	**1.66**	**3.50**	**1.99**	**2.00**	**1.93**	**1.10**	**1.67**
Green	C	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	Z	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-10	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-87	6	2.67	0	N/A	5	1.60	1	1.00	3	1.33
	S-94	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
Average		**1.20**	**2.67**	**0.00**	**N/A**	**1.00**	**1.60**	**.20**	**1.00**	**.60**	**1.33**
Red	S-20	2	2.5	0	N/A	0	N/A	3	1.50	0	N/A
	S-30	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-44	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
Average		**.67**	**2.50**	**0.00**	**N/A**	**0.00**	**N/A**	**1.00**	**1.50**	**0.00**	**N/A**
Unclassified	S-12	6	1.33	1	4.00	1	4.50	2	1.50	1	1.00
	S-13	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-18	2	3.00	1	4.00	2	3.00	2	3.50	2	1.50
	S-24	5	2.60	0	N/A	2	1.00	1	3.00	3	1.33
	S-35	1	5.00	0	N/A	0	N/A	3	2.67	1	2.00
	S-48	7	2.57	4	2.75	6	2.17	1	1.00	0	N/A
	S-63	2	5.00	1	2.00	0	N/A	1	1.00	1	1.00
	S-67	2	1.50	1	6.00	0	N/A	1	5.00	0	N/A
Average		**3.13**	**3.00**	**1.00**	**3.75**	**1.38**	**2.67**	**1.38**	**2.52**	**1.00**	**1.37**

Total number of species calling and the average size category of each chorus illustrated by date and Vegetative Health Rating. Size categories are as follows: 1 (1-10 calling males), 2 (11-25 calling males), 3 (26-50 calling males), 4 (51-100 calling males), 5 (100-500 calling males), and 6 (greater than 500 calling males). Blue, Green and Red categories refer to Vegetative Health Rating described in the Qualitative Analysis of Vegetation Section.

Table 3.5 2002 Calling Male Summary Table.

Wetland		Sampling Event #1		Sampling Event #2		Sampling Event #3		Sampling Event #4		Sampling Event #5		Sampling Event #6		Sampling Event #7	
		25 June 2002		01 July 2002		09 July 2002		13 July 2002		30 July 2002		15 August 2002		25 August 2002	
		# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category	# of Species	Avg. size Category
Blue	S-27	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-68	0	N/A	8	2.63	4	4.25	5	3.60	3	4.67	2	1.50	3	1.33
	S-73	1	1.00	4	1.75	2	4.00	4	3.50	*	N/A	*	N/A	*	N/A
	S-75	0	N/A	4	4.00	2	1.50	4	1.50	4	2.00	2	1.00	2	1.00
	S-76	0	N/A	5	1.60	5	2.40	5	1.80	4	1.25	4	1.25	4	1.50
	S-89	0	N/A	2	1.00	5	3.60	5	3.40	4	3.50	2	1.50	1	2.00
	S-95	0	N/A	0	N/A	0	N/A	6	4.67	4	5.25	4	1.75	2	1.50
	S-96	0	N/A	7	3.29	0	N/A	3	3.00	3	4.33	4	1.75	4	1.00
	S-97	0	N/A	4	3.25	1	1.00	5	3.60	3	5.00	2	2.00	2	2.00
	S-106	0	N/A	0	N/A	0	N/A	6	3.67	5	4.20	4	2.00	1	1.00
Average		**.10**	**1.00**	**3.40**	**2.50**	**1.90**	**2.79**	**4.30**	**3.19**	**3.33**	**3.78**	**2.67**	**1.78**	**2.11**	**1.42**
Green	C	0	N/A	0	N/A	0	N/A	4	4.75	3	4.33	2	1.00	3	1.00
	Z	0	N/A	0	N/A	0	N/A	0	N/A	4	2.25	3	1.67	2	2.00
	S-10	0	N/A	0	N/A	0	N/A	2	3.50	0	N/A	0	N/A	1	1.00
	S-87	0	N/A	3	1.67	2	1.00	5	3.40	4	3.50	3	1.67	2	2.00
	S-94	0	N/A	0	N/A	0	N/A	0	N/A	6	3.00	1	6.00	2	2.00
Average		**0**	**N/A**	**.60**	**1.67**	**.40**	**1.00**	**2.20**	**3.88**	**3.40**	**3.27**	**1.80**	**2.59**	**2.00**	**1.60**
Red	S-20	0	N/A	0	N/A	0	N/A	6	2.00	2	2.00	3	1.33	3	1.33
	S-30	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-44	0	N/A	0	N/A	0	N/A	0	N/A	1	2.00	1	1.00	0	N/A
Average		**0**	**N/A**	**0**	**N/A**	**0**	**N/A**	**2.00**	**2.00**	**1.00**	**2.00**	**1.33**	**1.17**	**1.00**	**1.33**
Unclassified	S-12	5	3.60	2	4.50	2	3.50	4	3.00	3	1.67	2	1.00	0	N/A
	S-13	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-18	5	4.20	2	3.50	3	3.33	4	3.00	3	2.67	3	2.67	2	1.50
	S-24	0	N/A	0	N/A	0	N/A	7	4.43	4	2.75	2	1.00	2	1.00
	S-35	0	N/A	0	N/A	1	3.00	4	4.50	6	3.67	3	2.33	3	1.33
	S-48	0	N/A	4	4.50	4	2.00	5	2.60	3	5.33	3	1.33	2	1.50
	S-63	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A
	S-67	0	N/A	8	1.63	0	N/A	0	N/A	1	3.00	2	1.50	2	2.50
Average		**1.25**	**.975**	**2.0**	**3.53**	**1.25**	**2.96**	**3.00**	**3.51**	**2.50**	**3.18**	**1.88**	**1.64**	**1.38**	**1.57**

Total number of species calling and the average size category of each chorus is illustrated by date and Vegetative Health Rating. Size categories are as follows: 1 (1-10 calling males), 2 (11-25 calling males), 3 (26-50 calling males), 4 (51-100 calling males), 5 (100-500 calling males), and 6 (greater than 500 calling males). Blue, Green and Red categories refer to Vegetative Health Rating described in the Qualitative Analysis of Vegetation Section.

The number of individuals per unit effort and the number of taxa captured during each sampling event for tadpoles and all predators are presented in Tables 3.6 and 3.7. Tadpoles, invertebrates, and non-fish vertebrate predators were captured at a consistently higher rate in Blue wetlands than either Green or Red wetlands over both years. Fish were captured at a slightly higher rate in Blue wetlands consistently in Year 1, however in Year 2, were captured at a rate higher in Green wetlands than Blue wetlands in several events. The tables are organized by VHR.

Table 3.6 2001 Quantitative Tadpole Sampling Summary.

Wetland		Sampling Event #1				Sampling Event #2				Sampling Event #3				Sampling Event #4			
		04 August 2001				25 August 2001				22 September 2001				13 October 2001			
		Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
Blue	S-68	2.46(2)	3.23(7)	.10(1)	0(0)	.60(3)	.67(3)	1.23(3)	0(0)	23.00(2)	1.17(6)	.70(2)	0(0)	0(0)	.77(4)	1.13(2)	0(0)
	S-96	2.33(3)	.90(5)	0(0)	0(0)	4.60(4)	1.47(5)	0(0)	0(0)	1.20(4)	.97(6)	0(0)	0(0)	.37(3)	1.70(5)	0(0)	.07(1)
	S-97	6.90(5)	.80(4)	0(0)	0(0)	10.13(4)	1.77(5)	0(0)	0(0)	.90(4)	1.53(5)	0(0)	0(0)	.26(2)	1.60(5)	0(0)	0(0)
	S-95	1.53(2)	1.17(6)	0(0)	0(0)	9.37(5)	.80(5)	0(0)	0(0)	1.10(2)	2.00(1)	0(0)	0(0)	.23(2)	1.70(5)	2.37(1)	0(0)
	S-106	15.5(2)	.80(1)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.60(1)	3.55(5)	0(0)	0(0)	1.10(1)	.65(4)	0(0)	0(0)
Totals		**2.96(7)**	**1.38**	**.02**	**0**	**8.23(5)**	**.94**	**.25**	**0**	**5.36(4)**	**1.84**	**.14**	**0**	**.39(4)**	**1.28**	**.70**	**.01**
Green	C	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.05(1)	1.05(4)	0(0)	0(0)	.30(2)	1.7(4)	0(0)	0(0)
	Z	4.45(3)	.75(2)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.50(1)	3.15(4)	0(0)	0(0)	.05(1)	2.00(3)	0(0)	0(0)
	S-10	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.60(3)	0(0)	0(0)	0(0)	.75(4)	0(0)	0(0)
	S-94	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.90(3)	0(0)	0(0)	0(0)	.55(4)	0(0)	0(0)
	S-87	.80(2)	1.67(5)	0	.07(1)	2.50(3)	.87(6)	0(0)	.03(1)	.33(3)	1.90(5)	0(0)	0(0)	.23(2)	1.63(4)	0(0)	0(0)
Totals		**1.05(4)**	**.48**	**0**	**.01**	**.50(3)**	**.17**	**0**	**.01**	**.18(3)**	**1.92**	**0**	**0**	**.12(4)**	**1.33**	**0**	**0**
Red	S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	.70	0(0)	0(0)	0(0)	.90	0(0)	0(0)
	S-44	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1.70	0(0)	0(0)	0(0)	1.55	0(0)	0(0)
Totals		**0(0)**	**0**	**0**	**0**	**0(0)**	**0**	**0**	**0**	**0(0)**	**1.20**	**0**	**0**	**0(0)**	**1.23**	**0**	**0**

Each cell represents the total number of individuals captured per unit effort followed by the number of groups (species, family, etc.) captured in each wetland sampled during each event. Blue, Green and Red categories refer to Vegetative Health Rating described in the Qualitative Analysis of Vegetation Section.

Table 3.6 Continued

Wetland		Sampling Event #5 10 November 2001				Sampling Event #6 14 December 2001			
		Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
Blue	S-68	.20(1)	1.2(6)	4.10(2)	0(0)	0(0)	0(0)	0(0)	0(0)
	S-96	.25(2)	2.4(5)	0(0)	0(0)	4.55(2)	3.10(4)	0(0)	0(0)
	S-97	.93(1)	4.10(5)	0(0)	0.07(1)	20.20(1)	11.20(5)	0(0)	0(0)
	S-95	.30(1)	2.10(6)	0.87(1)	0(0)	.55(1)	2.05(4)	.55(1)	0(0)
	S-106	1.10(3)	4.95(6)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Totals		**.56(4)**	**2.95**	**.99**	**.01**	**5.06(2)**	**3.27**	**.11**	**0**
Green	C	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	Z	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	S-10	0(0)	3.60(4)	0(0)	0(0)	0(0)	23.00(1)	0(0)	0(0)
	S-94	0(0)	3.50(3)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	S-87	0.1(3)	1.80(5)	0(0)	0.03(1)	.37(2)	1.47(6)	0(0)	.03(1)
Totals		**.02(3)**	**1.78**	**0**	**.01**	**.074(2)**	**4.89**	**0**	**.01**
Red	S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	S-44	0(0)	2.70(4)	0(0)	0(0)	0(0)	30.00(2)	0(0)	0(0)
Totals		**0(0)**	**1.35**	**0**	**0**	**0**	**15**	**0**	**0**

Table 3.7 2002 Quantitative Tadpole Sampling Summary.

Wetland		Sampling Event #1 20 July 2002				Sampling Event #2 10 August 2002				Sampling Event #3 30 August 2002				Sampling Event #4 19 September 2002			
		Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
Blue	S-68	1.27(3)	2.73(5)	.03(1)	0(0)	.47(1)	4.07(6)	.53(3)	0(0)	.27(2)	1.07(3)	.40(2)	0(0)	.07(2)	1.93(5)	.60(2)	0(0)
	S-96	1.97(4)	5.33(6)	0(0)	0(0)	3.63(4)	4.70(7)	0(0)	0(0)	2.77(5)	5.87(8)	0(0)	0(0)	.83(3)	2.83(6)	0(0)	.03(1)
	S-97	1.67(3)	3.83(7)	0(0)	0(0)	2.70(4)	5.60(8)	0(0)	.03(1)	1.97(5)	4.70(7)	0(0)	0(0)	.43(3)	2.40(8)	.06(1)	.03(1)
	S-95	3.70(2)	3.43(5)	0(0)	0(0)	2.77(3)	7.93(8)	0(0)	0(0)	1.00(3)	4.30(6)	.70(1)	0(0)	.83(4)	2.73(5)	2.16(1)	0(0)
	S-106	.93(2)	1.97(5)	0(0)	0(0)	2.67(4)	1.40(4)	0(0)	0(0)	2.00(4)	2.70(7)	0(0)	0(0)	.77(3)	3.9(8)	.17(1)	0(0)
Totals		**1.91(5)**	**3.46(7)**	**.01(1)**	**0(0)**	**2.45(4)**	**4.74(8)**	**.11(3)**	**.01(1)**	**1.60(6)**	**3.72(8)**	**.22(2)**	**0(0)**	**.59(5)**	**2.76(8)**	**.60(2)**	**.01(2)**
Green	C	.10(2)	1.40(3)	0(0)	0(0)	1.93(7)	3.63(5)	.43(1)	0(0)	1.60(6)	2.80(7)	1.87(3)	0(0)	.70(2)	1.17(5)	1.53(2)	0(0)
	Z	0(0)	0(0)	0(0)	0(0)	7.00(6)	3.23(6)	0(0)	0(0)	5.17(4)	2.23(5)	0(0)	0(0)	2.43(5)	2.10(6)	.07(1)	0(0)
	S-10	0(0)	0(0)	0(0)	0(0)	.03(1)	3.10(7)	0(0)	0(0)	.20(1)	2.67(7)	0(0)	0(0)	.47(3)	1.80(4)	0(0)	0(0)
	S-94	0(0)	0(0)	0(0)	0(0)	.23(1)	3.7(7)	0(0)	0(0)	.60(2)	2.23(6)	0(0)	0(0)	.27(2)	3.67(7)	1.50(1)	0(0)
	S-87	5.37(3)	5.20(7)	0(0)	0(0)	2.77(3)	3.83(7)	0(0)	0(0)	1.07(1)	3.87(7)	0(0)	0(0)	.20(1)	2.13(7)	0(0)	0(0)
Totals		**1.25(4)**	**1.32(7)**	**0(0)**	**0(0)**	**2.39(8)**	**3.50(7)**	**.09(1)**	**0(0)**	**1.73(6)**	**2.76(7)**	**.37(3)**	**0(0)**	**.81(5)**	**2.17(7)**	**.62(2)**	**0(0)**
Red	S-30	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	14(3)	0(0)	0(0)	0(0)	2.07(5)	0(0)	0(0)
	S-44	0(0)	0(0)	0(0)	0(0)	0(0)	2.33(5)	0(0)	0(0)	.40(2)	144(6)	0(0)	0(0)	0(0)	8.43(7)	0(0)	0(0)
Totals		**0(0)**	**0(0)**	**0(0)**	**0(0)**	**0(0)**	**1.17(5)**	**0(0)**	**0(0)**	**.20(2)**	**158(6)**	**0(0)**	**0(0)**	**0(0)**	**5.25(7)**	**0(0)**	**0(0)**

Each cell represents the total number of individuals captured per unit effort followed by the number of groups (species of tadpoles, family of all other groups) captured in each wetland sampled during each event. Blue, Green and Red categories refer to Vegetative Health Rating described in the Qualitative Analysis of Vegetation Section.

Table 3.7 Continued.

Wetland		Sampling Event #5 11 October 2002				Sampling Event #6 01 November 2002				Sampling Event #7 27 November 2002			
		Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other	Tadpoles	Inverts	Fish	Other
Blue	S-68	0(0)	1.2(4)	1.36(3)	0(0)	0(0)	.67(4)	1.53(3)	0(0)	0(0)	.63(4)	1.93(2)	0(0)
	S-96	.33(4)	3.37(9)	0(0)	0(0)	.17(3)	2.8(6)	0(0)	0(0)	.17(1)	2.5(5)	0(0)	0(0)
	S-97	.10(2)	3.27(7)	.03(1)	0(0)	.43(2)	2.77(7)	1.13(1)	0(0)	.43(1)	1.3(5)	2.27(1)	0(0)
	S-95	.10(2)	3.60(8)	5.03(1)	0(0)	.13(1)	2.00(6)	3.70(1)	0(0)	0(0)	2.50(6)	17.97(1)	0(0)
	S-106	0(0)	84(5)	61(1)	0(0)	0(0)	58(6)	127(1)	0(0)	1(1)	90(7)	4.20(1)	0(0)
Totals		**.11(4)**	**2.84(9)**	**1.76(3)**	**0(0)**	**.15(4)**	**2.03(7)**	**2.12(3)**	**0(0)**	**.13(1)**	**1.99(7)**	**5.27(2)**	**0(0)**
Green	C	.07(2)	1.07(5)	3.03(2)	0(0)	.03(1)	1.17(6)	2.10(2)	0(0)	.03(1)	.77(4)	10.50(2)	0(0)
	Z	.37(4)	2.97(6)	2.77(2)	0(0)	.13(1)	2.77(5)	4.87(2)	0(0)	.13(1)	1.93(6)	.07(1)	0(0)
	S-10	0(0)	1.00(4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	S-94	0(0)	3.30(7)	1.70(1)	0(0)	.23(1)	3.97(7)	3.73(1)	0(0)	.07(1)	3.17(5)	2.93(1)	0(0)
	S-87	.37(1)	2.87(8)	0(0)	0(0)	.67(1)	3.10(8)	0(0)	0(0)	1.56(2)	3.93(5)	0(0)	0(0)
Totals		**.16(4)**	**2.24(8)**	**1.50(2)**	**0(0)**	**.213(1)**	**2.2(8)**	**2.14(2)**	**0(0)**	**.36(2)**	**1.96(6)**	**2.85(2)**	**0(0)**
R	S-30	0(0)	1.20(5)	0(0)	0(0)	0(0)	8.30(7)	0(0)	0(0)	0(0)	5.53(6)	0(0)	0(0)
	S-44	.07(2)	5.33(6)	0(0)	0(0)	0(0)	2.33(6)	0(0)	0(0)	0(0)	4.73(4)	0(0)	0(0)
Totals		**.03(2)**	**3.27(6)**	**0(0)**	**0(0)**	**0(0)**	**5.32(7)**	**0(0)**	**0(0)**	**0(0)**	**5.13(6)**	**0(0)**	**0(0)**

Figures 3.3A and 3.3B illustrate the relationship between the WAP and the number of tadpoles captured per unit effort (Figure 3.A) and the number of tadpole species captured per year (Figure 3.3B). Table 3.8 provides descriptive statistics for six tadpole variables separated by VHR. Included in the table and separated by VHR are number of tadpoles captured per unit effort in 2001 and 2002, number of tadpole species captured per event in 2001 and 2002, the average tadpoles captured per unit effort over both years and the average number of species captured per wetland over both years.

Figure 3.3 Spearman Rank Correlations Between Average WAP Scores and Tadpole Variable

Figure 3.3A Spearman Rank Correlation between average WAP score and number of tadpoles captured per unit effort (Spearman R= 0.71, p <.05).

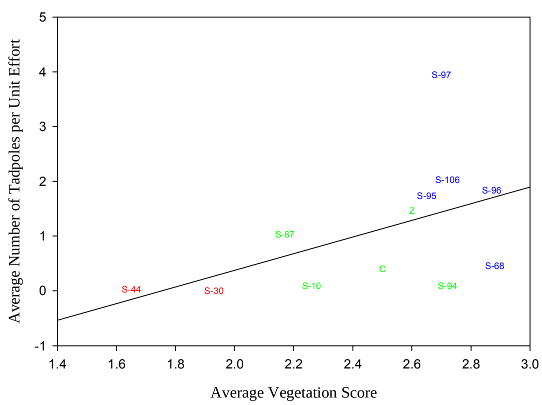


Figure 3.3B Spearman Rank Correlation between average WAP score and number of tadpole species captured per year (Spearman R= .53, p <.10).

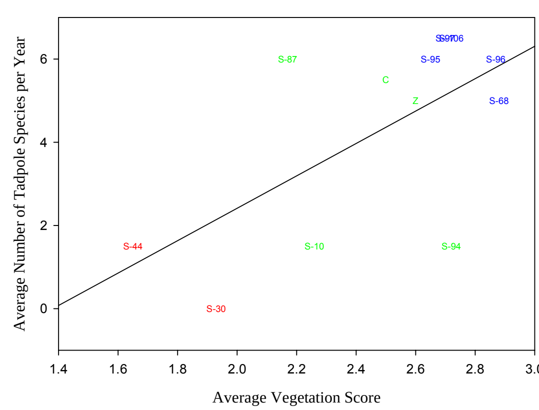


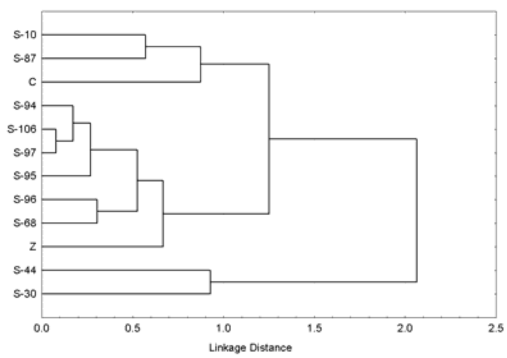
Table 3.8 Tadpole Descriptive Statistics Categorized by Vegetative Health Rating.

		N	Mean	Confid. -95 %	Confid. 95 %	Min	Max	Range	Variance	Std. Dev.	Std. Error	Skewness	Std.Err. Skewness	Kurtosis	Std.Err. Kurtosis
RED	TP #/effort 2001	2	0	--	--	0	0	0	0	0	0	--	--	--	--
	TP spp./event 2001	2	0	--	--	0	0	0	0	0	0	--	--	--	--
	TP #/effort 2002	2	0.029	-0.334	0.392	0	0.057	0.057	0.002	0.040	0.029	--	--	--	--
	TP spp./event 2002	2	0.143	-1.672	1.958	0	0.286	0.286	0.041	0.202	0.143	--	--	--	--
	Avg TP #/effort	2	0.014	-0.167	0.196	0	0.029	0.029	0.000	0.020	0.014	--	--	--	--
	Avg TP spp./effort	2	0.071	-0.836	0.979	0	0.143	0.143	0.010	0.101	0.071	--	--	--	--
	Avg spp./wetland	2	0.750	-8.780	10.280	0	1.500	1.500	1.125	1.061	0.750	--	--	--	--
GREEN	TP #/effort 2001	5	0.323	-0.196	0.841	0.000	0.833	0.833	0.175	0.418	0.187	0.635	0.913	-3.079	2
	TP spp./event 2001	5	0.767	-0.514	2.047	0.000	2.500	2.500	1.064	1.031	0.461	1.628	0.913	2.738	2
	TP #/effort 2002	5	0.903	-0.114	1.921	0.173	2.084	1.912	0.672	0.819	0.366	0.721	0.913	-0.924	2
	TP spp./event 2002	5	1.764	0.873	2.655	1.250	2.857	1.607	0.515	0.718	0.321	1.132	0.913	-0.358	2
	Avg TP #/effort	5	0.613	-0.146	1.372	0.086	1.459	1.373	0.373	0.611	0.273	0.691	0.913	-1.735	2
	Avg TP spp./effort	5	1.265	0.528	2.003	0.625	1.893	1.268	0.353	0.594	0.266	-0.349	0.913	-2.931	2
	Avg spp./wetland	5	3.900	1.144	6.656	1.500	6.000	4.500	4.925	2.219	0.992	-0.494	0.913	-3.165	2
BLUE	TP #/effort 2001	5	2.916	0.159	5.674	0.582	6.553	5.972	4.932	2.221	0.993	1.318	0.913	2.546	2
	TP spp./event 2001	5	2.067	0.966	3.168	1.000	3.000	2.000	0.786	0.887	0.397	-0.205	0.913	-2.563	2
	TP #/effort 2002	5	1.082	0.525	1.638	0.337	1.451	1.114	0.201	0.448	0.200	-1.565	0.913	2.288	2
	TP spp./event 2002	5	2.543	1.756	3.330	1.429	3.000	1.571	0.402	0.634	0.284	-2.038	0.913	4.349	2
	Avg TP #/effort	5	1.999	0.446	3.552	0.459	3.946	3.487	1.565	1.251	0.560	0.789	0.913	2.201	2
	Avg TP spp./effort	5	2.305	1.472	3.138	1.381	3.000	1.619	0.450	0.671	0.300	-0.593	0.913	-1.504	2
	Avg spp./wetland	5	6.000	5.240	6.760	5.000	6.500	1.500	0.375	0.612	0.274	-1.361	0.913	2.000	2

Figure 3.4 Comparison of vegetation and anuran cluster analyses

Figure 3.4A Cluster analysis using average quantitative variables, unweighted pair-group average linkage method and Euclidean distance measures.

Figure 3.4B Cluster analysis created using nine anuran and anuran predator variables, Unweighted Pair Group Average Linkage Method, and a Euclidean distance dissimilarity matrix.



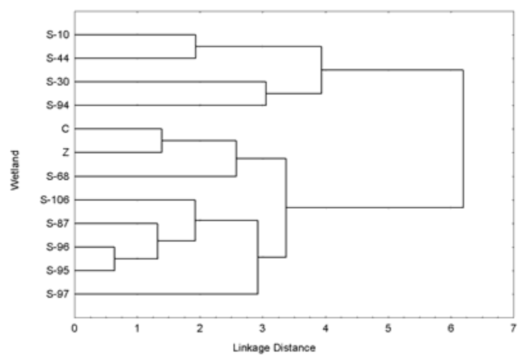


Figure 3.4 provides a comparison of cluster analyses using vegetation (3.4A) and anuran measures (3.4B) as indicators. Figure 3.4A has three clusters, while Figure 3.4B clearly illustrates two clusters.

Figure 3.4A was created using the averages of all eighteen variables collected each season and year. The dendrogram provides evidence that S-44 and S-30 form a separate cluster, and S-87, C, and S-10 form a separate cluster; however, the relationship between these two groups and the remaining wetlands is because of the potential rotation of each axis. All relationships are separated by a maximum of one distance unit.

Nine variables were used to create the cluster analysis in Figure 3.4B. The figure was created using the average number of individuals per unit effort, the average taxa (species for tadpoles and non-fish vertebrate predators, and family for invertebrate predators and fish) per event over two years, and the number of tadpole species per year. This cluster analysis provides a comprehensive illustration of the data that were collected over the two-year study. Similar to other cluster analyses (not reported), the four wetlands with the fewest numbers and species of tadpoles fall into a group while the remaining wetlands fall into a separate group. This consistency is notable because tadpole variables comprise only three of nine variables used in analysis used to create Figure 3.4B.

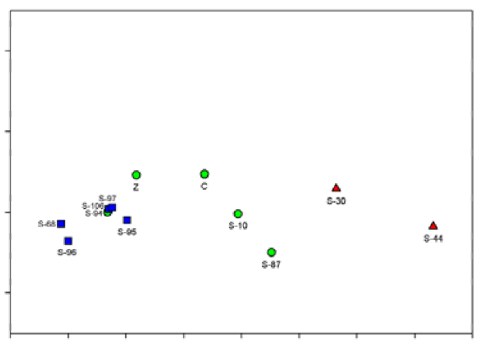
The NMDS plots in Figure 3.5 illustrates the relationships between the clusters observed in Figure 3.4. Figure 3.5A illustrates the distance between Wetlands S-30, S-44, and all other wetlands. Wetlands C, S10 and S-87 are intermediate, and all other wetlands (Z, S-68, S-94, S-95, S-96, S-97, and S106) are separate to the left. Figure 3.5A was created using the distance matrix derived from Figure 3.4A. Four-hundred forty iterations were performed. The final configuration stress value was .028, alienation value was .048, D-Star: Raw stress was .333 and D-Hat: Raw stress was .112.

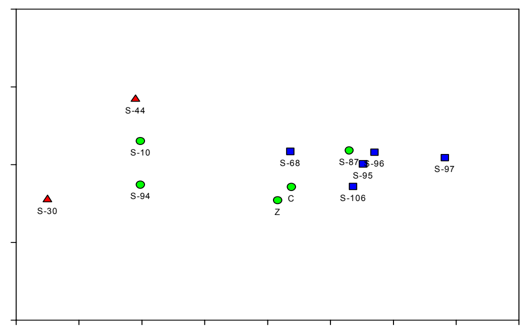
In Figure 3.5B, it is evident that four wetlands (S-10, S-30, S-44, and S-94) are separate from the remaining wetlands. Examination of the tadpole summary tables (Tables 3.6 and 3.7) show that the separation of these four wetlands reflects their lack of tadpole numbers and diversity. Figure 3.5B was created using the distance matrix derived from Figure 3.4B. Three hundred twenty-nine iterations were performed . The final configuration stress value was .0199, alienation value was .0321, D-Hat Row Stress .0576, and D-Star Row Stress .1476.

Figure 3.5 NMDS Comparison of Vegetative and Anuran Indicators

Figure 3.5A NMDS plot of average quantitative variables for spring and fall 2000, 2001 and 2002.

Figure 3.5B NMDS plot created using nine anuran and anuran predator variables and a Euclidean distance dissimilarity matrix.





Figures 3.6 and 3.7 illustrate the strong correlations between length of inundation and number and species of tadpoles captured. Wetlands with less than 90 days of inundation had fewer species and individuals captured the wetlands inundated longer than 90 days. Conversely, the Julian date of inundation was negatively correlated with both the number of species and number of individuals captured (Figures 3.8 and 3.9). Wetlands that were not inundated before day 235 (August 23) had fewer individuals and species.

Figure 3.6 Spearman Rank Correlation between average length of inundation in 2001 and 2002 and number of tadpoles captured per unit effort in 2001 and 2002 (Spearman R=.73, p <.01). Blue, Green and Red categories refer to Vegetative Health Rating described in the Analysis of Vegetation Section.

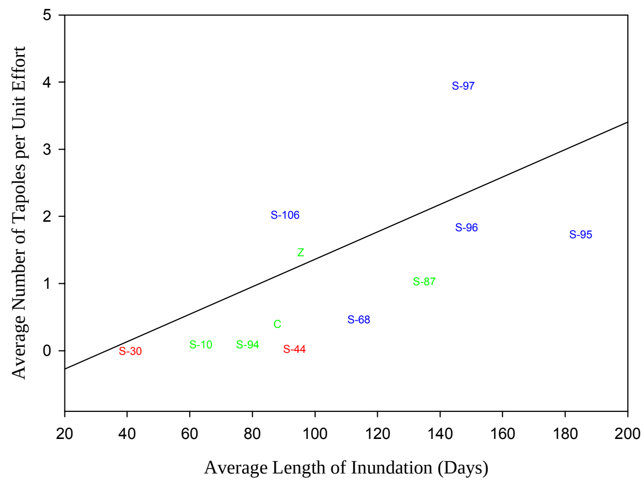


Figure 3.7 Spearman Rank Correlation between average length of inundation in 2001 and 2002 and number of tadpole species captured each year in 2001 and 2002 (Spearman R=.70, p <.05). Blue, Green and Red categories refer to Vegetative Health Rating described in the Analysis of Vegetation Section.

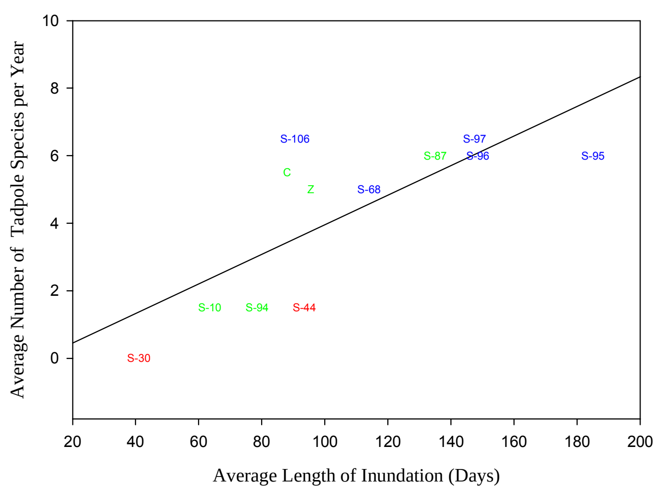


Figure 3.8 Spearman Rank Correlation between average Julian Date of inundation in 2001 and 2002 and number of tadpoles captured per unit effort each year in 2001 and 2002 (Spearman R=-.81, p <.01). Blue, Green and Red categories refer to Vegetative Health Rating described in the Analysis of Vegetation Section.

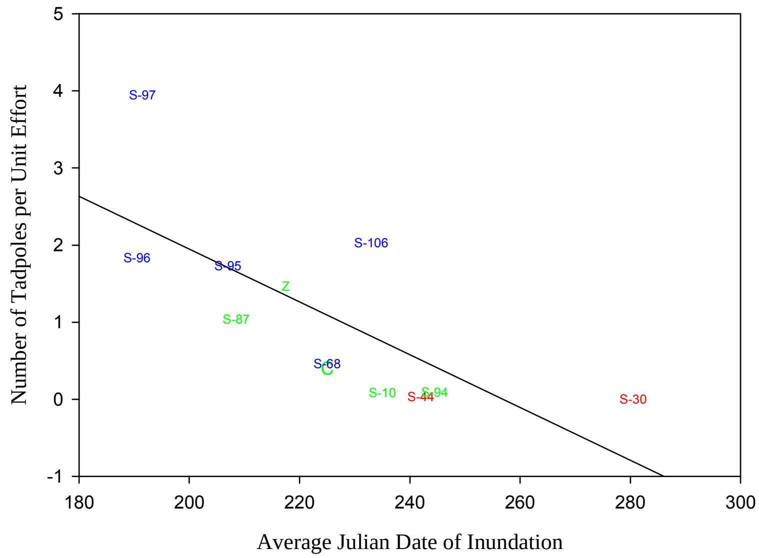


Figure 3.9 Spearman Rank Correlation between average Julian Date of inundation in 2001 and 2002 and number of tadpole species captured each year in 2001 and 2002 (Spearman R= -.78, p <.01). Blue, Green and Red categories refer to Vegetative Health Rating described in the Analysis of Vegetation.

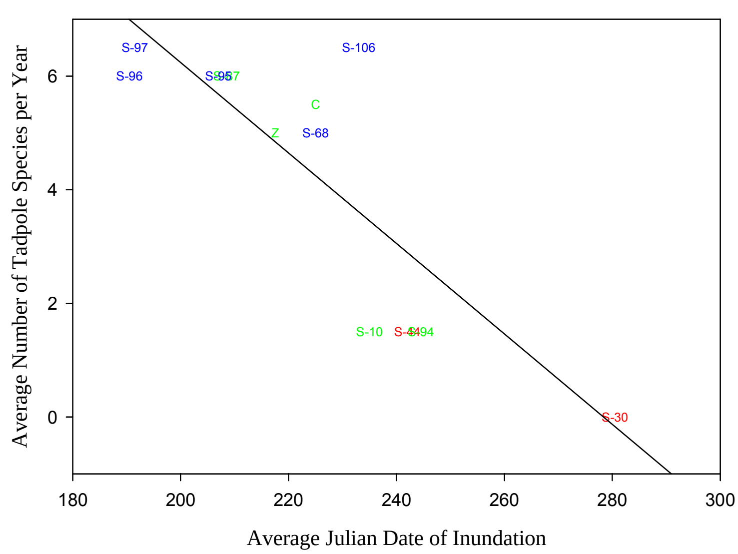


Figure 3.10 Spearman Rank Correlation between average number of species heard calling and the average number of tadpole species captured in 2001 and 2002 (Spearman R=.87, p <.001). Blue, Green and Red categories refer to Vegetative Health Rating described in the Analysis of Vegetation Section.

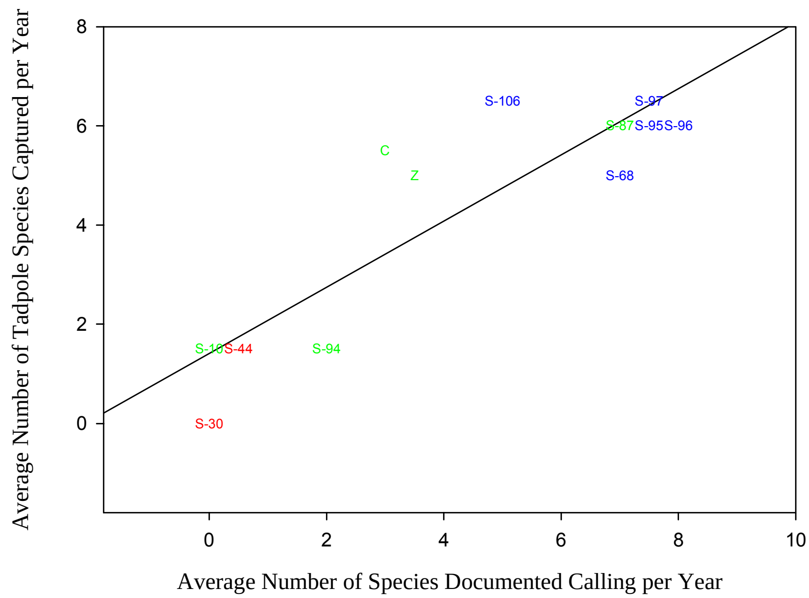


Figure 3.10 illustrates the correlation between the number of species heard calling and the number of tadpole species captured per year. Similar to other analyses presented in this study, these data are separated into a group of four wetlands with low numbers and a group of eight wetlands with high numbers. Based on these data, I present Figure 3.11. Figure 3.11 illustrates two new wetland success categories based on anuran variables (Figures 3.11B and 3.11D) and two new wetland success categories based on vegetative variables (Figure 3.11A and 3.11C). Table 3.9 is a comparison of the alternate success categories with the original VHR presented in the Analysis of Vegetation Section and Table 3.1.

Both Red wetlands were judged to be unsuccessful in terms of reproductive success and scored distinctly lower by vegetative measure. Similarly, four of the five Blue wetlands were judged to be successful anuran reproduction wetlands and all five scored distinctly higher than other wetlands vegetatively. The few differences in the new classification of wetlands lie within the intermediate category.

Figure 3.11 Box and Whisker Comparison of Vegetation and Anuran Indicators

Figure 3.11A Box and Whisker Plot of Average Quantitative Variables for two-category reclassification.

Figure 3.11B Box and Whisker plot using average number of tadpoles species captured per unit effort for two-category reclassification.

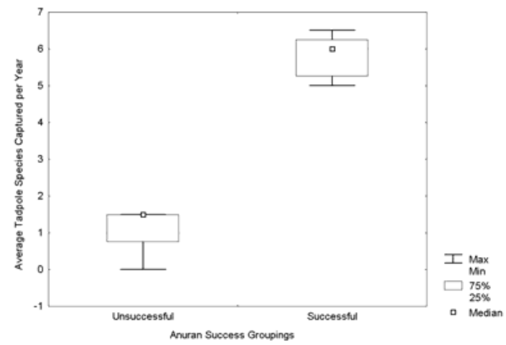


Figure 3.11C Box and Whisker Plot of Average Quantitative Variables for three-category reclassification.

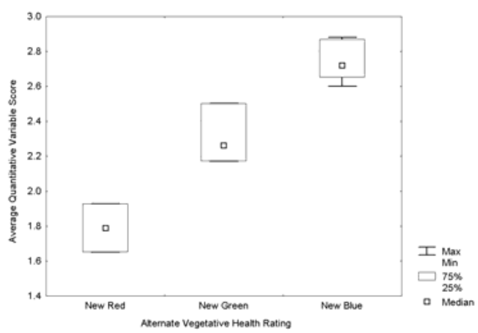


Figure 3.11D Box and Whisker plot using average number of tadpoles species captured per unit effort for three-category reclassification.

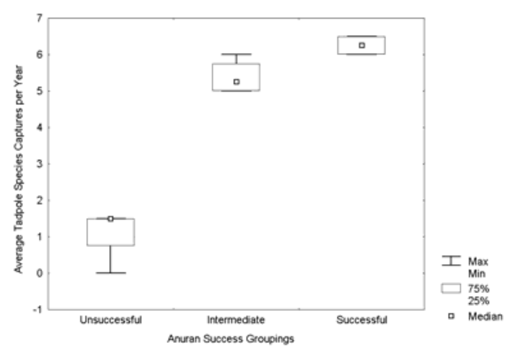


Table 3.9 Comparison of Alternate Wetland Health Ratings

ID	Original VHR	Alternate Three-Category Vegetative	Alternate Three-Category Anuran	Alternate Two-Category Vegetative	Alternate Two-Category Anuran
S-30	Red	Red	Red	Red	Red
S-44	Red	Red	Red	Red	Red
S-10	Green	Green	Red	Red	Red
S-87	Green	Green	Green	Red	Blue
S-94	Green	Blue	Red	Blue	Red
C	Green	Green	Green	Blue	Blue
Z	Green	Blue	Green	Blue	Blue
S-68	Blue	Blue	Green	Blue	Blue
S-95	Blue	Blue	Blue	Blue	Blue
S-96	Blue	Blue	Blue	Blue	Blue
S-97	Blue	Blue	Blue	Blue	Blue
S-106	Blue	Blue	Blue	Blue	Blue

Discussion

Amphibians have characteristics of a good indicator taxon. They are sensitive to perturbations in aquatic and terrestrial environments because of their biphasic life-cycle, physiological adaptations, and specific microhabitat (Vitt et al. 1990, Wake 1990, Blaustien 1994, Welsh and Ollivier 1998). Despite these characteristics, it is difficult to separate natural population variability from true population decline. For a variety of reasons, especially extreme variability in population sizes (e.g., Berven 1990, Dodd 1992), anuran studies need to be planned as long-term efforts at multiple locations. Using anurans as a surrogate for wetland health may be misleading without some knowledge about nearby wetlands (EPA 2002). Similarly, plants are useful as biological indicators because of their established sampling protocols and taxonomy, immobility, ubiquitous presence and sensitivity to disturbance. There is an inherent lag time in the response of established plants to anthropogenic change.

This study provides data on 12 wetlands during two years. NMDS, cluster analysis, and descriptive statistics provide evidence that there are two groups of wetlands based on amphibian reproductive success. The first group includes all Red wetlands (S-30 and S-44) and two Green wetlands (S-10 and S-94). This group had no calling activity in 2001 and little activity in 2002. No tadpoles were captured in any of the four wetlands in 2001 and few were captured in 2002. The average capture rate for each wetland within this group over two years was less than 0.10 individual per unit effort and less than 2 species per year. The second group consists of three Green wetlands (S-87, C, and Z) and all Blue wetlands (S-68, S-95, S-96, S-97, and S-106). This group had relatively large breeding choruses, a capture rate of 0.39 or more individual per unit effort (6 of 8 wetlands had a capture rate of over 1.03) and more than 4 species per year. These groupings were confirmed using box and whisker plots for average number of tadpole species captured per year. Various alternate groupings were tested, however, all diminished the significance of the separation. The clear separation of wetlands based solely on larval amphibian capture rates provides evidence for amphibian reproduction as an indicator of wetland health on the SWF. Although this two-category classification scheme is statistically valid, it may be beneficial to add an intermediate class to assist land managers. This study did not provide evidence that a statistically valid intermediate category exists using Anuran measures. Using only anurans, there was some distinction between three categories with minimal overlap, and with more data the three categories may become valid.

The group of four wetlands with relatively low reproductive success both years (S-10, S-30, S-44, and S-94) remains a distinct group whether using a two-category or three-category reclassification. These four wetlands had relatively low individual capture rates and species richness for tadpoles, invertebrates, fish and other vertebrate predators. Using vegetation and a three-category classification system, only two wetlands warrant a Red rating.

A group of four wetlands (S-95, S-96, S-97, and S-106) were distinct and distant from the low success group in the cluster and NMDS analyses. These three wetlands had relatively high individual tadpole capture rates, tadpole species richness, invertebrate predator capture rates, and relatively low individual fish capture rates and fish richness in both years. All of these wetlands were also categorized as Blue in a three-category vegetative scheme. Also, wetlands S-68 and Z were classified as Blue in the three-category vegetative measure, but Green when using the anuran measure. There is evidence to explain these misclassification. Wetland S-68 had relatively high capture rates during the first sampling event each year, but the number dropped sharply during subsequent events resulting in overall intermediate numbers each year. Wetland S-68 was the closest wetland to the Cross Cypress branch of the Anclote River and flooding of the river routinely contributed to the water level in the wetland. Fish capture rates and richness in wetland S-68 increased sharply after the first event of both years and included regular captures of known voracious tadpole predators in the family Centrarchidae. River overflow may not affect vegetation composition, but could have detrimental effects on the anurans by supplying a constant source of fish predators.

Wetland S-94 was classified originally as Green, and in the alternate three-category schemes Red and Blue when using anurans and vegetation, respectively. This wetland provides an excellent example of the sensitivity of anurans as indicators and the lag time inherent in using vegetation as indicators. The anurans responded immediately to the hydroperiod as illustrated by the lack of calling activity (Figure 3.10) and the correlations between tadpole numbers and inundation (Figures 3.6 – 3.9). The vegetation has not yet responded, yielding high WAP scores.

Wetland S-87 also had intermediate capture rate and tadpole richness, however, no fish were captured either year. The same method of sampling Wetlands S-68 and S-87 produced an average of 1.31 individual fish per unit effort in wetland S-68 and none in S-87. Water depth over 1 meter and fallen trees made sampling Wetland S-87 difficult and could have reduced the capture rate. A few *Amphiuma means* and *Siren lacertina* were captured in wetland S-87 and nowhere else on the site. The presence of these predators could have also reduced the tadpole capture rate. There is obviously soil subsidence at the edges of Wetland S-87 increasing tree stress and treefall, but the hydroperiod remains adequate for frog reproduction.

Strong correlative evidence suggests the hydroperiod of wetlands contributed to capture rates and species richness within wetlands on the SWF. This evidence was most apparent in numbers of the high and low success groups. Figures 3.6 and 3.7 show wetlands with an average inundation length of less than 90 days had a tadpole capture rate of less than 0.10 individuals per unit effort; Wetlands with an average inundation length of less than 80 days had an average of less than 2 species per year captured. Similarly, Figures 3.8 and 3.9 illustrate that in wetlands not inundated before day 235 (August 23), individual capture rates were less than 0.10 and an average of less than less than 2 species were captured over the study. The average hydroperiod of the high success wetlands was relatively long (>120 days) and began early in the year (before day 207). The timing of the inundation in relation to reproduction is especially notable because the published breeding season for most of the frogs in central Florida extends to October and the maximum larval period for 14 of the 17 species is 90 days or less (Table 3.3). One explanation for the correlation between anuran success and length of inundation is that a longer period of inundation allows for a suite of asynchronous individuals and species to call, breed, and go through metamorphosis. That is, several large breeding events over several weeks could all produce new metamorphs. A shorter inundation period would allow fewer successful breeding events throughout the season because some tadpoles may not have time to complete metamorphosis.

No significant correlation existed between wetland size and tadpole capture rate or species richness. A significant correlation did exist between quantitative vegetation score and tadpole capture rate and richness (Figures 3.3A and 3.3B). Because changes in hydroperiod are known to affect vegetation composition and zonation, however, we suggest that vegetation is not regulating anuran success, but both vegetation and anurans are responding to the hydroperiod.

Human activities are known to be detrimental to the natural biota (Duellman and Trueb 1986). The two most dramatic ecological trends of the past century are anthropogenic changes in biotic diversity and alterations to the structure and function of natural systems (Vitousek 1997). To preserve the functions of the natural systems on the SWF, and extensive monitoring protocol is followed. Monitoring efforts on the J. B. Starkey Wellfield produce valuable data that may be used to predict the occurrence and reproductive success of the natural amphibian community.

Maintenance and protection of biological diversity are best accomplished when ecologists and natural resource managers coordinate their efforts (Semlitsch 2000). The monitoring data should be evaluated in a timely manner to allow land managers to make necessary management strategy adjustments.

The primary challenge with an indicator species is to separate natural population fluctuations from fluctuations occurring because of anthropogenic change (Welsh and Ollivier 1998, Penchman and Wilbur 1994). In this study, I see changes in the categorization of wetlands based upon variation in tadpole abundance and richness over two years. If results from only one year were examined as opposed to both years individually and the average of both, different conclusions could be reached. Intermediate anuran reproductive success in wetlands C, Z, and S-87 was, in part, because of differential success over two years. Whether the differential success is part of a natural fluctuation or anthropogenic change is unknown. Further examination of the length and dates of historic inundation could offer insight into this question.

Categorization of wetlands into two groups and elimination of the intermediate category would provide a statistically strong result. Such a limited categorization strategy, however, could usher in unforeseen problems. If management decisions are made on the basis of the two-category system, then the wetlands are deemed either successful or unsuccessful at providing amphibian-breeding habitat. The danger in this strategy is that rehabilitation of an unsuccessful wetland may be perceived to be much more difficult and/or costly than rehabilitation of an intermediate wetland, when in reality, such is not the case. A limited categorization strategy would likely result in neglect and further deterioration of unsuccessful wetlands. Furthermore, because amphibian populations exist as metapopulations, a change in the success of a small number of seemingly isolated ponds for a short time period could have far-reaching detrimental effects on the amphibians across the landscape. Changes in management strategies should account for natural variability and focus on prevention of long-term reductions in hydroperiod.

Categorization of wetlands into three groups and allowing potentially natural fluctuations in reproductive success to be deemed overall intermediate success could lead to erroneous conclusions. Actions taken as a result of such erroneous conclusions to correct perceived problems in reproductive success could be costly, unnecessary, or even detrimental to the long-term success of amphibian assemblage. Thus, it may be useful to measure vegetation and reproductive success of anurans. Monitoring these two measures separately allows the sensitivity of the anurans to alert managers of a problem, but the vegetation measures provide the long-term relatively consistent measure to prevent snap decisions made because of sensitivity of anurans.

Determining the value of seasonal wetlands to anuran and other vertebrate populations is the focus of much contemporary research (Gibbs 1993 and 2000, Johnston 1994). For example, Gibbs (1993) reported that small wetlands play a greater role in the metapopulation dynamics of certain taxa of wetland animals than the modest area covered by such small wetlands might imply. In South Carolina, wetlands that retain water for about eight to ten months each year tended to have more anuran species than wetlands with longer or shorter hydroperiods (Snodgrass et al. 2000). In general, wetlands that retain water for long periods of time tend to support fish, which, in turn, tend to reduce the number of amphibian species breeding in them (Moler 1992). Factors other than wetland size and length of inundation may influence amphibian populations as well. In Montana, amphibian species richness declined as wetland isolation and road density increased, regardless of the spatial scale used for the evaluation (Lehtinen et al. 1999). Habitat fragmentation, road density, habitat quality, or other landscape-scale urbanization affects are not relevant to the SWF at this time. The habitat is well managed and generally characterized by native land cover. Wetland size, depth, water temperature and pH had no significant relationship with anuran reproductive success. The positive correlation between healthy, natural wetland vegetation was significant, but we do not believe it is causative. It is more likely that the vegetation and anurans are responding to the same variables in which case length and timing of inundation could be used to predict the vegetative and anuran success on the SWF. Source of inundation could also be important in determining amphibian success because of different predator contributions or water chemistry from the contributing water source.

We conclude that amphibians are excellent indicators of wetland health on the SWF. Using amphibian success to supplement the ongoing vegetative and hydroperiod monitoring would provide a time-sensitive measure to complement the more stable current measures. Using both measures separately would provide the greatest protection from discounting important anthropogenic changes and provide a basis for understanding natural population fluctuations in anurans.

Conclusions & Recommendations

- The rapid, qualitative measure of wetland health used by long-term land managers accurately predicts the highest and lowest quantitative scores produced by a more intensive quantitative vegetation measure.
- Using standard sampling techniques presented in Heyer et al. (1994), anuran variables, such as individuals captured per unit effort and species captured per year, can be used to separate wetland breeding habitats into two success categories. Long-term studies may elucidate more categories not apparent in this study.
- Information on the wetland (size, hydroperiod, water chemistry, etc) and the community (vegetation, predators, etc.) should be collected to provide potential causative factors.
- Multivariable analysis should be used if categorization of wetlands is the goal. Distilling the data into a single value such as a diversity index masks potentially important information.
- A natural (non-augmented) hydroperiod of greater than 120 days is recommended as a minimum value. Other studies have shown that a hydroperiod of 240 to 300 days provides a more diverse amphibian community (Snodgrass et al., 2000a, Snodgrass et al., 2000b, Paton and Crouch III 2002).
- A natural (non-augmented) hydroperiod beginning before mid-July is ideal and before mid-August is essential for anuran reproductive success.

- If a natural (non-augmented) hydroperiod is not possible in the foreseeable future, then augmentation should be explored in the form of a controlled experiment. The augmented wetland(s) should mirror similar nearby wetlands with similar surrounding habitat.
- Success in both augmented and non-augmented wetlands should be documented with methods similar to this study. Because of the differences between surface water and groundwater chemistry, detailed water quality parameters should be collected on both control and experimental wetlands.
- Anuran call census should be performed on a subset of wetlands on all wellfields within the district.
- Periodic active tadpole sampling can be used to spot-check the correlation between calling activity and reproductive success.
- Wetlands exhibiting low reproductive success should be sampled and examined more closely to evaluate the reproductive success and determine if anthropogenic change or natural community interactions is causative.
- A long-term study focusing on anurans could be used to examine the natural variability in the moderate-success category.

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