A PREDICTIVE HABITAT OCCUPANCY MODEL FOR NORTH AMERICAN RIVER OTTER (*Lontra canadensis*) ALONG LOW ORDER STREAMS IN INLAND NEW JERSEY

by

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ABSTRACT

The North American river otter (*Lontra canadensis*) is a semi-aquatic furbearer species that historically ranged throughout North America. Starting in the mid-1800s and continuing through the early 1900s, the negative effects associated with anthropogenic disturbances (i.e. overharvest, development and ultimately habitat alternation) led to local extinctions. Researchers debate whether current land use patterns are affecting river otter occupancy. New Jersey is the most densely populated state in the United States, thus it provides a perfect study area to test potential anthropogenic effects on river otters. Using occupancy modeling to examine river otter habitat preferences, I measured presence/absence at 244 low order stream sites from January-April 2011–2012 along with 19 corresponding site/landscape covariates in both Northern and Southern New Jersey. In Southern New Jersey, I detected otters at 83/141 sites (58.9%) with a detection probability of 97.7% across repeat visits and a predicted occupancy of 59.4 ± 0.04%. In Northern New Jersey I detected otters at 31/103 sites (30.1%) with a detection probability of 44.5% across repeat visits and a predicted occupancy of 58.8 ± 0.04%. I used program PRESENCE to construct 50 occupancy models per region. The top model for both regions shared 3 covariates including water depth, water quality, and % Low Intensity Development. The Southern model also included % Commercial/Industrial/Transportation/Recreational (CITR), distance to lake and bank slope while the Northern model included stream width and mink presence. I determined the influence of each covariate on otter occupancy for both models and found that water

depth, water quality, stream width and mink presence were positively correlated with otter occupancy. While %CITR, %Low Intensity Development, bank slope, and distance to lake were negatively correlated with otter occupancy. Thus, I would suggest constructing lakes and ponds and protecting wider and deeper streams in order to maintain river otter populations.

Chapter 1

INTRODUCTION

Historically, North American river otters (*Lontra canadensis*) were found throughout the majority of North America (Crimmins et al. 2009). However, their population experienced local extinctions around the mid-1800s and early 1900s due to anthropogenic disturbances such as overharvest, pollution, and urbanization (Herrighty 1978, Latch et al. 2008). Declines continued until the late 1970s at which river otters occupied less than 75% of their historic range (Crimmins et al. 2009). As a result, there have been increased efforts to develop river otter monitoring and reintroduction programs. Since 1976, twenty-one states and one Canadian province have implemented reintroduction projects (Gallant et al. 2009).

Specifically in the state of New Jersey, reports show that river otters have been trapped since the mid 1930s, either as a means of determining population size and/or for sport (Herrighty 1978). River otters are currently listed as a game species and are harvested from late December to early January. Thus wildlife officials in New Jersey want to ensure that river otter populations are maintained throughout the state. As part of New Jersey's river otter monitoring efforts, the state wants to 1) identify and map areas of river otter habitat and 2) determine which variables, such as water quality and specific habitat characteristics, correlate with river otter occurrence (New Jersey Department of Environmental Protection-Division of Fish and Wildlife 2008).

River otters are semi-aquatic, spending most of their time in or near both freshwater (wetlands, rivers, and lakes) and/or coastal marine environments (Cote et al. 2008). However, they have been known to travel long distances over land (Melquist and Hornecker 1983). River otter home ranges are expressed linearly (km of waterway) and estimates include 12.9–19.3 km (Wilson 1959), 24.1 km (Burt and Grossenheider 1976), 8–78 km (Melquist and Hornecker 1983), and ≤ 96.6 km (Liers 1951). Many habitat parameters have been associated with the presence of river otters. Herrighty (1978) described 4 crucial habitat parameters including 1) the amount of water and the density of streams, lakes, ponds, and coastlines, 2) the availability of fish and invertebrates, 3) human population density, and 4) water quality. Melquist and Hornecker (1983) hypothesized that the variability associated with otter home range size was influenced by prey availability, habitat, weather conditions, topography, the reproductive cycle, and conspecifics. Additionally, Gallant et al. (2009) identified access to prey and availability of potential shelter as the two most important river otter habitat characteristics.

The effects of anthropogenic development on river otter occurrence have been the subject of debate. Given the secretive nature of river otters, it has been suggested that they may avoid areas of high human density, choosing instead to inhabit undeveloped areas (Herrighty 1978). Melquist and Hornocker (1983) found that river otters in Idaho preferred sites with lower levels of human development but would still inhabit disturbed sites as long as they could locate adequate food and shelter. Further, Barbosa et al. (2001) found that environmental factors (e.g. mean annual temperature, annual days of precipitation, altitude range and mean woodland area) had a greater influence than anthropogenic factors on the presence of Eurasian otters (*Lutra lutra*) in Spain. Gallant et al. (2009) also suggested that habitat features were more important than anthropogenic disturbances when attempting to explain the occurrence of river otters in Canada. Thus, although human density or development has the potential to negatively impact otter populations, the effect may vary at a regional scale or with habitat quality. Specifically, it is unclear how river otter presence could be affected in areas of high human density, such as the state of New Jersey, which is the most densely populated state in the United States (462 inhabitants/km^2, US Census, 2010). Between 1995 and 2002 agricultural land decreased by 8.5% and developed land increased by 7.9% (NJDEP 2007), furthering the potential effect of human disturbance on river otter presence and habitat use in New Jersey.

My objectives were to 1) determine which habitat variables, including anthropogenic land uses, affect river otter presence during winter and spring using occupancy modeling and 2) develop a detailed predictive habitat model for river otter occupancy within the state of New Jersey to aid future monitoring and management.

Chapter 2

STUDY AREA

I conducted surveys for river otters at select stream sites in 5 physiographic regions of New Jersey including the Inner and Outer Coastal Plain, the Piedmont, the Highlands, and the Ridge and Valley (Figure 1). For the purpose of constructing both accurate and meaningful occupancy models, I split the state of New Jersey into two basic areas, Southern New Jersey and Northern New Jersey, based on similarities in the vegetation communities of the physiographic regions (Table 1) (Citizens United to Protect the Maurice River & Its Tributaries Inc. 2011). Southern New Jersey is comprised of the Inner and Outer Coastal Plain regions while Northern New Jersey is comprised of the Piedmont, Highlands and Ridge and Valley regions.

Southern New Jersey

The Coastal Plain physiographic region, which is composed of both the Inner and Outer Coastal Plain, is the largest region in New Jersey. It is approximately 12,087 km^2, representing 59.5% of the state's total area and is home to about 30% of the state's human population. The Coastal Plain is generally characterized by flat terrain and is comprised of southern mixed oak forests, upland pine forests, and marshland (Citizens United to Protect the Maurice River & Its Tributaries Inc. 2011, Dalton 2003, Collins and Anderson 1994).

Southern New Jersey habitat types are dominated by the 1) Pine Barrens, 2) Uplands, and 3) Freshwater Wetlands (Collins and Anderson 1994). The Pine Barrens of

Southern New Jersey is located on the Outer Coastal Plain and represents 30% of the entire state. The presence of mostly sandy, infertile soils within this area influences the plant communities that are able to survive in this habitat. These plant communities include, 1) Pine Dominated, with the common species being the Pitch Pine (*Pinus rigida*); 2) Pine Plains or Dwarf Pine, with the dominant plant species being Pitch Pine and Blackjack Oak (*Quercus marilandica*) and 3) Oak Dominated, with Black Oak (*Quercus velutina*) and Chestnut Oak (*Quercus prinus)* being the most common plant species (Collins and Anderson 1994).

The Southern New Jersey Uplands occur mainly in the Inner Coastal Plain with certain parts extending into the Northern and Southern sections of the Outer Coastal Plain. The majority of Southern New Jersey is either Wetlands or Pine Barrens and thus there is limited land in South Jersey that can be classified as mesic uplands. The four major plant community types within this habitat include 1) Mixed Oak Forest, with Black Oak and White Oak (*Quercus alba*) being the most common species; 2) Beech-Oak Forest, with American Beech (*Fagus grandifolia*) being very abundant; 3) Virginia Pine Successional Forest, which occurs mainly in the Inner Coastal Plain but also along some borders of the Pine Barrens; and 4) Sweet Gum Successional Forest, with Sweet Gum (*Liquidambar styraciflua*) being the dominate tree species (Collins and Anderson, 1994).

Southern New Jersey has very unique freshwater wetland habitats primarily due to the presence of numerous rivers that flow and meander through the flat terrain of this region. Unlike Northern New Jersey, Southern New Jersey has never been glaciated and as a result has few natural ponds or lakes and no true bogs. The major vegetation communities within this habitat include 1) Freshwater Marshes, which are typically found along stream borders and mouths of rivers; 2) Swamps and Floodplains, which can be further broken down into Cedar Swamp Forests, Hardwood Swamp Forests and Pitch Pine Lowland Forests and 3) Peatlands, including Fens and Savannahs, which primarily occur in the Outer Coastal Plain (Collins and Anderson 1994).

Northern New Jersey

The "Piedmont" region is approximately 4,144 km^2, representing 20% of the state's total area and is home to about 60% of the state's human population. It is characterized by the presence of low rolling plains divided by a series of higher ridges and a northern mixed oak forest. The "Highland" region is approximately 2,538 km^2, representing 12% of the state's total area and is also home to about 5% of the state's human population. This region is characterized by the presence of discontinuous rounded ridges separated by deep narrow valleys and a northern mixed oak forest. The "Ridge and Valley" region is approximately 1,388 km^2, representing 8.5% of the state's total area and is home to about 5% of state's the human population. It is characterized by the presence of steep sided linear ridges, broad valleys, and a northern mixed oak forest.

Northern New Jersey habitat types are dominated by the 1) Ridgetops, Steep Slopes and Rocky Outcroppings; 2) Uplands and 3) Freshwater Wetlands (Collins and Anderson 1994). The Ridgetops, Steep Slopes and Rocky Outcroppings habitat is typically associated with the Highlands, Valley and Ridge and some sections of the Piedmont. The three characteristic plant communities within this habitat type include 1) Chestnut-Oak Forests, which are found on slopes and ridgetops of higher elevations of

Northern New Jersey; 2) Pitch Pine-Scrub Oak Forests, which are located on the highest ridgetops of New Jersey and 3) Long Lasting Successional Types, which are found on rocky outcroppings. The Long Lasting Successional Type starts off with a lichen or moss stage and then transitions to either a Chestnut Oak or Pitch Pine-Scrub Oak Forest type (Collins and Anderson 1994).

The Northern New Jersey Uplands are comprised of three plant communities which include, 1) Mixed Oak Forests that are the most common community within this habitat type, 2) Hemlock-Mixed Hardwood Forests that are most abundant on cool/moist sites, and 3) Sugar Maple-Mixed Hardwood Forests that are the least common community within this habitat type. Successional plant communities can also be found in this area and their presence is typically attributed to human activity (Collins and Anderson 1994).

The Northern New Jersey Freshwater Wetlands can be broken down into 1) Freshwater Marshes, which tend to be found along edges of lakes and ponds, 2) Swamps and Floodplains that are generally associated with glaciated areas of North Jersey and thus are found in broad valleys of larger rivers such as the Raritan, Passaic, and Ramapo, and 3) Peatlands, including Bogs and Fens, that can be found in previously glaciated areas (Collins and Anderson 1994).

Table 1: Ecological communities found in each physiographic region, New Jersey, USA. Grayed habitats show presence in each physiographic regions and dark gray represent areas of overlap within either Southern New Jersey or Northern New Jersey.

		Southern New Jersey		Northern New Jersey		
Habitat type	Community	Inner Coastal Plain	Outer Coastal Plain	Pied-mont	Valley and Ridge	High-lands
Forests	Beech-Oak Forest					
	Southern Mixed Oak Forest					
	Upland Pine Forest					
	Red Maple-Sweet Gum Forest					
	Virginia Pine Successional Forest					
	Upland Oak Forest					
	Pine Plains					
	Pitch Pine Lowland Forest					
	Coastal Dune Forest					
	Chestnut Oak Forest					
	Northern Mixed Oak Forest					
	Hemlock-Mixed Hardwood Forest					
	Sugar Maple-Mixed Hardwood Forest					
	Ridgetop Pitch Pine-Scrub Oak Forest					
Early Succes-ional	Successional Communities					
	Pine Barrens Savannah					
	Coastal Dune Grassland					
	Coastal Dune Shrubland					
	Limestone Rock Outcrop					
	Limestone Glade					
	Talus Slope					
Wet	Coastal White Cedar Swamp					
	Freshwater Tidal Marsh					
	Hardwood Swamp					
	Emergent Marsh					
	Pine Barrens Shrub Swamp					
	Salt Marsh					
	Grass-Sedge Marsh					
	Shrub Swamp					
	Pond Shore					
	Glacial Bog					
	Inland White Cedar Swamp					
	Black Spruce Swamp					
	Limestone Fen					
	Limestone Pond Shore					

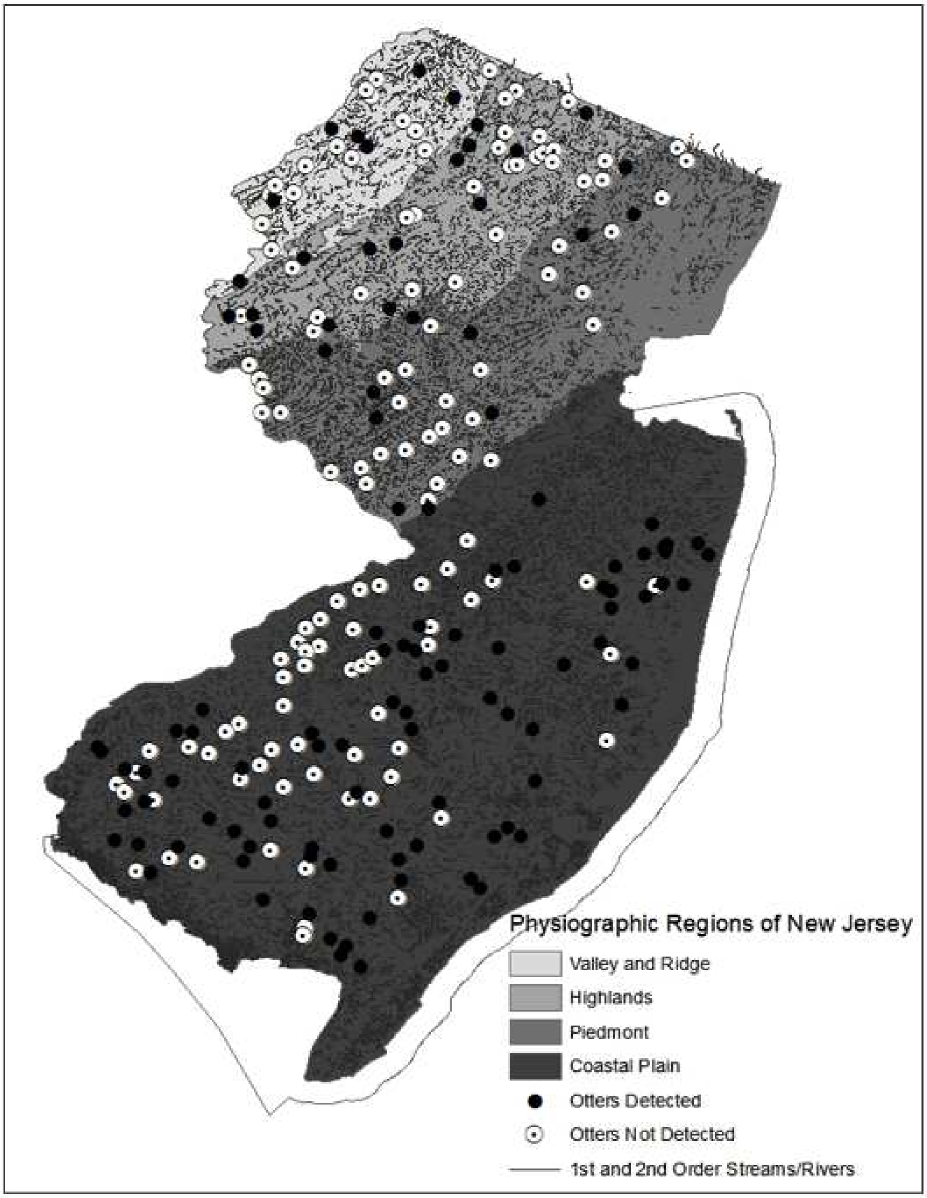


Figure 1: The four physiographic regions of New Jersey that were sampled for river otter occupancy, January-April 2010–2012.

Chapter 3

METHODS

Site Selection

Potential sites were restricted to lower order streams that could be waded and/or had accessible stream banks that could be surveyed by foot. Higher order streams that were known to be too wide and deep were excluded a priori due to the safety risks associated with surveying these larger waterways. Sites classified as either Ambient Biomonitoring Network (AMNET) sites or Index of Biotic Integrity (IBI)/Fish Index of Biotic Integrity (FIBI) sites were given first preference. The New Jersey Department of Environmental Protection has visited these sites to sample for the presence of benthic macro-invertebrates and fish species respectively in order to assess overall water quality and stream health. Not only is this a good indication that these streams were of adequate size and depth for my surveys but each AMNET and IBI/FIBI point also has corresponding water quality and habitat quality data, which I planned to use as covariates for my occupancy models. Additionally, I consulted otter harvest records from 2003-2010 and otter sighting information (both provided by the New Jersey Division and Fish and Wildlife) to identify general areas of otter activity. Finally, I identified random stream sites in close proximity to AMNET, FIBI or Otter Sighting/Harvest sites in order to approximate a stratified distribution of points throughout the state. Using this information, I placed survey points at the nearest road/bridge crossing of the stream (Roberts and Crimmins 2008, Crimmins et. al 2009). Positioning survey sites at road/bridge crossings primarily ensured that I would be surveying in an area where there would be some level of human traffic, which is a necessary component of my study. Additionally, bridges provided easier access to the stream sites for my team of surveyors. Not all AMNET, FIBI, or otter harvest/otter sighting points were on road/bridge crossings and as a result they had to be moved to the closest road/bridge crossing on that stream or tributary.

Prior to the start of sampling, I visited all potential sites to determine their usability (i.e. if the surveyors could wade the stream or walk the banks). From all usable stream sites, I sampled a total of 244 unique sites throughout the state over the course of this two-year study (124 sites in 2011 and 120 sites in 2012) (Figure 1, Chapter 3). Of these 244 sites, 147 were AMNET sites, 24 were IBI sites, 25 were FIBI sites, 42 were otter sighting or otter harvest sites and 6 were the random stream sites. Using ArcGIS I then determined whether the sites were a part of the Southern or Northern New Jersey sampling regions. Ultimately, 141 sites were located in Southern New Jersey, while 103 sites were located in Northern New Jersey.

Field Protocol

To sample the presence of otters, I conducted 6 repeat walking transect surveys 1 January - 30 April 2011 and 2012 every 14 ± 4 d at each survey site. The purpose of these 4 days of flexibility was twofold, 1) to allow for the potential of missing survey days due to inclement weather such as snow, ice, and heavy rain and 2) to provide the opportunity for surveyors to be proactive and survey certain sites in advance in anticipation of extended periods of inclement weather. Additionally, depending on the physical characteristics of the sites, surveys were not conducted ≤ 2 d after heavy rain or snow/ice storms to ensure the safety of surveyors and because scat and track signs could be washed away or hidden under snow. Due to extenuating circumstances such as extended periods of inclement weather, it was not always possible to adhere to the planned survey schedule. For example, in 2011 the surveys took a month longer than 2012 (4 January - 29 April 2011 versus 2 January – 28 March 2012). Repeated snowstorms, heavy rain, and subsequent flooding required temporary suspension of surveys at negatively impacted stream sites, which were primarily located in Northern New Jersey. Consequently the number of repeat visits varied amongst all 244 stream sites (Table 2).

I conducted 600 m long stream bank walking sign surveys, usually 300 m on each side of a bridge crossing (Roberts et al. 2008). If there were any impediments on a particular side of the crossing, such as a lake, extremely dense vegetation or deep water, I walked an additional distance on the other side in order to make up the difference. I took GPS coordinates at each site and recorded the start/end time for each stream survey. For each replicate visit I recorded the following weather related variables: 1) current, overnight, and previous day's temperature, 2) the presence or absence of precipitation (snow/ice/rain) during the survey, overnight, and the previous day and 3) the presence or absence of snow or ice cover at the sites at the time of the survey. Snow cover can both negatively and positively impact the ability of the surveyors to locate animal sign. Ice cover on the waterways makes wading impossible as well as poses a major safety risk. I also recorded average site-level habitat characteristics including water depth and bankfull height, which were taken at each replicate visit while stream width, bank height, and bank slope were only taken once per site.

While visiting each site, I made note of live otter sightings and the presence of otter tracks, scat, latrines, and slides. I also identified and recorded the substrate where that particular type of otter sign was found. GPS coordinates were taken for otter latrines and otter slides so that the New Jersey Fish and Wildlife Department could monitor these locations in the future. I also made note of beaver sign (including the presence of chewed trees, dams, and lodges and whether they were upstream or downstream of the bridge), mink sign, and muskrat sign for companion studies.

Water Quality Assessment of Sites

Water quality and habitat quality assessments were based on previously gathered and readily available AMNET (NJDEP 2011; NJDEP GIS 2013) and FIBI (NJDEP 2012*a*) data. Because not all survey points were AMNET or FIBI points, not all points had this background data that I could use. Thus I created the following guidelines to provide estimated water and habitat quality values for all survey points:

1) For those points that were AMNET or FIBI, I just used the corresponding water and habitat quality assessment scores/ratings for those sites.
2) For those points that were characterized as either Random or Otter Harvest/Otter Sighting, I first tried to find an equivalent AMNET or FIBI point, which would have provided the water and habitat quality scores/ratings. If there was no equivalent AMNET or FIBI point, I chose the closest AMNET or FIBI point to that survey point, with preference given to AMNET or FIBI points that were on the same stream as the survey point.

I also had to consider the year in which the AMNET and FIBI points were surveyed. The New Jersey Department of Environmental Protection (NJDEP) conducts water quality and habitat quality assessments at these sites however theses assessments are not done annually at every site. Thus there is variation regarding the year in which the water quality or habitat quality assessments are made. As part of the process of assigning water and habitat quality values to a survey site, I chose the most recent available values (Table 3). Each survey site, whether it was characterized as AMNET (NJDEP 2013) or FIBI (NJDEP 2010), was given a water quality rating of excellent, good, fair, or poor. Survey sites characterized as AMNET (NJDEP 2007) or FIBI (NJDEP 2006) were given habitat quality ratings (and corresponding scores) of optimal (160-200), suboptimal (110-159), marginal (60-109), and poor (<60). The NJDEP evaluated and scored the individual condition of 10 habitat parameters and then totaled those scores to determine an overall score/rating for a site (NJDEP 2007).

Based on this process, 160 points were located precisely at the initial AMNET or FIBI point location, 60 were located on the same stream as the initial AMNET or FIBI point, 11 were located on tributaries of the stream where the AMNET or FIBI point was initially located and 13 were located on different, but nearby, streams.

Data Analysis: Occupancy and Predictive Habitat Modeling

I defined the "survey site" as the area within 600 m of the 600 m stream transect. I quantified 10 site level habitat configuration and quality variables including: stream width, water depth, bank height, bankfull height, bank slope, distance to the closest lake/pond, AMNET/FIBI water quality, AMNET/FIBI habitat quality, beaver presence, mink presence.

For landscape level covariates, I reclassified the 84 land use/land cover types of the New Jersey Land Use Land Cover (NJLULC) dataset into a reduced set of 8 habitat types including: 1) High Intensity Development; 2) Low Intensity Development; 3) Commercial, Industrial, Transportation and Recreational (CITR); 4) Agriculture; 5) Upland Natural; 6) Fresh Water; 7) Non-coastal Wetlands; and 8) Other (Table 4). To quantify habitat composition, I measured the proportion of each habitat type (excluding Other). For each covariate measured at the landscape scale, I determined the buffer radius around the site at which each covariate was most strongly correlated to otter presence among a set of buffer radii ranging from 0.6 km to 16.2 km (being within the range of home range estimates of the river otter) at 600 m increments for all the sites in each sampling region. I used bootstrapping to obtain Spearman's Rank Correlation Coefficients on 10,000 random samples of 10 sites that were 25.2 km apart in Southern New Jersey and 9 sites that were 22.8 km apart in Northern New Jersey. I chose fewer sites and smaller distances per bootstrapped replicate in Northern New Jersey to better accommodate the smaller area of the Northern study area. I used Student's t-test (α = 0.05) to identify the habitat specific landscape distances that exhibited the strongest correlation to river otter presence at the site. The smallest radius that was significantly correlated was used as the scale for measuring that landscape covariate. Using the shortest distance reduced the overlap of landscape buffers between points. Therefore, I examined 8 spatially explicit landscape covariates and 10 site level covariates for occupancy analysis (Table 5).

I estimated site occupancy and detection probability using the modeling approach of Mackenzie et al. (2002), which accounts for the probability of an individual occupying the site and being detected during a survey. I used Akaike's Information Criterion (AIC) to evaluate and select models (Burnham and Anderson 2002) and performed analysis using the program PRESENCE (Hines 2006). In order to overcome or avoid variation in detection probability, which was considered to be a nuisance parameter, I first modeled detection probability among survey points considering four explanatory covariates including: month, observer, snow cover, and presence of precipitation as well as a constant detection probability. I selected a best model from that analysis to control for detection probability for subsequent modeling of otter occupancy. I modeled otter occupancy for Northern and Southern New Jersey separately using logistic regression with the covariates of site and landscape scale metrics.

I limited the total number of the candidate models in an iterative step-wise manner according to the following criteria:

1) Each model, except for the initial individual covariate models, included at least one site-scale and one landscape-scale covariate. Models were not required to have the same number of site and landscape covariates. Finally, to avoid the construction of overly complex models, no model was allowed to have more than 6 total covariates.
2) Covariates that are correlated ($|r| \geq 0.5$) were not used in the same model.
3) All covariates were used at least once. Some covariates were used more than others because they repeatedly appeared in higher-ranked models. Covariates that consistently appeared in low-ranked models were used less often. Additional covariates were individually added to high-ranked models to determine their effect on the model. Covariates that did not improve the log-likelihood estimate of the model by a value of >2 were removed.

4) Within the set of candidate models, I also included a global model of all covariates and a null model in which occupancy was held constant.

I calculated the small-sample-corrected information criterion AICc for all models (Hurvich and Tsai 1989) because sample size was small with respect to the number of parameters (K) in the analyses. I performed multiple-model averaging to predict occupancy using those models that had substantial support for fitting the data given the candidate set of models to address model selection uncertainty (Burnham and Anderson 2002). To determine the direction and magnitude of effect sizes for covariates, I calculated the mean standardized partial regression coefficients across all the models containing the variables of interest, and estimated precision using an unconditional variance estimator that incorporates model selection uncertainty (Burnham and Anderson 2002, p. 162).

I ultimately validated the accuracy of my best-fit occupancy models for Southern and Northern New Jersey by constructing an error matrix as part of a classification analysis. This analysis required the use of observed and conditional occupancy values for every site in both sampling regions. I averaged conditional occupancy values for each site in both sampling regions across all models that had the best support for fitting the data (i.e. those models that were used in the model averaging process). Thus each site in both regions had representative observed and conditional occupancy values. Using the constructed matrix, I determined the overall accuracy and my omission and commission errors for the best-fit occupancy models in both regions (Congalton 1991).

Table 2: Number of stream survey sites having a given number of replicate visits, January-April 2011–2012, New Jersey, USA

Number of Replicate Visits	Total Number of Survey Sites
1	1
2	10
3	33
4	3
5	13
6	184

Table 3: Number of stream survey sites utilizing AMNET and FIBI water quality and habitat quality assessment data from specific years (for the purposes of data analysis), New Jersey, USA.

Assessment Year	Total Number of Survey Sites
2010–2011	58
2010	10
2009	26
2008	23
2007–2008	36
2007	4
2006–2007	80
2006	4
2005	2
2002–2003	1

Table 4. Original and reclassified land cover types based on New Jersey Land Use Land Cover dataset to model river otter occupancy in New Jersey, USA, from January – April, 2011–2012.

Reclassified Land Cover Type	Original NJ Land Cover Type (and associated code)	% of New Jersey
High Intensity Development	1110 - Residential, high density or multiple dwellings 1120 - Residential, single unit, medium density 1150 - Mixed residential	9.40%
Low Intensity Development	1130 - Residential, single unit, low density 1140 - Residential, rural, single unit	8.80%
Commercial/ Industrial/ Transportation/ Recreational	1200 - Commercial/services 1211 - Military installations 1214 - No longer military 1300 - Industrial 1400 - Transportation/communications/utilities 1410 - Major roadway 1411 - Mixed transportation corridor overlap area 1419 - Bridge over water 1420 - Railroads 1440 - Airport facilities 1462 - Upland rights-of-way developed 1499 - Stormwater basin 1500 - Industrial and commercial complexes 1600 - Mixed urban or built-up land 1700 – Other urban or built-up land 1741 - Phragmites dominate urban area 1810 - Stadium, theaters, cultural centers and zoos 1850 - Managed wetland in built-up maintained rec area	7.60%
Agriculture	2100 - Cropland and pastureland 2140 - Agricultural wetlands (modified) 2150 - Former agricultural wetland (becoming shrubby) 2200 - Orchards/vineyards/nurseries 2300 - Confined feeding operations 2400 – Other agriculture	11.70%
Upland Natural	4110 - Deciduous forest (10-50% crown closure) 4120 - Deciduous forest (>50% crown closure) 4321 - Mixed forest (>50% deciduous, 0-50% crown closure)	28.30%

	4322 - Mixed forest (>50% deciduous, >50% crown closure) 4210 - Coniferous forest (10-50% Crown closure) 4220 - Coniferous forest (>50% crown closure) 4230 - Plantation 4311 - Mixed forest (>50% coniferous, 10-50% crown closure) 4312 - Mixed forest (>50% coniferous, >50% crown closure) 1461 - Wetlands rights-of-way 1463 - Upland rights-of-way undeveloped 4410 - Old field (< 25% brush covered) 4411 - Phragmites dominate old field 4420 - Deciduous brush/shrubland 4430 - Coniferous brush/shrubland 4440 - Mixed deciduous/coniferous brush/shrubland 4500 - Severe burned upland vegetation	
Water	5100 - Streams and canals 5200 - Natural lakes 5300 - Artificial lakes	1.77%
Wetlands	6120 - Freshwater tidal marshes 6210 - Deciduous wooded wetlands 6220 - Coniferous wooded wetlands 6221 - Atlantic white cedar wetlands 6231 - Deciduous scrub/shrub wetlands 6232 - Coniferous scrub/shrub wetlands 6233 - Mixed scrub/shrub wetlands (deciduous dom.) 6234 - Mixed scrub/shrub wetlands (coniferous dom.) 6240 - Herbaceous wetlands 6241 - Phragmites dominate interior wetlands 6251 - Mixed wooded wetlands (deciduous dom.) 6252 - Mixed wooded wetlands (coniferous dom.) 6290 - Unvegetated flats	13.30%
Other	1710 - Cemetery 1711 - Cemetery on Wetland 1750 - Managed wetland in maintained lawn greenspace 1800 - Recreational land 1804 - Athletic fields (schools) 5190 - Exposed flats 5410 – Tidal rivers, inland bays, and other tidal waters 5411 – Open tidal bays 5420 - Dredged lagoon 5430 - Atlantic ocean	19.69%

6111 - Saline marsh (low marsh)
6112 - Saline marsh (high marsh)
6130 - Vegetated dune communities
6141 - Phragmites dominate coastal wetlands
6500 - Severe burned wetland vegetation
7100 - Beaches
7200 - Bare exposed rock, rock slides, etc.
7300 - Extractive mining
7400 - Altered lands
7430 - Disturbed wetlands (modified)
7500 - Transitional areas
7600 - Undifferentiated barren lands

Table 5: Covariates used in Occupancy Models for Otters in New Jersey, USA from January-April 2011-2012.

Covariate Name	Description
Beaver Occupancy	Beaver sign/activity at survey site: (0) Absence, (1) Presence
Mink Occupancy	Mink sign/activity at a survey site: (0) Absence, (1) Presence
Water Depth	Average water depth at a site during the field season: (1) 0-15 cm, (2) 16-30 cm, (3) 31-45 cm, (4) 46-60 cm, (5) 61-75 cm, (6) 76-90 cm, (7) 91-105 cm, (8) >106 cm
Bank Height	Average bank height, measured from the stream bed to the top of the stream bank, for the surveyed portion of the stream: (1) 0-31 cm, (2) 31-62 cm, (3) 62-93 cm, (4) 93-124 cm, (5) 124-155 cm, (6) 155-186 cm, (7) >186 cm.
Bankfull Height	Average bankfull height, measured from the top of the water line to the top of the bank, at a site during the field season: (1) 0-31 cm, (2) 31-62 cm, (3) 62-93 cm, (4) 93-124 cm, (5) 124-155 cm, (6) 155-186 cm, (7) >186 cm.
Bank Slope	Average bank slope (or most frequently occurring bank slope) for the surveyed portion of the stream: (1) <30 degrees, (2) 30-60 degrees, (3) >60 degrees.
Stream Width	Average stream width for the surveyed portion of the stream: (1) 0-2 m, (2) 2- 4 m, (3) 4-6 m, (4) 6-8 m, (5) 8-10, (6) >10 m
Distance to Lake	Distance to closest lake or pond from the survey site: (0) 0-.5 km, (1) .5-1 km, (2) 1-1.5 km, (3) 1.5-2 km, (4) 2-2.5 km, (5) 2.5-3 km, (6) >3 km.
Water Quality	Overall water quality for a site, determined by the NJDEP: (1) Poor, (2) Fair, (3) Good, (4) Excellent.
Habitat Quality	Overall habitat quality for a site, collected by the NJDEP: (1) Poor, (2) Marginal, (3) Sub-optimal, (4) Optimal.
% Agriculture	% Agriculture within buffers surrounding the survey site
% Commercial, Industry, Transportation, Recreation (% CITR)	% Commercial, Industry, Transportation and Recreation within buffers surrounding the survey site
% High Intensity Development	% High Intensity Development within buffers surrounding the survey site
% Low Intensity Development	% Low Intensity Development within buffers surrounding the survey site
% Upland Natural	% Upland Natural within buffers surrounding the survey site
% Other	% Other within buffers surrounding the survey site
% Water	% Water within buffers surrounding the survey site
% Wetland	% Wetland within buffers surrounding the survey site

Chapter 4

RESULTS

Southern New Jersey

I detected otters at 83 of 141 sites (58.9%) with a predicted occupancy of 59.4 ± 0.04% in Southern New Jersey (Figure 1, Chapter 3). If an otter was present, overall detection probability during a single visit was 53.1 ± 0.04% and 97.7% across the repeat visits. I detected river otters only once at 22 sites, twice at 14 sites, three times at 13 sites, four times at 9 sites, five times at 11 sites and every time at 14 sites. There were a total of three detection models that had a ΔAIC ≤ 2 (Table 6*a*). Model averaging of these top detection models resulted in a detection model consisting of three covariates, month, precipitation, and snow, all which negatively impacted detection: *Southern New Jersey Otter Detection (p)=-0.104 (Month)-0.103 (Precipitation)-1.042 (Snow Cover).*

Prior to running the occupancy models, I had to determine at which spatial scale each of the landscape level covariates best correlated with otter occupancy. High Intensity Development had the highest correlation (r = -0.347) at 1200 m; however, I used 600 m because it represented the shortest distance that still correlated with otter occupancy (r = -0.291) (Figure 2A-i). Low Intensity Development had the highest correlation (r = -0.313) at 600 m, which also represents the shortest distance (Figure 2A-ii). Commercial/Industrial/Transportation/Recreational had the highest correlation (r = -0.315) at 600 m as well (Figure 2A-iii). Agriculture had the highest correlation (r =

-0.240) at 15000 m but the shortest correlative distance was 1200 m (r = -0.107) (Figure 2A-iv). Upland Natural had the highest correlation (r = 0.366) at 3000 m; however, the shortest correlative distance occurred at 600 m (r = 0.324) (Figure 2A-v). Wetland had the highest correlation (r = 0.339) at 600 m, which also represented the shortest distanceof correlation (Figure 2A-vi). Finally, Water had the highest correlation (r = 0.196) at 7800 m but the shortest correlative distance occurred at 1200 m (r= 0.173) (Figure 2A-vii). The 8 chosen spatially explicit habitat variables listed above were used for habitat occupancy models.

Of the 50 tested habitat occupancy models, a total of 3 models had a $\Delta AIC \leq 2$. The top-ranked model included three site-scale covariates including 1) water depth, 2) distance to lake, and 3) bank slope and two landscape scale covariates including 1) % CITR, and 2) % Low Intensity Development. The remaining two models with a $\Delta AIC \leq 2$ added one additional site level covariate, water quality. These top three models accounted for 85.2% of the AIC weight (Table 7A). Model averaging of the top three models resulted in the final predictive occupancy model for Southern New Jersey:

Southern New Jersey Otter Occupancy (psi) = 0.761(water depth) +0.415(water quality) – 0.099(% CITR) - 0.061(% low intensity development) – 0.438(distance to lake) – 0.570(bank slope).

Water depth had a strong effect (95% confidence intervals not including zero) and positive magnitude. Distance to lake, bank slope, and % CITR and % Low Intensity Development had strong effects but had negative magnitudes (Figure 3A). The effect size of water quality and % Low Intensity Development did not differ from zero. I found that on average, sites where I detected otters had significantly lower percentages of CITR (5%

vs. ~11%). Additionally, on average, these occupied sites had a higher water depth, lower or more gently sloped banks, and were located closer to a lake/pond than sites where otters were not detected (Table 8A).

Results from the classification analysis to determine model accuracy showed that the Southern New Jersey best-fit occupancy model was 100% accurate with 0% omission and commission error (Table 9A).

Northern New Jersey

I detected otters during at least one visit at 31 of 103 sites (30.1%) with a predicted occupancy of 58.8 ± 0.04% in Northern New Jersey (Figure 1, Chapter 3). If an otter was present, overall detection probability during a single visit was 14.1 ± 0.04% and 44.5% across the repeat visits. I detected river otters only once at 23 sites, twice at 7 sites and three times at one site. There were a total of 4 detection models that had a ΔAIC ≤ 2 (Table 6B). Three of the 4 detection covariates including: month, precipitation, and snow appeared at least once in 3 of the top 4 detection models. The null model was also in the top 4 detection models. Therefore I decided to use the simplest model, which is the null model to represent detection in our otter occupancy models for Northern New Jersey.

I also determined the spatial scales for the landscape level covariates that best correlated with otter occupancy in Northern New Jersey. High Intensity Development was best correlated ($r = 0.167$) at 1800 m but the closest correlative distance was 600 m ($r = 0.154$). This covariate showed positive correlation values initially but as the buffer width increased, starting at 3600 m, the correlation values became negative (Figure 3B-i). Low Intensity Development was best correlated ($r = -0.107$) at 600 m, which was also the shortest correlative distance (Figure 3B-ii).

Commercial/Industrial/Transportation/Recreational was best correlated (r = 0.126) at 600 m, which also represents the shortest correlative distance. This was another covariate that initially had positive correlation values but at 2400 m, the values started becoming negative (Figure 3B-iii). Agriculture was best correlated (r = 0.136) at 600 m, which was the shortest possible distance (Figure 3B-iv). Upland Natural was best correlated (r = 0.166) with otter occupancy at 16200 m but the shortest distance for correlation was 1800 m (r= 0.061) (Figure 3B-v). Wetland had the highest correlation (r = -0.147) at 1800 m but the shortest possible distance for correlation was at 600 m (r = -0.106) (Figure 3B-vi). Finally, Water was best correlated (r = 0.195) with otter occupancy at 7200 m but the shortest distance for correlation was at 4800 m (r = 0.099) (Figure 3B-vii).

Of the 50 tested habitat occupancy models, a total of 3 models had a $\Delta AIC \leq 2$. The top-ranked model included 4 site-scale covariates including water depth, mink presence, water quality, and stream width and 1 landscape scale covariate, % Low Intensity Development. The remaining two models with a $\Delta AIC \leq 2$ did not add any additional covariates. These top 3 models accounted for 48.1% of the AIC weight (Table 7B) and model averaging resulted in the final predictive occupancy model for Northern New Jersey: *Northern New Jersey Otter Occupancy (psi) = 3.128(water depth) +2.662(mink) + 0.983(stream width) + 1.212 (water quality) - 0.097(% low intensity development).*

Water depth, water quality, mink, and stream width had positive magnitudes (95% confidence intervals not including zero) and % Low Intensity Development had a negative magnitude (Figure 4B) but none of the effect sizes differed from zero. Results from the classification analysis to determine model accuracy showed that the Northern

New Jersey best-fit occupancy model was only 72.8% accurate with 38.9% omission error and 47.5% commission error (Table 9B).

Table 6A-B**:** Summary of model-selection procedure examining covariates affecting the probability of detection of otters in (A) Southern and (B) Northern New Jersey, USA, from January-April, 2011–2012. I report Akaike's Information Criterion (AIC), the relative difference in AIC values compared to the top-ranked model (Δ AIC), the AIC model weight (W), and the number of parameters in the model (K).

A.

Model	AIC	ΔAIC	W	K
psi(.),p(Snow Cover)	864.73	0.00	0.3881	3
psi(.),p(Month, Snow Cover)	865.47	0.74	0.2681	4
psi(.),p(Precipitation, Snow Cover)	866.38	1.65	0.1701	4
psi(.),p(Month, Precipitation, Snow Cover)	867.23	2.50	0.1112	5
psi(.),p(7 Observers, Snow Cover)	870.36	5.63	0.0232	10
psi(.),p(Month, 7 Observers, Snow Cover)	870.73	6.00	0.0193	11
psi(.),p(7 Observers, Precipitation, Snow Cover)	872.23	7.50	0.0091	11
psi(.),p(Global)	872.67	7.94	0.0073	12
psi(.),p(.)	875.73	11.00	0.0016	2
psi(.),p(Precipitation)	876.84	12.11	0.0009	3
psi(.),p(Month)	877.73	13.00	0.0006	3
psi(.),p(Month, Precipitation)	878.82	14.09	0.0003	4
psi(.),p(7 Observers)	881.96	17.23	0.0001	9
psi(.),p(7 Observers, Precipitation)	883.48	18.75	0	10
psi(.),p(Month, 7 Observers)	883.89	19.16	0	10
psi(.),p(Month, 7 Observers, Precipitation)	885.40	20.67	0	11

B.

Model	AIC	ΔAIC	W	K
psi(.),p(Snow Cover)	271.94	0.00	0.2448	3
psi(.),p(.)	272.82	0.88	0.1577	2
psi(.),p(Precipitation, Snow Cover)	273.38	1.44	0.1192	4
psi(.),p(Month, Snow Cover)	273.41	1.47	0.1174	4
psi(.),p(Precipitation)	274.34	2.40	0.0737	3
psi(.),p(Month)	274.79	2.85	0.0589	3
psi(.),p(7 Observers)	275.06	3.12	0.0514	9
psi(.),p(Month, Precipitation, Snow Cover)	275.11	3.17	0.0502	5
psi(.),p(Month, Precipitation)	276.34	4.40	0.0271	4
psi(.),p(7 Observers, Snow Cover)	276.35	4.41	0.0270	10
psi(.),p(7 Observers, Precipitation)	276.90	4.96	0.0205	10
psi(.),p(Month, 7 Observers)	277.06	5.12	0.0189	10
psi(.),p(7 Observers, Precipitation, Snow Cover)	278.14	6.20	0.0110	11
psi(.),p(.7 Observers, Month, Snow Cover)	278.28	6.34	0.0103	11
psi(.),p(Month, 7 Observers, Precipitation)	278.85	6.91	0.0077	11
psi(.),p(Global)	280.13	8.19	0.0041	12

Table 7A-B: Summary of model-selection procedure examining covariates affecting the probability of occupancy of otters in (A) Southern and (B) Northern New Jersey, USA, from January-April 2011-2012. All occupancy models are modeled as a function of detection, using the Month, Precipitation and Snow model in Southern New Jersey and the null model in Northern New Jersey. I report Akaike's Information Criterion (AIC), the relative difference in AIC values compared to the top-ranked model (Δ AIC), the AIC model weight (*W*) and the number of parameters in the model (K).

A.

Model	AIC	ΔAIC	W	K
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Low Intensity Development)	814.23	0.00	0.3763	10
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Low Intensity Development, Water Quality)	814.49	0.26	0.3304	11
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, Water Quality)	816.14	1.91	0.1448	10
psi(Water Depth, %CITR, Bank Slope, Distance to Lake)	816.87	2.64	0.1005	9
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Wetlands)	818.40	4.17	0.0468	10
psi(Water Depth, %CITR, Bank Slope, %Low Intensity Development)	827.62	13.39	0.0005	9
psi(Water Depth, %CITR, Bank Slope, Water Quality)	829.37	15.14	0.0002	9
psi(Water Depth, %Low Intensity Development, %CITR)	829.97	15.74	0.0001	8
psi(Water Depth, Distance to Lake, %Wetlands)	829.99	15.76	0.0001	8
psi(Water Depth, %CITR)	831.47	17.24	0.0001	7
psi(Water Depth, Mink, %Low Intensity Development, Stream Width, %CITR)	832.36	18.13	0	10
psi(Water Depth, %CITR, Mink)	832.65	18.42	0	8
psi(.Water Depth, %Wetlands)	837.04	22.81	0	7
psi(Water Depth, %Low Intensity Development)	837.28	23.05	0	7
psi(Water Depth, %Water)	837.62	23.39	0	7
psi(Water Depth, Mink, %Low Intensity Development, Water Quality)	837.77	23.54	0	9
psi(Water Depth)	837.98	23.75	0	6
psi(Water Depth, %Low Intensity Development, Mink)	838.54	24.31	0	8
psi(Water Depth, %Low Intensity Development, %High Intensity Development)	838.56	24.33	0	8
psi(Water Depth, Stream Width, %Wetlands)	838.84	24.61	0	8
psi(Water Depth, Mink, %Low Intensity Development, Stream Width, Water Quality)	839.48	25.25	0	10
psi(Water Depth, Mink, %Low Intensity Development, %High Intensity Development)	839.95	25.72	0	9
psi(Water Depth, Mink, %Low Intensity Development, Stream Width)	840.47	26.24	0	9
psi(Mink, Water Depth, Stream Width, %Water)	840.96	26.73	0	9
psi(Water Depth, Stream Width, %Low Intensity Development)	842.64	28.41	0	8
psi(%Wetlands, Distance to Lake)	847.02	32.79	0	7

psi(%Water, Distance to Lake, Water Quality)	848.76	34.53	0	8
psi(Mink, Bank Slope, Distance to Lake, %Low Intensity Development)	849.19	34.96	0	9
psi(Bank Slope, %CITR)	850.83	36.60	0	7
psi(%Wetlands, Stream Width)	855.41	41.18	0	7
psi(%Wetlands)	855.66	41.43	0	6
psi(Bank Slope, %Low Intensity Development)	857.19	42.96	0	7
psi(Bank Slope)	857.65	43.42	0	6
psi(%CITR)	858.20	43.97	0	6
psi(Mink, %CITR)	858.70	44.47	0	7
psi(%Water)	859.17	44.94	0	6
psi(Distance to Lake)	859.71	45.48	0	6
psi(Water Quality)	861.43	47.20	0	6
psi(Bankfull Height)	861.79	47.56	0	6
psi(Habitat Quality)	863.55	49.32	0	6
psi(%Upland Natural)	864.06	49.83	0	6
psi(%Low Intensity Development)	864.89	50.66	0	6
psi(%High Intensity Development)	866.74	52.51	0	6
psi(%Other)	867.09	52.86	0	6
psi(.)	867.23	53.00	0	5
psi(Stream Width)	867.69	53.46	0	6
psi(Mink)	867.76	53.53	0	6
psi(%Agriculture)	868.38	54.15	0	6
psi(Beaver)	869.20	54.97	0	6
psi(Bank Height)	869.23	55.00	0	6

B.

Model	AIC	ΔAIC	W	K
psi(Water Depth, Mink, %Low Intensity Development, Stream Width, Water Quality),p(.)	256.36	0.00	0.1837	7
psi(Water Depth, Mink, %Low Intensity Development, Stream Width),p(.)	256.49	0.13	0.1721	6
psi(Water Depth, %Low Intensity Development, Mink),p(.)	257.13	0.77	0.125	5
psi(Water Depth, Mink, %Low Intensity Development, Stream Width, %CITR),p(.)	258.49	2.13	0.0633	7
psi(Water Depth, Mink, %Low Intensity Development, %High Intensity Development),p(.)	258.61	2.25	0.0596	6
psi(Water Depth, Mink, %Low Intensity Development, Water Quality),p(.)	258.86	2.50	0.0526	6
psi(Water Depth, %Low Intensity Development),p(.)	258.99	2.63	0.0493	4
psi(Water Depth),p(.)	259.33	2.97	0.0416	3
psi(Water Depth, Stream Width, %Low Intensity Development),p(.)	259.91	3.55	0.0311	5
psi(Mink, Water Depth, Stream Width, %Water),p(.)	260.04	3.68	0.0292	6
psi(Water Depth, %High Intensity Development, %Low Intensity Development),p(.)	260.45	4.09	0.0238	5

psi(Water Depth, %CITR, Mink),p(.)	260.61	4.25	0.0219	5
psi(Water Depth, %Low Intensity Development, %CITR),p(.)	260.89	4.53	0.0191	5
psi(Water Depth, %CITR),p(.)	260.96	4.60	0.0184	4
psi(Water Depth, %Wetlands),p(.)	260.99	4.63	0.0181	4
psi(Water Depth, %Water),p(.)	261.05	4.69	0.0176	4
psi(Water Depth, %CITR, Bank Slope, Water Quality),p(.)	261.15	4.79	0.0167	6
psi(Water Depth, Stream Width, %Wetlands),p(.)	261.7	5.34	0.0127	5
psi(Water Depth, %CITR, Bank Slope, %Low Intensity Development),p(.)	261.72	5.36	0.0126	6
psi(Water Depth, Distance to Lake, %Wetlands),p(.)	262.99	6.63	0.0067	5
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, Water Quality),p(.)	263.13	6.77	0.0062	7
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Low Intensity Development, Water Quality),p(.)	263.65	7.29	0.0048	8
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Low Intensity Development),p(.)	263.67	7.31	0.0047	7
psi(Water Depth, %CITR, Bank Slope, Distance to Lake),p(.)	263.79	7.43	0.0045	6
psi(Water Depth, %CITR, Bank Slope, Distance to Lake, %Wetlands),p(.)	265.25	8.89	0.0022	7
psi(Mink, Bank Slope, Distance to Lake, %Low Intensity Development),p(.)	267.54	11.18	0.0007	6
psi(%Water, Distance to Lake, Water Quality),p(.)	269.01	12.65	0.0003	5
psi(Mink),p(.)	269.61	13.25	0.0002	3
psi(Mink, %CITR),p(.)	269.8	13.44	0.0002	4
psi(Bankfull Height),p(.)	270.03	13.67	0.0002	3
psi(%Low Intensity Development),p(.)	270.39	14.03	0.0002	3
psi(Stream Width),p(.)	272.01	15.65	0.0001	3
psi(Bank Slope, %Low Intensity Development),p(.)	272.09	15.73	0.0001	4
psi(.),p(.)	272.82	16.46	0	2
psi(Habitat Quality),p(.)	273.18	16.82	0	3
psi(%Wetlands, Stream Width),p(.)	273.25	16.89	0	4
psi(Bank Height),p(.)	273.7	17.34	0	3
psi(Distance to Lake),p(.)	274.02	17.66	0	3
psi(%Wetlands),p(.)	274.09	17.73	0	3
psi(%Upland Natural),p(.)	274.14	17.78	0	3
psi(%High Intensity Development),p(.)	274.16	17.80	0	3
psi(%Water),p(.)	274.54	18.18	0	3
psi(Bank Slope),p(.)	274.55	18.19	0	3
psi(Water Quality),p(.)	274.62	18.26	0	3
psi(Beaver),p(.)	274.71	18.35	0	3
psi(%Agriculture),p(.)	274.78	18.42	0	3
psi(%Other),p(.)	274.8	18.44	0	3
psi(%CITR),p(.)	274.82	18.46	0	3
psi(%Wetlands, Distance to Lake),p(.)	275.29	18.93	0	4
psi(Bank Slope, %CITR),p(.)	276.54	20.18	0	4

Table 8A-B: Mean ± SE of covariate measures in top model for sites where otters were detected and not detected in (A) Southern and (B) Northern New Jersey, USA, from January – April, 2011-2012. T-test results for differences between groups also presented.

A.

	Detected (n=83)		Not Detected (n=58)			
Covariate	Mean	SE	Mean	SE	t_{139}	*P*
Water Depth (cm)	60.15	2.05	40.53	2.66	5.93	<0.01
Distance to Lake (km)	1.17	0.15	1.96	0.23	3.03	<0.01
Bank Slope (degrees)	40.27	3.69	58.58	4.26	3.23	<0.01
Water Quality*	2.53	0.09	2.16	0.10	2.66	0.01
% Low Intensity Development	7.04	0.70	9.84	1.23	2.11	0.04
%CITR	5.02	0.75	10.74	1.75	3.33	<0.01

B.

	Detected (n=31)		Not Detected (n=72)			
Covariate	Mean	SE	Mean	SE	t_{101}	*P*
Water Depth (cm)	47.57	5.22	34.25	2.84	2.39	0.02
Mink	0.84	0.07	0.57	0.06	2.70	0.01
Stream Width (m)	8.72	1.14	6.49	0.55	1.98	0.05
% Low Intensity Development	9.30	1.40	13.08	1.54	1.50	0.14
Water Quality*	2.71	0.17	2.63	0.11	0.43	0.67

*Water Quality: (1) Poor, (2) Fair, (3) Good, (4) Excellent

Table 9A-B: Classification analysis to determine overall model accuracy, omission and commission error for the best-fit occupancy model in (A) Southern New Jersey and (B) Northern New Jersey, USA.

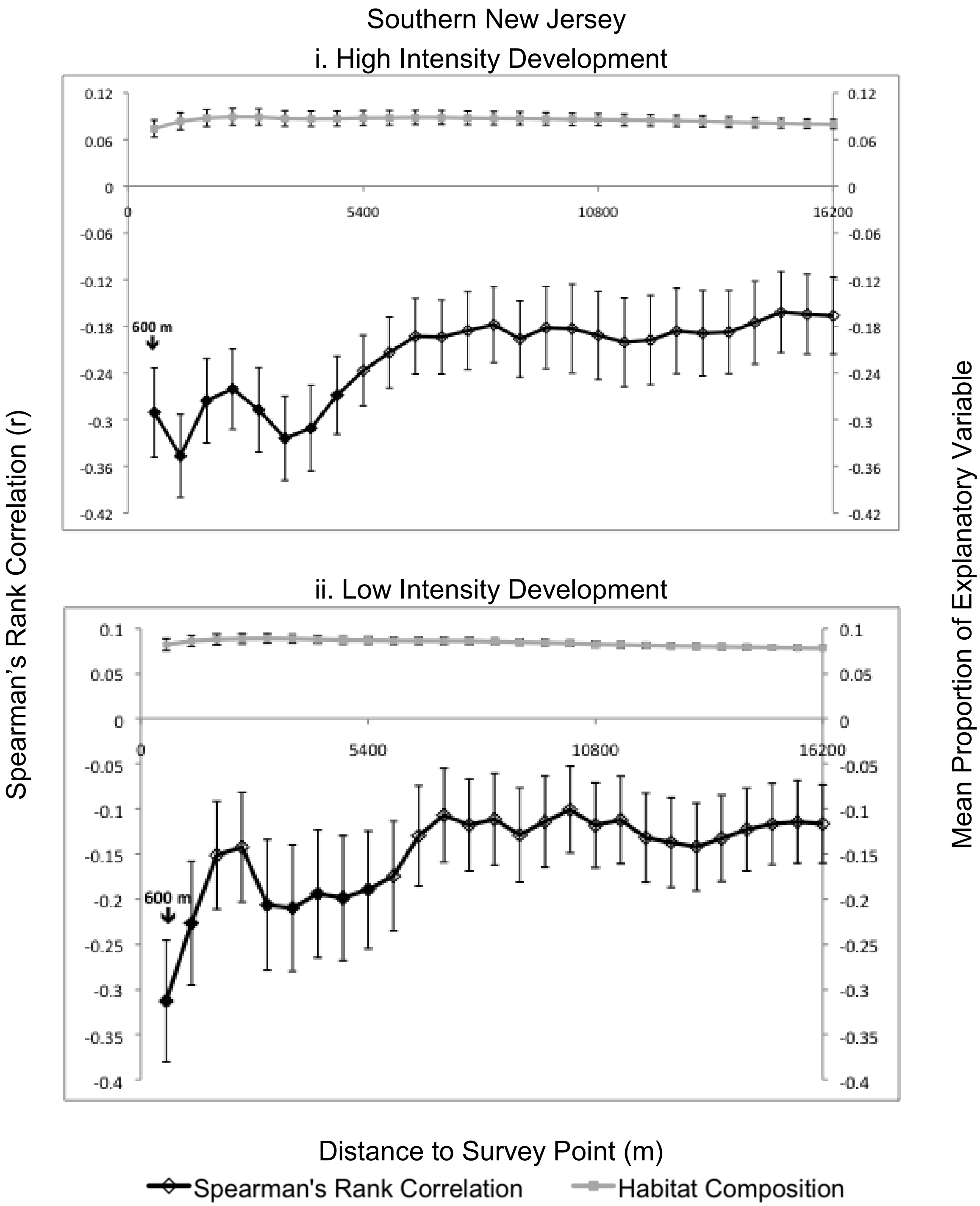
A.

		Observed			
Classified		Occupied	Unoccupied	Total	User's Accuracy
Conditional	Occupied	83	0	83	100%
	Unoccupied	0	58	58	100%
	Total	83	58	141	
	Producer's accuracy	100%	100%		
				Overall accuracy = 100%	

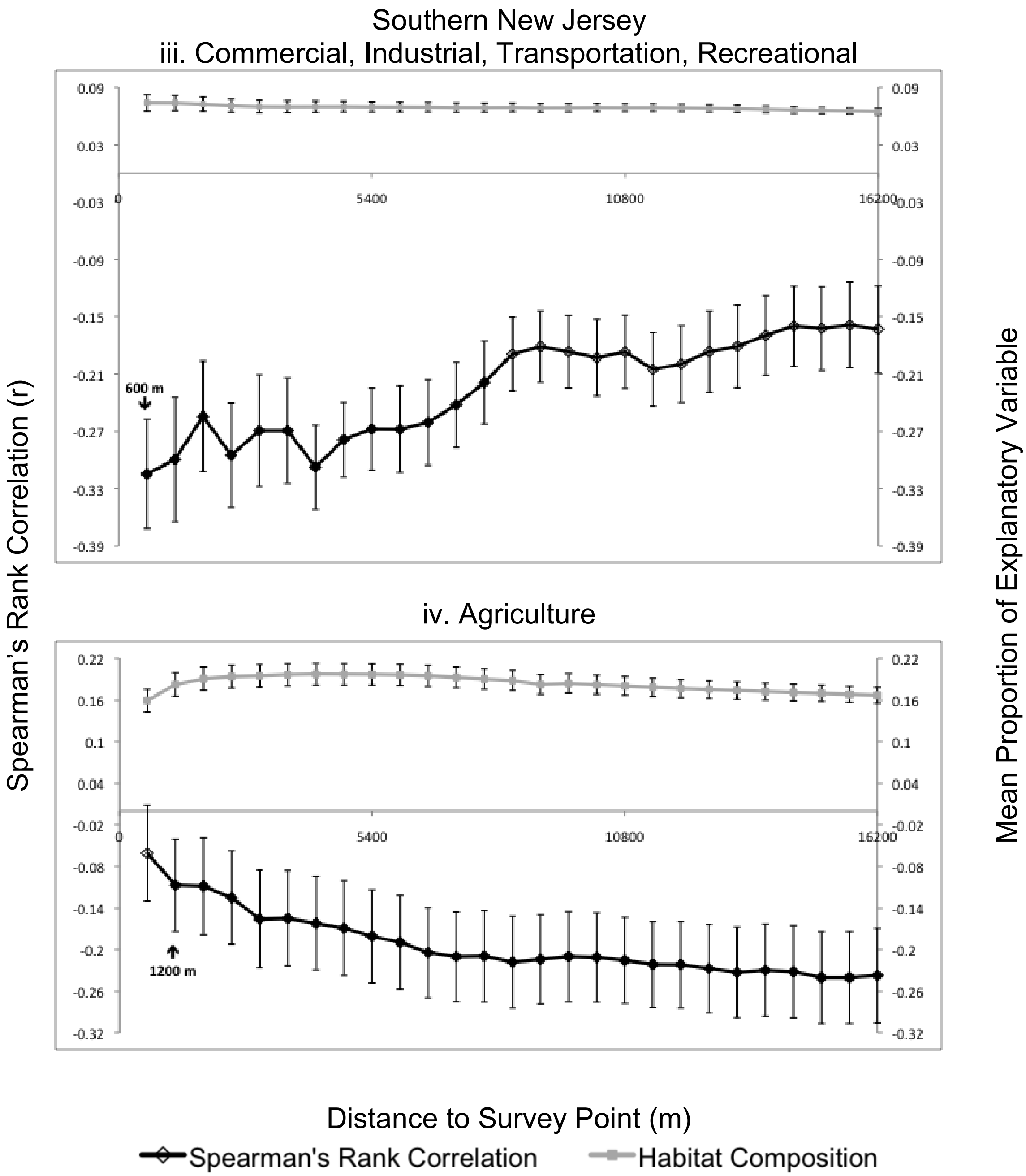
B.

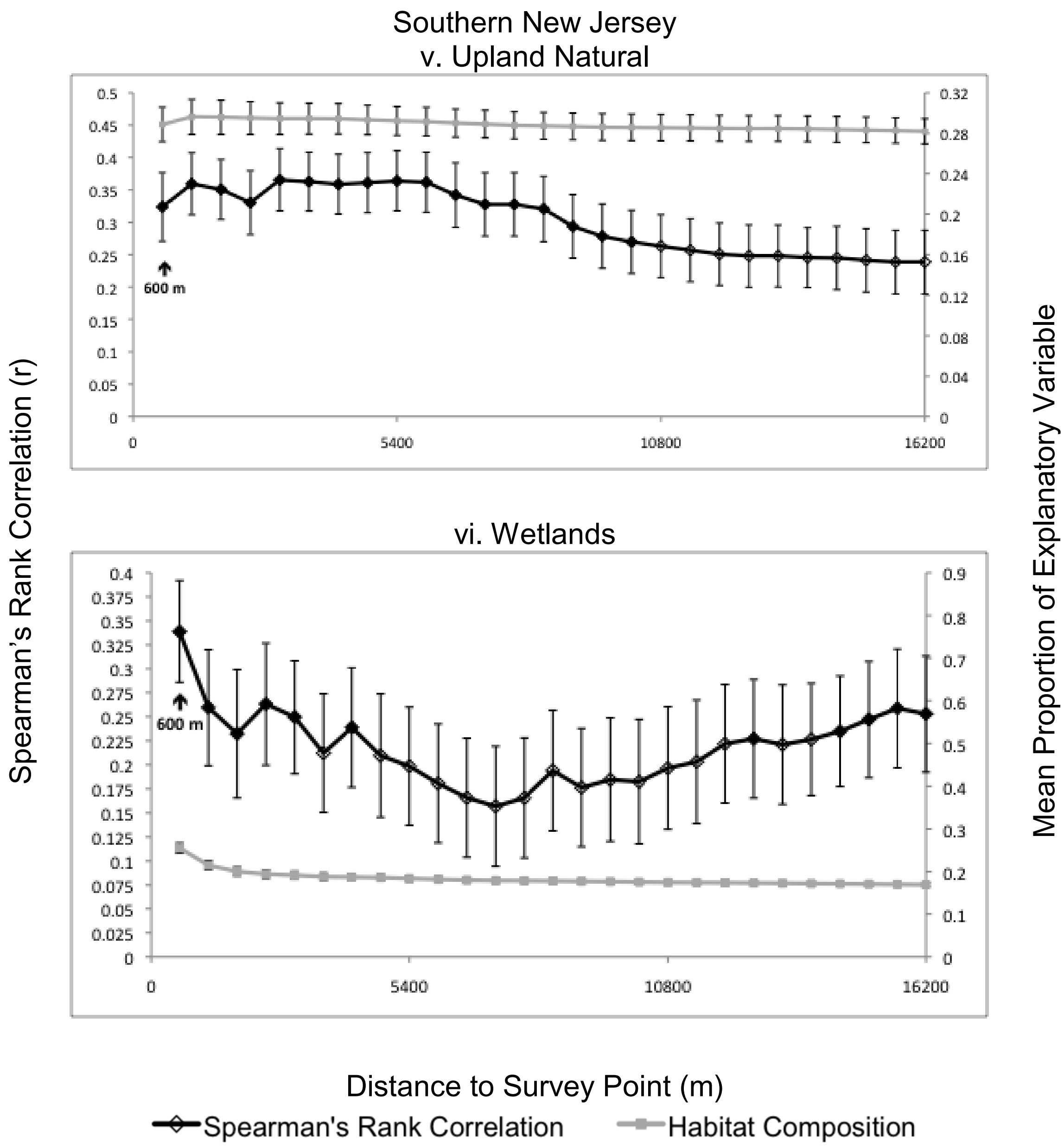
		Observed			
Classified		Occupied	Unoccupied	Total	User's Accuracy
Conditional	Occupied	31	28	59	53%
	Unoccupied	0	44	44	100%
	Total	31	72	103	
	Producer's accuracy	100%	61%		
				Overall accuracy = 73%	

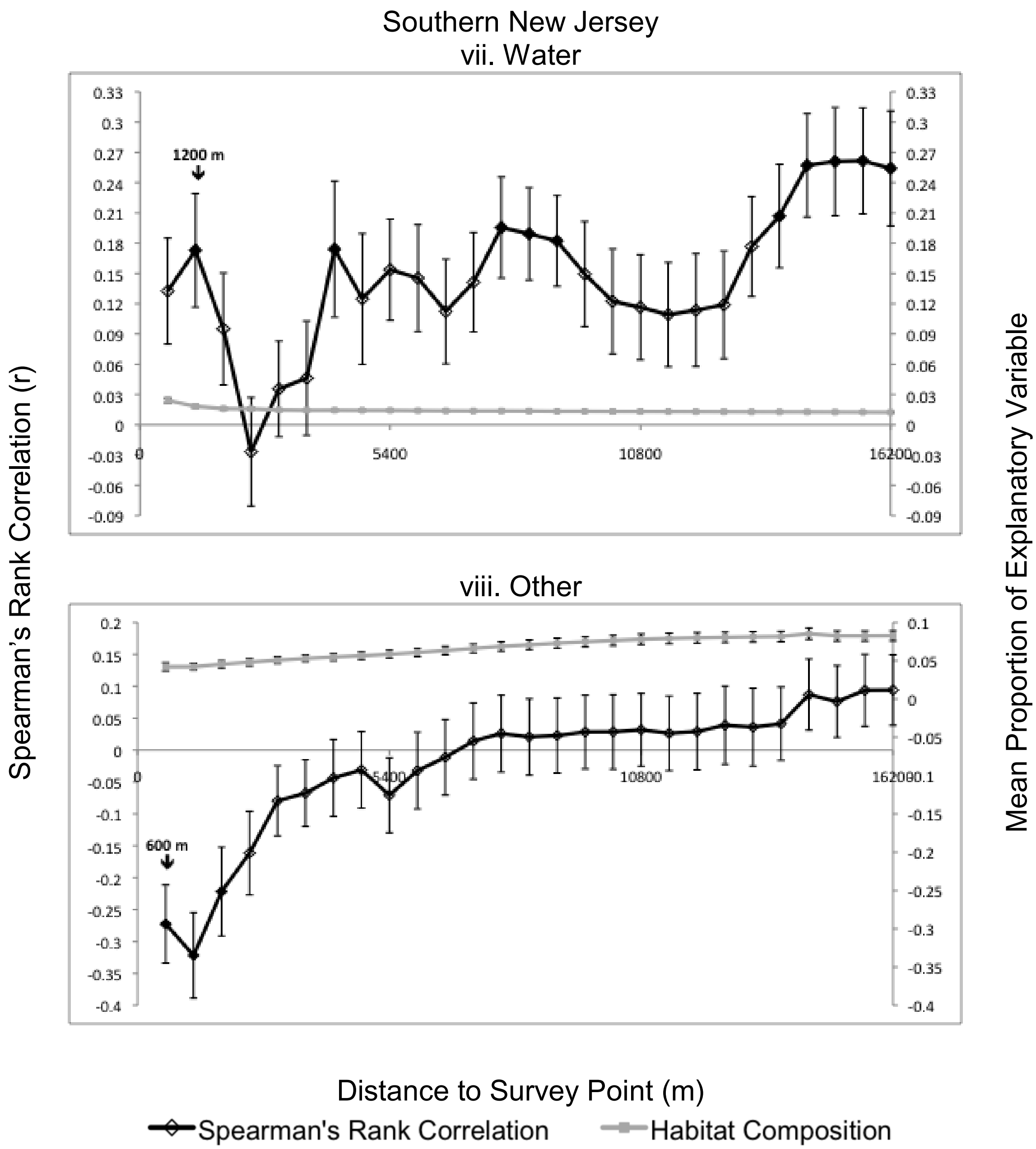
A.

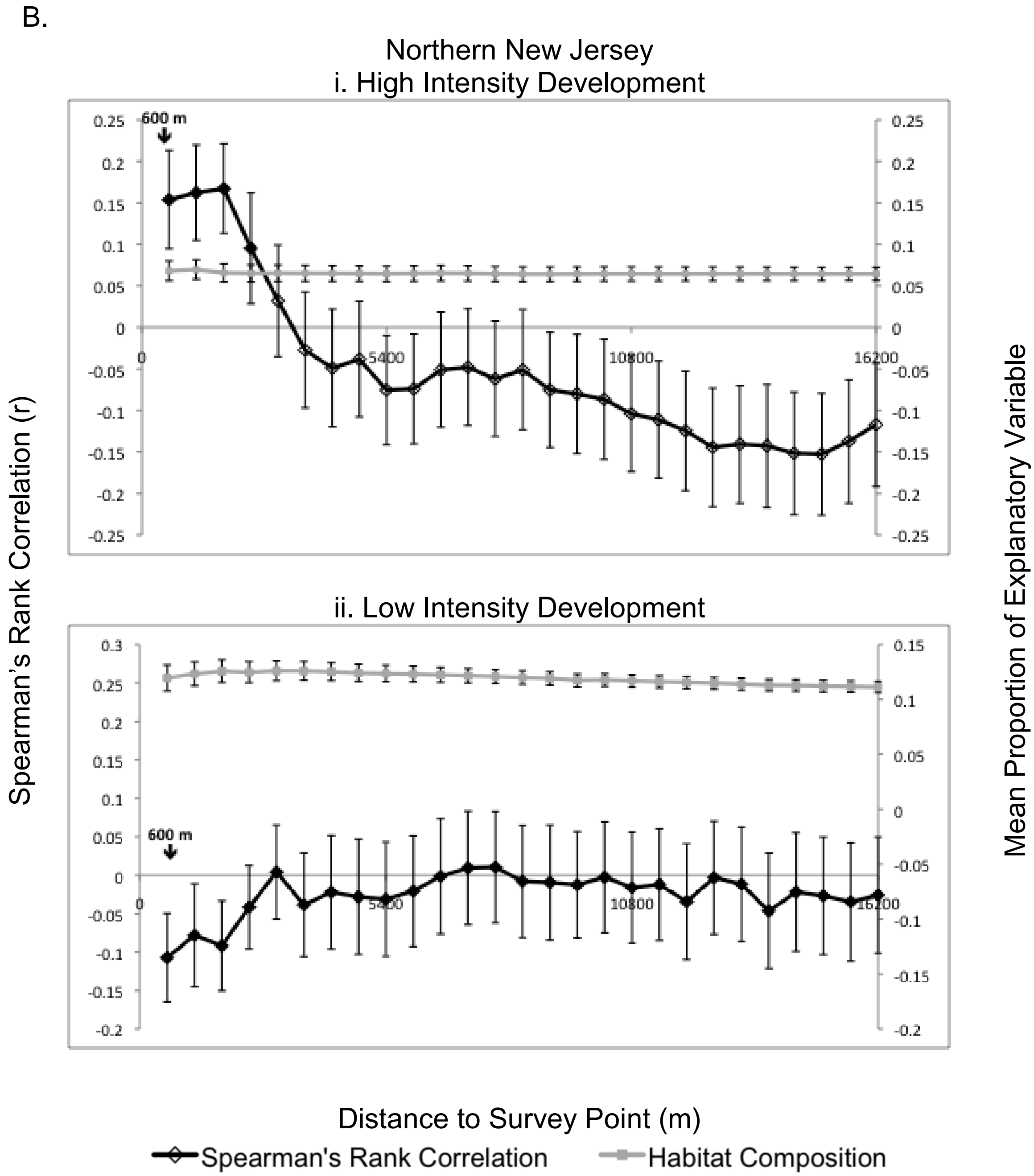


Southern New Jersey
i. High Intensity Development
600 m
ii. Low Intensity Development
600 m
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition

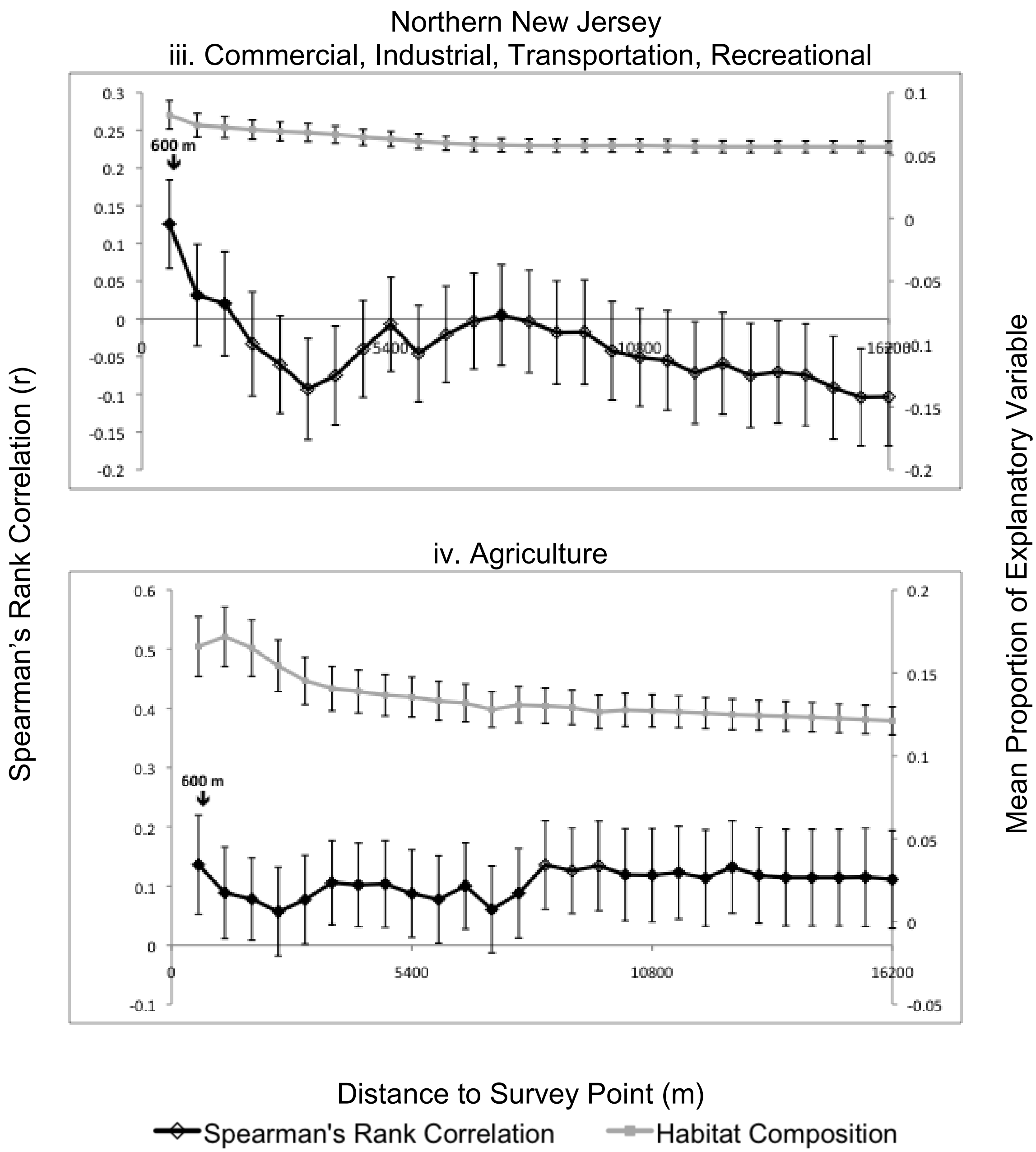

Southern New Jersey
iii. Commercial, Industrial, Transportation, Recreational
600 m
iv. Agriculture
1200 m
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition

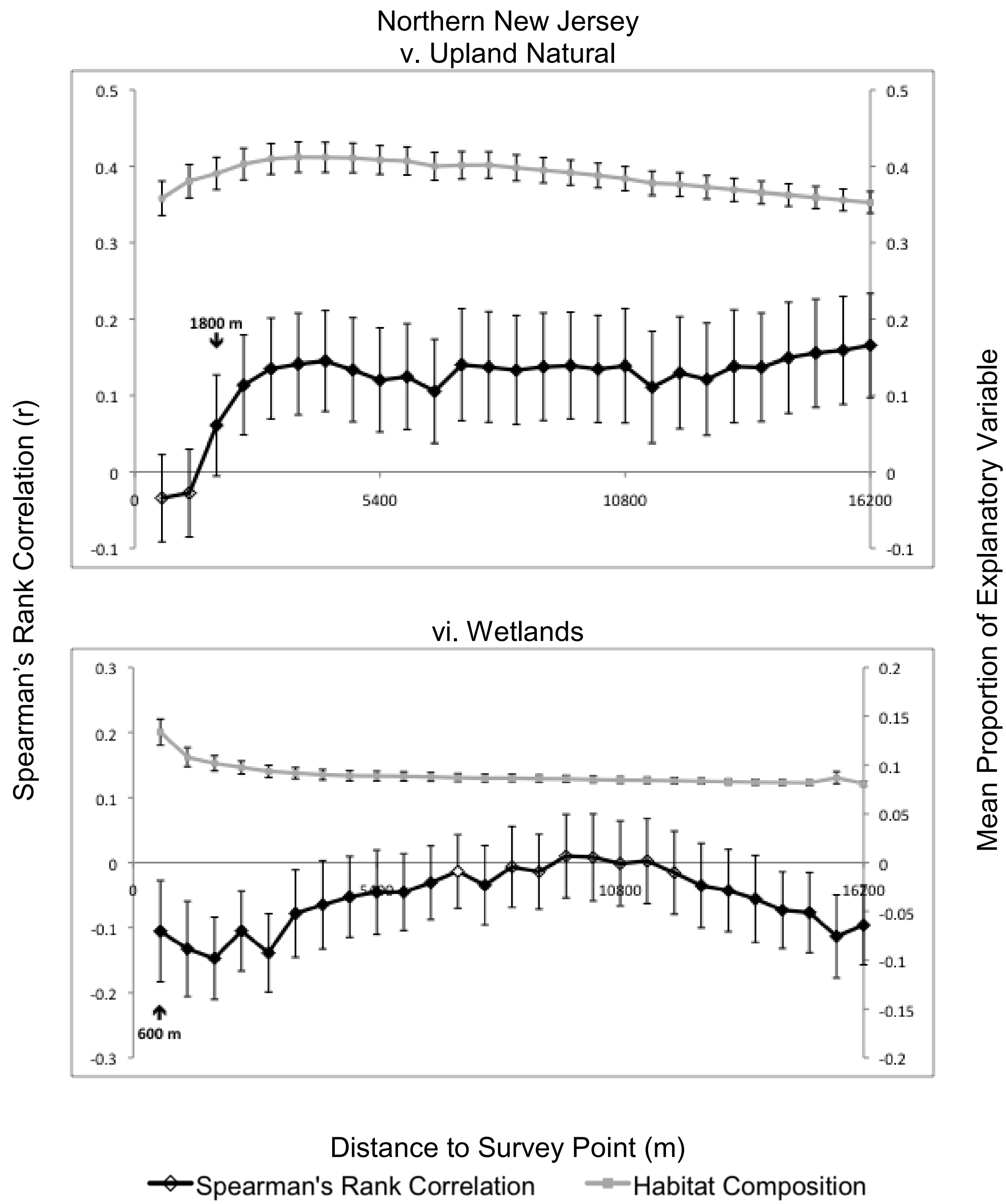

Southern New Jersey
v. Upland Natural
600 m
vi. Wetlands
600 m
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition


Southern New Jersey
vii. Water
1200 m
0.33
0.3
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
-0.03
-0.06
-0.09
0
5400
10800
16200
viii. Other
600 m
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition



B.
Northern New Jersey
i. High Intensity Development
600 m
ii. Low Intensity Development
600 m
0
5400
10800
16200
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition


Northern New Jersey
iii. Commercial, Industrial, Transportation, Recreational
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
600 m
0
5400
10800
16200
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
iv. Agriculture
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
600 m
0
5400
10800
16200
0.2
0.15
0.1
0.05
0
-0.05
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition


Northern New Jersey
v. Upland Natural
1800 m
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
5400
10800
16200
vi. Wetlands
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
600 m
0.2
0.15
0.1
0.05
-0.05
-0.1
-0.15
-0.2
10800
16200
Spearman's Rank Correlation (r)
Mean Proportion of Explanatory Variable
Distance to Survey Point (m)
Spearman's Rank Correlation
Habitat Composition

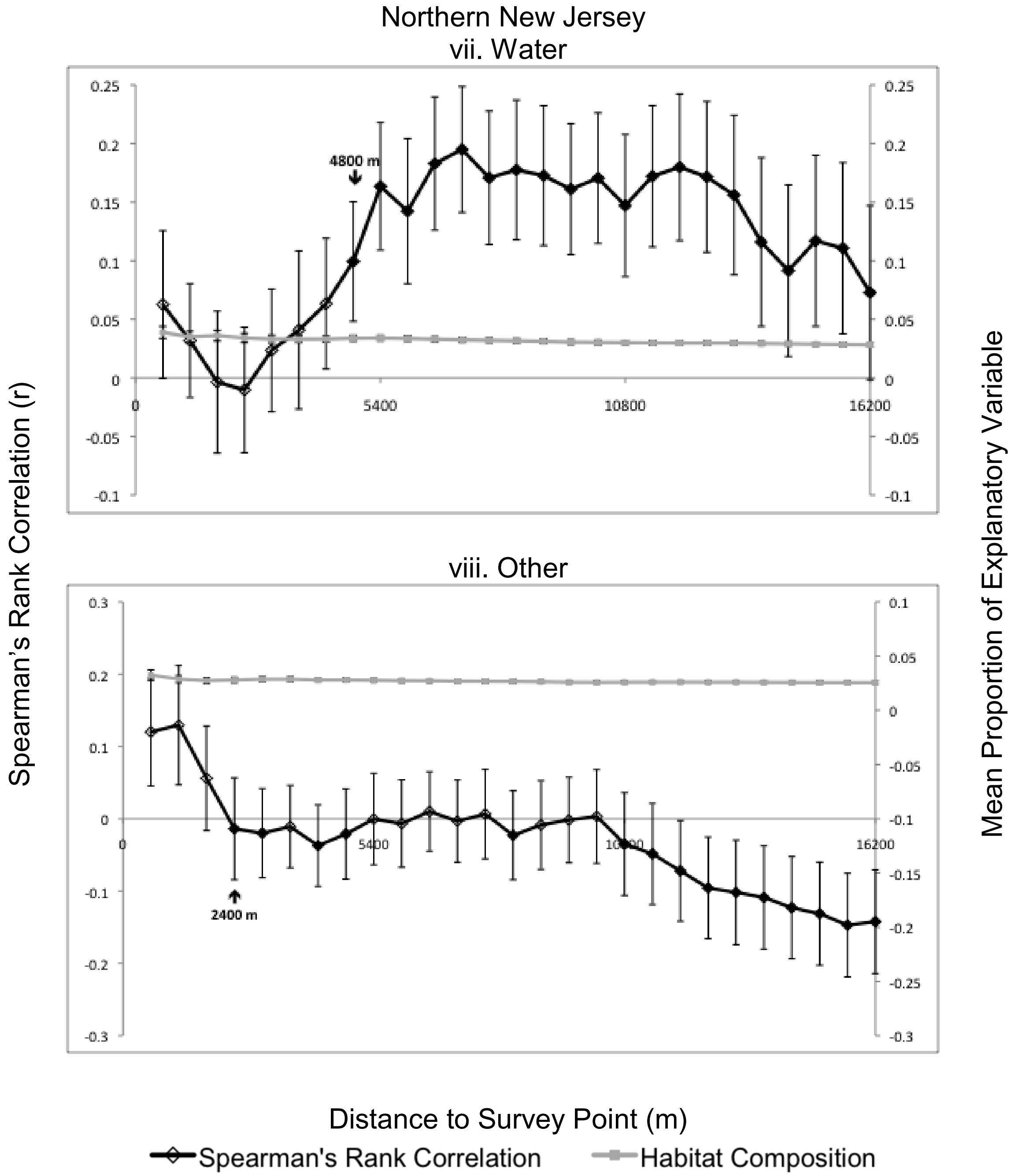


Figure 2A-B: Mean ± standard error of Spearman's Rank Correlation Coefficient between explanatory habitat variables measured within buffers of 0.6km to 16.2km in 600m increments around each stream survey site in (A) Southern and (B) Northern New Jersey, USA, 2011-2012. Mean proportions of habitat variables measured at each spatial scale are depicted in grey. Black points indicate distances statistically similar to the buffer distance with the strongest correlation. Arrows indicate distance used.

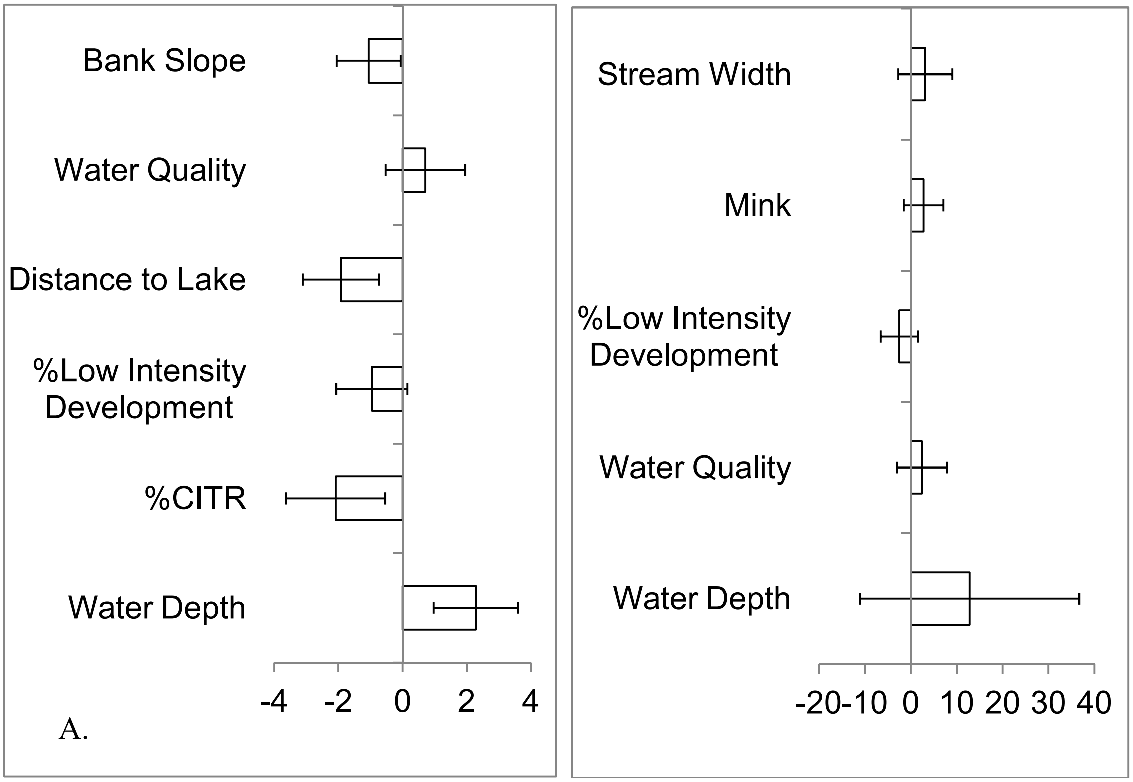


Figure 3A-B: Direction and relative effect size (standardized model-averaged partial regression coefficient) for covariates in the top model for (A) Southern and (B) Northern New Jersey, USA. Error bars denote 95% confidence intervals of strong effects for both Southern and Northern New Jersey respectively while being based on unconditional variance estimates.

Chapter 5

DISCUSSION

The primary objective of this study was to determine which habitat variables, while accounting for detection, affected river otter occupancy in a highly developed anthropogenic system. As expected, precipitation and snow cover had a negative impact on otter detection for Southern New Jersey. Every stream site is different in its capabilities to drain, so site-specific precipitation and drainage has the potential to wash away otter tracks or scat. While I did find that snow can be a viable substrate for otter tracks and scat, it more often would cover otter sign, supporting the observation of Jeffress et al. (2011*a*) that snow had the lowest detection probability of the substrates in their study. The ability to detect river otters varies seasonally, with river otters known to me most active during those months associated with winter/spring because it corresponds to their breeding season (Melquist and Hornecker 1983, Stevens and Serfass 2008). The My results indicate that there is still slight monthly variation in otter activity during this four month time period. Interestingly, increasing time in months had a negative effect on detection in Southern New Jersey, indicating that observers had a higher likelihood of detecting otter sign early in winter.

Previous literature has debated the effectiveness of bridge sign surveys to most accurately determine river otter occupancy (Gallant et al. 2008, Roberts et al. 2008, Crimmins et al. 2009, Stevens et al. 2011, Just et al. 2012). Due to the increased human activity associated with bridge sites versus random stream sites, otters could choose to avoid bridge sites. Thus by relying solely on bridge sign surveys, it's possible that one could underestimate occupancy. Unlike those studies, my research did not seek to compare the effectiveness between bridge surveys and random or select site surveys. However, they do share two key similarities with my own research, 1) the bridge sign survey component and 2) surveys taking place in the winter/spring, sometime between January and April. In Missouri, Roberts et al. (2008) detected otter sign at 82% of 225 bridge crossings and Crimmins et al. (2009) detected otter sign at 67.5% of 40 visits to 10 bridge sites. While in Pennsylvania and Maryland, Just et al. (2012) and Stevens et al. (2011) detected otter sign/latrines at only ~30% of 15 bridge sites and ~10% of 26 bridge sites respectively. Finally, Jeffress et al. (2011*a,b*) detected river otter sign in Kansas at 35 of 110 sites for a naïve occupancy of 0.318 and predicted occupancy of 0.329. These studies present a wide range of values for otter detection/occupancy due to different habitat types, population sizes, and survey methodologies; however, my values for both Southern and Northern New Jersey lie within that range. However my naïve occupancy percentages for each sampling region could have been different if I had chosen to survey random stream sites as well as bridge sites or been able to survey higher order streams. Additionally, my study only focused on inland freshwater streams but sign surveys conducted in coastal habitats could also produce different results.

The level of impact that anthropogenic related activity has on river otter occupancy has been questioned and addressed in previous literature (Herrighty 1978, Melquist and Hornecker 1983, Jeffries 1987, Durbin 1998, Barbosa et al. 2001, Gallant et al. 2009, Lundy and Montgomery 2010). However, given that New Jersey has the densest human population of any state, it was important to determine what effect, if any, it could have on otter occupancy. If human activity/development impacts otter occupancy, it can do so either directly or indirectly. Direct effects on otter occupancy occur if anthropogenic disturbance causes otters to avoid a particular area regardless of the condition of the habitat while indirect effects would involve corresponding changes to a habitat as a result of increased anthropogenic activity. Gallant et al. (2009) and Barbosa et al. (2001) found that environmental or habitat related factors are more likely to influence otter occupancy than direct anthropogenic activity. Melquist and Hornecker (1983) suggested that as long as adequate habitat is present, otters are tolerant of some level of human-related disturbance. Jeffries (1987) and Durbin (1998) also observed that otters were not negatively influenced by the presence of humans or anthropogenic structures such as roads or bridges. However, Lundy and Montgomery (2010) found that otter occupancy was negatively associated with urban land cover. In my study, the occupancy models for both Southern and Northern New Jersey also showed that urban land cover negatively impacted river otter occupancy. Whether the negative relationships with % Low Intensity Development and % CITR in this study are a function of direct or indirect effect remains unknown; however, because I often observed otter sign near bridges, roads, or close proximity to human habitation, it is possible indirect effects could play a larger role.

In my study, % Upland Natural habitat did not appear in my final predictive occupancy models for both Southern and Northern New Jersey. Literature has shown that the presence of surrounding upland forests or trees along the stream bank is positively related to otter occupancy (Bas et al. 1984, Dubuc et al. 1990, Newman and Griffin 1994, Crowley et al. 2012). Bas et al. (1984) mentioned the positioning of otter scat/latrines in close proximity to trees and wooded areas. Newman and Griffin (1994) and Crowley et al. (2012) found that the presence of conifers in particular was associated with otter occupancy. While % Natural Upland was not a significant predictor, at some survey sites I noticed otter scat/latrines located within tree root systems or very close to individual trees. Additionally, I observed otters would use fallen leaves or pine needles to construct mounds, on which they would defecate. These field observations would imply that streamside zones and riparian areas, specifically the presence of tree species, are important components of river otter habitat. Perhaps future research comparing the %vegetation cover and tree species present along the stream banks of unoccupied and occupied stream sites would reveal more information regarding the importance of these areas for river otters.

The amount of water, water quality and the density of water bodies are all known habitat parameters for river otters (Herrighty 1978). In my study, occupied sites had deeper water than unoccupied sites in both Southern and Northern New Jersey. Previous literature has also shown that water depth is typically higher at sites occupied by river otters (Madsen and Prang 2001, Prenda et al. 2001). Water quality positively appeared in the predictive model for both Southern and Northern New Jersey but effect size standard error overlapped with zero. This weakly supported the observation of Prenda et al. (2001) that otters occupied unpolluted sites. Distance to lake, which was negatively correlated with river otter occupancy and had a strong effect size, also only appeared in the predictive model for Southern New Jersey. Thus river otters tended to be detected at sites that were positioned closer to these other open water bodies (i.e. lakes, ponds, or reservoirs). Melquist and Hornecker (1983) found that otters used lakes, reservoirs, and ponds most often during the winter. In New Jersey, I observed that some open water bodies were stocked with fish, which could be driving otter usage. Additionally, some of the stream sites that I surveyed either flowed into or out of these open water bodies. So, given that otters are potentially foraging in these open water bodies and knowing that they tend to move along streams to navigate through the environment (Melquist and Hornecker 1983), there is a good chance of finding otter sign along those connecting or nearby streams. The final water related covariate, stream width, only appeared in the Northern New Jersey predictive occupancy model as a positive relationship but its effect size did not differ from zero. Prenda et al (2001) found that otters were more likely to occupy wider stream sites (2–20 m) instead of narrower sites (<1 m) and Durbin (1998) also observed that otters spent more time in wider stream sections.

When discussing the factors that affect otter occupancy and habitat use, it is important to consider the interaction with two other furbearer species, mink (*Mustela vison*) and beaver (*Castor canadensis*). Mink activity/presence only appeared in the predictive otter occupancy model for Northern New Jersey and showed a weak positive correlation. While a correlation existed, it is unlikely it indicated a causative effect. Previous literature would suggest that there is overlap in habitat type preferences for both species (Erlinge 1972, Ben-David et al. 1996, Lundy and Montgomery 2010). Mink and otters are able to coexist within the same habitats ultimately because they each fill a different niche, which includes utilizing different parts of the habitat and favoring different prey species (Erlinge 1972, Ben-David et al. 1996). Erlinge (1972) suggests that even in the winter, when there is increased overlap/competition, that mink and otters are still capable of coexisting. Additionally, Melquist and Hornecker (1983) never observed aggressive interactions between these two species. This provides further support of resource partitioning between mink and otters.

Literature suggests that beaver presence/activity can be a key predictor for otter activity/presence and even the location of otter latrines (Dubuc et al. 1990, Newman and Griffin 1994, Swimley et al. 1998, Swimley et al. 1999, LeBlanc et al. 2007). Otters are also known to use/inhabit beaver created wetlands and ponds (Newman and Griffin 1994, Gallant et al. 2007) and beaver lodges (Melquist and Hornecker 1983). While I did observe otter and beaver activity/presence at the same stream sites and even found otter sign in close proximity to beaver lodges or dams, results from my study indicated that beaver activity/presence did not correlate with otter occupancy. Thus it did not appear in the Southern or Northern New Jersey predictive models. This result could indicate that while beaver presence/activity could be beneficial for otters, it is not necessarily a determinant of otter occupancy at a site.

Chapter 6

MANAGEMENT IMPLICATIONS

Knowing the location of occupied stream sites and specifically otter latrines will assist the New Jersey Division of Fish and Wildlife in their efforts to monitor river otter populations. Furbearer biologists can further utilize this information to help estimate river otter density throughout the state. These density estimates are ultimately used to set harvest regulations. Also, by determining the covariates that best correlate with otter occupancy and understanding the nature of the relationship between those covariates and otter occupancy, it's possible to predict occupancy at sites that have not yet been surveyed.

Overall, river otter occupancy in both Southern and Northern New Jersey seems to be more influenced by environmental/habitat factors over direct anthropogenic effects. However, indirect effects of anthropogenic activity, including habitat alteration and loss especially associated with Commercial/Industrial/Transportation/Recreation or Low Intensity Development is still a cause for concern. That being said, it is important for wildlife managers to reduce, or when possible, eliminate anthropogenic activity in close proximity to high quality otter habitat in order to prevent habitat degradation. Going forward, the water and habitat quality surveys conducted by the New Jersey Department of Environmental Protection will be a critical tool to determine if or how habitats are being affected as a result of changes in anthropogenic activity and human population growth.

At least in Northern New Jersey, protecting this high quality habitat should also have a positive impact on the mink populations. Even though beaver presence/activity did not appear in either the Southern or Northern New Jersey predictive otter occupancy models, I still believe that maintaining beaver populations can be beneficial to otters. Further research would be helpful to investigate mink/otter and beaver/otter interactions in New Jersey. Finally, wildlife managers can enhance the habitat by constructing lakes, ponds (i.e. irrigation ponds), etc and by doing so it should help facilitate otter presence/occupancy at that specific site and movement through the surrounding area.

Chapter 7

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APPENDIX A: Location and occupancy of river otters at sampled stream sites in (A) Southern New Jersey and (B) Northern New Jersey, USA.

A.

Site Identifier	General Location	GPS Coordinates (Decimal Degree)		Otter Occupancy (Y/N)
		Longitude	Latitude	
ANO-115A	Miry Run where it crosses rt 533	-74.686958	40.249608	Y
IBI-161	Millstone River where it crosses Jamesburg-Perrinville Rd	-74.437058	40.272306	Y
RP-72	Wreck Pond Brook where it crosses Rt 138	-74.078680	40.170770	Y
OH-87	Manasquan River where it crosses Rt 547	-74.154510	40.161660	Y
OH-51	S Br Metedeconk River where it crosses Brewers Bridge Rd	-74.265330	40.116310	Y
OH-52	Dove Mill Brook where it crosses Grawtown Rd	-74.291130	40.069120	Y
OH-81	Beaver Dam Creek where it crosses Rt 88	-74.109270	40.074830	Y
OH-65	Metedeconk River where it crosses cr 549	-74.156740	40.078770	Y
OH-78	Cedar Bridge Brook where it crosses cr 528	-74.172030	40.070870	N
IBI-142	Pine Mount Creek where it crosses cr 623	-75.347778	39.413611	N
OH-16	Sheppard's Mill Creek cr 650	-75.320000	39.411111	Y
ANO-712	Cohansey River where it crosses Holding Rd and cr 607	-75.255556	39.472500	Y
IBI-135	Indian Field Br where it crosses cr 638 Burlington Rd	-75.210278	39.435556	N
ANO-749	Muddy Run where it crosses cr 638 Jessie Bridge Rd	-75.092222	39.470556	Y
ANO-756	Buckshutem Str where is crosses 555 Dividing Creek Rd	-75.062500	39.347778	Y
IBI-126	Scotland Run where it cross rt 322	-75.041111	39.693056	N
OS-4	Fourmile Br where it crosses rt 536	-74.981389	39.704722	N
RP-52	Great Egg Harbor River where it crosses CR 705 Sicklervile Rd and rt 536 spur	-74.937500	39.701667	Y
OH-3	Pump Branch where it crosses road (perpendicular to Beebetown Rd)	-74.883889	39.706111	Y
ANO-637	Deep Run where it crosses Weymouth Rd rt 559	-74.781944	39.507500	Y
RP-002	Hospitality Br where it crosses Whitehall Rd	-74.948056	39.638056	N
OH-89	Little Mill Creek where it crosses cr 616 main st	-74.966111	39.284722	N
OH-50	Crowder Run where it crosses rt 47	-74.969167	39.266111	N
ANO-765	West Creek where it crosses rt 550 Leesburg-Belleplain Rd	-74.911944	39.260000	Y
ANO-766	Savages Run where it crosses Sunset Rd	-74.876389	39.242222	Y
OH-47	East Creek where it crosses rt 347	-74.885833	39.221944	Y
OH-19	Dennis Creek (tributary) where it crosses rt 47	-74.841389	39.194722	Y
ANO-696	Game Br where it crosses rt 48	-75.437222	39.699444	Y
OH-11	Game Creek where it crosses rt 48	-75.428333	39.691389	Y

OH*	Oldman's Creek where it crosses cr 605 Swedesboro Rd	-75.318056	39.691111	N
OH-24 Raccoon Creek	Raccoon Creek where it crosses rt 538 Swedesboro Franklinville Rd	-75.229722	39.700833	N
OH-24 Springers Creek	Springer's Brook where it crosses rt 206	-74.738333	39.779167	Y
ANO-679	Misery Run where it crosses cr 641 Ellis Mill Rd	-75.184722	39.685833	N
OH-22	Alloway Creek where it crosses rt 581	-75.330278	39.576111	Y
ANO-157	Jade Run where it crosses rt 206	-74.743056	39.936389	Y
ANO-156	S Br Rancocas Creek where it crosses cr 642 Ridge Rd	-74.717778	39.923333	Y
RP-51	Mullica River where it crosses rt 206	-74.726389	39.740556	Y
OH-70	Gum Br where it crosses rt 206	-74.753056	39.698333	N
OH-34	Hammonton Creek where it crosses rt 30	-74.771111	39.631111	N
OH-54	Assicunk Creek (tributary) where it crosses cr 660 Fountain Woods Rd	-74.841111	40.063333	N
CP-1	Assicunk Creek where it crosses cr 660 Old York Rd	-74.798889	40.071944	N
ANO-129	Doctor's Creek where it crosses Breza Rd (New Rd)	-74.598889	40.176944	N
ANO-124	Lahaway Creek where it crosses cr 27 Holmes Mill Rd	-74.536389	40.106944	Y
ANO-121	Crosswicks Creek where it crosses rt 537 Mt Holly Freehold Rd	-74.540833	40.084167	N
IBI-130	Lahaway Creek where it crosses SmithsMill rd (probably has new name now)	-74.493611	40.117500	Y
OH-10	Tuckahoe River where it crosses rt 49	-74.820556	39.306389	Y
OH-31	Gibson's Creek where it crosses rt 50	-74.756111	39.352778	N
OH-57	Stephen's Creek where it cross rt 50	-74.749167	39.392778	Y
ANO-644	South River where it crosses Walkers Forge rd	-74.755556	39.440278	Y
RP-014	Watering Race Br where it crosses rt 50	-74.715278	39.472778	Y
OH-26	Muskee Creek where it crosses rt 548 Weatherby Rd	-74.958333	39.315833	Y
ANO-151A	N Br Rancocas Creek where it crosses Birmingham Buddtown rd	-74.709722	39.979444	Y
RP-050	Friendship Creek where it crosses Friendship Rd	-74.693056	39.871111	Y
IBI-133	Burrs Mill Bk where it crosses Burrs Mill Rd	-74.657222	39.886111	Y
IBI-132	Jade Run where it crosses Burrs Mill Rd	-74.688611	39.935556	N
ANO-145	Mt. Misery Bk where it crosses rt 70	-74.531111	39.928889	Y
RP-046	W Br Wading River where it crosses rt 532 Chattsworth Barnegat Rd	-74.546944	39.814444	Y
OH-17	Mantua Creek where it crosses cr 635 Lambs Rd	-75.117500	39.754722	N
OS-2	Still Run where it crosses cr 610 Clayton Rd	-75.108889	39.652778	Y
IBI-125*	Little Ease Run where it crosses cr 610 Clayton Williamstown Rd	-75.067500	39.659444	N
OH-12	Indian Br where it crosses Station ave	-75.015833	39.607222	N
ANO-725	Scotland Run where it crosses rt 40	-75.058333	39.573333	Y
RP-040	Mullica River where it crosses rt 534	-74.799722	39.778056	N

	Jackson Rd/Shamong Rd			
OH-99	Indian Mills Bk where it crosses rt 534 Oakshade Rd	-74.767500	39.804167	Y
ANO-160	Little Creek where it crosses cr 616 Chruch Rd	-74.788056	39.922778	Y
ANO-166	Barton Run where it crosses cr 620 Tuckerton Rd	-74.860278	39.878889	N
ANO-168	SW Br Rancocas Creek where it crosses Hartford Rd	-74.835833	39.888611	N
ANO-169	Haynes Creek(SW Br Rancocas Creek) where it cross rt 70	-74.812500	39.904444	N
ANO694	Major Run where it crosses Pointer Sharptown Rd	-75.374440	39.648610	Y
ANO697	Culliers Run where it crosses Bassett Rd (moved to rt 45)	-75.391670	39.615280	N
ANO698	Swedes Run where it crosses Swedes Bridge rd	-75.375830	39.596390	N
ANO692	Nichomus Run where it crosses rt 45	-75.349170	39.639720	N
ANO691	Creek by Memorial Lake where it crosses Mill Street	-75.330280	39.643610	Y
ANO690	Salem River where it crosses rt 581	-75.268060	39.621670	Y
ANO753	Mill Creek where it crosses rt 52-West Sherman ave	-75.107500	39.438060	Y
ANO758	Panther Branch where it crosses genoa avenue	-74.951670	39.467220	Y
ANO757	Cedar Branch where it crosses Italia Avenue (moved to Hance Bridge Rd)	-74.956110	39.450560	Y
ANO759	Menatico Creek where it crosses rt 552	-74.965830	39.419170	N
ANO762	Manumuskin River where it crosses rt 522	-74.911940	39.428610	Y
ANO191	Cooper River S Br where it crosses rt 41	-75.021940	39.903330	N
ANO183	Pennsauken Creek S Br where it crosses rt 41	-74.982780	39.940280	N
ANO178	Pennsauken Ck N Br where it crosses Church Rd	-74.933890	39.932500	N
IBI-131	S Br Pennsauken Creek where it crosses CR 673 Springdale Rd	-74.964440	39.920830	N
ANO187	Cooper River N Br where it crosses Springdale Rd	-74.968610	39.888610	N
ANO190	Cooper River where it crosses W Evesham Rd	-75.015830	39.859440	N
ANO621	Great Egg Harbor River where it crosses rt 536 (williamstown-new freedom Rd)	-74.951390	39.733890	Y
ANO570	Blue Anchor Bk where it crosses rt 143	-74.853060	39.682780	N
ANO626	Penny Pot Stream where it crosses 8th street	-74.817500	39.580000	N
ANO625	Great Egg Harbor River where crosses rt 54	-74.851670	39.594720	Y
ANO634	Three Pond Bk where it crosses rt 54	-74.867220	39.581110	N
IBI-121	Pompeston Creek where it crosses New Albany Rd (off CR 603)	-74.965830	39.973330	N
IBI-120	Swede Run where it crosses Garwood Rd	-74.933060	39.995280	N
ANO-175	Mill Creek where it crosses Levitt Parkway	-74.893890	40.035830	N
ANO-171	Bobby's Run where it crosses Municipal Drive	-74.805280	39.963610	Y
ANO-173	Mason's Creek where it crosses rt 38	-74.857220	39.972220	N
ANO713	Barrett Run where it crosses Maple Ave	-75.273330	39.444720	N

	(could move to where crosses rt 49)			
ANO705	Stow Creek where it crosses rt 624	-75.345830	39.477780	Y
ANO707	Canton Drain where it crosses Maskell Mill Rd-cr 658	-75.400000	39.485830	Y
ANO703	Deep Run where it crosses Waterworks Rd	-75.373610	39.554440	Y
ANO700	Cool Run where it crosses Stockingham-Pleasant hill rd	-75.309440	39.578890	N
ANO683	Racoon Creek where it crosses Tomlin Station Rd	-75.258610	39.740280	Y
ANO-674	Edwards Run where it crosses Jessup Mill Rd	-75.198060	39.785560	Y
ANO-680	Raccoon Creek where it crosses N Main Street	-75.224170	39.736390	Y
ANO670	Chesnut Br where it crosses Lambs Rd	-75.145280	39.736110	N
IBI-206	Mason's Run where it crosses Little Mill Rd	-75.014170	39.795000	N
ANO731	Reed Branch where it crosses cr 667-Willow Grove rd	-75.112500	39.625560	N
ANO735	Burnt Mill Bk where it crosses rt 47	-75.044720	39.531670	Y
ANO750	Parvin Brook where it crosses rt 47	-75.043890	39.462220	N
ANO748	Muddy Run where it crosses Parvin's Mill Rd	-75.128890	39.506940	Y
ANO747	Indian Run where it crosses Husted Station Rd	-75.183890	39.535560	Y
ANO136	Crafts Creek where it crosses Island Rd	-74.701390	40.073890	N
ANO-150	Budds Run where it crosses Pemberton-Julioustown Rd	-74.681110	39.976390	N
ANO-148	Greenwood Br where it crosses New Lisbon Rd	-74.629170	39.960000	Y
IBI-130	North Run where it crosses cr 680-McGuire access highway	-74.589170	40.039440	N
ANO-132	Blacks Creek where it crosses Chesterfield-Georgetown Rd	-74.641670	40.109440	N
ANO-484	Hannabrand Bk where it crosses Old Mill Rd	-74.053230	40.143550	Y
ANO-495	Mingammahone Bk where it crosses rt 524	-74.149930	40.166030	Y
ANO-491	Marsh Bog Brook where it crosses Cranberry Rd	-74.181250	40.214460	Y
ANO-497	Squankum Bk where it crosses 549	-74.153410	40.150990	Y
ANO-503	Haystack Bk where it crosses Southard Rd	-74.199300	40.146390	Y
ANO-528	Ridgeway Bk where it crosses rt 70	-74.273710	40.021290	Y
ANO-515	Kettle Creek where it crosses New Hampshire Ave	-74.196750	40.049230	Y
ANO-523	Toms River where it crosses rt 547	-74.274630	40.061550	Y
ANO-521	Maple Root Bk where it crosses Bowman Rd	-74.327030	40.081230	N
ANO-545	Webbs Mill Bk where it crosses rt 539 @ northern most crossing	-74.380193	39.891313	Y
ANO-548	Cedar Creek where it crosses Double Trouble Rd	-74.225200	39.894080	Y
ANO-542	Jakes Br where it crosses Dover Rd	-74.273571	39.915400	N
ANO-541	Davenport Branch where it crosses CR 530	-74.296870	39.941610	Y
ANO-597	Shoal Bk where it crosses Jones Mill Rd	-74.508373	39.776399	Y
ANO-605	Papoose St where it crosses Jenkins Rd	-74.452581	39.742035	Y
ANO-552	Oyster Creek where it crosses rt 532	-74.250189	39.798305	Y

ANO-555	Mill Creek where it crosses rt 72	-74.281730	39.714920	N
ANO-618	Patcong creek where it crosses spruce avenue	-74.593120	39.395670	Y
ANO-619	Maple Run where it crosses Mill rd	-74.571740	39.375550	Y
ANO-590	Landing Creek where it crosses rt 30	-74.657580	39.535650	N
ANO-593	Indian Cabin Creek where it crosses 5th avenue	-74.663830	39.571040	Y
ANO-614	Morses Mill Stream where it crosses S Pomona rd	-74.540280	39.494950	Y
ANO-613	Clarks Mill Stream where it crosses rt 575	-74.507780	39.516010	Y
ANO-610	W Br Bass River where it crosses Stage rd	-74.446010	39.624250	Y
ANO-615	Matrix Run where it crosses Moss Mill rd (rt 561)	-74.479310	39.494260	Y
IBI-166	Devil's Brook off New Rd	-74.545140	40.362100	N

B.

Site Identifier	General Location	GPS Coordinates (Decimal Degree)		Otter Occupancy (Y/N)
		Longitude	Latitude	
FIBI-065	Little Flat Brook where it crosses cr 656	-74.803669	41.239514	N
FIBI-066	Big Flat Brook where it crosses rt 560	-74.815597	41.199982	N
IBI-27	Little Flat Brook where it crosses rt 560	-74.908828	41.126729	Y
IBI-72	Flatbrook tributary where it crosses Mountain Rd	-74.826675	41.215798	N
IBI-88	Big Flat Brook where it crosses Deckerton Turnpike	-74.708481	41.257886	Y
OH-93	Paulins Kill where it crosses rt 206	-74.714510	41.119055	N
AN0-299	Wallkill River where it crosses unknown Rd	-74.578789	41.133502	Y
FIBI-040	Papakating Creek tributary where it crosses cr 639	-74.631533	41.197141	Y
IBI-233	Pequannock River tributary where it crosses unknown Rd	-74.527614	41.079487	N
OH-73	Wallkill River where it crosses cr 642	-74.548727	41.260110	N
OH-74	Black Creek where it crosses cr 644	-74.489313	41.211199	N
OH-75	Black Creek where it crosses McPeek Rd or Sandhill Rd	-74.511233	41.194568	N
FIBI-055	Paulins Kill where it crosses cr 603	-75.020590	40.966592	N
OH-35	Paulins Kill where it crosses W Chrisman Rd	-75.038164	40.957307	Y
OH-38	Jacksonburg Creek where it crosses Millbrook Rd (cr 602)	-74.965265	41.039279	N
OH-84	Delaware Creek where it crosses cr 605 or Lime Klin Rd	-75.062437	40.905467	N
OH-95	Yards Creek where it crosses Wishing Well Rd	-75.044787	40.972890	N
OH-96	Yards Creek where it crosses Mt Vernon Rd	-75.032165	40.995413	N
FIBI-012	Unknown stream where it crosses cr 622	-74.827056	41.084636	Y
FIBI-081	Trout Brook where it crosses cr 612	-74.861480	41.055697	N

FIBI-100	Paulin's Kill tributary (Dry Brook) where it crosses unknown Rd	-74.745378	41.143753	N
IBI-23	Swartswood Creek (tributary) where it crosses Mt Benevolence Rd	-74.849094	41.106161	Y
OH-36	Unknown stream where it crosses cr 617	-74.893664	41.085048	N
OH-42	Paulins Kill River where it crosses Lambert Rd	-74.992683	40.978000	N
FIBI-049	Wallkill River where it crosses unknown Rd	-74.594945	41.086917	Y
IBI-220	Paulins Kill tributary where it crosses Garrison Rd	-74.694736	41.076200	N
OH-27	Lubbers Run where it crosses rt 206	-74.718740	40.926670	N
OH-4	Wallkill River where it crosses W Mountain Rd	-74.622045	41.053861	Y
OH-56	Weldon Brook where it crosses unknown Rd	-74.582821	40.990456	N
OH-7	Rockaway River where it crosses cr 699-Berkshire Valley Rd	-74.570963	40.954130	Y
FIBI-010	Clinton Brook where it crosses La Rue Rd	-74.440271	41.060038	N
FIBI-075	Pequannock River where it crosses rt 23	-74.487215	41.075565	Y
IBI-183	Pequannock River where it crosses Oak Ridge Rd (cr 699)	-74.501602	41.039037	N
IBI-311	Pequannock River where it crosses Cozy Lake and Oak Ridge Rd	-74.484488	41.042700	N
OH-18	Pequannock River where it crosses cr 515	-74.513413	41.115451	N
OH-41	Kanouse Brook where it crosses Conklin Rd	-74.426783	41.068247	N
FIBI-077	Pequannock River where it crosses rt 511	-74.334681	41.003694	N
FIBI-096	Wanaque River where it crosses cr 689	-74.292463	41.007292	N
OH-5	Wanaque River where it crosses cr 704	-74.330381	41.159944	Y
OH-66	Long House Creek where it crosses unknown Rd (by Upper Greenwood)	-74.370451	41.186482	N
OH-91	Macopin River where it crosses Gould Rd	-74.402378	41.074039	N
OH-92	Macopin River where it crosses Echo Lake Rd (cr 695)	-74.406377	41.048144	N
FIBI-044	Deepavaal Brook where it crosses cr 613	-74.272422	40.886575	N
OH-45	Weasel Creek where it crosses unknown rd (maybe cr 667)	-74.158555	40.964948	N
OH-61	Black Brook where it crosses Columbia turnpike (rt 510)	-74.412813	40.790609	N
OH-90	Passaic River where it crosses Horse Neck rd (cr 626)	-74.340136	40.882165	Y
ANO-243	Rockaway River where it crosses West Main Street (by train tracks)	-74.533551	40.880288	N
FIBI-047	Beaver Brook where it crosses Hope Crossing Rd	-75.040376	40.845485	N
FIBI-058	Musconectong River where it crosses rt 46	-74.820388	40.848024	Y
OH-21	Musconectong River where it crosses Waterloo Rd	-74.736642	40.919290	N
OH-8	Black River (lamington river) where it crosses state park Rd	-74.722516	40.753217	N
OH-88	Furnace Brook where it crosses rt 31	-74.994732	40.803709	N
FIBI-041	Shabakunk Creek where it crosses rt 206	-74.755271	40.249160	Y

FIBI-053	Mulhockaway Creek where it crosses cr 635	-74.947949	40.659450	N
OH-37	S Branch Raritan River where it crosses rt 202	-74.813602	40.519109	Y
OH-58	Assunpink Creek where it crosses Bakers Basin Rd	-74.688393	40.267987	N
FIBI048	Buckhorn Creek where it crosses Reeder Rd	-75.116520	40.773600	Y
FIBI004	Lopatcong Creek where it crosses rt 519	-75.140860	40.694670	Y
IBI-270	Merrrill Creek where it crosses Stewartsville Rd and CR 638-New Village Rd	-75.111070	40.694490	N
FIBI067	Pohatcong Creek where it crosses Willow Grove Rd	-75.084980	40.698220	Y
FIBI061	Musconectcong River where it crosses rt 78 or rt 173	-75.078890	40.661790	Y
FIBI003	Pequest River where it crosses Pequest Furnace Rd	-74.971010	40.828770	Y
ANO260	Mossman's Bk where it crosses Clinton Rd	-74.434310	41.107020	N
FIBI011a	High Mountain Brook where it crosses Mullen ave	-74.286410	41.050320	N
FIBI006	Ramapo River where it crosses unknown Rd	-74.241320	41.036700	Y
ANO-286	Ramsey Bk where it crosses Masonicus Rd	-74.122660	41.081970	N
FIBI007	Saddle River off Upper Cross Rd	-74.100960	41.050620	N
FIBI098	Singac Brook where it crosses Preakness ave	-74.222980	40.929890	Y
FIBI069	Troy Bk where it crosses S Beverwyck Rd	-74.389740	40.854550	N
ANO231D	Canoe Bk where it crosses cr 606	-74.336900	40.748670	N
FIBI020	Rahaway River off Rt 509	-74.312960	40.673390	N
ANO226	Dead River where it crosses Somerville Rd	-74.592550	40.656390	Y
IBI-167	Middle Brook where it crosses Lamington Rd	-74.682320	40.668790	N
IBI-047	Raritan River where it crosses Washington Turnpike near Ralston	-74.625584	40.771231	N
IBI-119	S Br Raritan River off rt 46	-74.760830	40.859470	Y
IBI-272	Teetertown Brook where it crosses Trimmer Rd	-74.838640	40.743770	N
IBI-120	Boulder Hill Brook where it crosses Farmersville Rd	-74.776070	40.711030	Y
FIBI054	Lamington River where it crosses Mccan Hill Rd	-74.722670	40.690100	Y
ANO320	Willoughby Bk where it crosses rt 31	-74.915250	40.671790	Y
FIBI036	Spruce Run where it crosses rt 31	-74.936920	40.691290	N
IBI-282	Hakihokake Creek where it crosses Javes Rd	-75.091920	40.580150	N
FIBI-034	Unknown stream where it crosses Milford-Frenchtown Rd	-75.069020	40.548070	N
FIBI-026	Nishisakawick Creek where it crosses rt 12	-75.059480	40.527120	N

ANO-085	Warford Ck where it crosses rt 29	-75.062010	40.469400	N
FIBI-027	Lockatong Creek where it crosses rt 519	-75.021020	40.471470	N
ANO-335	Back Bk where it crosses rt 609	-74.806230	40.459400	Y
FIBI-087	Neshanic Creek where it crosses rt 514	-74.753250	40.493460	N
FIBI-092	Holland Brook where it crosses cr 620	-74.738200	40.568660	N
FIBI-017	Pleasant Run where it crosses Locust Rd	-74.785210	40.552460	N
FIBI-008a	S Br Raritan River (tributary) where it crosses cr 617	-74.924220	40.613640	Y
FIBI-030	Stony Brook where it crosses Mine Rd	-74.793800	40.374150	N
ANO-102	Jacob's ck where it crosses Woosamonsa Rd	-74.838380	40.341560	N
FIBI-028	Moores Creek where it crosses Pleasant Valley Rd	-74.906840	40.332580	N
ANO-104	Woolsey's Bk where it crosses rt 546	-74.826190	40.307610	N
IBI-172	Back Brook off Bridgepoint Rd	-74.656320	40.435800	N
ANO-407	Tenmile Run where it crosses Canal Rd	-74.585790	40.456400	N
FIBI-022	Sixmile Run where it crosses cr 615	-74.544400	40.469660	Y
ANO-412	Royce Bk where it crosses rt 206	-74.647230	40.496870	N
ANO-415	Cuckels Bk where it crosses rt 28	-74.570100	40.568850	N
ANO-400	Rock Bk where it crosses Burnt Hill Rd	-74.684510	40.413680	N
ANO-398	Beden's Bk where it crosses Aunt Molly Rd	-74.739530	40.383690	N
FIBI-013	Heathcote Brook where it crosses Mapleton Rd	-74.615700	40.369980	N
ANO-394	Duck Pond Bk where it crosses rt 1	-74.667730	40.306760	N