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HABITAT DISTRIBUTION AND ABUNDANCE OF CRAYFISHES IN TWO FLORIDA SPRING-FED RIVERS

by

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ABSTRACT

Crayfish are an economically and ecologically important invertebrate, however, research on crayfish in native habitats is patchy at best, including in Florida, even though the Southeastern U.S. is one of the most speciose areas globally. This study investigated patterns of abundance and habitat distribution of two crayfishes (*Procambarus paeninsulanus* and *P. fallax)* in two Florida spring-fed rivers (Wakulla River and Silver River, respectively). Study sites were surveyed once each season from April 2015 to March 2016 with baited minnow traps checked every other day, four times each survey. Habitat and environmental parameters evaluated included dominant vegetation or bottom type, percent cover, organic matter content, water depth, moon illumination and dissolved oxygen. Abundance was estimated with N-mixture models. Model selection judged the relative evidence between hypotheses relating habitat and environmental covariates to crayfish abundance. *P. paeninsulanus* distribution and abundance in Wakulla River was explained by time of year, dissolved oxygen and dominant bottom and vegetation type. *P. fallax* distribution and abundance in Silver River was explained by time of year and percent coverage of vegetation. Detection of *P. paeninsulanus* was higher than *P. fallax* and abundance of *P. paeninsulanus* was more heterogenous than *P. fallax* (6-18 versus 12-14 per site in summer survey). Distribution of *P. paeninsulanus* as described by vegetation and bottom type also seems to follow heterogeneity in management areas in Wakulla River. Results will assist managers in understanding potential impact of herbicidal control of *Hydrilla verticillata* on crayfish. This study also fills knowledge gaps on Florida crayfish natural history and ecology.

Dedicated to Matthew, for your grounding kindness, steadiness and support.

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CHAPTER ONE: INTRODUCTION

Crayfishes (Order Decapoda) are ecologically and economically important to freshwater ecosystems worldwide (Hobbs & Lodge, 2010; Helms *et al.*, 2013). They have multiple roles, such as contributing to nutrient cycling, acting as prey, predator and ecosystem engineer, all of which makes them an important group whose loss could negatively impact freshwater ecosystem processes (Crandall & Buhay, 2008).

Crayfishes engineer ecosystems through their burrowing and feeding activities (Creed & Reed, 2004; Moore, 2006). Burrows are used by crayfishes to adjust to environmental humidity and temperature, avoid desiccation, brood eggs, and for protection from predators. Deep and complex burrows are found in terrestrial areas and ephemeral water bodies, but even open water areas have crayfishes that make simple and shallow tunnels (Hobbs & Lodge, 2010). This burrowing aerates sediments influencing nutrient cycling (Palmer *et al.,* 1997; Covich, Palmer & Crowl, 1999) and creates habitat for other species; for example, snakes and toads are documented as utilizing burrows of cambarid *Fallicambarus gordoni* in Mississippi (Welch *et al.* 2008). Crayfishes regulate littoral food webs by eating detritus, plants, other crayfishes and invertebrates such as gastropods (Lodge *et al.,* 1994; Momot, 1995; Covich *et al.,* 1999; Nyström, 2002; Dorn & Wojdak, 2004). They influence nutrient cycling through grazing on and shredding detritus (Anderson & Sedell, 1979; Palmer *et al.,* 1997; Covich, Palmer & Crowl, 1999; Graça, 2001). For example, they will increase the rate of breakdown of leaf litter and decrease the amount of fine particulate organic matter and inorganic sediment in headwater streams (Creed & Reed, 2004). Crayfishes are prey to many species, including birds, fish and snakes (Hobbs & Lodge, 2010); for instance, they are the primary food source of the striped crayfish snake *Regina alleni* (Family Colubridae) in Florida (Franz 1977; Godley 1980). Crayfishes are also a possible place of contaminant accumulation in the food web because they bioaccumulate heavy metals into tissues available to predators (Kouba, Buřič & Kozák 2010, Suárez-Serrano *et al.* 2010).

Crayfishes are commercially harvested worldwide, have been consumed for centuries in European countries and are subsistence food in Papua New Guinea, for example (Holdich, 2002). Due to human transport for food, bait or pets (Lodge *et al.,* 2000; Holdich, 2002), crayfishes have become established in Europe and North America as non-native invasive species. For example, the cambarid *Procambarus clarkii*, the Louisiana swamp crayfish, was brought to Italy in the 1980s (Gherardi *et al.,* 2000) and *Pacifastacus leniusculus* (Family Astacidae), signal crayfish, was brought to Northern Europe (Bubb *et al.,* 2004). Invasive crayfishes impact abundance of prey species (e.g., vegetation, snails), directly compete with native species, and are likely the source of crayfish fungal parasite (*Aphanomyces astaci*, 'crayfish plague', Family Leptolegniaceae) introduction, which appears to be a main factor in decline of native European crayfishes (Holdich, 2002; Gherardi & Acquistapacae, 2007; Hobbs & Lodge, 2010).

There are crayfish native to all continents except Africa where they are introduced and Antarctica (Hobbs & Lodge, 2010). Even though crayfishes are widespread and ecologically and economically important, The Society for Freshwater

Science meeting in 2012 revealed many gaps in the understanding of basic biology and ecology of native crayfishes and called for targeted research on these topics (Helms *et al.,* 2013). There has been limited study on the ecology of crayfishes in parts of the southeast United States (U.S.), particularly Florida, where this study occurs. The southeast U.S., alongside Southeastern Australia, is a center of global crayfish diversity. At least 176 species out of 640 known globally occur across the southeast U.S. coastal plain and of the 369 known species to the U.S., at least 57 of these species occur in Florida (Fetzner, 2016). Most of these are in the genus *Procambarus* (Family Cambaridae).

Basic crayfish biology and ecology was explored for the first time for many of those species in The Crayfishes of Florida (Hobbs, 1942), which documented life history, general species distributions, methods of trapping and methods of identification. Aspects of general natural history for Florida Cambaridae species have been addressed by other researchers including localities and distributions (*Procambarus fallax, Procambarus paeninsulanus and Procambarus youngi,* Mason, 1994; *Cambarus miltus*, Taylor *et al.*, 2011), population structure (*Procambarus spiculifer* and *P. paeninsulanus*, Breinholt, Moler & Crandall, 2011), and population response to environmental stress (*Procambarus alleni, P. fallax*, Acosta & Perry, 2001; Dorn & Volin, 2009). Observation and experiments on tolerance to abiotic and biotic factors have been studied for several surface and cave species (*P. spiculifer, P. paeninsulanus, Procambarus leonensis, Procambarus kilbyi, Procambarus horsti, Procambarus orcinus and Cambarus cryptodytes*, Caine, 1978).

However, there are gaps in knowledge regarding habitat distribution, abundance, life history, and demography for many species that occur in Florida. Although there is high regional (gamma) diversity, there is low local (alpha) diversity; most watersheds have a limited number of species each, at most, because original populations were isolated then radiated in different, individual watersheds during their evolutionary history (Hobbs & Lodge, 2010). So, studying crayfishes in one watershed does not necessarily translate to other species or other watersheds. In addition to these global and regional research needs, study of crayfish population dynamics, ecology and abundance is desired by local managers of Florida rivers (Matt Phillips, unpubl. data).

To address some of the specific knowledge gaps in rivers associated with two major Florida spring systems, this study investigated patterns of habitat distribution and abundance of two crayfishes in two Florida spring systems (*P. paeninsulanus* and *P. fallax* in the Wakulla and Silver Rivers, respectively). This study confirms previous reports of these species' occurrence in Wakulla and Silver Rivers. Both species are commonly reported in streams and lotic environments in Florida and Georgia. Both form tertiary (shallow) burrows, although *P. paeninsulanus* is known to burrow more readily than *P. fallax.,* P.paeninsulanus is possibly is a secondary, more complex tunnel burrower (Hobbs, 1942; Franz, 2002; Taylor *et al.*, 2007; Crandall, 2010a; Crandall, 2010b).

A suite of model hypotheses relevant to the physiology, behavior, life history and ecology of crayfish were tested to attempt to explain abundance and detection probability of each species across a time span of one year. By comparing a suite of models of habitat and environmental covariates, this study provides new insight into the basic ecology and habitat preferences of these species and provides critical population information such as relative abundance estimates which can be used as baseline data for informing conservation management planning and future management actions related to the sustainability of the populations of these species.

CHAPTER TWO: METHODS

Study areas

The study was conducted in two first magnitude spring-fed rivers in Florida, USA. The Wakulla River, in northwest Florida, is approximately 14.5 kilometers long from where it originates at Wakulla Springs to where it meets the St. Mark's River before entering the Gulf of Mexico. This survey covers approximately 6.5 kilometers of the river from the springhead downstream. Sally Ward, a spring-fed creek that flows into the Wakulla River, was also included. The first 4.8 kilometers of the river is closed to the public and boat traffic is controlled by the state park. The Wakulla River is one to three meters deep and approximately 100 meters at its widest point (Matt Phillips, unpubl. data).

The Silver River, in north central Florida, originates at Silver Spring and runs for 8 kilometers until it meets the Ocklawaha River. The full length of Silver River was surveyed. It is open to public boat traffic. The Silver River may reach depths of up to 6 meters (J. Sowards, unpubl. data) and approximately 60 meters at its widest point.

Survey design and crayfish collection

Each river was sampled in April 2015 (Spring), July & August 2015 (Summer), October & November 2015 (Fall) and February & March 2016 (Winter). During each survey, 50 minnow traps (except 42 in Wakulla River in April 2015) were set. The traps were checked every other day (in other words, set for two nights) four times each survey.

The choices for trap days and bait type were based on the literature and a pilot study. The minnow traps had 2.54-centimeter (one inch) diameter openings. A perforated 20 mL plastic vial was filled halfway with canned cat food (Friskies brand mixed grill classic paté) as bait and placed in the trap. I conducted a pilot study in the Wakulla River and return on effort was the same for two nights as three to four, so two nights were used to reduce total length of each survey to eight days. During the pilot study baited minnow traps were also compared with throw traps and baited three-holed pyramid traps. Baited minnow traps produced the highest catch, which is commensurate with recommendations for trapping crayfishes in vegetated and non-wadeable areas (Larson & Olden, 2016). It is known that this method is biased in that juveniles or smaller adults and females will be undersampled (Hobbs & Lodge, 2010).

Points along the stream bank were randomly selected and traps were placed at least 60 meters apart for independence since the analysis used assumes occupancy and detection between points is independent. The choices for trap location were based upon literature evaluations of general movement, home range behavior and food-finding behavior of related crayfishes. Crayfishes use chemical cues to find food. They are known to move toward a food source and use various organs including the antennules and walking legs to detect food at close and far distances. The outer rami of the antennules have been identified in detecting a food source up to a distance of 0.7 meters in *P. clarkii*) (Giri & Dunham, 1999; Moore & Grills, 1999; Hobbs & Lodge 2010). Sampling areas for baited traps were tested in Florida Everglades for *P. alleni* and were 56 meters ^{2} (Acosta & Perry 2000), indicating that this species can find and detect food at least 4.2 meter radius from the trap center. Crayfishes are known to have home ranges and have been tracked to move up to 60 meters and less frequently up to 400 meters (over weeks) (Black, 1963; Gherardi, Barbaresi & Salvi, 2000; Gherardi, Tricarico & Ilheu, 2002; Bubb, Thom & Lucas, 2004). See Figure 1 for sampling schematic.

Whole specimens of a subset of 1st form male crayfish and samples of the 1st left male pleopod of other first form males were taken for species identification (Hobbs, 1989; Hobbs & Hobbs, 1991; Fenzter, 2015). Dr. D. Christopher Rogers at the University of Kansas was consulted and verified identities and taught identification techniques during a visit to his laboratory. Voucher specimens are preserved with 70% ethanol and are stored for future researcher use at the Stuart M. Fullerton Collection of Arthropods at the University of Central Florida.

Abiotic and biotic habitat parameters considered important to crayfish physiology, feeding or shelter were recorded at each site and during each survey. Parameters collected include percent cover of vegetation, species, vegetation or bottom type (emergent, submerged or bottom/algae), water depth, moon illumination and dissolved oxygen (milligrams/liter) (Caine, 1978; Nyström, 2002; Franke & Hoerstgen-Schwark 2013). Species of vegetation (floating, submerged, and emergent) were recorded within a 1 m^2 quadrat along with percent cover of each species and the total percent cover of all vegetation. Percent of algal covered-bottom and bare bottom (sediment) was combined and recorded as one value because often these bottom types occurred together and without any vegetation. The water depth was recorded to the nearest hundredth of a meter. Dissolved oxygen was recorded with an YSI ProODO^{TM} (Yellow Springs, OH, USA) meter; this instrument measures both water temperature and milligrams/liter and percent dissolved oxygen. Percent organic matter was determined from a sediment sample at a subset of sites selected by dominant vegetation each survey. Sediment samples were collected by sweeping a dip net on the bottom to collect approximately 3.8 liters (one gallon) of sediment. These sediments were subsequently dried at 60°C in a Fisher Scientific^{TM} Isotemp^{TM} oven (Waltham, MA, USA). The sediments were sifted with a 2mm sieve. Twenty-five grams (in five gram subsamples) were ashed in a 550° C Fisher Scientific^{TM} (Waltham, MA, USA) or Neytech Vulcan 3-550 muffle furnace (Bloomfield, CT) for loss on ignition. Weights before and after ashing were used to calculate percent organic matter in each sample. A moon illumination index was created by taking the hours the moon was out per day multiplied by the fraction of the moon illuminated by the sun (Navy Astronomical Applications) and summed across both nights for each of the four survey days.

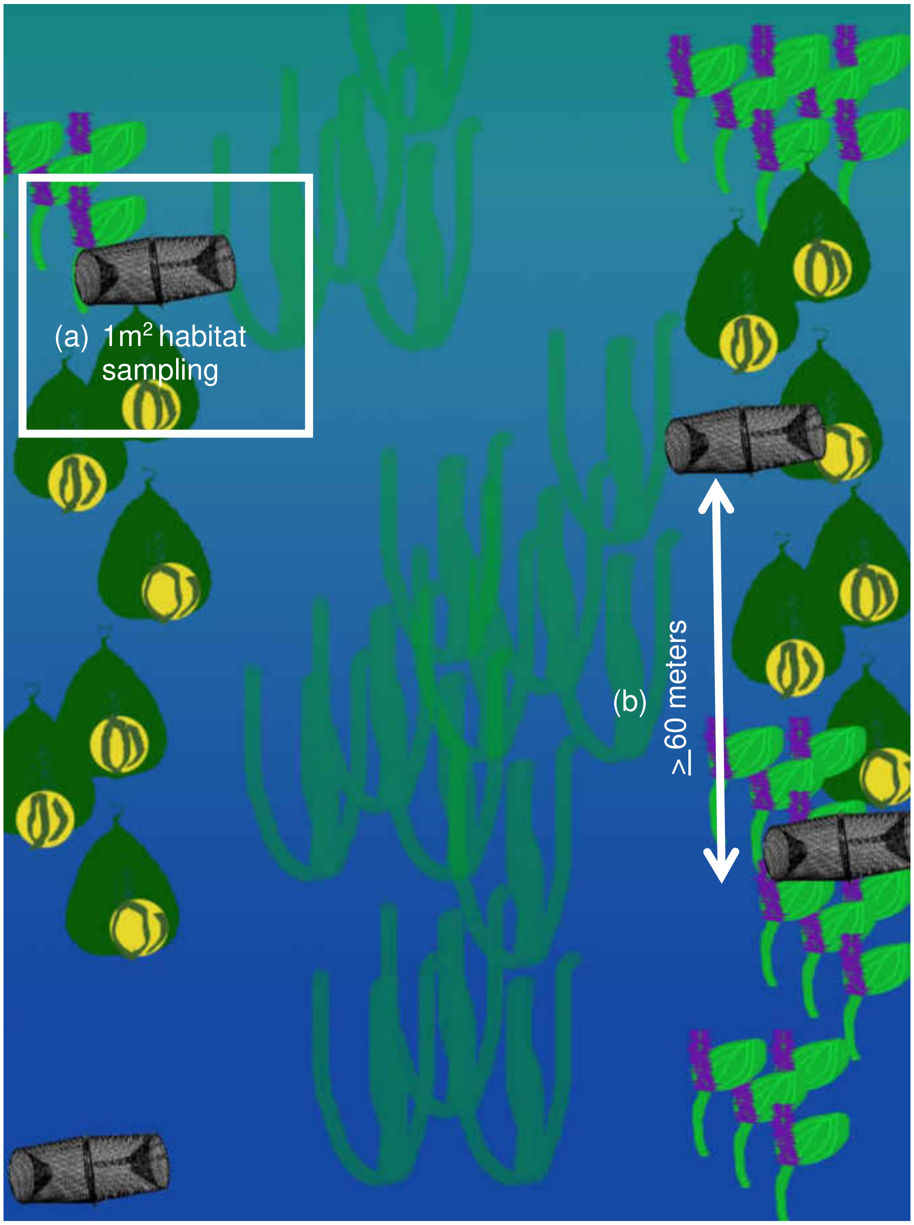

Figure 1. Sampling scheme cartoon. (a) At each trap site, within a 1 m^2 quadrat, habitat parameters were recorded. (b) Each trap was at least 60 meters apart and bank position was randomly selected.

N-mixture modeling justification

Abundance was estimated with N-mixture models in package *unmarked* in R (Vienna, Austria) (Royle, 2004; Fiske & Chandler 2011). Although capture-mark-recapture (CMR) is a common and well-known approach, it was not utilized because of the specific goals of this study and potential limitations of CMR in the data analysis stage. There was no preliminary data in these rivers of capture rates or best method of capture before the pilot study. Counts of crayfish were expected to be sparse (producing many zero counts), based on other studies of abundance and the n-mixture model literature (e.g. Royle, 2004). Because CMR may not make good estimates with sparse data, N-mixture models (a class of hierarchical models) were employed.

N-mixture models require no marking or recapturing, only replication spatially and temporally. The end goal of using this approach was to estimate site-level abundance termed lambda. This is explained by the state equation, or process model, which takes the form of a probability distribution for count data like the Poisson distribution. However, since the data were observed counts subject to detection, an equation must be included for measurement error. This equation, the observation model, takes the form of a binomial distribution and describes the variability in observed counts, given the counts per site. The observation model estimates p, or detection probability. Previous to these models, there was not a method to estimate both detection probability and abundance from the same count data (Anderson, 2003; Kéry, Royle & Schmid, 2005). Covariates can be applied to both abundance and detection, and these covariates can be the same (Kéry, 2008). Abundance can be more accurately estimated if imperfect detection is accounted for (Kéry *et al*., 2005).

An example of this approach in a similar study estimated bird abundance in Switzerland (Kéry *et al.,* 2005). In that study, multiple quadrats (sites) were sampled two to three times in a breeding season for several species of birds. Habitat covariate data included in the analyses were elevation of the mountain and forest cover. They compared the covariate models to null models and compared the negative binomial versus Poisson mixture distributions on the process model as well. For most of the species, the negative binomial covariate models best explained the data when compared with AIC (Akaike's Information Criterion). They found for the species surveyed that different relationships occurred between abundance and forest cover and/or elevation; for example, the skylark had a negative relationship with both, but blackbirds had a positive relationship with forest cover and negative relationship with elevation. Detection probability differed between species and between covariates, which were effort (minutes spent surveying per kilometer) and survey date (how far along into breeding season they were sampling). Previous information was available on difficulty of detection of these species, and they found their results commensurate; detection of the easier species was on average 0.84 (out of 1.0) and for the harder species was on average 0.53. They note that abundance estimates are greater with mixture models than with the use of territory mapping (a method of finding bird abundance), possibly due to bias in either approach. However, they also note that because mixture modeling accounts for detection, the territory method may in fact be underestimated. So, the authors purport that this method seems appropriate for the type of abundance and distribution questions they set out to solve, and which are similar to this study.

Multi-model inference

Temporally and spatially replicated count data were analyzed and covariates applied to both abundance and detection. Inference was based on multi-model selection. A suite of hypotheses was developed. These hypotheses for habitat distribution, detection and abundance were carefully chosen based on known crayfish general ecology, physiology and behavior from the literature and on the specific conditions of the rivers in this study. The models chosen before analysis were those that best reflect the hypotheses. The statistical models describe effects of covariates on both detection and abundance.

Detection parameters

The covariates of moon illumination index, water depth, percent cover of vegetation and trap day were selected. These parameters may impact the probability of the crayfish to intersect a trap. The phase of the moon is implicated in synchronization of molting in *Astacus astacaus* (Astacidae) (Franke & Hoerstgen-Schwark, 2013) and therefore, may relate to how actively they are doing other activities, like food searching, since crayfishes will find shelter during molting(Hobbs & Lodge, 2010). Water depth may impact the ability to access the trap based on preliminary observation during the pilot study. Percent cover of vegetation may influence how crayfish search for food or may provide shelter from predators and conspecifics. Trap day (the number of days the trap was set within a survey, i.e. the sampling day) is used to explain possible variation that is not ascribed to any other habitat or environmental parameter. Each of the parameters was included in a univariate detection model and within additive models (see Tables 1 and 3 for statistical models). The null model is included in case none of the covariates explain the variation in the data or if there is too little data to assess the covariates included.

Abundance parameters

The covariates of dissolved oxygen, dominant bottom type (submerged vegetation, emergent vegetation or bare/algal-covered bottom), percent cover of vegetation, percent organic matter and survey time of year were selected. These parameters were considered relevant to defining crayfish abundance at a site and may be used as measures of habitat preference or quality. Crayfishes are known to have physiological tolerance limits to dissolved oxygen (Caine, 1978). Vegetation is important to crayfish shelter and food supply. Organic matter is also a potential food supply. Time of year (for example, connected to changes in temperature or day length) is tied to breeding and molting to adult and/or reproductive stages (Hobbs & Lodge, 2010). Although sites were the same GPS location between seasons they are considered unique for the analysis in terms of the crayfish population present and so the sites and survey time of year were combined into one data set; time of year therefore is a site covariate in the analysis. Temperature of the water, although potentially relevant to crayfish physiology (Caine, 1978) was excluded because of its similarity across surveys and along the length of the rivers. Each of the covariates was included in a univariate detection model and within additive models. The null model is included in case none of the covariates explain the variation in the data or if there is too little data to assess the covariates included. See Table 1 for a summary of the parameters used, the expected direction of effect for each, and the models in the model set in which that parameter was included.

Table 1. The parameters included in the models (first column), the effect that each was predicted to have on abundance and/or detection probability (second column), and the models into which that parameter was included (third and fourth columns). M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year.

Parameter	**A: effect on abundance** **D: effect on detection**	**Models for detection**	**Models for abundance**
Moon illumination index (M)	A: NA D: Higher detection at lower illumination	M WD+M PC+M	NA
Water Depth (WD)	A: NA D: Lower detection at greater depth	WD WD + PC WD + M	NA
Trap day (TD)	A: NA D: heterogeneity between days	TD	NA
Percent cover of vegetation (PC)	A: Higher abundance at higher coverage D: Lower detection at higher coverage (more difficult to find trap)	PC WD + PC M + PC	PC PC + TOY PC + DBT + TOY PC + DO + TOY PC + OM + TOY PC * TOY
Dominant bottom type (DBT)	A: Higher abundance in vegetated bottom types D: NA	NA	DBT DBT + TOY DBT + DO + TOY PC + DBT + TOY DBT * TOY
Dissolved oxygen (DO)	A: Higher abundance at higher DO D: NA	NA	DO DO + TOY PC + DO + TOY DO + DBT + TOY DO * TOY
Organic matter content (OM)	A: Higher abundance at higher organic matter content D: NA	NA	OM OM + TOY OM + PC + TOY OM * TOY
Survey time of year (TOY)	A: Higher abundance in summer and fall surveys D: NA	NA	TOY; TOY + DO; TOY + OM; TOY + DBT; TOY + PC ; TOY + PC + DBT; TOY+DBT+DO; TOY+PC+DO; TOY+PC+OM; TOY * PC; TOY*DO; TOY * OM; TOY*DBT

Model selection and averaging

AICc model selection was used. AICc is a form of AIC, Akaike Information Criterion, that adjusts for smaller sample sizes (Johnson & Omland, 2004). The model selection on detection covariates first was conducted with the full interactive abundance model applied to all detection models. The most informative model of detection was selected, which was then applied to the suite of candidate abundance model hypotheses. The Poisson mixture distribution was applied to all models, which has been demonstrated as effective for describing count data of organisms provided that the covariates can explain spatial variation of abundance not described by just the Poisson (K*éry et al*., 2005). The Zero-inflated Poisson, although possibly appropriate for a distribution of counts like those in Silver River (see Appendix A for histograms of counts for both rivers), would be better suited if attempting to estimate 'true' abundances instead of relative abundances. Adjustment for overdispersion (having high frequency of zeros in the count data) was made by applying the Goodness of Fit test ĉ (variance inflation factor) (see Appendix B) during the estimation & model-averaging phase. This procedure inflates the estimated standard errors to account for uncertainty due to unmodeled overdispersion. Estimates of abundance were made by model averaging on the candidate model set, whereby the weights of the models were applied to the abundance estimates for each model and then those estimates were averaged. Model-averaging was conducted using package AICcmodavg in R (Mazerolle, 2016).

CHAPTER THREE: RESULTS

Summary of data collected

The raw count data for each river for each survey are presented in Table 2. Wakulla River spring survey produced the fewest crayfish at 109 and fall survey produced the most at 456. Silver River winter survey produced the fewest crayfish at 25 and summer survey produced the most at 118. Males made up 56% to 74% of the total individuals captured (pooled across time of year and rivers). Table 3 shows summary statistics of the site -level habitat covariate data collected for each river pooled across time of year. A plant species list and all habitat covariate data plotted and pooled by time of year are in Appendix C.

Table 2. The raw counts of crayfish for each river and each species for each time of year survey, pooled across trap day. So, for Wakulla River in Spring, 109 *P. paeninsulanus* were recorded after checking the 42 traps 4 times.

Survey:	**Spring**	**Summer**	**Fall**	**Winter**
Wakulla (*P. paeninsulanus*)	109	444	456	167
Silver (*P. fallax*)	92	118	33	25

Table 3. The summary statistics for habitat covariates recorded at the site level, pooled across time of year. Rows are minimum, mean and maximum values (except for number of species of vegetation, columns 6 and 7).

River	**Dissolved oxygen (mg/L)**	**Cover of vegetation * (percent)**	**Organic Matter content (percent)**	**Water depth (meters)**	**Dominant emergent vegetation (species no.)**	**Dominant submerged vegetation (species no.)**
Wakulla	Min. 1.90	0.00	0.8	0.13	6	5
	Mean 4.94	43.10	20.08	0.70		
	Max. 7.73	125.00	58.90	1.80		
Silver	Min. 1.90	0.00	15.38	0.22	4	5
	Mean 5.00	96.28	36.45	0.83		
	Max. 7.24	275.00	67.38	1.62		

* percent cover of vegetation can be greater than 100 because the coverage of different types of vegetation (for example, submerged, emergent and floating vegetation) were summed.

Table 4. The most informative models for each river for detection and abundance based on AICc. AICc= Akaike's Information Criterion with correction for small sample size. K is the number of fitted parameters. The Δ AICc is a measure of a model relative to the most informative or 'top' model. The AICc weight is the relative importance of the model compared to the rest of the set and is applied during model averaging. LL is log likelihood. When conducting model selection for detection, the full abundance model (~DO:DBT:OM:TOY:PC) was included. When conducting abundance model selection, the corresponding detection model was included. M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year.

River/Type	**Model**	**K**	**LL**	**AICc**	**ΔAICc**	**AICc weight**
Wakulla-Detection	WD+M	16	-1185.10	2405.28	0	0.45
Wakulla-Abundance	DBT+DO+ TOY	10	-1098.30	2217.84	0	0.98
	PC+DBT+ TOY	10	-1102.80	2226.81	8.97	0.01
	DBT+ TOY	9	-1104.60	2228.13	10.28	0.01
Silver-Detection	TD	17	-604.71	1246.78	0	0.96
Silver-Abundance	PC+ TOY	9	-576.14	1171.23	0	0.27
	TOY	8	-577.47	1171.68	0.46	0.21
	PC+DO+ TOY	10	-575.88	1172.92	1.70	0.12
	PC+OM+ TOY	10	-576.09	1173.35	2.12	0.09
	DO+ TOY	9	-577.29	1173.53	2.30	0.09
	OM+ TOY	9	-577.41	1173.76	2.53	0.08
	DBT+ TOY	10	-576.58	1174.33	3.10	0.06
	PC+DBT+TOY	11	-575.98	1175.36	4.13	0.03
	DBT+DO+TOY	11	-576.33	1176.06	4.83	0.02
	PC*TOY	12	-575.29	1176.26	5.03	0.02

Wakulla River (Species: *Procambarus paeninsulanus*)

Detection probability

The top detection model was defined by the additive effect of moon illumination and water depth (Table 4, complete model selection tables in Appendix D), and had Akaike weight of 0.45. This was the only model with a ΔAICc less than or equal to 2 (Δ2 is a common cut-off for separating the most informative models from the rest, Anderson *et al.*, 2001). Water depth and moon illumination were important to estimate detection and did so at approximately 25% detection. Although there were not differences between water depths and moon illumination estimates given the 95% confidence intervals that overlapped each other, these were still the best parameters of those included in the model set. Figure 2 shows estimates of moon illumination and water depth divided at the 25%, 50% and 75% quantiles. A table of the values of detection probability and confidence intervals shown in Figure 2 is in Appendix E.

Site-level abundance

The top abundance model included the additive effects of dominant bottom type, time of year and dissolved oxygen, and had overwhelming support as the top model with an Akaike weight of 0.98 (Table 4, complete model selection tables in Appendix D). Estimates of abundance and detection probability based on combinations of these parameters are shown in Figure 3. Confidence intervals often overlap, but there are some differences in abundance between some habitat parameter combinations. For example, in Figure 3, spring and winter estimates in bare/algal bottom and submerged vegetation were lower than estimates in all dominant bottom types in summer and fall.

Additionally, in summer, emergent vegetation estimates were greater than submerged vegetation estimates. The trend in increased abundance associated with increases in dissolved oxygen was also apparent, although confidence intervals overlapped across all combinations. The values of lambda and the confidence intervals are in Appendix E. Finally, parameter estimates and their confidence intervals demonstrate that the dissolved oxygen, emergent vegetation and fall and summer surveys were all significant (confidence intervals do not overlap zero) and the parameters of submerged vegetation and winter survey were negative making them relatively different from the positive values of emergent vegetation, dissolved oxygen, and summer and fall surveys (Appendix F). Figure 4 is a map of estimates from summer with a buffer with a 60 meter^2 area (4.4 meter radius), which is the approximate area sampled based on the known crayfish movement and response to baited traps as described earlier. The estimates range six to 18 crayfish per site depending on combinations of habitat parameters found at those sites.

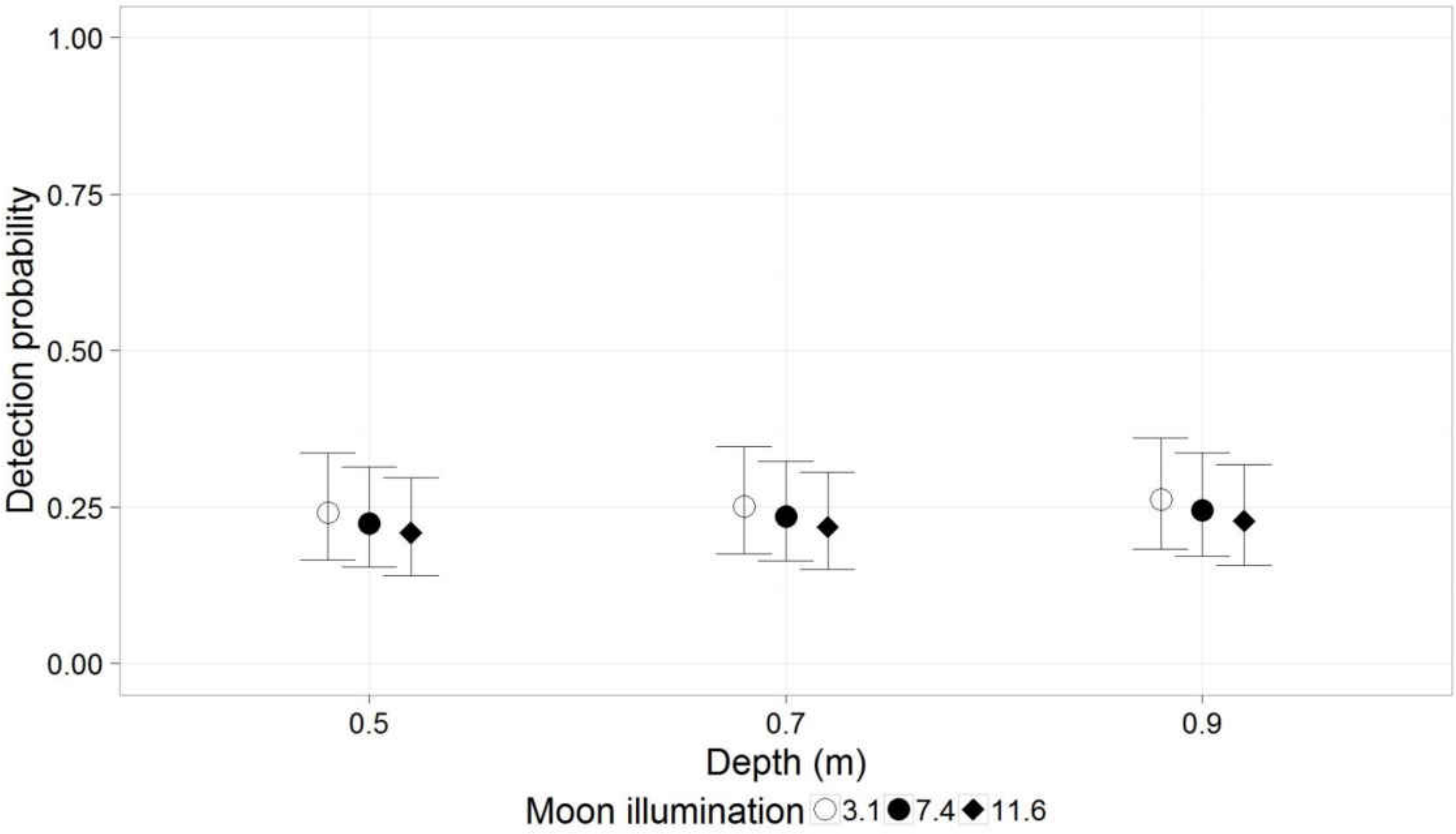

Figure 2. Estimates of detection probability from the top detection model (moon illumination + water depth) for Wakulla River at the 25%, 50% and 75% quantiles of water depth and moon illumination. Bars represent 95% confidence intervals.

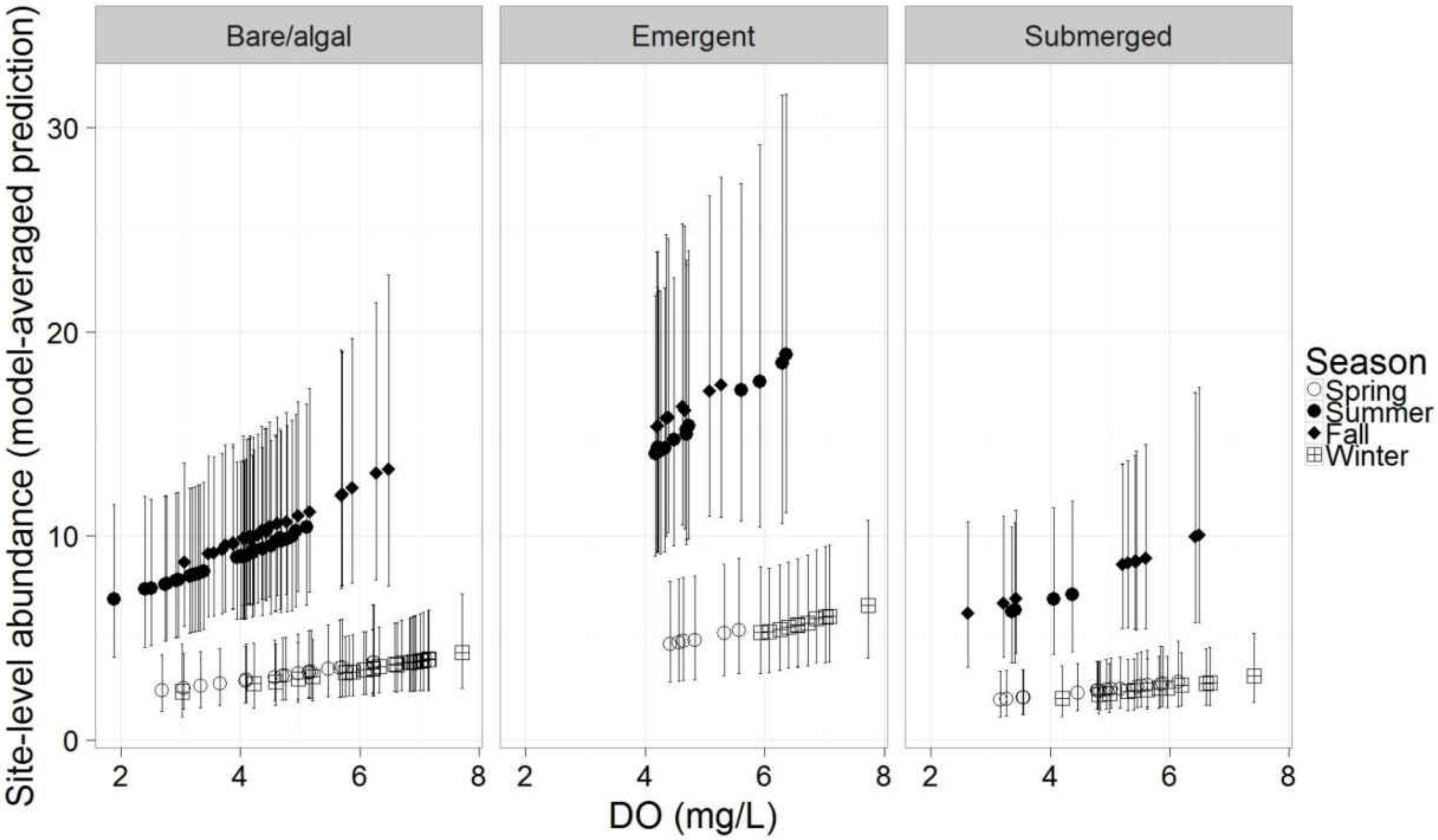

Figure 3. Estimates of model-averaged abundance for Wakulla River for each survey (spring, summer, fall, winter) at the measured values of dissolved oxygen (x-axis) and sorted by dominant bottom type (bare/algal, emergent vegetation and submerged vegetation). Bars represent 95% confidence intervals.

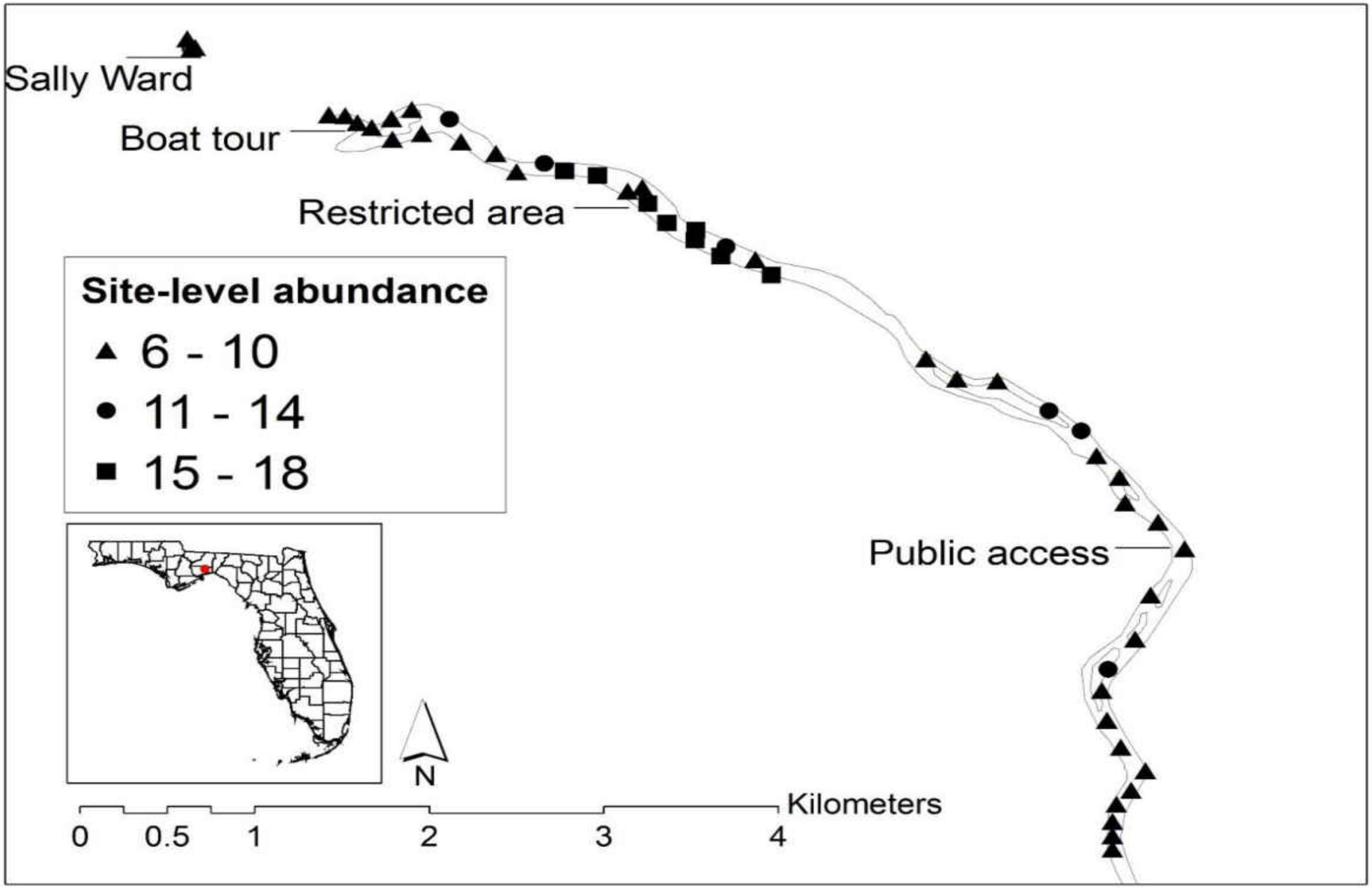

Figure 4. Map of Wakulla River showing summer survey abundance estimates at each site. The buffer around each point is a 60 meter^2 circle and approximates the maximum area sampled by each trap. Delineation of management areas are included; Sally Ward is a small, spring-fed creek that meets the Wakulla River, Boat Tour is where the state park allows only public access on managed boat tours, Restricted Area is only researcher and park staff access, and Public Access is not state park managed and where public boat traffic occurs.

Silver River (Species: *Procambarus fallax*)

Detection probability

The top detection model was defined by trap day (Table 4, complete model selection tables in Appendix D), and had overwhelming support with an Akaike weight of 0.96. This was the only model with a ΔAICc less than or equal to 2. Trap day was the best covariate to estimate detection, although estimates of detection were less than 10% across all days; days were not different given that the 95% confidence intervals for each day overlap each other (Figure 5). A table of the values of detection probability and confidence intervals shown in Figure 5 is in Appendix E.

Site-level abundance

The top abundance model included the additive effect of percent cover and time of year and had an Akaike weight of 0.27. It was not the only model with a ΔAICc equal to or less than 2; the model 'percent cover + dissolved oxygen + time of year' and the model 'time of year' were also relevant (Table 4, complete model selection tables in Appendix D). Based on these criteria, percent cover and time of year were the most important covariates affecting abundance. The confidence intervals of estimates were wide and overlapped between surveys and measures of percent cover (Figure 6), meaning that there were no differences in abundance estimates between these measures. The values of lambda and confidence intervals shown in Figure 6 are in Appendix E. The parameter estimates for some surveys were significant (confidence intervals did not overlap zero) and percent cover and summer survey were positive estimates making them relatively different than fall and winter surveys which are negative estimates (Appendix F). Figure 7 is a map of estimates from summer with a buffer with a 60 meter^2 area (4.4 meter radius). The estimates range from 12 to 14 crayfish per site depending on percent cover of vegetation at the site.

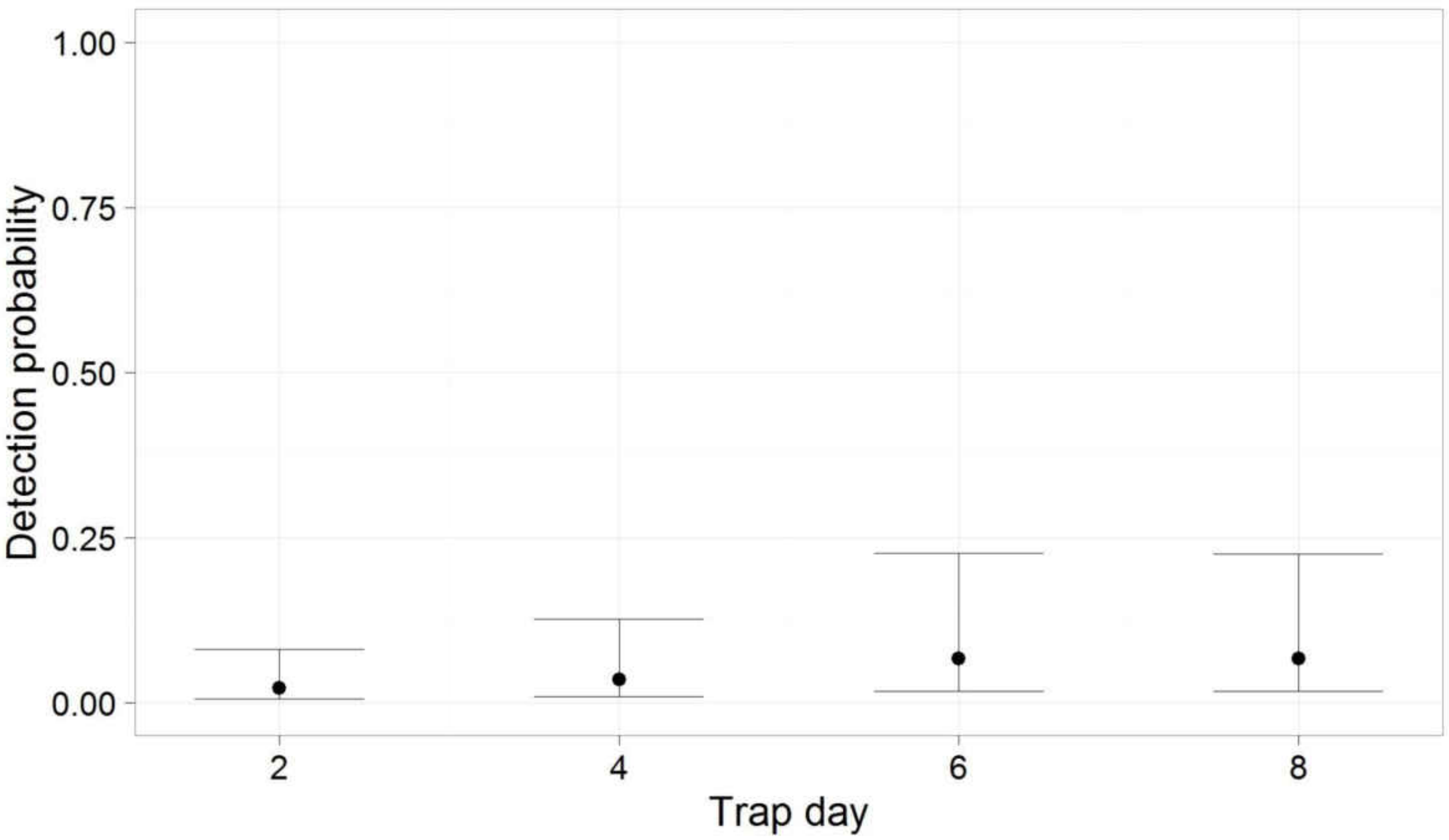

Figure 5. Estimates of detection probability from the top detection model (trap day) for Silver River for each trap day (x-axis is the number of days since trap was first set). Bars represent 95% confidence intervals.

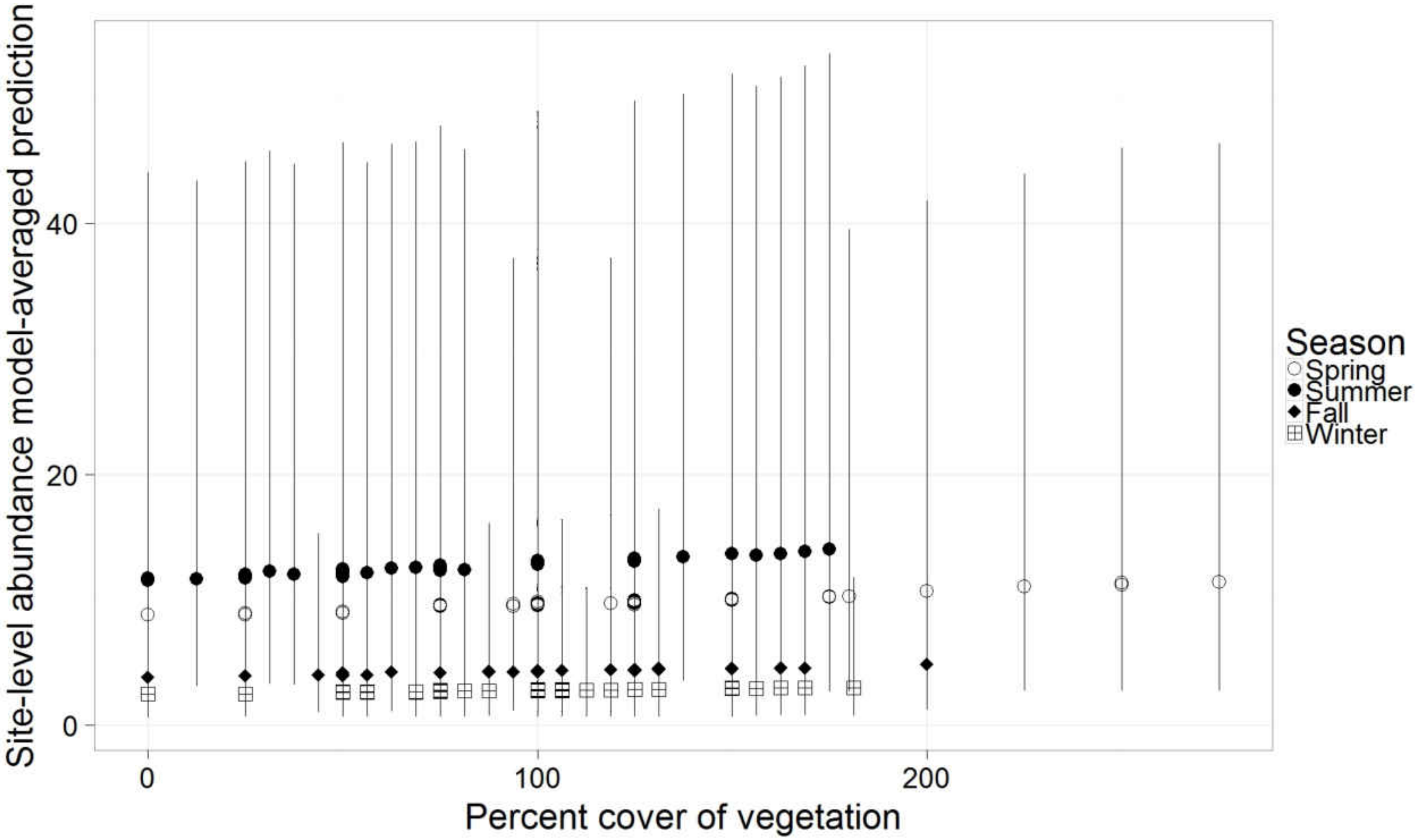

Figure 6. Estimates of model-averaged abundance for Silver River for each survey for the percent cover of vegetation found during the surveys. Bars represent 95% confidence intervals.

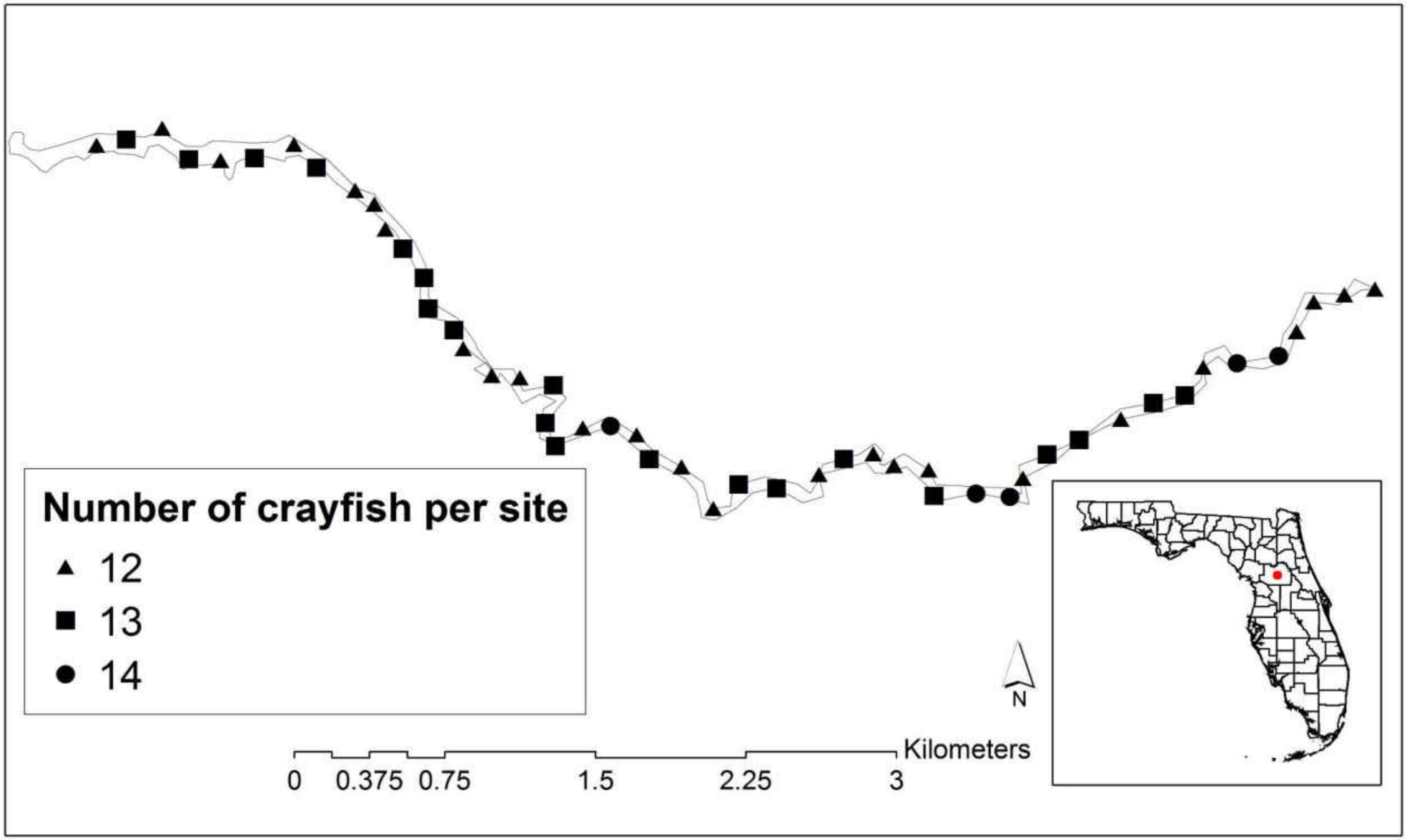

Figure 7. Map of Silver River showing summer survey abundance estimates at each site. The buffer around each point is a 60 meter^2 circle and approximates the maximum area sampled by each trap.

CHAPTER FOUR: DISCUSSION

This study confirmed the identification of the stream-dwelling species of crayfish in the Wakulla River as *P. paeninsulanus* and confirmed the identification of the stream-dwelling species in the Silver River as *P. fallax*.

The results suggest that dissolved oxygen was important to defining *P. paeninsulanus* abundance. Abiotic parameters impact crayfishes in a density-independent way and can affect physiology (Caine, 1978; Hobbs & Lodge, 2010). The values of dissolved oxygen measured in this study are generally within its physiological tolerance (above its critical oxygen level). Caine (1978) states the critical oxygen level is the level below which respiration starts to become anaerobic. For temperatures of 22 °C (closest to measured values in Wakulla River), the critical oxygen level is 1.72 mg/L (Caine, 1978). All dissolved oxygen levels recorded are above this threshold, the lowest measurement being 1.9 mg/L. It is possible that the lower dissolved oxygen areas reach levels outside of the physiological limit (thereby excluding crayfish) but this was not detected because dissolved oxygen was not monitored continuously. It has been shown that *P. paeninsulanus* is observed to form relatively shallow and simple burrows, withstand drying and lower dissolved oxygen, and can wander terrestrially up to 400 meters from nearest water source (Hobbs, 1942; Caine, 1978; Breinholt *et al.* 2011). This may contradict the importance of dissolved oxygen to this species. However, and in light of this study, it is possible *P. paeninsulanus* is tolerant of more stressful conditions but does not readily detect or select those habitats when better (higher dissolved oxygen level) areas are available.

The type of bottom cover was important to defining *P. paeninsulanus* abundance. Plants act as food and are a shelter from competitors and predators. Non-plant (i.e. other invertebrates) food source quantity and quality may be impacted by plant species and percent cover thereof (Hobbs & Lodge, 2010). Cronin *et al.* (2002) found that crayfish preferentially feed on more filamentous vegetation, although this preference shifts to relative nutrient content when texture is the same. Florida crayfish *P. alleni* in wetlands in the Everglades were more abundant in dense vegetation and used these vegetated areas relative to other cover types, seemingly to avoid predators (Jordan, DeLeon & McCreary, 1996). In the Wakulla River, *P. paeninsulanus* prefers emergent vegetation over either submerged or bare/algal-covered bottom types. The areas with dominant emergent vegetation were anecdotally more diverse than areas with submerged vegetation; the submerged areas were usually dominated by one or the other of two submerged species (*Sagittaria kurziana,* Family Alismataceae, and *Vallisneria americana,* Family Hydrocharitaceae)*.* It is possible that emergent vegetation provides more root and stem structure that serves as shelter from conspecifics and predators and more plant food options than does submerged vegetation.

The results suggest that there is heterogeneity in habitat across the area of the river sampled. Wakulla River has four management areas: Sally Ward, a smaller spring run fed by its own springhead; the boat tour area, that is state park run and only allows human access via guided pontoon boat tours; the restricted area, where only managers and researchers are allowed; and the public access area, which is not state park property, and which has public boat traffic and private property along it. There was variation in abundance at the site-level as shown in the map in Figure 4. The sites with higher abundance were in the restricted area of the river. These sites were dominated by emergent vegetation. The rest of the river areas were dominated by submerged vegetation or algal/bare bottom. It is possible that management areas of the river influence the type of vegetation that can grow, which therefore defines the heterogeneity of habitat and abundance across the landscape.

Percent cover of vegetation was most important to defining *P. fallax's* distribution. This is most likely for reasons of protection from conspecifics and predators and possibly for food availability. These results supported Hobbs's (1942) observation that *P. fallax* was found wherever there was sufficient vegetation and that plant species composition was not important in defining its distribution. The Silver River's average percent cover of vegetation was high in the sites sampled. Habitat is seemingly homogenous across the length of the river, so variation in abundance estimates at the site level, as evidenced by summer estimates seen in the map in Figure 7, was low as well, when compared to Wakulla River and *P. paeninsulanus.*

There may also be other parameters not surveyed in this study that are relevant to *P. fallax*. Dorn & Volin (2009) and Dorn & Trexler (2007) show differences in *P. fallax* residence in different hydroperiods in Florida Everglades and different burrowing abilities (a way to avoid desiccation) in different substrates. *P. fallax* seems to have slower growth, requires more inundation and does not burrow in dense sandy substrates compared with peat and marl relative to *P. alleni.* In the future, it would be worthy to add parameters like this that have been assessed for this species in other parts of its range.

Temporal trends of survey time of year explained abundance for *P. paeninsulanus* and *P. fallax*. Although this study does not replicate over multiple seasons, the literature suggests that crayfishes, both males and females, are more active during fall for breeding (Hobbs & Lodge, 2010). There is evidence in the Family Astacidae that crayfish maturing and mating is in part influenced by water temperature and day length which is commensurate with seasonality. Although water temperature was fairly constant, day length changes seasonally and may trigger life cycle events in these crayfish (Reynolds, 2002).

Moon illumination and water depth were important to detection of *P. paeninsulanus.* Crayfish molting is shown to synchronize to the new moon lunar phase in astacid *Aastacus astacus*, possibly through triggering an internal clock; crayfish behavior changes during molt (less active and usually more secluded) (Franke & Hoerstgen-Schwark, 2013). Alternatively, lab-reared crayfish were less active in general on moon illuminated nights (Franke & Hoerstgen-Schwark, 2015). *P. paeninsulanus* may also have this syncing and change in behavior although the direction of response is not clear from this study. For *P. fallax,* detection was quite low but was best explained by some differences between trap days. One hypothesis is that detection range of the bait changes over the sample days (for example, with variation in flow) and may play into crayfish ability to find and enter the trap.

This study contributes to potentially understanding *P. fallax* on a global scale in addition to the regional scale. It is the first known parthenogenic decapod crustacean (meaning it can reproduce from unfertilized eggs) (Martin *et al.,* 2010; Scholtz *et al.,* 2013). It is called the ‘Marmorkrebs’ or ‘marbled crayfish’ and is known from the pet trade (Faulkes, 2015). Females with eggs have been documented in Ukraine (Novitsky & Son, 2016) and the parthenogenic form has also been documented in Germany, Netherlands, Italy, Madagascar and Japan (Martin *et al*., 2010). Broadly, habitat and environmental factors important to this species can be applied in predictions of its expansion in nonnative ranges and different habitat types and therefore highlight areas to focus on preventing its establishment.

Management implications and recommendations

The method employed in this study is trustworthy, even with low detectability, because the analysis adjusts abundance based on detection. However, there is uncertainty in the area sampled, which makes extrapolating to overall abundance estimates difficult and not recommended. The area sampled is a fraction of the area of the river that crayfish inhabit and trapping area itself is an approximation. The sum of abundance at the sites is likely a small fraction of the total crayfish present. Monitoring for total abundance numbers is inappropriate because of the uncertainty of extrapolating the sites sampled to whole-river abundance. However, monitoring at the site-level for abundance, with this conservative approach, is useful for future monitoring. Managers can trust that the method, if repeated, will produce a reliable estimate based upon crayfish caught and give appropriate, if not underestimated, relative crayfish abundance at the site or habitat level. Site level changes will reflect changes in the overall crayfish population if data collected is repeated across years, seasons and habitat (time and space).

Hypotheses for crayfish die-off

Taylor *et al.* (2007) notes that habitat degradation and pollutants are of concern to crayfish conservation. This may be true of the crayfishes in this study. Herbicidal treatment for control of *Hydrilla verticillata* (Family Hydrocharitaceae)*,* an invasive aquatic plant, has been conducted previously in Wakulla River. During that treatment, a pronounced crayfish die-off occurred. The managers of the river note that many hundreds of dead crayfish were observed along the length of the river (M. Phillips, unpubl. data). A subsequent laboratory study revealed the treatment concentrations used and the levels measure in the river for herbicidal treatment were not lethal to crayfish (FDEP, 2005). So, it is possible there was an indirect effect of treatment that caused crayfish mortality. There were no baseline population data at that time to inform local management of Wakulla River whether such a dieback could have implications toward the population stability of *P. paeninsulanus.* Managers may also use herbicidal treatment in Silver River for control of *H. verticillata.* An herbicide byproduct, terbuthylazine-2-hydroxy, although not the product used in this river, showed impact to *P. fallax* growth and causes oxidative stress at concentrations above environmental levels (Koutnik *et al*., 2016), which reinforces the concern that herbicide may impact crayfishes in these rivers in a negative way even if they do not kill immediately or directly.

There are a few hypotheses as to why the Wakulla River dieback may have occurred. First, crayfish may have responded to reduced dissolved oxygen levels in the water column from decomposing vegetation, in which microorganism respiration causes a massive reduction in oxygen levels. Second, crayfish may have been feeding on *H. verticillata* and were exposed to levels of herbicide not measured in the FDEP study. Third, crayfish olfactory systems may have been impaired, leading to a sustained inability to find food; Wolf & Moore (2002) found that other herbicides (metolachlor) reduced cambarid crayfish *Orconectes rusticus's* ability to search for food with chemoreception. Fourth, crayfish may have been feeding on *H. verticillata*, and lost a food source when the plant was removed from the system. These questions may be worthy of further study if the management of *H. verticillata* in the system becomes more routine and frequent. *In situ* experiments that sample before and after herbicidal treatment could elucidate these hypotheses.

Wakulla River and Silver River monitoring

Herbicidal treatment will likely occur again in Wakulla River and may occur in Silver River since *H. verticillata* is present. If herbicidal treatment is to occur, a sample of ‘sentinel’ crayfish could be collected and placed in traps within the rivers before, during and after treatment. These sites should be monitored for herbicide concentration as well as dissolved oxygen. Crayfish should be re-collected and observed for mortality. That way direct mortality can be related to factors such as the herbicide concentration and/or dissolved oxygen.

In Wakulla River, sampling should occur at least in areas of emergent vegetation, if dissolved oxygen levels are above 4mg/L, in summer and fall surveys to ensure the highest catch rate of crayfish. A few key sites could be monitored each year. Habitat data at these sites should also be collected in case there are changes in key parameters like dissolved oxygen. These sites can serve as a proxy for the river in case of future herbicide treatment. I do not recommend using Sally Ward creek as a control site during herbicidal treatment. Counts of crayfish in Sally Ward were consistently low, and the important habitat parameters such as dissolved oxygen and vegetation type are not reflective of the rest of Wakulla River, so it is likely that abundances of crayfish in this area are not reflective of those in the main channel of Wakulla River.

In Silver River, further full river study could be done to better understand habitat parameters that inform *P. fallax'*s abundance. Estimates of abundance have broader confidence intervals because of the low detectability in this river for this species; therefore, I also recommend more traps to best guarantee higher catch rates. It is possible that several traps could be set in a smaller area for easier access and this repeated at several sites across the length of the river. I recommend that sampling be conducted in spring and/or summer, when the greatest catch in this study occurred.

Sampling may be improved by offering multiple food sources (for example, chicken liver, Nowicki *et al.,* 2008) and other sampling methods (throw trap or manual sampling or higher density of traps). Other sampling methods may also validate the densities observed in this study. Count data recorded should be at multiple sites and on at least 3 sampling days within a short (1 to 2 week) period of time during each season or year sampled. This effort would provide trends across years and seasons (with spatial and temporal replication).

APPENDIX A: DISTRIBUTIONS OF COUNTS

These figures show the frequency histograms of counts and raw count totals and recaptures for each season and each river.

Wakulla River histogram of counts

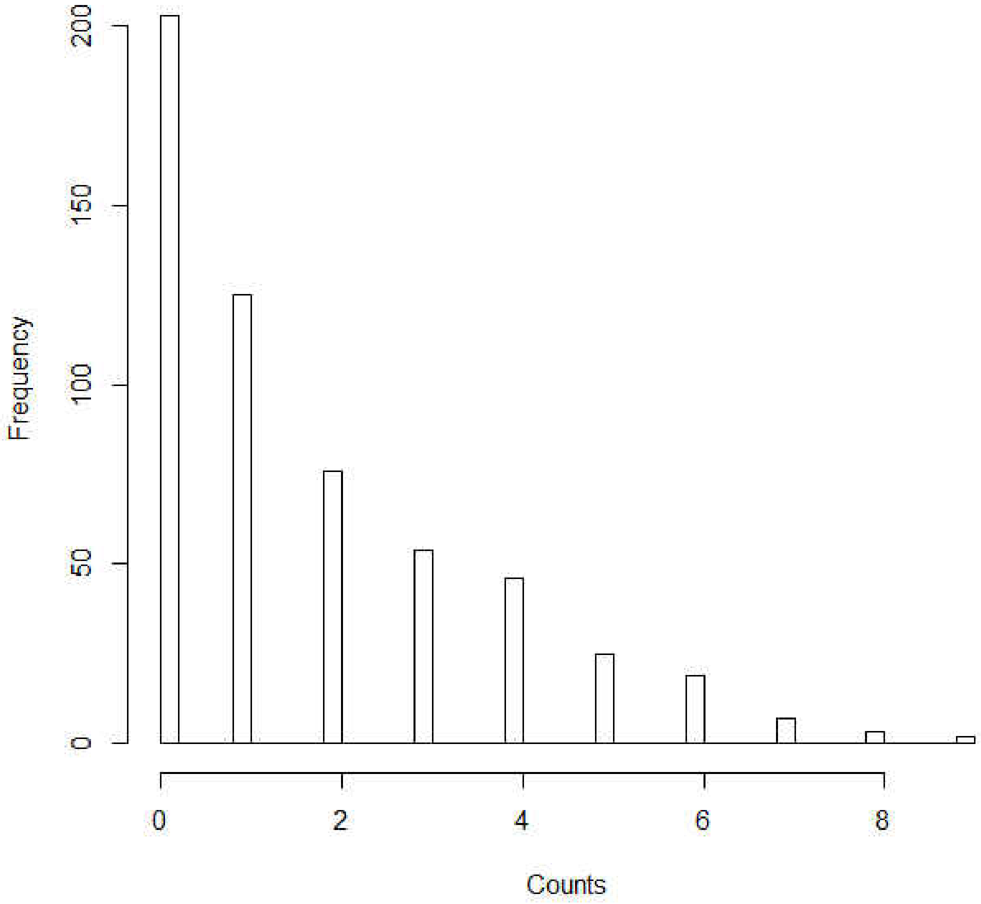

Figure 8. Wakulla River histogram of crayfish counts where the x-axis is the number of crayfish and the y-axis is how many occasions (sites x surveys) this count occurred and with seasons combined.

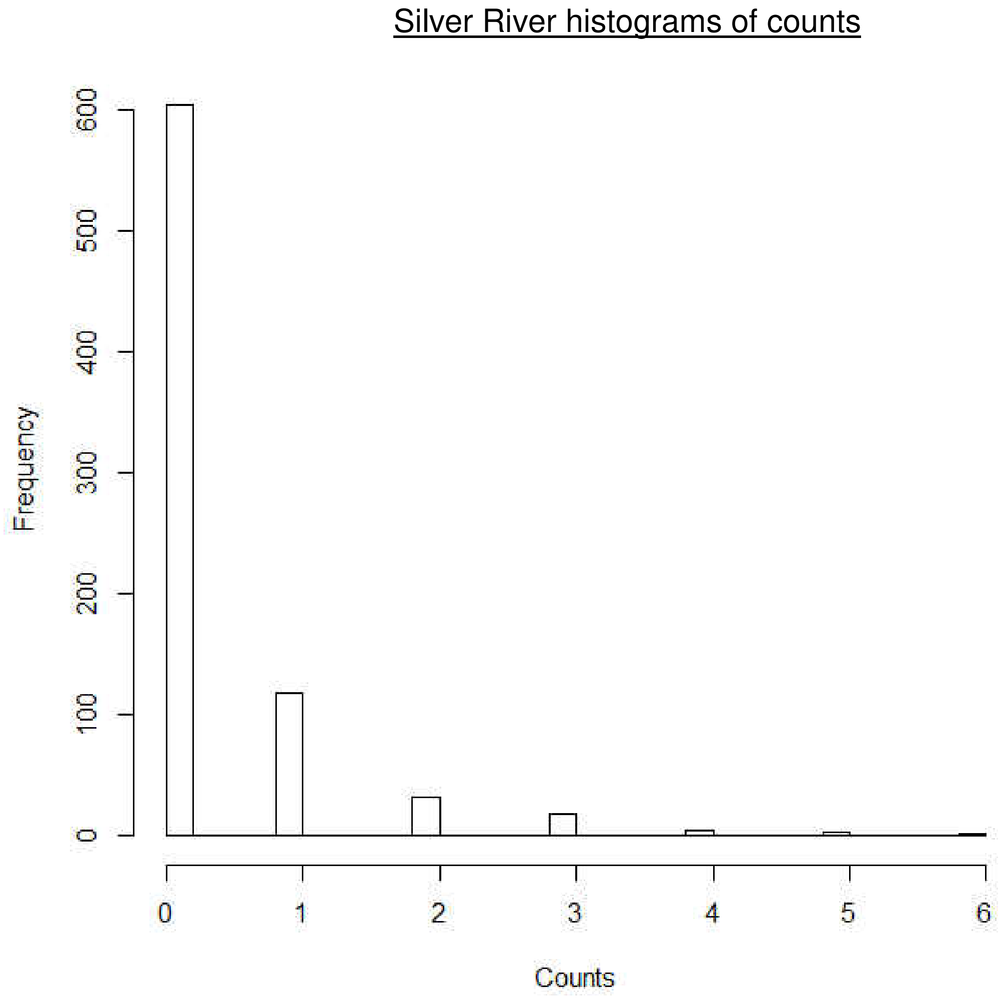

Figure 9. Silver River histogram of crayfish counts where the x-axis is the number of crayfish and the y-axis is how many occasions (sites x surveys) this count occurred and with seasons combined.

APPENDIX B: GOODNESS OF FIT TESTS

These figures show the results of a Goodness of Fit test for the full interactive model for both rivers. 1000 iterations were performed. The overdispersion parameter is listed in the figure description.

Goodness of Fit table and graph (Wakulla River)

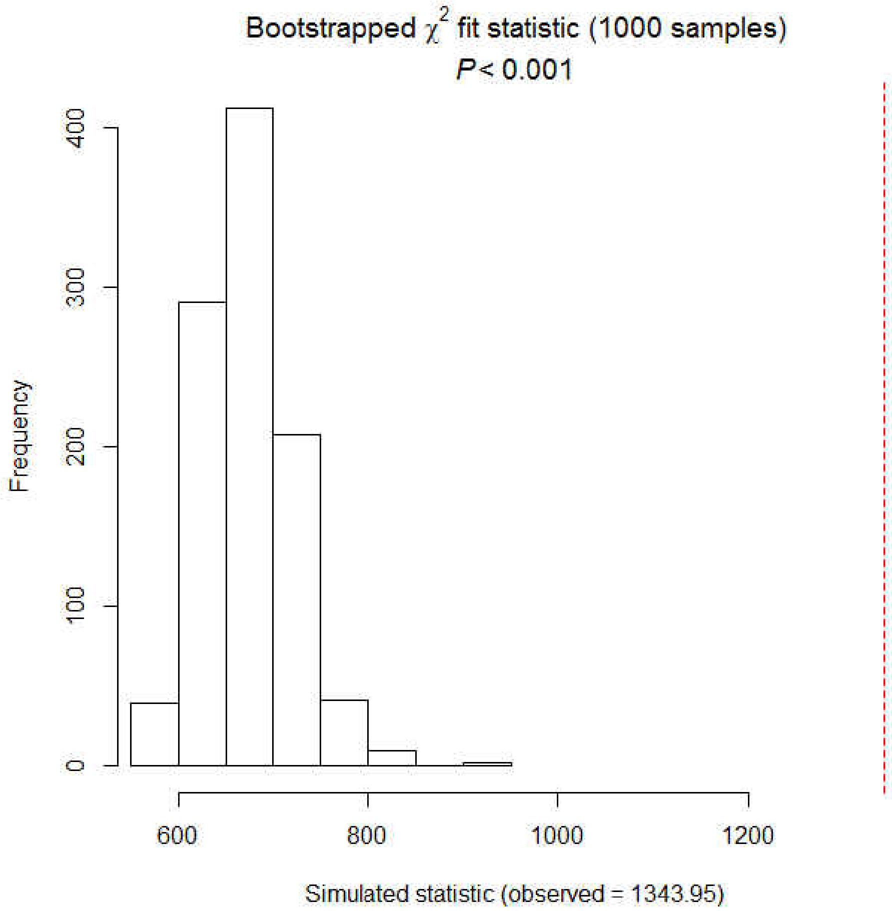

Figure 10. Chi square goodness of fit conducted, where observed statistic is 1343.95, number of bootstrap samples 1000, and P<0.001. The observed statistic was outside of the 567 to 930 0 to 100% quantiles. The estimate of c-hat is 2, and was incorporated into prediction estimates for detection and lambda to account for overdispersion.

Goodness of Fit table and graph (Silver River)

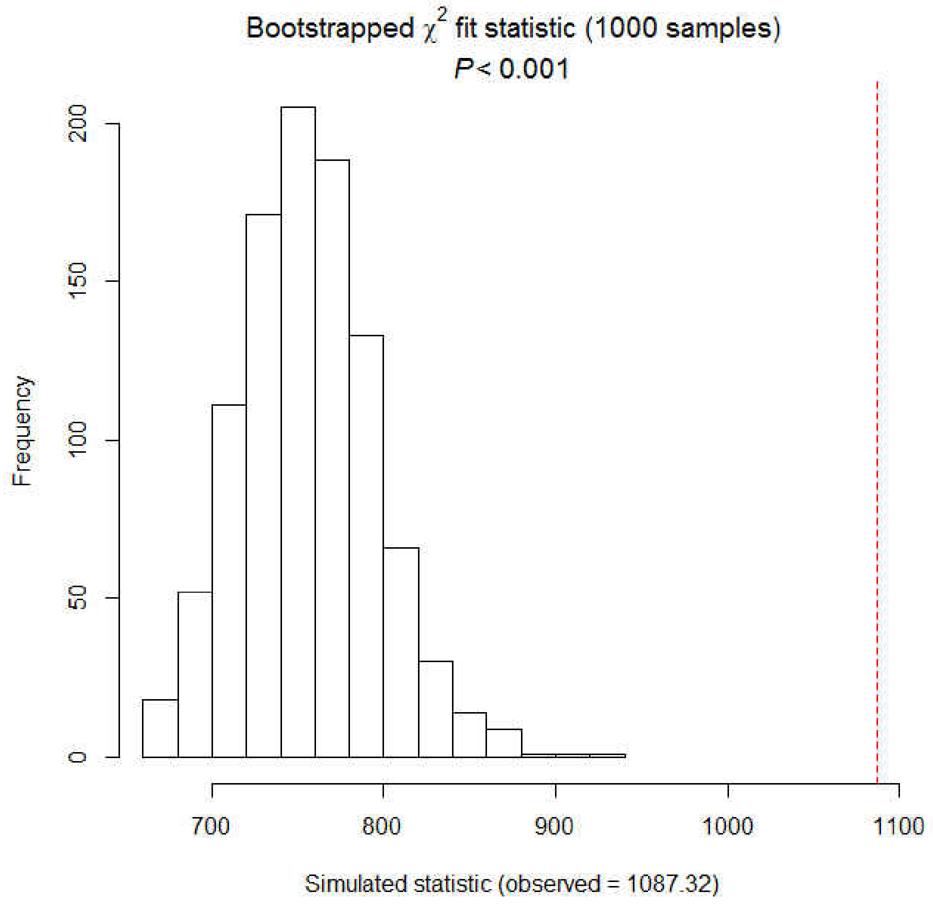

Figure 11. Chi square goodness of fit conducted, where observed statistic is 1087.32, number of bootstrap samples 1000, and P<0.001. The observed statistic was outside of the 663 to 940, 0 to 100% quantiles. The estimate of c-hat is 1.44, and was incorporated into prediction estimates for detection and lambda to account for overdispersion.

APPENDIX C: HABITAT PARAMETER RAW DATA

The below figures show the recorded values for all habitat parameters for both rivers, across sites, with seasons combined.

Wakulla River habitat parameters

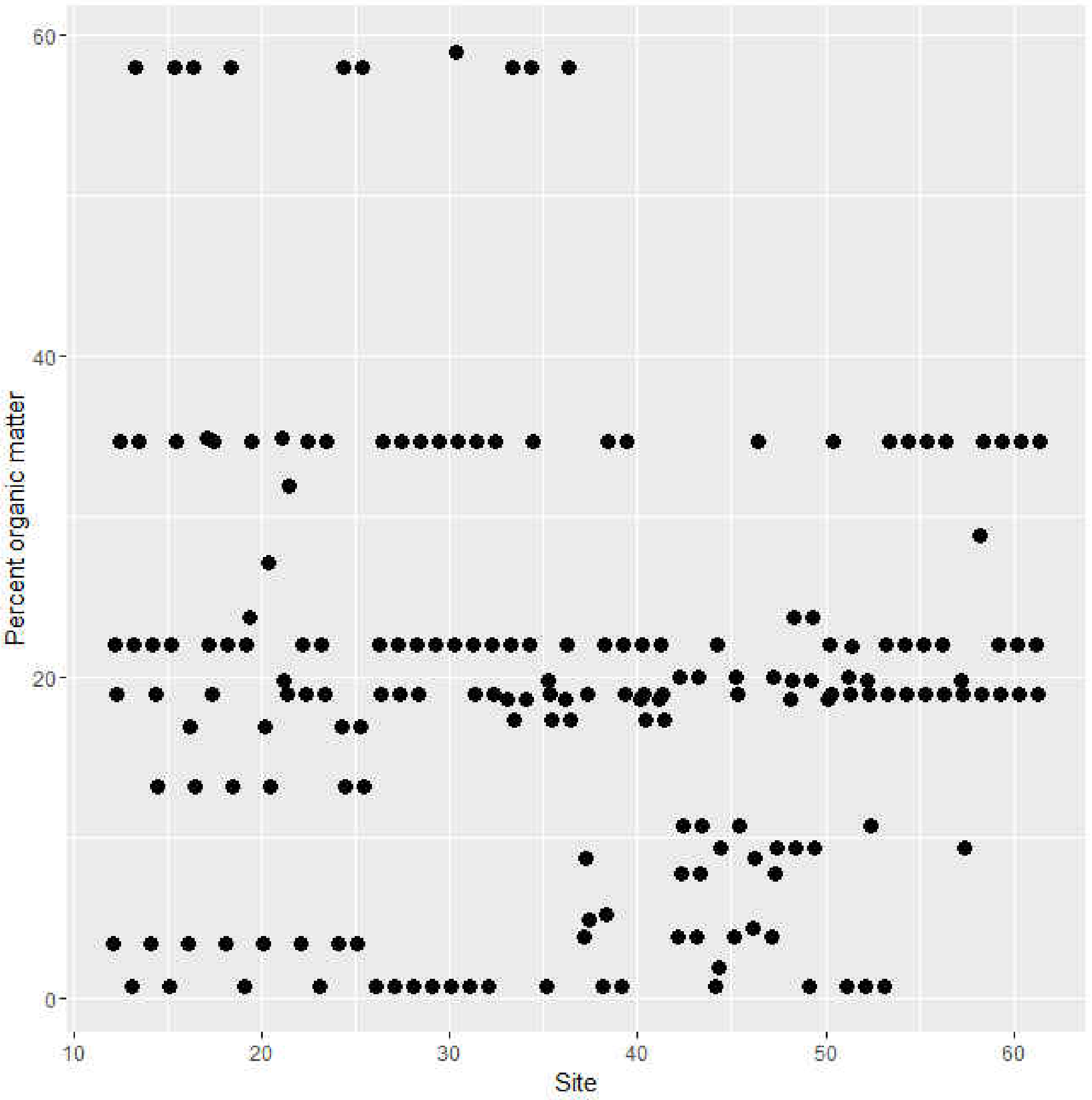

Figure 12. Wakulla River organic matter (percent) where x-axis is site and y-axis is percent organic matter.

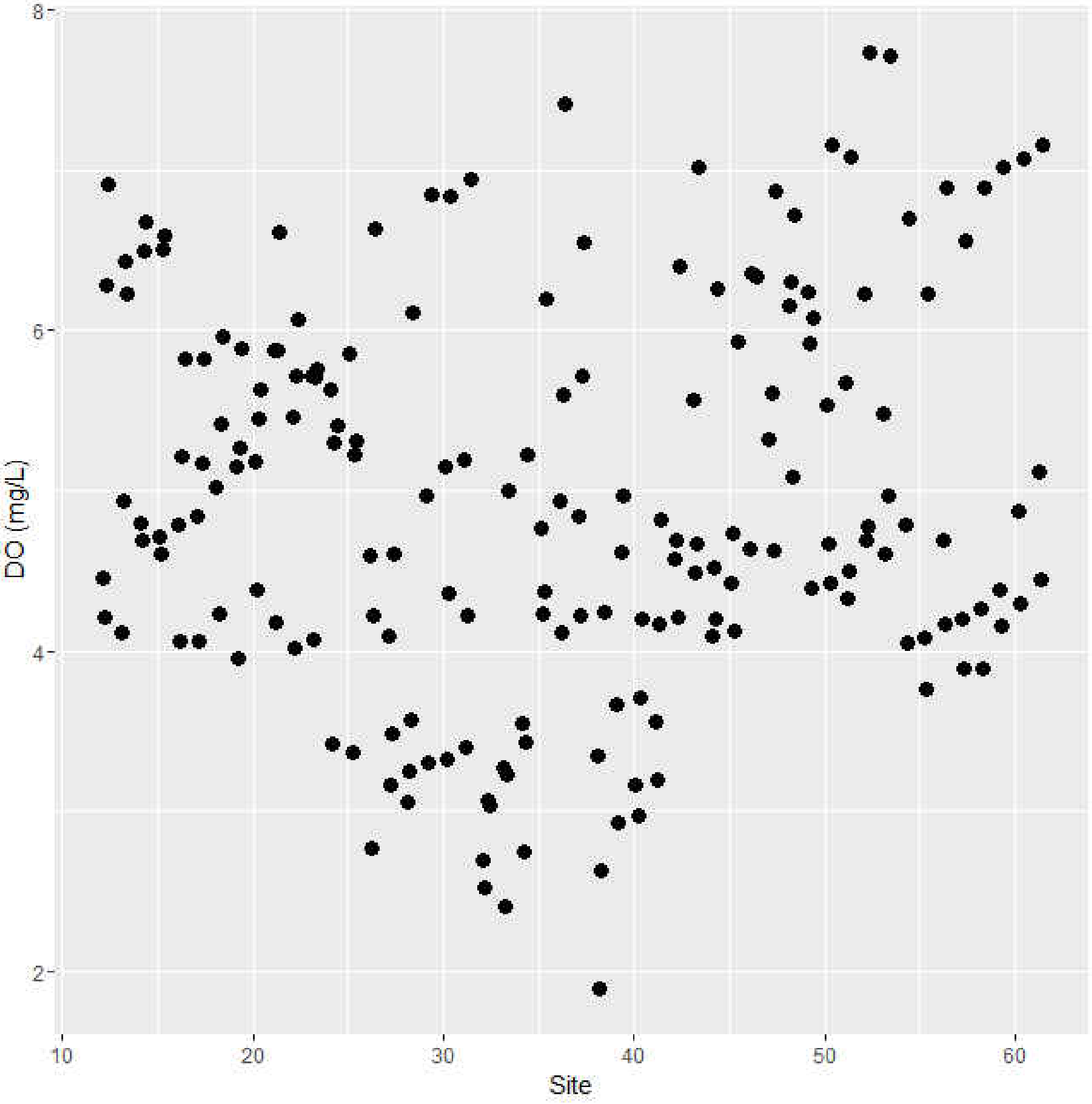

Figure 13. Wakulla River dissolved oxygen across sites where x-axis is site and y-axis is dissolved oxygen (DO) in (mg/L).

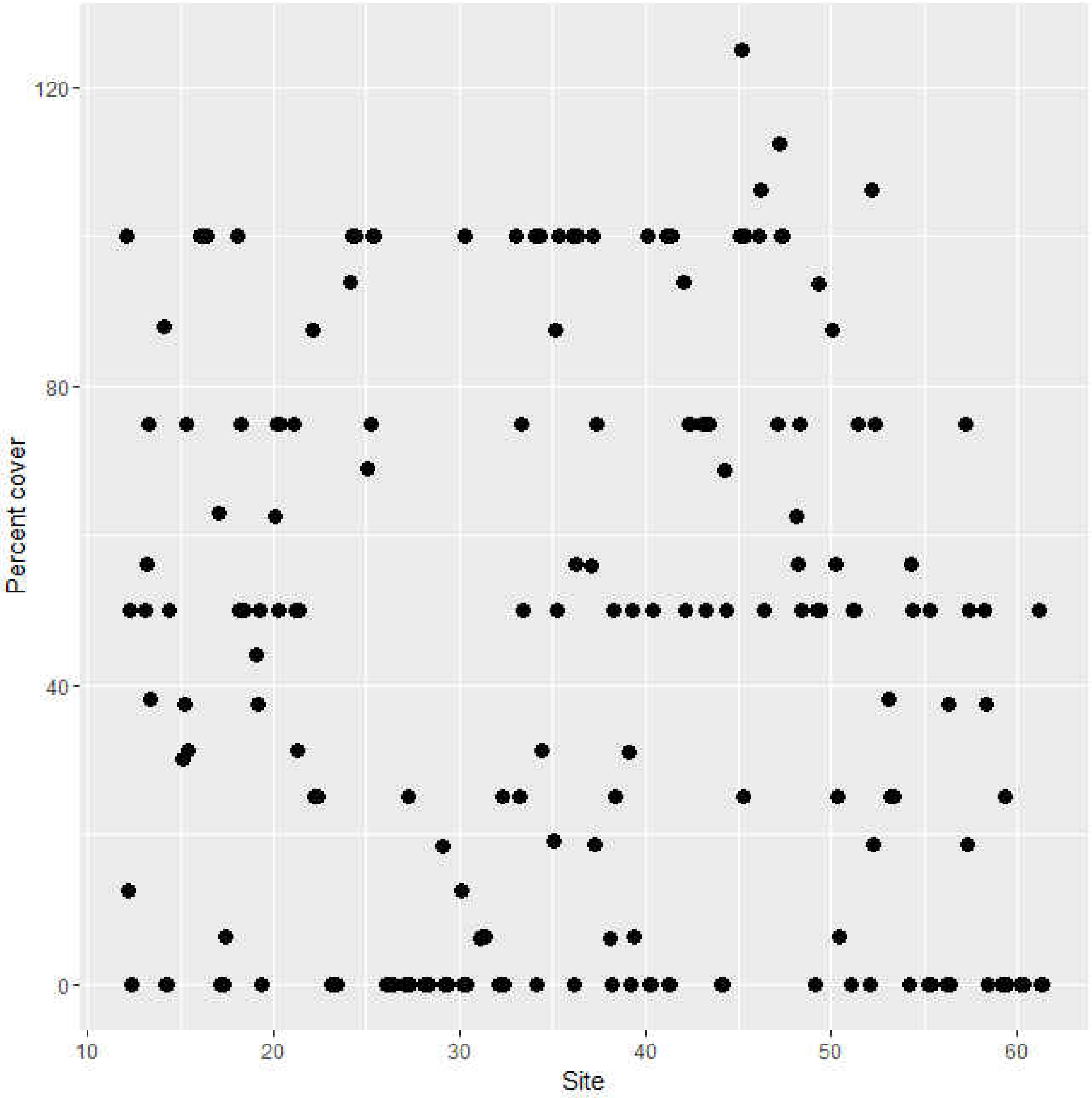

Figure 14. Wakulla River percent cover of vegetation across sites where x-axis is site and y-axis is percent cover.

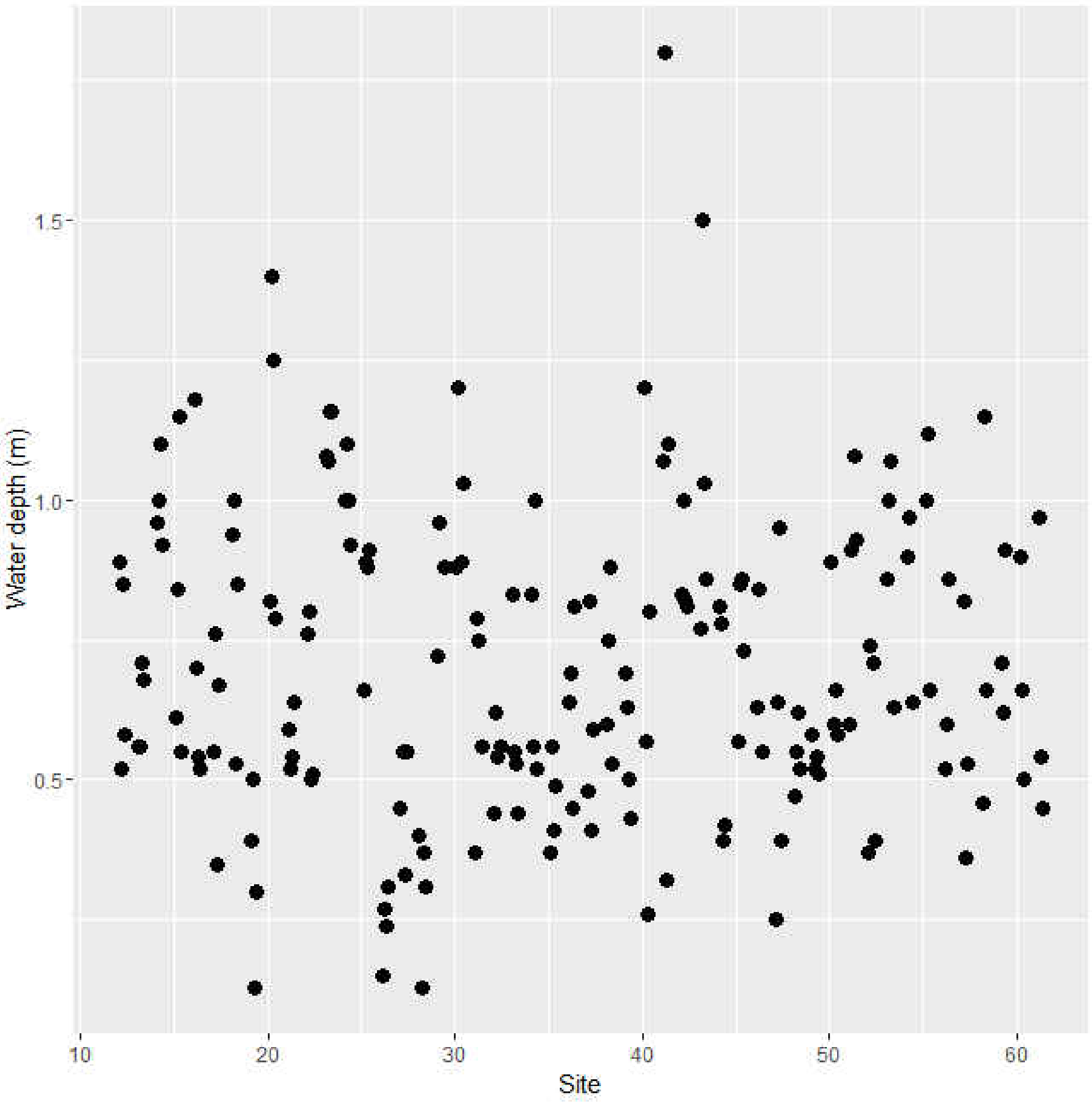

Figure 15. Wakulla River water depth (meters) across sites where x-axis is site and y-axis is depth in meters.

Silver River habitat parameters

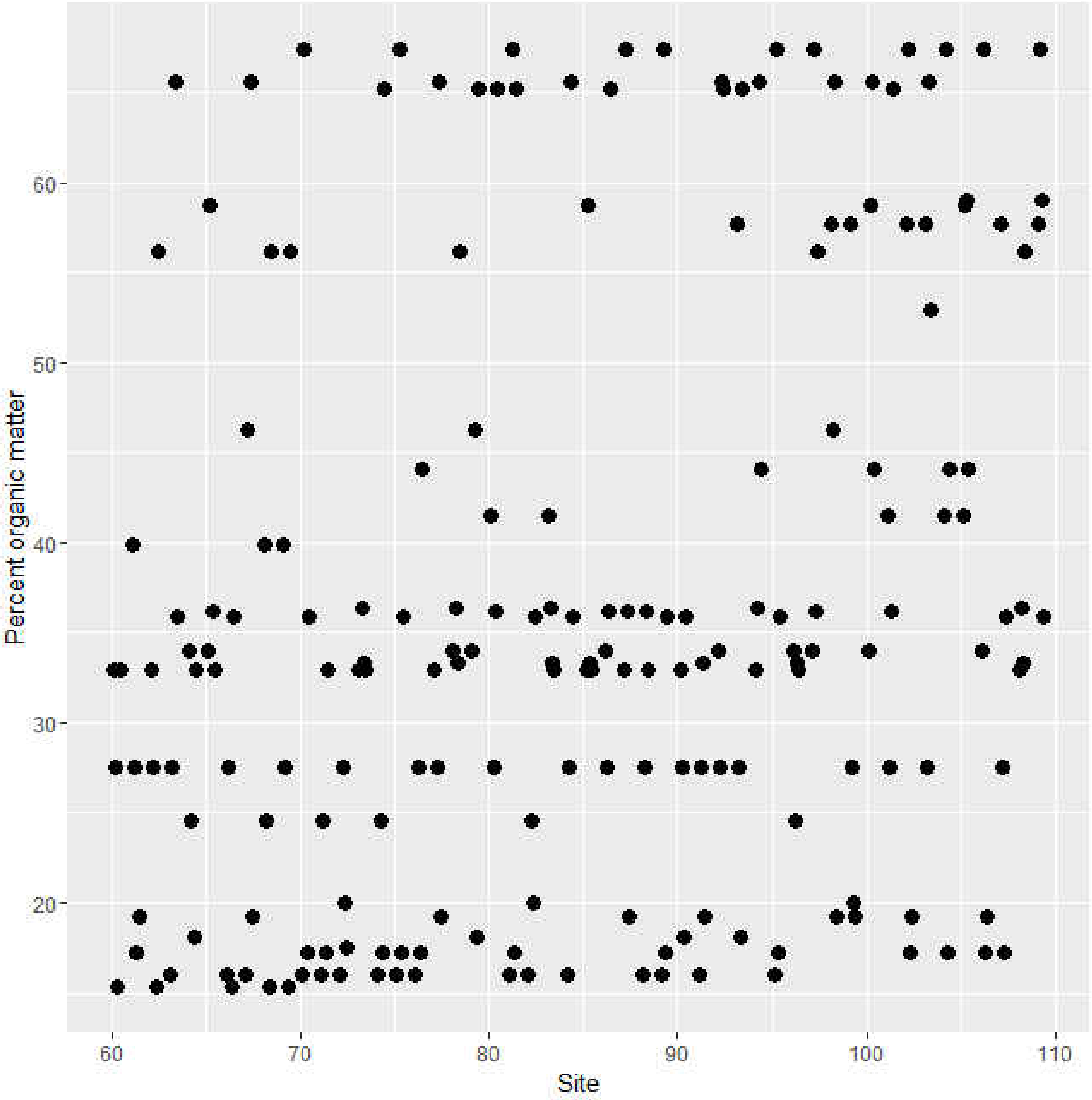

Figure 16. Silver River organic matter (percent) across sites where x-axis is site and y-axis is percent organic matter.

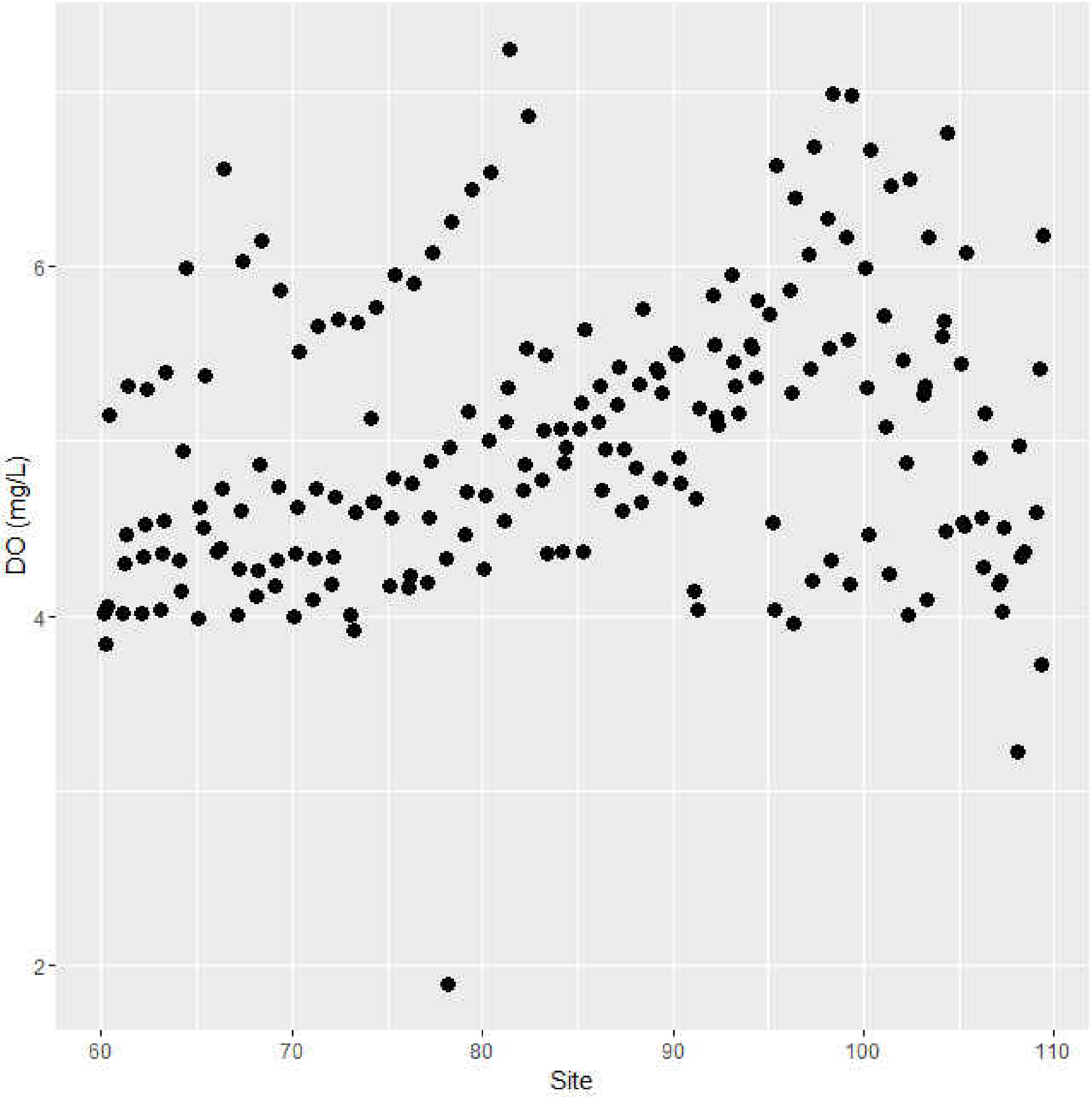

Figure 17. Silver River dissolved oxygen (DO) across sites where x-axis is site and y-axis is DO in milligrams/liter.

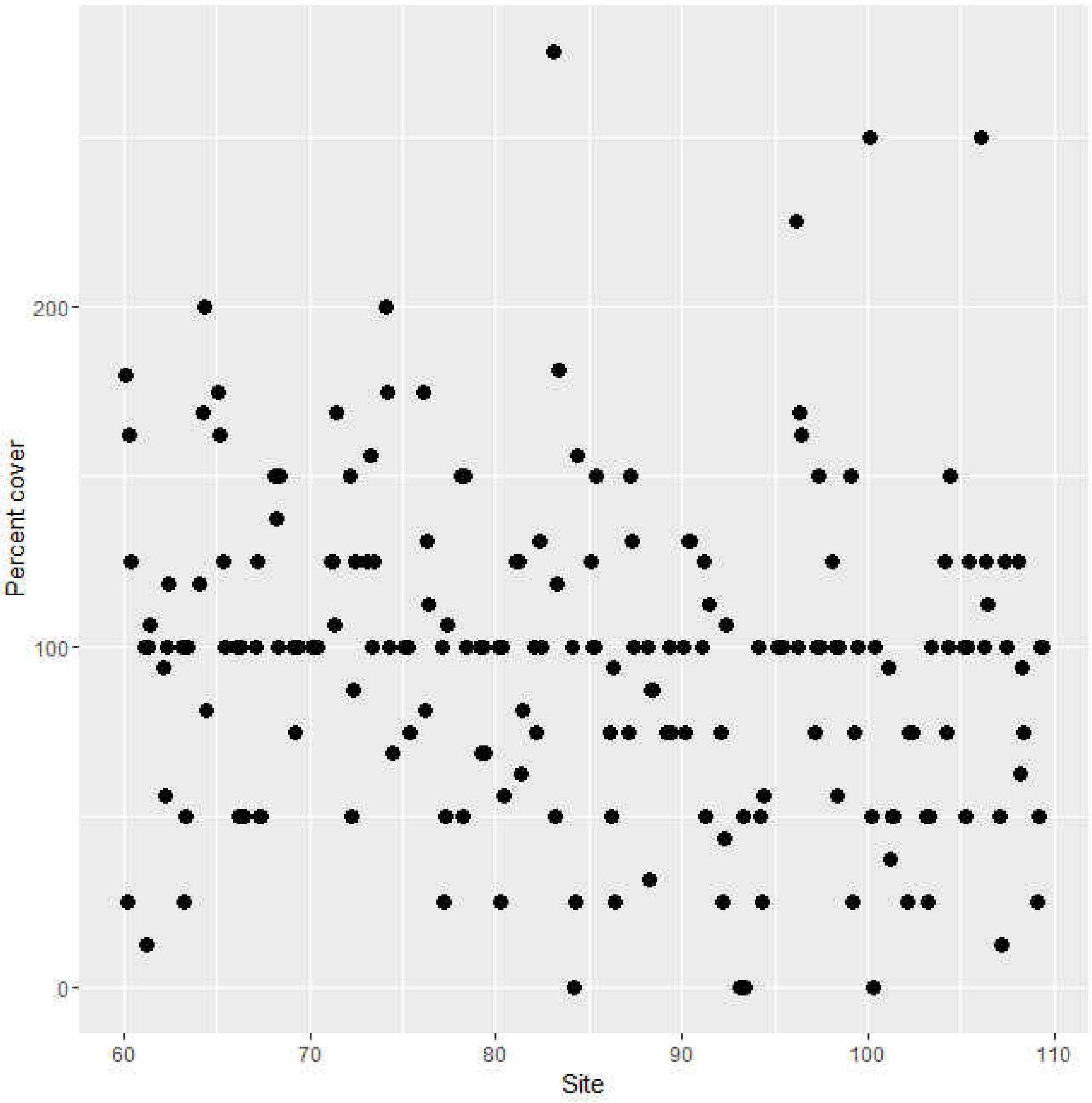

Figure 18. Silver River percent cover of vegetation across sites where x-axis is site and y-axis is percent cover.

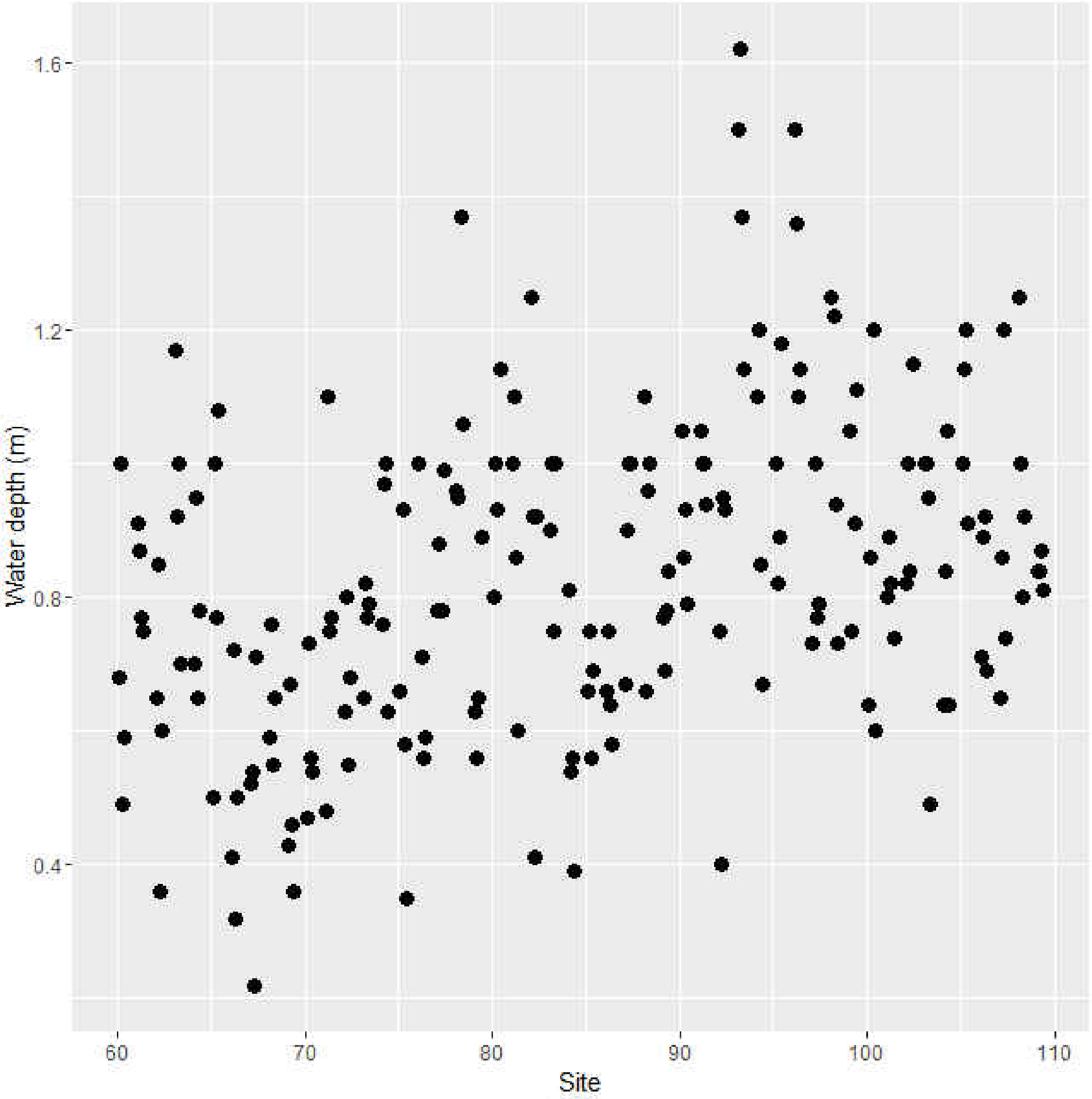

Figure 19. Silver River water depth (meters) across sites where x-axis is site and y-axis is depth in meters.

Dominant plants

Table 5. This table shows the dominant (meaning that it was at least 50% of the cover at least at one site) for both rivers; emergent vegetation (above waterline) and submerged vegetation (below waterline) are separated (Wunderlin *et al.* 2016 for plant identification).

River	Emergent	Submerged
Wakulla	*Mikania scandens*	*Ceratophyllum demersum*
	Polygonum hydropiperoides	*Ludwigia* spps.
	Pontederia cordata	*Myriophyllum* spps.
	Rhynchospora inundata	*Sagittaria kurziana*
	Schoenoplectus californicus	*Vallisneria americana*
	Typha spps.	
Silver	*Hydrocotyle* spps.	*Ceratophyllum demersum*
	Nuphar advena	*Hydrilla verticillata*
	Nymphaea odorata	*Najas guadalupensis*
	Pontederia cordata	*Sagittaria kurziana*
		Vallisneria americana

APPENDIX D: MODEL SELECTION TABLES

Table 6. Detection model selection for Wakulla River based on AICc. Here, the abundance part of the model stayed constant while a suite of detection parameters and additive models were compared. AICc= Akaike's Information Criterion with correction for small sample size. K is the number of fitted parameters. The Δ AICc is a measure of a model relative to the most informative or 'top' model. The AICc weight is the relative importance of the model compared to the rest of the set and is applied during model averaging. LL is log likelihood. M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year. The full abundance model run was ~ DBT: DO: PC: OM: TOY.

Detection ~	**K**	**AICc**	**Δ AICc**	**AICc Weight**	**LL**
WD+M	16	2405.28	0	.45	-1185.07
M	15	2407.37	2.09	.16	-1187.31
WD	15	2407.5	2.22	.15	-1187.37
Null	14	2408.77	3.49	.08	-1189.18
WD+PC	16	2409.32	4.04	.06	-1187.09
PC+M	16	2409.52	4.24	.05	-1187.19
TD	17	2410.66	5.38	.03	-1186.55
PC	15	2410.8	5.52	.03	-1189.02

Table 7: Abundance model selection for Wakulla River based on AICc. Two-part model includes detection covariate from Table 1 (Water Depth + Moon) that stayed constant while the suite of abundance parameters, additive models and interactions were compared. AICc= Akaike's Information Criterion with correction for small sample size. K is the number of fitted parameters. The Δ AICc is a measure of a model relative to the most informative or 'top' model. The AICc weight is the relative importance of the model compared to the rest of the set and is applied during model averaging. LL is log likelihood. M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year.

Abundance~	**K**	**AICc**	**Δ AICc**	**AICc Weight**	**LL**
DBT+DO+TOY	10	2217.84	0	0.98	-1098.31
PC+DBT+TOY	10	2226.81	8.97	0.01	-1102.79
DBT+TOY	9	2228.13	10.28	0.01	-1104.56
DBT*TOY	15	2232.68	14.84	0	-1099.96
DO*TOY	11	2233.37	15.52	0	-1104.94
PC+OM+ TOY	9	2241.47	23.63	0	-1111.24
PC+DO+ TOY	9	2246.38	28.54	0	-1113.69
DO+ TOY	8	2250.15	32.31	0	-1116.68
OM* TOY	11	2250.75	32.9	0	-1113.63
OM+ TOY	8	2253.91	36.07	0	-1118.56
PC* TOY	11	2257.77	39.93	0	-1117.14
PC+ TOY	8	2260.18	42.34	0	-1121.69
TOY	7	2269.54	51.70	0	-1127.46
DBT	6	2378.03	160.19	0	-1182.79
DBT: DO: PC: OM: TOY	16	2405.28	187.44	0	-1185.07
DO	5	2430.93	213.09	0	-1210.30
PC	5	2432.55	214.71	0	-1211.11
Null	4	2434.01	216.17	0	-1212.90
OM	5	2435.89	218.05	0	-1212.78

Table 8. Detection model selection for Silver River based on AICc. Here, the abundance part of the model stayed constant while a suite of detection parameters and additive models were compared. AICc= Akaike's Information Criterion with correction for small sample size. K is the number of fitted parameters. The Δ AICc is a measure of a model relative to the most informative or 'top' model. The AICc weight is the relative importance of the model compared to the rest of the set and is applied during model averaging. LL is log likelihood. M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year. The full abundance model run was ~ DBT: DO: PC: OM: TOY.

Detection~	**K**	**AICc**	**Δ AICc**	**AICc Weight**	**LL**
TD	17	1246.78	0	0.96	-604.71
WD	15	1254.47	7.69	0.02	-610.93
WD +M	16	1255.94	9.16	0.01	-610.48
WD +PC	16	1256.58	9.80	0.01	-610.80
Null	14	1294.14	47.37	0	-631.94
M	15	1295.76	48.98	0	-631.58
PC	15	1296.43	49.65	0	-631.91
PC+M	16	1298.01	51.23	0	-631.52

Table 9. Abundance model selection for Silver River based on AICc. Two-part model includes top detection covariate from Table 3 (trap day) that stayed constant while the suite of abundance parameters, additive models and interactions were compared. AICc= Akaike's Information Criterion with correction for small sample size. K is the number of fitted parameters. The Δ AICc is a measure of a model relative to the most informative or 'top' model. The AICc weight is the relative importance of the model compared to the rest of the set and is applied during model averaging. LL is log likelihood. M=moon illumination, WD=water depth, TD=trap day, PC=percent cover, DBT=dominant bottom type, DO=dissolved oxygen, OM=organic matter content, TOY=survey time of year.

Abundance~	**K**	**AICc**	**Δ AICc**	**AICc Weight**	**LL**
PC+TOY	9	1171.23	0	0.27	-576.14
TOY	8	1171.68	0.46	0.21	-577.47
PC+DO+ TOY	10	1172.92	1.7	0.12	-575.88
PC+OM+ TOY	10	1173.35	2.12	0.09	-576.09
DO+ TOY	9	1173.53	2.3	0.09	-577.29
OM+ TOY	9	1173.76	2.53	0.08	-577.41
DBT+ TOY	10	1174.33	3.1	0.06	-576.58
PC+DBT+ TOY	11	1175.36	4.13	0.03	-575.98
DBT+DO+ TOY	11	1176.06	4.83	0.02	-576.33
PC* TOY	12	1176.26	5.03	0.02	-575.29
DO* TOY	12	1179.42	8.19	0	-576.87
OM*TOY	12	1180.22	8.99	0	-577.28
DBT* TOY	16	1180.28	9.05	0	-572.66
DO	6	1232.5	61.27	0	-610.03
Null	5	1236.09	64.86	0	-612.89
PC	6	1237.94	66.71	0	-612.75
OM	6	1238.21	66.98	0	-612.89
DBT	7	1240.05	68.82	0	-612.73
DBT: DO: PC: OM: TOY	17	1246.78	75.55	0	-604.71

APPENDIX E: LAMBDA AND DETECTION PROBABILITY TABLES OF VALUES AND CONFIDENCE INTERVALS

Table 10. The lambda estimates with 95% confidence intervals for Wakulla River. For example, row one shows the lambda, lower confidence level, upper confidence level, and the habitat parameter corresponding to that estimate. For bottom type, B=bare/algal, E=emergent vegetation and S=submerged vegetation. For season, A=spring, B=summer, C=fall, D=winter. DO=dissolved oxygen.

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
2.34	1.45	3.75	S	A	4.45	100.0	3.44
2.96	1.85	4.72	B	A	4.10	50.0	0.80
2.43	1.52	3.88	S	A	4.80	88.0	3.44
3.16	2.00	5.01	B	A	4.71	30.0	0.80
2.43	1.52	3.90	S	A	4.79	100.0	3.44
2.42	1.50	3.88	S	A	4.84	63.0	34.92
2.50	1.56	4.01	S	A	5.02	100.0	3.44
3.36	2.10	5.37	B	A	5.15	44.0	0.80
2.53	1.56	4.09	S	A	5.18	62.5	3.44
2.77	1.65	4.61	S	A	5.88	75.0	34.92
2.64	1.62	4.28	S	A	5.46	87.5	3.44
3.56	2.12	5.94	B	A	5.71	0.0	0.80
2.70	1.65	4.41	S	A	5.63	94.0	3.44
2.76	1.64	4.59	S	A	5.85	69.0	3.44
3.09	1.94	4.91	B	A	4.58	0.0	0.80
2.90	1.82	4.61	B	A	4.08	0.0	0.80
2.56	1.53	4.24	B	A	3.05	0.0	0.80
3.26	2.04	5.19	B	A	4.97	18.5	0.80
3.33	2.06	5.35	B	A	5.15	12.5	0.80
3.34	2.06	5.39	B	A	5.19	6.0	0.80
2.45	1.43	4.17	B	A	2.69	0.0	0.80
2.02	1.18	3.42	S	A	3.26	100.0	18.64
2.09	1.25	3.47	S	A	3.54	100.0	18.64
3.18	2.00	5.04	B	A	4.77	19.0	0.80
2.48	1.55	3.96	S	A	4.94	100.0	18.64
4.91	2.98	8.06	E	A	4.84	56.0	3.87
2.65	1.62	4.33	B	A	3.34	6.0	0.80
2.78	1.72	4.49	B	A	3.66	31.0	0.80
2.00	1.16	3.41	S	A	3.16	100.0	18.64
2.09	1.25	3.47	S	A	3.55	100.0	18.64
4.80	2.91	7.89	E	A	4.56	94.0	3.87
5.41	3.26	8.94	E	A	5.57	75.0	3.87
2.90	1.82	4.61	B	A	4.08	0.0	0.80
4.72	2.85	7.80	E	A	4.41	100.0	3.87

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
4.85	2.94	7.97	E	A	4.63	100.0	4.38
5.24	3.18	8.60	E	A	5.32	75.0	3.87
2.86	1.66	4.87	S	A	6.15	62.5	18.64
3.82	2.17	6.63	B	A	6.24	0.0	0.80
2.66	1.63	4.32	S	A	5.53	87.5	18.64
3.55	2.11	5.89	B	A	5.67	0.0	0.80
3.81	2.16	6.62	B	A	6.23	0.0	0.80
3.50	2.15	5.66	B	A	5.48	38.0	0.80
9.20	6.05	13.97	B	B	4.20	12.5	22.05
10.23	6.54	15.95	B	B	4.94	56.3	22.05
9.75	6.25	15.13	B	B	4.68	0.0	22.05
9.74	6.34	14.93	B	B	4.59	37.5	22.05
6.92	4.20	11.36	S	B	4.05	100.0	16.92
8.99	5.92	13.66	B	B	4.05	0.0	22.05
9.33	6.12	14.21	B	B	4.22	50.0	22.05
8.97	5.92	13.60	B	B	3.94	37.5	22.05
7.15	4.35	11.71	S	B	4.37	75.0	16.92
14.03	9.03	21.75	E	B	4.17	50.0	19.82
9.02	5.96	13.64	B	B	4.01	25.0	22.05
9.00	5.92	13.68	B	B	4.06	0.0	22.05
6.40	3.82	10.66	S	B	3.41	100.0	16.92
6.30	3.79	10.44	S	B	3.36	75.0	16.92
7.66	4.88	11.97	B	B	2.76	0.0	22.05
8.03	5.23	12.33	B	B	3.15	0.0	22.05
8.12	5.31	12.42	B	B	3.24	0.0	22.05
8.17	5.35	12.48	B	B	3.29	0.0	22.05
8.21	5.38	12.52	B	B	3.32	0.0	22.05
8.29	5.45	12.62	B	B	3.39	6.2	22.05
7.43	4.65	11.80	B	B	2.51	0.0	22.05
7.40	4.54	11.95	B	B	2.40	25.0	22.05
7.64	4.87	11.96	B	B	2.74	0.0	22.05
14.28	9.24	22.05	E	B	4.22	87.5	19.82
9.05	5.95	13.76	B	B	4.10	0.0	22.05
14.34	9.24	22.19	E	B	4.21	100.0	8.77
6.90	4.08	11.53	B	B	1.89	0.0	22.05
7.81	5.03	12.10	B	B	2.92	0.0	22.05
7.85	5.06	12.14	B	B	2.96	0.0	22.05
8.07	5.27	12.37	B	B	3.19	0.0	22.05

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
14.97	9.58	23.29	E	B	4.68	50.0	19.95
14.70	9.53	22.64	E	B	4.48	75.0	19.95
9.54	6.17	14.69	B	B	4.51	0.0	22.05
15.39	9.87	23.95	E	B	4.73	125.0	19.95
18.87	11.14	31.60	E	B	6.36	106.3	8.77
17.14	10.73	27.25	E	B	5.61	112.5	19.95
18.48	10.63	31.57	E	B	6.30	56.3	19.82
17.55	10.42	29.15	E	B	5.92	50.0	19.82
9.89	6.40	15.24	B	B	4.66	56.3	22.05
14.30	9.21	22.16	E	B	4.32	50.0	19.95
15.22	9.83	23.52	E	B	4.68	106.3	19.82
9.70	6.31	14.89	B	B	4.59	25.0	22.05
9.88	6.29	15.42	B	B	4.79	0.0	22.05
9.02	5.93	13.70	B	B	4.07	0.0	22.05
9.75	6.25	15.13	B	B	4.68	0.0	22.05
14.17	9.17	21.87	E	B	4.19	75.0	19.82
14.17	9.10	22.00	E	B	4.25	50.0	28.77
9.37	6.10	14.35	B	B	4.37	0.0	22.05
9.98	6.32	15.65	B	B	4.87	0.0	22.05
10.45	6.61	16.44	B	B	5.12	50.0	22.05
13.07	7.88	21.42	B	C	6.28	50.0	18.98
9.98	5.76	17.03	S	C	6.43	75.0	58.00
13.27	7.55	22.79	B	C	6.49	0.0	18.98
10.07	5.77	17.29	S	C	6.50	75.0	58.00
8.61	5.47	13.52	S	C	5.21	100.0	58.00
11.20	7.24	17.22	B	C	5.17	0.0	18.98
8.77	5.48	13.97	S	C	5.42	75.0	58.00
17.41	10.92	27.58	E	C	5.27	50.0	23.70
8.77	5.39	14.14	S	C	5.45	50.0	27.14
12.36	7.69	19.67	B	C	5.88	31.3	18.98
12.07	7.61	19.00	B	C	5.71	25.0	18.98
11.98	7.43	19.11	B	C	5.70	0.0	18.98
8.70	5.51	13.71	S	C	5.30	100.0	58.00
8.62	5.48	13.54	S	C	5.22	100.0	58.00
9.94	6.66	14.85	B	C	4.21	0.0	18.98
9.17	6.02	13.92	B	C	3.47	25.0	18.98
9.19	6.07	13.88	B	C	3.56	0.0	18.98
15.78	9.99	24.77	E	C	4.35	100.0	58.90

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
9.96	6.68	14.85	B	C	4.21	6.2	18.98
8.73	5.58	13.59	B	C	3.06	25.0	18.98
6.72	4.09	10.98	S	C	3.22	75.0	58.00
6.94	4.24	11.28	S	C	3.42	100.0	58.00
10.29	6.90	15.34	B	C	4.36	50.0	18.98
8.93	5.45	14.51	S	C	5.60	56.3	58.00
12.05	7.57	19.02	B	C	5.71	18.8	18.98
6.25	3.58	10.71	S	C	2.62	50.0	5.17
10.61	7.10	15.83	B	C	4.61	50.0	18.98
9.34	6.21	14.05	B	C	3.70	0.0	18.98
9.88	6.62	14.76	B	C	4.16	0.0	18.98
15.40	9.88	23.93	E	C	4.20	75.0	7.74
16.17	10.35	25.16	E	C	4.66	50.0	7.74
15.35	9.85	23.87	E	C	4.19	68.8	1.96
9.90	6.65	14.73	B	C	4.11	25.0	18.98
16.34	10.53	25.28	E	C	4.62	100.0	7.74
17.12	10.96	26.64	E	C	5.08	75.0	23.70
15.82	10.16	24.56	E	C	4.38	93.8	23.70
10.27	6.91	15.27	B	C	4.41	25.0	18.98
10.45	7.01	15.59	B	C	4.49	50.0	18.98
10.72	7.14	16.06	B	C	4.78	18.8	18.98
10.99	7.28	16.56	B	C	4.97	25.0	18.98
9.92	6.59	14.91	B	C	4.04	56.3	18.98
9.56	6.30	14.46	B	C	3.75	50.0	18.98
10.00	6.71	14.89	B	C	4.16	37.5	18.98
9.61	6.43	14.35	B	C	3.88	18.8	18.98
9.67	6.45	14.49	B	C	3.88	37.5	18.98
9.95	6.69	14.79	B	C	4.15	25.0	18.98
10.04	6.72	15.00	B	C	4.29	0.0	18.98
10.22	6.82	15.29	B	C	4.43	0.0	18.98
3.84	2.41	6.07	B	D	6.91	0.0	34.63
3.55	2.31	5.44	B	D	6.23	38.0	34.63
2.82	1.73	4.55	S	D	6.67	50.0	13.22
3.71	2.40	5.73	B	D	6.59	31.3	34.63
2.56	1.59	4.13	S	D	5.82	100.0	13.22
3.34	2.17	5.13	B	D	5.82	6.2	34.63
2.57	1.60	4.10	S	D	5.96	50.0	13.22
3.36	2.18	5.16	B	D	5.89	0.0	34.63

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
2.48	1.54	3.99	S	D	5.63	75.0	13.22
2.79	1.73	4.49	S	D	6.61	50.0	31.92
3.46	2.26	5.30	B	D	6.07	25.0	34.63
3.30	2.14	5.09	B	D	5.76	0.0	34.63
2.44	1.48	3.99	S	D	5.41	100.0	13.22
2.41	1.45	3.97	S	D	5.31	100.0	13.22
3.70	2.36	5.76	B	D	6.63	0.0	34.63
2.86	1.72	4.71	B	D	4.59	0.0	34.63
3.46	2.25	5.31	B	D	6.11	0.0	34.63
3.81	2.40	6.00	B	D	6.85	0.0	34.63
3.80	2.40	5.99	B	D	6.84	0.0	34.63
3.86	2.43	6.10	B	D	6.94	6.2	34.63
2.38	1.15	4.71	B	D	3.03	0.0	34.63
2.27	1.36	3.77	S	D	5.00	50.0	17.34
3.12	1.96	4.93	B	D	5.22	31.3	34.63
2.69	1.68	4.29	S	D	6.20	100.0	17.34
3.15	1.87	5.25	S	D	7.41	100.0	17.34
5.67	3.62	8.88	E	D	6.55	75.0	4.92
2.77	1.58	4.76	B	D	4.23	25.0	34.63
3.00	1.86	4.80	B	D	4.97	6.2	34.63
2.06	1.14	3.67	S	D	4.19	50.0	17.34
2.27	1.31	3.87	S	D	4.82	100.0	17.34
5.56	3.54	8.73	E	D	6.40	75.0	10.73
6.02	3.82	9.47	E	D	7.02	75.0	10.73
5.43	3.42	8.57	E	D	6.26	50.0	9.38
5.29	3.27	8.50	E	D	5.93	100.0	10.73
3.61	2.34	5.55	B	D	6.33	50.0	34.63
5.95	3.79	9.33	E	D	6.87	100.0	9.38
5.75	3.64	9.07	E	D	6.72	50.0	9.38
5.30	3.33	8.42	E	D	6.08	50.0	9.38
3.98	2.46	6.38	B	D	7.16	6.2	34.63
6.07	3.83	9.58	E	D	7.08	75.0	21.87
6.61	4.03	10.77	E	D	7.73	75.0	10.73
4.30	2.54	7.19	B	D	7.71	25.0	34.63
3.79	2.44	5.87	B	D	6.70	50.0	34.63
3.51	2.28	5.40	B	D	6.23	0.0	34.63
3.83	2.41	6.05	B	D	6.89	0.0	34.63
5.64	3.57	8.88	E	D	6.56	50.0	9.38

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
3.83	2.41	6.05	B	D	6.89	0.0	34.63
3.90	2.43	6.21	B	D	7.02	0.0	34.63
3.92	2.43	6.27	B	D	7.07	0.0	34.63
3.96	2.44	6.38	B	D	7.15	0.0	34.63

Table 11. The detection probability estimates with 95% confidence intervals for Wakulla River. For example, row one shows detection probability, lower confidence level, upper confidence level, and the parameter corresponding to that estimate.

Detection probability	Lower Confidence Level	Upper Confidence Level	Moon Illumination	Depth
0.24	0.17	0.34	3.09	0.52
0.22	0.15	0.31	7.37	0.52
0.21	0.14	0.30	11.65	0.52
0.25	0.18	0.35	3.09	0.70
0.23	0.16	0.32	7.37	0.70
0.22	0.15	0.31	11.65	0.70
0.26	0.18	0.36	3.09	0.88
0.24	0.17	0.34	7.37	0.88
0.23	0.16	0.32	11.65	0.88

Table 12. The lambda estimates with 95% confidence intervals for Silver River. For example, row one shows the lambda, lower confidence level, upper confidence level, and the habitat parameter corresponding to that estimate. For bottom type, B=bare/algal, E=emergent vegetation and S=submerged vegetation. For season, A=spring, B=summer, C=fall, D=winter. DO=dissolved oxygen.

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
10.24	2.64	39.53	E	A	4.01	179.9	32.97
9.52	2.48	36.47	S	A	4.01	100.0	39.85
9.44	2.47	36.14	E	A	4.01	93.7	32.97
9.57	2.48	36.81	S	A	4.03	100.0	16.03
9.73	2.54	37.24	S	A	4.31	118.7	34.01
10.22	2.63	39.46	S	A	3.98	174.9	34.01
9.61	2.50	36.95	S	A	4.36	100.0	16.03
9.57	2.48	36.80	S	A	4.00	100.0	16.03
9.98	2.59	38.29	S	A	4.10	150.0	39.85
9.54	2.49	36.53	S	A	4.16	100.0	39.85
9.56	2.48	36.80	S	A	3.99	100.0	16.03
9.80	2.55	37.64	S	A	4.08	125.0	16.03
10.04	2.60	38.66	S	A	4.17	150.0	16.03
9.71	2.54	37.13	E	A	4.00	125.0	32.97
10.69	2.70	41.86	S	A	5.13	199.9	16.03
9.59	2.49	36.86	S	A	4.16	100.0	16.03
10.28	2.64	39.83	S	A	4.15	174.9	16.03
9.52	2.49	36.38	E	A	4.18	100.0	32.97
10.02	2.61	38.45	S	A	4.32	150.0	34.01
9.59	2.50	36.72	S	A	4.47	100.0	34.01
9.51	2.49	36.34	E	A	4.26	100.0	41.53
9.86	2.56	37.85	S	A	4.54	125.0	16.03
9.66	2.51	37.14	S	A	4.72	100.0	16.03
11.41	2.72	46.42	E	A	4.78	274.9	41.53
9.71	2.52	37.38	S	A	5.07	100.0	16.03
9.86	2.58	37.72	E	A	5.07	125.0	32.97
9.47	2.45	36.47	S	A	5.11	75.0	34.01
9.45	2.45	36.34	E	A	5.21	75.0	32.97
9.68	2.51	37.22	S	A	4.85	100.0	16.03
9.55	2.46	36.99	S	A	5.41	75.0	16.03
9.70	2.52	37.26	E	A	5.50	100.0	32.97
9.58	2.49	36.85	S	A	4.13	100.0	16.03
9.57	2.46	37.13	S	A	5.83	75.0	34.01
8.78	2.16	35.11	B	A	5.95	0.0	57.69

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
9.71	2.52	37.31	E	A	5.55	100.0	32.97
9.81	2.53	37.98	S	A	5.73	100.0	16.03
11.05	2.73	43.97	S	A	5.86	224.9	34.01
9.60	2.46	37.40	S	A	6.07	75.0	34.01
9.83	2.51	38.35	B	A	6.28	125.0	57.69
10.05	2.56	39.29	B	A	6.18	150.0	57.69
11.36	2.74	46.01	S	A	5.99	249.9	34.01
9.66	2.50	37.22	E	A	5.72	93.7	41.53
8.89	2.25	34.93	B	A	5.46	25.0	57.69
9.05	2.32	35.18	B	A	5.27	50.0	57.69
9.92	2.58	38.12	E	A	5.60	125.0	41.53
9.67	2.52	37.13	E	A	5.44	100.0	41.53
11.18	2.73	44.77	S	A	4.91	249.9	34.01
8.91	2.29	34.55	B	A	4.17	50.0	57.69
9.61	2.49	36.98	E	A	3.21	125.0	32.97
8.78	2.23	34.34	B	A	4.59	25.0	57.69
11.70	3.13	43.59	B	B	3.83	25.0	27.55
11.64	3.11	43.46	B	B	4.29	12.5	27.55
12.13	3.27	44.89	B	B	4.33	56.2	27.55
11.78	3.16	43.83	B	B	4.35	25.0	27.55
13.83	3.58	52.63	S	B	4.13	168.7	24.61
13.68	3.57	51.70	E	B	4.62	162.4	58.75
12.06	3.26	44.68	B	B	4.38	50.0	27.55
13.17	3.51	49.12	S	B	4.26	125.0	46.25
13.41	3.54	50.35	S	B	4.25	137.5	24.61
12.34	3.33	45.67	B	B	4.31	75.0	27.55
12.80	3.43	47.63	S	B	4.35	100.0	67.37
13.25	3.52	49.56	S	B	4.32	125.0	24.61
12.06	3.25	44.65	B	B	4.33	50.0	27.55
13.52	3.55	50.97	E	B	3.91	156.2	36.40
14.02	3.62	53.56	S	B	4.65	174.9	24.61
12.84	3.44	47.78	S	B	4.56	100.0	67.37
12.40	3.35	45.91	B	B	4.22	81.2	27.55
11.82	3.17	43.96	B	B	4.56	25.0	27.55
11.85	3.08	45.35	E	B	1.88	50.0	36.40
12.54	3.37	46.50	S	B	4.71	68.7	46.25
11.84	3.18	44.05	B	B	4.69	25.0	27.55
13.27	3.51	49.78	S	B	5.11	125.0	67.37

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
12.71	3.41	47.29	S	B	4.87	75.0	24.61
12.37	3.32	45.94	E	B	5.06	50.0	36.40
11.52	3.06	43.20	B	B	4.36	0.0	27.55
12.94	3.47	48.14	E	B	5.22	100.0	58.75
12.23	3.28	45.48	B	B	5.32	50.0	27.55
13.68	3.56	51.91	S	B	5.42	150.0	67.37
12.23	3.26	45.77	E	B	5.33	31.2	27.55
12.68	3.38	47.38	S	B	5.39	75.0	67.37
12.55	3.37	46.74	B	B	5.49	75.0	27.55
13.04	3.47	48.70	B	B	4.67	125.0	27.55
11.99	3.19	44.89	B	B	5.55	25.0	27.55
11.70	3.09	44.12	B	B	5.45	0.0	27.55
12.46	3.33	46.46	E	B	5.53	50.0	36.40
12.83	3.43	47.76	S	B	4.53	100.0	67.37
13.10	3.49	48.97	S	B	5.28	100.0	24.61
13.00	3.46	48.66	S	B	5.41	100.0	67.37
13.08	3.49	48.90	S	B	5.53	100.0	46.25
11.99	3.19	44.92	B	B	5.58	25.0	27.55
12.35	3.31	45.98	E	B	5.31	50.0	58.75
12.04	3.23	44.78	B	B	5.08	37.5	27.55
12.59	3.37	46.83	S	B	4.88	75.0	67.37
11.95	3.19	44.63	B	B	5.32	25.0	27.55
12.74	3.38	47.77	S	B	5.69	75.0	67.37
12.21	3.29	45.26	E	B	4.53	50.0	58.75
12.84	3.44	47.78	S	B	4.56	100.0	67.37
11.62	3.10	43.41	B	B	4.19	12.5	27.55
12.50	3.37	46.33	E	B	4.97	62.5	36.40
12.39	3.30	46.39	S	B	5.41	50.0	67.37
4.57	1.19	17.44	S	C	4.05	162.4	15.39
4.31	1.15	16.21	S	C	4.47	100.0	17.26
4.32	1.15	16.24	S	C	4.52	100.0	15.39
3.98	1.05	15.12	B	C	4.54	50.0	65.56
4.83	1.22	18.81	S	C	4.94	199.9	18.13
4.39	1.17	16.46	E	C	4.50	125.0	36.15
4.33	1.15	16.31	S	C	4.73	100.0	15.39
3.99	1.05	15.14	B	C	4.60	50.0	65.56
4.34	1.15	16.36	S	C	4.87	100.0	15.39
4.33	1.15	16.31	S	C	4.74	100.0	15.39

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
4.32	1.15	16.26	S	C	4.62	100.0	17.26
4.36	1.16	16.40	S	C	4.73	106.2	17.26
4.27	1.13	16.06	S	C	4.68	87.5	20.01
4.29	1.14	16.05	E	C	4.59	100.0	33.35
4.32	1.15	16.27	S	C	4.65	100.0	17.26
4.33	1.15	16.31	S	C	4.79	100.0	17.26
4.47	1.18	16.89	S	C	4.76	131.2	17.26
4.01	1.05	15.24	B	C	4.89	50.0	65.56
4.54	1.19	17.19	E	C	4.96	150.0	33.35
4.36	1.15	16.46	S	C	5.17	100.0	18.13
4.31	1.15	16.18	E	C	5.00	100.0	36.15
4.21	1.11	16.02	S	C	5.31	62.5	17.26
4.52	1.18	17.22	S	C	5.53	131.2	20.01
4.43	1.17	16.76	E	C	5.49	118.7	33.35
3.92	1.02	15.02	B	C	4.88	25.0	65.56
4.27	1.14	15.99	E	C	4.36	100.0	33.35
4.27	1.14	15.98	E	C	4.72	93.7	36.15
4.42	1.17	16.62	E	C	4.60	131.2	36.15
4.24	1.13	15.87	E	C	4.65	87.5	36.15
4.33	1.15	16.31	S	C	4.79	100.0	17.26
4.48	1.18	16.94	S	C	4.91	131.2	18.13
4.05	1.07	15.29	E	C	4.03	50.0	33.35
4.00	1.04	15.27	B	C	5.14	43.7	65.56
4.17	1.09	15.88	S	C	5.32	50.0	18.13
3.95	1.02	15.21	B	C	5.36	25.0	65.56
4.28	1.14	16.12	S	C	4.03	100.0	17.26
4.56	1.19	17.37	E	C	3.95	168.7	33.35
4.48	1.18	16.93	E	C	4.19	150.0	36.15
3.99	1.05	15.13	B	C	4.31	56.2	65.56
4.19	1.11	15.77	S	C	4.17	75.0	20.01
3.80	0.97	14.76	B	C	4.47	0.0	65.56
4.06	1.08	15.32	E	C	4.23	50.0	36.15
4.18	1.11	15.76	S	C	4.00	75.0	17.26
3.96	1.04	15.02	B	C	4.08	50.0	65.56
4.31	1.15	16.22	S	C	4.49	100.0	17.26
4.27	1.13	16.08	S	C	4.51	100.0	59.02
4.41	1.17	16.62	S	C	4.27	125.0	17.26
4.39	1.16	16.56	S	C	4.02	125.0	17.26

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
4.25	1.13	15.89	E	C	4.33	93.7	33.35
4.22	1.12	15.93	S	C	3.71	100.0	59.02
2.82	0.72	10.96	E	D	5.15	125.0	32.92
2.79	0.71	10.90	S	D	5.32	106.2	19.27
2.80	0.72	10.91	S	D	5.30	118.7	56.16
2.77	0.71	10.76	S	D	5.39	100.0	35.92
2.73	0.70	10.63	E	D	5.99	81.2	32.92
2.76	0.71	10.70	E	D	5.37	100.0	32.92
2.69	0.68	10.61	S	D	6.57	50.0	35.92
2.68	0.68	10.56	S	D	6.03	50.0	19.27
2.92	0.74	11.49	S	D	6.16	150.0	56.16
2.77	0.71	10.79	S	D	5.86	100.0	56.16
2.77	0.71	10.78	S	D	5.51	100.0	35.92
2.97	0.75	11.69	E	D	5.66	168.7	32.92
2.85	0.73	11.12	E	D	5.70	125.0	17.58
2.84	0.73	11.03	E	D	5.68	125.0	32.92
2.63	0.67	10.30	B	D	5.77	68.7	65.18
2.72	0.70	10.63	S	D	5.95	75.0	35.92
2.81	0.72	10.89	E	D	5.90	112.5	44.10
2.82	0.72	11.03	S	D	6.08	106.2	19.27
2.79	0.71	10.88	S	D	6.26	100.0	56.16
2.65	0.67	10.44	B	D	6.45	68.7	65.18
2.63	0.66	10.38	B	D	6.55	56.2	65.18
2.72	0.68	10.80	B	D	7.25	81.2	65.18
2.82	0.72	11.10	S	D	6.87	100.0	35.92
2.96	0.73	11.79	E	D	4.35	181.2	32.92
2.91	0.74	11.44	S	D	4.96	156.2	35.92
2.91	0.74	11.38	E	D	5.64	150.0	32.92
2.50	0.62	9.96	B	D	4.95	25.0	65.18
2.76	0.71	10.80	S	D	4.95	100.0	19.27
2.74	0.71	10.64	E	D	5.76	87.5	32.92
2.70	0.69	10.53	S	D	5.28	75.0	35.92
2.83	0.72	11.06	S	D	4.76	131.2	35.92
2.81	0.72	10.96	S	D	5.19	112.5	19.27
2.70	0.69	10.56	B	D	5.09	106.2	65.18
2.45	0.60	9.90	B	D	5.16	0.0	65.18
2.66	0.68	10.38	E	D	5.80	56.2	44.10
2.81	0.72	11.01	S	D	6.59	100.0	35.92

Lambda	Lower Confidence Level	Upper Confidence Level	Bottom Type	Season	DO	Percent Cover	Organic Matter
2.98	0.75	11.75	E	D	6.40	162.4	32.92
2.80	0.71	11.00	S	D	6.69	100.0	56.12
2.84	0.72	11.23	S	D	7.00	100.0	19.27
2.84	0.72	11.22	S	D	6.99	100.0	19.27
2.80	0.72	10.94	E	D	6.67	100.0	44.10
2.61	0.66	10.32	B	D	6.47	50.0	65.18
2.76	0.70	10.84	S	D	6.51	75.0	19.27
2.78	0.71	10.79	E	D	6.18	100.0	52.91
2.95	0.74	11.62	E	D	6.77	150.0	44.10
2.85	0.73	11.08	E	D	6.08	125.0	44.10
2.80	0.72	10.95	S	D	5.16	112.5	19.27
2.74	0.70	10.70	S	D	4.50	100.0	35.92
2.66	0.67	10.43	S	D	4.36	75.0	56.12
2.80	0.72	10.90	S	D	6.19	100.0	35.92

Table 13. The detection probability estimates with 95% confidence intervals for Silver River. For example, row one shows detection probability, lower confidence level, upper confidence level, and the parameter corresponding to that estimate.

Detection Probability	Lower Confidence Level	Upper Confidence Level	Trap Day
0.02	0.01	0.08	2
0.03	0.01	0.13	4
0.07	0.02	0.23	6
0.07	0.02	0.22	8

APPENDIX F: PARAMETER ESTIMATES

This appendix provides the estimates of the model-averaged parameters and their confidence intervals.

Table 14. Model-averaged parameter estimates. Estimates and confidence intervals are not back-transformed. The highlighted parameters have confidence intervals that do not overlap zero.

River	Parameter	Estimate	Confidence Interval
Wakulla	Dissolved Oxygen	0.19	0.04-0.33
	Dominant bottom type -Emergent	0.42	0.15-0.69
	Dominant bottom type-Submerged	-0.30	-0.65-0.06
	Season- Summer	0.22	0.71-1.57
	Season -Fall	1.22	0.84-1.59
	Season - Winter	-0.08	-0.59-0.43
	Intercept (reference – includes Season-Spring and Dominant Bottom Type-Bare)	1.18	0.72-1.65
Silver	Percent Cover	0.10	-0.50 – 0.25
	Season - Summer	0.30	-0.80, 0.67
	Season – Fall	-0.80	-1.29, -0.32
	Season - Winter	-1.26	-1.84, -0.67
	Intercept (reference – includes Season-Spring)	2.24	0.90-3.59

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