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Factors Affecting Occupancy and Abundance of American Alligators at the Northern Extent of Their Range

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ABSTRACT.—**Populations of American Alligators (*Alligator mississippiensis*) generally are considered more abundant at present than historically; however, little information exists to assess the population of alligators in North Carolina at the northern extent of the species' range. Investigation of the factors influencing the distribution and abundance of alligators in North Carolina could shed light on the species' response to rapid environmental change in the region. We conducted a two-phase study: 1) to assess the distribution of alligators in North Carolina using a site-occupancy design; and 2) to assess the patterns in abundance using a repeated sampling design for population estimation. Results showed that both occupancy and abundance decreased in more northern sites, in sites with higher salinity, and in sites that were generally more westward. Sites sampled later in June were more likely to be occupied than those sampled earlier in the month. Abundance also increased with greater shoreline vegetation complexity and varied between lakes, rivers, and estuaries. Compared with studies from 30 years prior, the population seems fairly stable in terms of abundance and distribution. Given the northern limits of the species and the negative association with salinity, continued monitoring is warranted to understand changes in distribution and abundance with respect to predicted rates of sea-level rise, salinization, and urbanization locally around coastal cities like Wilmington.**

Since removal from the Endangered Species list in 1987, American Alligator (*Alligator mississippiensis*) populations have continued to rebound. Historically, unregulated harvest and habitat loss led to decreased alligator abundance throughout their range, resulting in federal protection. Following population recovery, many states have since established monitoring programs, regulated harvest seasons, farming industries, and nuisance control (Owen et al., 2010). Populations of alligators generally are considered more abundant at present than historically (Hines, 1979; Irwin and Wooding, 2002; Lutterschmidt and Wasko, 2006; Barrow, 2009), and the species' present range is likely close to its historical range (Joanen, 1974; O'Brien, 1983). Although this recovery can be considered successful, alligator populations will face a new set of threats and challenges in the near future.

Confounding effects related to climate change are likely to affect alligator distributions and population sizes, particularly at the northern edge of their range (Dunham et al., 2014). Warming trends in the southeastern United States may allow for a northward expansion of the alligator range; however, local drought and dry conditions also could influence populations negatively (Mazzotti et al., 2009), as well as increase exposure to diseases. Sea level rise may lead to increased saltwater intrusions along the east coast that has seen greater increases in sea level rises than the global average (Sallenger et al., 2012). Although estuarine habitats are relatively protected, North Carolina continues to lose nontidal freshwater wetland resources to upland development, despite state and federal laws regulating wetland impact (Carle, 2011). Hence, human encroachment could reduce habitat quality and availability that may threaten alligator populations in the future (Guillete et al., 1994; Lutterschmidt and Wasko, 2006; Fujisaki et al., 2007; Mazzoti et al., 2009).

The pressure of expanding human populations and climate change effects may put pressure on alligator populations throughout their range; however, these challenges may be particularly important in North Carolina where human populations are rapidly growing and alligators are at the northern range limit. Significant life-history differences have been documented between alligators in North Carolina and those in more southern areas (Fuller, 1981; Klause, 1984). The relatively short growing season in North Carolina may restrict breeding, nesting, and hatching, especially in years with colder temperatures (Klause, 1984). Additionally, a statewide assessment of alligator distribution in the 1980s documented a large number of surveys with no alligator sightings, suggesting that alligators did not occur, or occurred at extremely low densities in significant portions of their potential North Carolina range (O'Brien and Doerr, 1986). Seventy-five percent of alligator observations were located on 25% of the total routes, and those routes were predominantly in protected areas. Most alligators were observed in the southern Cape Fear watershed with the greatest overall density of 0.3 alligators/km (O'Brien and Doerr, 1986). No follow-up assessment of the North Carolina population has been completed in the last 30 years, but projections from a recent population model by Dunham et al. (2014) suggested the northern population of American Alligators (i.e., North Carolina and South Carolina) could be declining.

Our objective was to determine the current distribution and abundance of alligators at the northern extent of the species, range, as well as the factors influencing these processes. To achieve these objectives, we designed a two-phase adaptive sampling approach (Conroy et al., 2008; Mathewson et al., 2012) by replicating surveys spatially and temporally across the range of alligators in North Carolina. We used nightlight surveys, a well-established sampling method for obtaining information on the distribution and abundance of crocodilians (Webb and Messel, 1979; Fujisaki et al., 2011). We combined data obtained from these surveys with hierarchical models to provide unbiased estimates of occupancy and abundance of alligators. We evaluated biotic and abiotic covariates to determine factors influencing the occurrence and abundance of alligators to better

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direct alligator conservation in the face of rapid environmental change.

Materials and Methods

Study Area.—We surveyed alligators across the 25 coastal counties in eastern North Carolina where previous research suggested alligators occur (O'Brien, 1983). The study area included portions of eight watersheds: the Chowan, Roanoke, Pasquotank, Tar-Pamlico, and Neuse Rivers flow into the Albemarle-Pamlico estuarine systems, whereas the Cape Fear River, Lumber, and White Oak River flow directly into the Atlantic Ocean (Street et al., 2005).

Surveys were stratified into three habitat types: rivers, lakes, and estuaries. Rivers were slow-flowing black and brown water streams with vegetation consisting almost entirely of forests of wetland trees. Lakes included human-made reservoirs, small millponds, and naturally occurring Carolina bay lakes. Estuaries included areas of open water, tidal flats, freshwater, brackish, and saltwater marshes, and submerged plant beds with wind and lunar tidal influences.

Data Collection.—We initiated a two-phase sampling approach (Conroy et al., 2008; Pacifici et al., 2012) that focused on occupancy surveys over a broad area in the first year (Phase I) and abundance surveys in areas of high predicted occupancy probability in the second year (Phase II). This approach provided a large-scale occupancy survey to determine distribution and landscape factors influencing alligator occupancy, a more fine-scale abundance survey to estimate population sizes at sites, and a method to determine factors influencing variation in population size.

In 2012, we used a stratified random sampling design to select 110 survey routes on rivers, lakes, and estuaries for Phase I occupancy surveys in the coastal counties of North Carolina (Fig. 1). All river and estuary survey routes were 16 km long and divided into 4-km spatial replicates. Because of variable sizes, the entire perimeter of lakes were surveyed and divided into as many 4-km spatial replicates as possible. Some survey routes were shortened or removed from sampling attributable to navigability issues or restricted access. Of the initial 110 selected survey routes, we were able to complete 103 survey routes.

Nightlight surveys were carried out from 2–30 June 2012. We selected the month of June to maximize detection of alligators, because this is when all size classes are most visible, and adult alligators move to more open waters (Woodward and Marion, 1978; Fuller, 1981; Lutterschmidt and Wasko, 2006). Trained field biologists followed a strict protocol to minimize observer and detectability bias. Survey teams, comprised of one observer and one navigator per boat, began each 16-km survey 30 min after sunset, and followed predetermined transects recorded in GPS units. The observer employed a 200,000 candlepower Q-beam spotlight, directly plugged into a constant power source to minimize battery strength variability. Observers swept the surface of the water with the beam to detect distinct red alligator eye shine. We recorded alligator eye shine detections within each spatial replicate. Because of logistical constraints associated with sampling over 100 survey routes, we used spatial, instead of temporal, replication for our study design.

For each survey route, we recorded the date, time of day, location (latitude and longitude), water and weather conditions, and habitat type. Using standardized protocols and measuring devices, we recorded water temperature (°C), air temperature (°C), water salinity (ppt), wind speed (mph), and percent cloud cover at the start of each spatial replicate. To reduce outside sources of variability in our data collection, surveys were not conducted on nights with heavy winds or rain (Woodward and Marion, 1978; Wood et al., 1985; Moore, 1994).

Using results from our initial occupancy study, we focused Phase II surveys in the following year to estimate abundance in areas with the highest probability of occupancy. We selected survey routes with at least one observed alligator, or those with no observed alligators, but surpassing a 0.35 threshold of estimated probability of occupancy. We chose this threshold because it approximated the mean of the expected occupancy probability at the survey routes and provided a reasonable number of routes to be sampled. A total of 46 survey routes from the original 103 were selected; however, because of constraints, we sampled only 43 of the survey routes (Fig. 1). All 43 survey routes were sampled from 4 June to 11 July 2013. Three temporal replicates were conducted within a week (except one site) to ensure a closed population and by the same observer to reduce observer and detectability bias. To better understand within route survey variability, we modeled each 4-km spatial replicate of the 2013 surveys as an individual sample site, resulting in 156 sites used in the analyses. The standardized sampling protocol from 2012 was followed in 2013 for the abundance surveys, with the addition of recording counts of alligators observed per site and an index of vegetation complexity. Because of difficulties in estimating size during night surveys, we did not distinguish any size or age classes when counting individual alligators. During 2012 surveys, we realized detection and occupancy probabilities could be influenced by aquatic and shoreline vegetation; therefore, in 2013, we recorded a binary index of the average amount of vegetation present for each 4-km site. We created an index of aquatic or overhanging vegetation present using an indicator of low or high vegetation. The low level denoted a mostly clear or visible shoreline with little to no overhanging vegetation. The high level was defined as having overhanging and aquatic vegetation present, with the shoreline mostly to completely not visible. The observer visually estimated the amount of vegetation present and assigned either high or low vegetation cover to that 4-km site.

Statistical Analyses.—We used a single season, single-species occupancy modeling framework for Phase I occupancy surveys that relies on detection/nondetection encounter histories to estimate probabilities of detection (p) and occupancy (ψ) (MacKenzie et al., 2006). We assigned a "0" to the spatial replicate if no alligators were detected and we assigned a "1" if at least one alligator was detected on the replicate. As is standard with single season occupancy models, we assumed the population was closed, no heterogeneity in detection occurred, other than measured covariate-induced heterogeneity, and the detection process was independent at each site. We anticipated weather and water conditions would impact detection and, therefore, included the observation covariates of wind speed, air temperature, cloud cover, and water temperature. We included date (given as the number of days since the first survey; for the first survey on 2 June 2012 the date was assigned 0) as a covariate to account for any temporal trends in detection. We also included habitat type as a detection covariate because of differences in vegetation cover and water levels among the three habitat categories, which could affect ability to detect eye shine.

Because North Carolina is the northern extent of American Alligator range, and we expected alligators to occur in southern

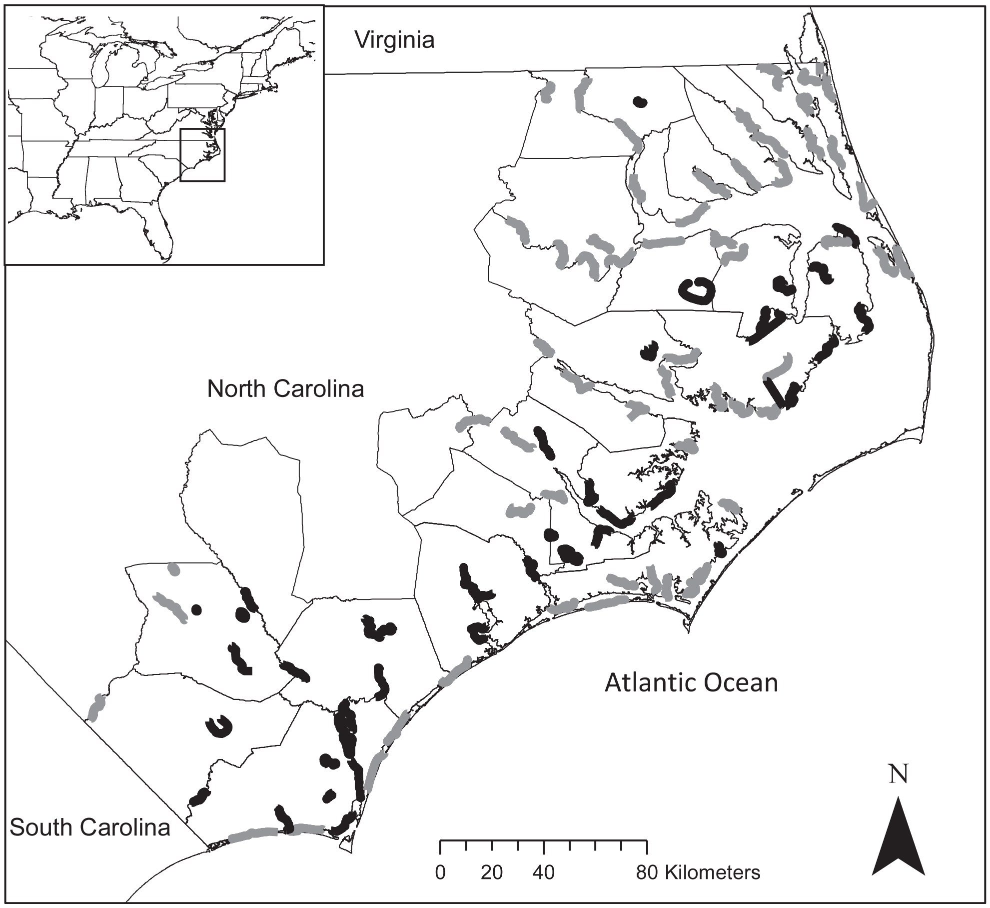

FIG. 1. Locations of survey sites on rivers, lakes, and estuaries, for American Alligators in 25 counties in North Carolina. Inset map shows the eastern part of the United States. All indicated locations were sampled during Phase I in 2012, and in black are sites that were selected for sampling during Phase II in 2013 for abundance.

portions of North Carolina where average temperatures are slightly warmer, we included latitude as a covariate on occupancy; longitude was also included to account for spatial variation in occupancy. Alligators prefer fresh to slightly brackish water, because of their low level of saltwater tolerance (Laurén, 1985); therefore, we included water salinity as a covariate for occupancy. Date (described above) was included to determine whether alligators were more available as the breeding season progressed and, therefore, would affect not only detection but occupancy in certain areas. Finally, we considered habitat type as an effect on occupancy but found that this created instability in the model (likely because habitat type was included as a covariate on detection and the small sample size within type); thus, the variable was not included in the final model set.

The global model used in the analyses included cloud cover, air temperature, wind speed, water temperature, date, and habitat type as covariates on detection. For the occupancy component, we included salinity, date, latitude, and longitude. All continuous covariates were standardized prior to analysis. Using the packages "unmarked" (Fiske and Chandler, 2011) and "MuMIn" (Barton, 2009) in R v. 3.0.1 (R Core Team, 2014), we fitted all possible combinations of covariates on detection and occupancy. We used the Akaike information criterion corrected for small sample sizes (AICc) for model selection (Burnham and Anderson, 2002). To account for model uncertainty, we averaged the parameter estimates and their corresponding standard errors for those models within two ΔAICc from the top model. We predicted the probability of occupancy for each survey route based on the model averaged parameter estimates. We selected all survey routes that surpassed a 0.35 occupancy probability threshold to resample in 2013.

Using the temporally replicated counts in the second year (2013) for Phase II abundance surveys, we fitted a series of binomial N-mixture models (Royle, 2004) to estimate site-specific alligator abundance (λ) while accounting for imperfect detection (p). Because our surveys were carried out in a similar manner in each year, we expected the same covariates to influence detection and occupancy/abundance. We included all covariates from the previous occupancy analysis, with the addition of moon illumination on detection and vegetation index on both detection and abundance. We also removed date as a covariate on abundance as the model assumes a closed population at each site and almost all replicates for a site were within a week. Using the packages unmarked (Fiske and Chandler, 2011) and MuMIn (Barton, 2009) in R v. 3.0.1 (R Core Team, 2014), we fit all possible combinations of covariates on detection and abundance. Because of the observed overdispersion in the count data, we used a Negative Binomial distribution for the counts in the abundance component of the model. We again used AICc for model selection and averaged the parameter estimates and their corresponding standard errors for those models within two ΔAICc from the top model (Burnham and Anderson, 2002). To estimate the conditional

TABLE 1. Occupancy results for models within two AICc of the top model; the global model and null model are included for reference. Abbreviations are lat = latitude; lon = longitude; sal = salinity; air = air temperature; hab = habitat category; wind = wind speed; cloud = percent cloud cover; water = water temperature. For column headings, np = number of parameters; logLik = logLikelihood; Weight = the model weight based on AICc (global and null models were not used in the model averaging; thus, weights for these are not shown).

Occupancy	Detection	np	logLik	AICc	ΔAICc	Weight
ψ(date, lat, lon, sal)	p(air, hab, wind)	10	−93.67	209.8	0.00	0.46
ψ(date, lat, lon, sal)	p(air, hab)	9	−95.15	210.3	0.50	0.36
ψ(date, lat, lon, sal)	p(air, hab, cloud, wind)	11	−93.35	211.7	1.89	0.18
ψ (global)	p(global)	13	−93.02	216.2	6.40	–
ψ (.)	p(.)	2	−121.98	248.1	38.30	–

abundance distribution at each site, we used empirical Bayes methods in the unmarked package (Fiske and Chandler, 2011).

RESULTS

In 2012, we surveyed 1,331 km of shoreline. We detected at least one alligator on 26 of the 103 survey routes (25.2%) with 117 individual observations of alligators. In the occupancy analysis, only the top three models were included in the model averaged parameter estimates as they were within two ΔAICc of the top model (Table 1). All models within two ΔAICc of the top model included date, latitude, longitude, and salinity in the occupancy component of the model. The model averaged parameter estimates indicated significant ($P < 0.05$) negative effects of latitude and salinity and a positive response to longitude and date (Table 2). As latitude increased (moving further north), occupancy probability decreased; additionally, as longitude increased (moving eastward), occupancy probability increased. The map of predicted occupancy probability shows these trends generally, particularly the effect of latitude (Fig. 2). Finally, as salinity increased, occupancy also decreased. The positive relationship with date indicated that sites were more likely to be occupied later in the survey.

Covariates affecting detection in occupancy surveys varied among the top models (Table 1). Habitat type was included in all top models (Table 1). Whereas detection in lakes and rivers were not statistically different (average detection probability was 0.43 for rivers and 0.62 for lakes), the average detection probability for estuaries was significantly lower at 0.16 (Table 2). Air temperature was in all models and had a positive relationship with detection (Table 2); therefore, warmer temperatures resulted in greater detection probabilities. Both wind speed and cloud cover were included in at least one of the top three models, and both had negative parameter estimates, but neither was considered statistically significant based on the model averaged P-values (Table 2).

In 2013, we sampled 156 sites (at 43 survey routes) and observed 115 alligators during the first temporal replicate, 116 on the second, and 110 on the third. Of these sites, 152 were sampled three times, whereas four were sampled only once. At least one alligator was detected once during the repeat visits at 58 of the 156 sites; scaling that up to the 43 survey routes, at least one alligator was detected at 24 survey routes. The minimum count for all three replicates was 0, and the maximum count at a site was 27 for the first replicate, 27 for the second replicate, and 22 for the third replicate (all from the same site).

The top five abundance models based on AICc are shown in Table 3; the top five were within two ΔAICc of the top model. Habitat type, vegetation, latitude, longitude, and salinity were in all the top five models for predicting abundance (Table 3). Similar to the occupancy analysis, the results show that as latitude increased, abundance estimates decreased, and as longitude increased (generally closer to the coast), abundance estimates increased. Additionally, when salinity increased, expected abundance of alligators decreased (Table 4). Abundance also had a negative relationship with rivers (Table 4), suggesting that alligators were less abundant in rivers than in lakes (the reference habitat type). Finally, the model showed a positive significant effect for vegetation (Table 4); therefore, expected abundance of alligators was higher with greater shoreline vegetation complexity. The overall estimated abundance for the survey (156 4-km sites) was 682.2 (95% CI: 316–1,577) alligators; 208.4 in lakes (22% of surveys were in lakes), 50.6 in rivers (32% of surveys were in rivers), and 423.2 in estuaries (46% of surveys were in estuaries).

For the detection component, there were some differences in parameters included among the top models, but habitat type, cloud cover, and wind were in all five top models. Water temperature and moon illumination were in two top models, date was in one, and air temperature was in none of the top five models (Table 3). Consistent with our occupancy results, a significant difference of detection occurred between estuaries and lakes/rivers, with lower detection in estuaries (average detection probability in estuaries was 0.09 and was 0.48/0.50 for lakes/rivers). Model averaged parameter estimates included significant negative effects of increasing aquatic vegetation and wind speed on detection probability (Table 4). Cloud cover and water temperature both had positive effects on detection,

TABLE 2. Model averaged parameter estimates, standard errors, and P-values for covariates of occupancy (ψ) and detection (p) for all models within two AICc of the top model for American Alligators in eastern North Carolina, 2012. The default habitat type is lake, and date is the number of days from the initial survey on 2 June 2012. Water temperature and date were not included in the detection component for any models within 2 ΔAIC of the top model and, therefore, do not appear in the model averaged estimates.

Covariate	Estimate	SE	P-value
Occupancy parameters (logit scale)			
Intercept	−3.33	1.18	0.004
Salinity	−1.74	0.61	0.004
Date	0.15	0.06	0.018
Latitude	−4.12	1.14	<0.001
Longitude	2.56	0.85	0.003
Detection parameters (logit scale)			
Intercept	0.50	0.46	0.289
Airtemp	0.86	0.32	0.008
River	−0.79	0.60	0.188
Estuary	−2.14	0.71	0.002
Wind speed	−0.33	0.35	0.338
Cloud cover	−0.03	0.12	0.785

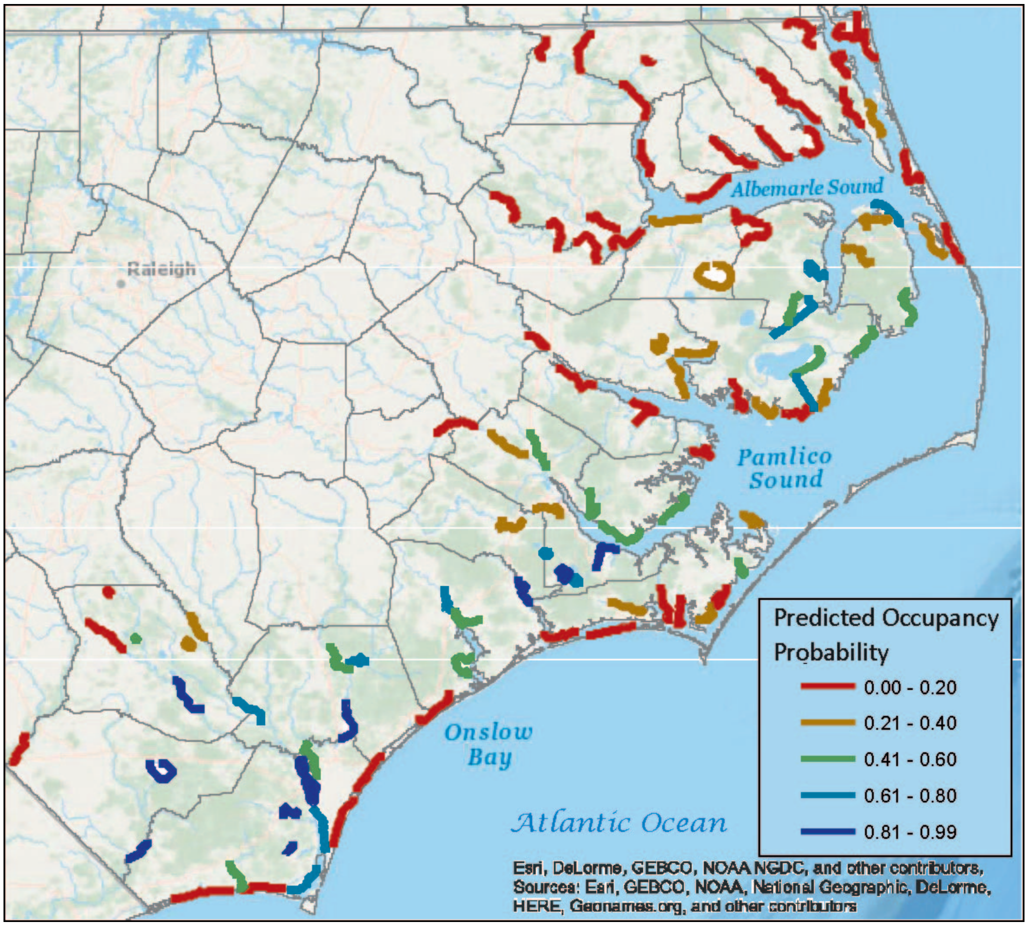

FIG. 2. Map of predicted occupancy ($\hat{\psi}$) across the 103 sampled sites from 2012 in North Carolina. Predictions are based on the model averaged parameters from the Phase I occupancy models.

suggesting that with more cloud cover and warmer waters, detection increased; however, neither of these values was significant as was the case with the 2012 detection results.

DISCUSSION

Consistent with ecological theory on species at the edge of their range, our results showed that latitude and longitude were significant predictors of both occupancy and abundance of alligators in North Carolina. Alligator densities decreased from south to north, and alligators were detected at only one location north of the Albemarle Sound. Whereas American Alligators are the northernmost occurring species of crocodilian and have behavioral adaptations to freezing events (Hagan et al., 1983), their distribution is limited by cold temperatures. When temperatures drop below 3.33°C for extended periods of time, alligators can become extremely cold stressed and can die of hypothermia (Brisbin et al., 1982). Other researchers have shown that smaller alligators are more susceptible to cold temperatures than larger ones (Smith and Adams, 1978), and cold stress can adversely affect reproductive physiology by reducing egg viability or nesting frequency (Klause, 1984). Alligators in North Carolina and South Carolina may nest every other year, and the growing season is one month less in North Carolina than Louisiana where alligators are the most reproductively fit (Klause, 1984). Alligators were less abundant or unobserved in several lakes located in northern latitudes, despite the apparent availability of habitat, suggesting that alligators remain limited by temperature at the northern extent of their distribution.

TABLE 3. Top five abundance (N-mixture) models fitted based on AICc; the global model and null model are included for reference. For reference, veg = vegetation level; moon = moon illumination; all other abbreviations are the same as in Table 1 (global and null models were not used in the model averaging: thus, weights for these are not shown).

Abundance	Detection	df	logLik	AICc	ΔAICc	Weight
λ(hab, lat, lon, sal, veg)	p(hab, veg, cloud, wind)	14	−338.27	707.52	0.00	0.33
λ(hab, lat, lon, sal, veg)	p(hab, moon, veg, cloud, wind)	15	−337.29	708.00	0.45	0.26
λ(hab, lat, lon, sal, veg)	p(hab, veg, water, cloud, wind)	15	−337.88	709.18	1.63	0.15
λ(hab, lat, lon, sal, veg)	p(date, hab, moon, veg, water, cloud, wind)	16	−336.68	709.28	1.73	0.14
λ(hab, lat, lon, sal, veg)	p(hab, cloud, wind)	13	−340.33	709.46	1.94	0.12
λ(global)	p(global)	18	−335.85	712.70	5.15	–
λ(.)	p(.)	3	−376.76	759.68	52.13	–

TABLE 4. Model averaged parameter estimates, standard errors, and *P*-values for covariates of abundance (λ) and detection (*p*) for all models within two AICc of the top model for American Alligators in eastern North Carolina, 2013. The default habitat type is lake (river and estuary are shown in the table).

Covariate	Estimate	SE	*P*-value
Abundance parameters (log scale)			
Intercept	0.10	0.54	0.857
River	−1.32	0.59	0.025
Estuary	1.38	1.09	0.205
Latitude	−1.09	0.36	0.002
Longitude	0.92	0.42	0.029
Salinity	−0.91	0.23	<0.001
Vegetation	1.62	0.62	0.008
Detection parameters (logit scale)			
Intercept	−0.08	0.69	0.904
River	0.12	0.70	0.855
Estuary	−2.21	1.14	0.052
Vegetation	−1.53	0.63	0.016
Cloud cover	0.11	0.07	0.114
Wind speed	−0.51	0.17	0.002
Moon	0.34	0.26	0.199
Water temp	0.14	0.15	0.374
Date	−0.36	0.34	0.285

Additionally, we found a strong negative relationship between water salinity and alligator occurrence and abundance. Although alligators were more likely to occur in coastal areas, their intolerance for saltwater was evident, limiting their distribution in coastal areas. Alligators do not usually occur in saline environments and are known to actively avoid saltwater (McIlheney, 1935; Joanen and McNease, 1989). Unlike American Crocodiles (*Crocodylus acutus*), alligators lack linguinal salt glands and, therefore, cannot remove excess salt from their bodies. Long-term exposure may cause intracellular dehydration and result in death (Laurén, 1985). Although estuaries may provide potential habitat, water salinity may be a limiting factor. Expected sea-level changes in the future may also lead to increases in saltwater intrusion in coastal areas (Moorhead and Brinson, 1995); as such, alligator habitat along the coast may be reduced or alligator distributions may shift further inland to avoid exposure to higher salinity levels. We note that longitude was a significant predictor in the both the distribution and abundance models. Considering the southwest to northeast orientation of the North Carolina coastline, moving eastward does not necessarily mean closer to the coast. When latitude was not included in the models, then longitude was no longer a significant predictor of occupancy or abundance. A strong latitudinal effect is apparent, but the area between the Albemarle Sound and Pamlico River, whereas not at the northernmost location, still was above the average latitude and had a number of alligator detections during the survey. This area also is one of the easternmost locations in the study, suggesting the longitudinal effect is interacting with the latitudinal effect. Instead of longitude, future studies may wish to consider a different measure (e.g., distance to the coast line).

Alligator abundance was greater in lakes and estuaries than rivers; however, almost half of the total estimated abundance for the lake habitat type was from two 4-km sites within one lake. One site within that lake had an estimated 103 alligators (a total observed of 76 during three repeated visits, with a maximum of 27 observed during one visit), and an adjacent site had an estimated 42 alligators (36 observed during three repeated visits). These are not necessarily abnormal as high abundances in lentic habitats, such as lakes and ponds, are not uncommon in more southern populations. For example, alligator densities in a Florida lake have exceeded 29 alligators/km (Woodward and Moore, 1990). Lentic habitats may provide alligators with fairly stable water levels (Fujisaki et al., 2009), food sources, and suitable vegetation for nesting and hiding cover (Webb et al., 2009). Lower densities of alligators in riverine systems also have been observed in other states, including South Carolina (0.25–1 alligator/km) (Murphy and Coker, 1983), Mississippi (0.82 alligators/km) (Duran, 2000), and Arkansas (0.6 alligators/km) (Irwin and Wooding, 2002).

Alligators occurred at low densities or were not present throughout large areas in eastern North Carolina. Their distribution appeared to be clumped and was relatively similar to the distribution described by O'Brien (1983) 30 years prior. Although alligator distribution appears to have remained consistent over the past three decades, there is some indication the population may have increased in certain areas. Raw counts from four lakes surveyed in the early 1980s (Fuller, 1981; O'Brien, 1983) were nearly doubled when revisited during our study. In Lake Ellis Simon, for example, a raw maximum count of 33 alligators in 1980 increased to a maximum count of 53 alligators in 2013 and Orton Pond increased from a raw maximum count of 40 to 79 between 1980 and 2013. Although similar sampling methods were used during both studies, other conditions, such as wind and vegetation, can influence detection probabilities and direct comparisons of raw counts should be taken with caution. In Lake Ellis Simon, we recorded some hatchlings as part of our count. In general, we did not record size during this study and observed relatively few young of year/hatchlings, but we note this because there could be some bias in abundance estimates associated with recording these individuals. We also were unable to sample all habitat types that alligators inhabit and future studies incorporating more habitat types are needed to better understand demographic rates of this population.

As suggested by O'Brien (1983), we also observed high alligator abundances in areas near military bases, national forests, and private property with restricted access to water bodies. In such areas, the opportunity for human interactions with alligators is reduced and will be passive; however, the southeastern United States is projected to experience rapid urbanization, especially nearby coastal cities and towns in the southern coastal plain (Wear, 2002; Terando et al., 2014). With alligators at the northern limit of their range and the negative association with salinity, the impacts of this urbanization on alligator populations in North Carolina are difficult to fully understand. Accordingly, long-term alligator conservation and management efforts in North Carolina should consider mechanisms to reduce potential human-alligator interactions in light of habitat changes for alligators and human development along the coastal areas and consider further monitoring of the species across the state.

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