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2017 Coastal Master Plan

Attachment C3-10: Alligator *Alligator mississippiensis,* Habitat Suitability Index Model

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Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration master plan.

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Executive Summary

The 2012 Coastal Master Plan utilized Habitat Suitability Indices (HSIs) to evaluate potential project effects on wildlife species. Even though HSIs quantify habitat condition, which may not directly correlate to species abundance, they remain a practical and tractable way to assess changes in habitat quality from various restoration actions. As part of the legislatively mandated five year update to the 2012 plan, the wildlife habitat suitability indices were updated and revised using literature and existing field data where available. The outcome of these efforts resulted in improved, or in some cases entirely new suitability indices. This report describes the development of the habitat suitability indices for the American alligator, *Alligator mississippiensis*.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

CPRA	Coastal Protection and Restoration Authority
HSI	Habitat Suitability Index
ICM	Integrated Compartment Model
LDWF	Louisiana Department of Wildlife and Fisheries
ppt	Parts Per Thousand
SI	Suitability Index

1.0 Species Profile

The American alligator (*Alligator mississippiensis*) is the iconic large predator of the swamps, marshes, and bayous of Louisiana. The distribution of the alligator runs along the Atlantic and Gulf Coastal Plains, from northeastern North Carolina westward to the Rio Grande in Texas. The inland distribution extends into southern Arkansas and southeastern Oklahoma along major rivers (Ross & Ernst, 1994). In Louisiana, the alligator may occur throughout the state within lakes, bayous, swamps, and canals (Dundee & Rossman, 1989), but alligators are most abundant in coastal marshes (McNease & Joanen, 1978).

The alligator has a long history of being hunted and managed in Louisiana. As early as the 1920's, shortly after canals were first dug into the vast coastal marshes, alligators were hunted extensively, especially when they congregated during low water conditions (Giles & Childs, 1949). It was recognized early on that unchecked hunting of alligators could lead to drastic reductions of populations of the species, but little was done to protect alligators in Louisiana before a 1960 state law authorizing the Louisiana Department of Wildlife and Fisheries (LDWF) to regulate hunting of the species (Chabreck, 1967). By 1964, alligators were at their lowest recorded population level in Louisiana and hunting was heavily restricted in the state. In 1967, alligators were placed on the federal endangered species list (Department of the Interior, 1967). Alligators responded quickly to the reduction in hunting pressure and rapidly increased in abundance (Newsom et al., 1987). Limited hunting was reopened in Cameron Parish in 1972 (LDWF, 2013). In 1978 the U.S. Fish and Wildlife Service proposed to change the listing of the alligator to "threatened under similarity of appearance" in nine coastal parishes of Louisiana (U.S. Fish and Wildlife Service, 1978), a move that would allow the state to develop a managed harvest program. Since 1979, there has been a managed hunt of alligators across all coastal parishes of Louisiana (LDWF, 2013).

The general habitat requirements for alligators are quite well documented (Newsom et al., 1987). Alligators occur in still or slow-moving water bodies near land (Dundee & Rossman, 1989). They use water for foraging (Delany & Abercrombie, 1986), thermal regulation (Seebacher et al., 2003), mating (Joanen & McNease, 1970), and as a refuge from predators (McIlhenny, 1935; McNease & Joanen, 1974). Because of their close association with water, it is quite reasonable to make a Habitat Suitability Index (HSI) model for alligators based primarily on hydrologic factors. The alligator is the renowned symbol of the wetlands of Louisiana and is culturally and economically important to the state, but the alligator's livelihood is also linked to the condition of the wetlands it inhabits.

Mating for alligators in coastal Louisiana occurs in April and May (McIlhenny, 1935; Joanen & McNease, 1975). Male alligators make bellowing vocalizations from deep water to declare territory and attract females (Dundee & Rossman, 1989). After mating occurs, female alligators will return to marsh habitat and construct a nest of vegetation cleared from a 2.4 m radius area around the nest mound. Nests average between 1.5–2 m in diameter and 0.6–0.9 m in height, and 2–58 eggs will be deposited in a covered cavity 18 cm below the top of the mound (McIlhenny, 1935; Joanen, 1969). The eggs incubate for 63-65 days (Figure 1), during which time the female stays in attendance at the nest to guard it from predators (Joanen, 1969). Upon hatching, the hatchling alligators will remain in shallow marsh habitat near their mother until the following spring (McIlhenny, 1935).

Juvenile alligators can grow rapidly (about 30 cm a year) during the first five and nine years for females and males, respectively (McIlhenny, 1934). Alligators become sexually mature at about 1.8 m total length, which is approximately 10 years old for females (Joanen, 1969). Males may reach sexual maturity at 1.8 m total length, but are usually prevented from breeding by social order until they are at least 2.7 m (Joanen & McNease, 1975); thus, though they may be sexually mature in 6 years, they generally are not breeding until more than 12 years old (Chabrek & Joanen, 1979). Once they reach the adult life stage, alligators may live up to an additional 40 years or more. Although annual survival rates are probably relatively high naturally, human alligator harvest undoubtedly plays a role in reducing the adult population in coastal Louisiana.

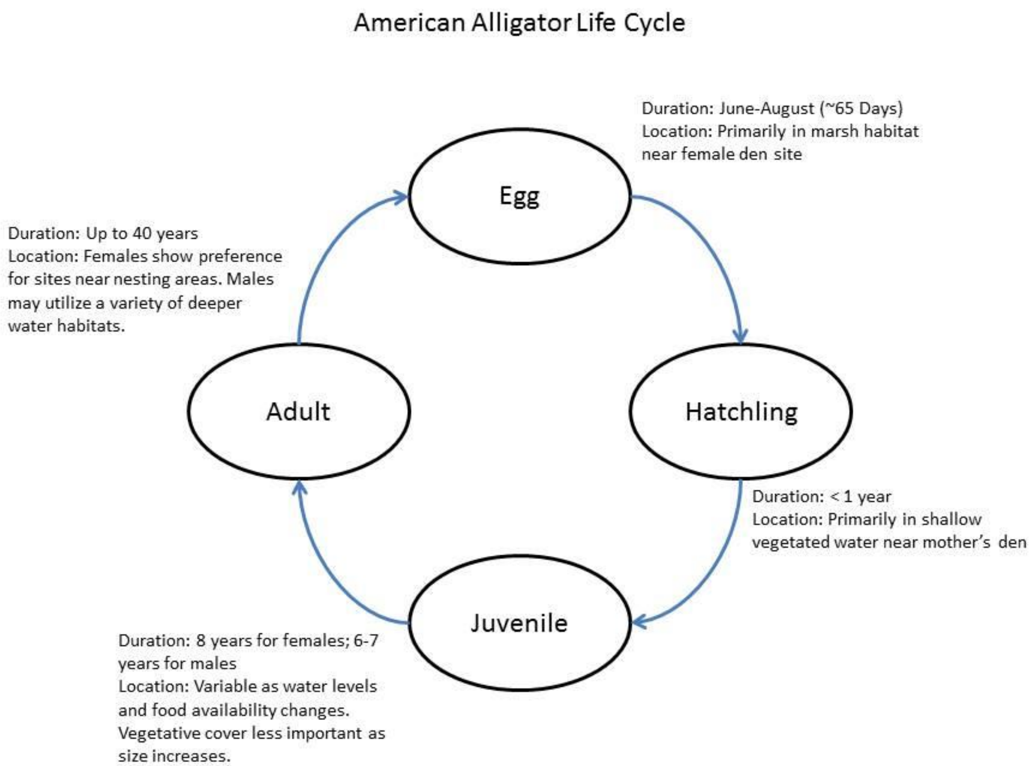

Figure 1: Life Cycle of the American Alligator Showing the Major Life Stages with Information on the Typical Habitat and Duration for Each Stage.

2.0 Approach

This model is an update to the model developed by Nyman (2012) for the 2012 Coastal Master Plan. That model was based on a series of habitat suitability index models going back to the original model of Newsom et al. (1987). The model that is described in this document takes the usual approach to modeling habitat suitability. A number of factors that are believed to affect the suitability of a given area for alligators are identified. A literature review was used to identify important factors for alligator habitat suitability to be included in this model. Raw data on distributions of alligator nests by habitat from the LDWF were analyzed to determine the suitability of the various habitat categories. Other factors were carried over from previous versions of the model, especially those of Newsom et al. (1987) and Nyman (2012). The various levels of each factor were then quantified and normalized such that all values range from 0–1, with the highest possible value for each scaled to equal 1.

Across the landscape of south Louisiana, cells are created for the general framework of the master plan models. The habitat suitability of each cell is determined by taking the geometric mean of the different habitat suitability factors (described below) within each cell. The habitat factors include model-based outputs from hydrological models as well as information from cartographic sources, such as aerial photography. When compiled, this model can determine the overall suitability of each cell in the landscape for alligators under current conditions, but also under projections of future conditions from different restoration scenarios for planning purposes.

This model does not follow individual alligators through time, so no information on alligator fecundity or survival of any life stages is necessary. This is appropriate, as the objective of this model is only to consider the habitat suitability of an area under current and projected future conditions. A model of the actual alligator population expected under various conditions would be an extremely complex and imprecise undertaking. Likewise, this model is not spatially explicit, such that dispersal from one cell to another cell is not considered. Therefore, clusters of cells that have excellent habitat carry no more weight than a single cell of excellent habitat. This is typical of HSI models and is necessary to reduce the complexity of the model. Finally, this model does not account for temporal dynamics. Each year in the model is independent of previous years, so an area of high suitability can convert immediately to an area of low suitability or vice versa. This would make it possible for alligator populations to be potentially out of sync with habitat suitability, but this is another limitation common to HSI models.

An alternative approach would be to attempt to model alligator production (i.e., reproductive output) on a grid cell basis. Shinde et al. (2013) have produced such a model for alligators in the Everglades. Whereas this approach has the advantage of specifically addressing an important component of the population dynamics of alligators, it relies heavily on a set of assumptions about alligator productivity and how it relates to water level. To successfully use and evaluate this approach in coastal Louisiana would require a large amount of additional research to determine how alligator production varies temporally and spatially with respect to hydrology, habitat, and location. This level of detail is likely unnecessary for the purposes of this model.

Although incorporating alligator hunting data such as harvest rates into an HSI model was suggested by Nyman (2012), harvest rate were not be added to this model. Although this is potentially interesting for a model of alligator abundance, it is unclear how it could be incorporated as a parameter to describe habitat suitability. There is no clear and consistent relationship between harvest rate and habitat suitability, and as mentioned above, this model does not follow individual alligators or alligator populations, only the suitability of the habitat.

2.1 Model Testing and Verification

This alligator HSI model was tested in an ad hoc way using data output from the 2012 Coastal Master Plan models. To begin the test, areas were identified that were believed to represent high, medium, and low suitability for alligators. The results of the LDWF helicopter surveys for alligator nests were used to determine areas within intermediate, fresh, and brackish marsh that had high, medium, and, low densities of alligator nests in 2012. These areas represented a range of conditions and helped identify sites where high and low suitability was expected.

For testing, EverView software was used to find HSI input data for each area for the year 2010. Because of the approach taken, values that we obtained were not representative of the entire areas of interest. Instead, a few points in each area of interest were selected, and an average value for that area was quickly estimated. These estimates were then run through the SI (suitability index) equations and an estimated HSI using variables SI_1 through SI_5 was calculated (Table 1).

In general, the SIs performed as expected. The sites deemed highly suitable scored relatively high, and the low suitability sites scored relatively low. One exception was the SI for the relative water depth variable at Rockefeller Wildlife Refuge. This site is known to be highly suitable for alligators, but the water depth measurements made in this ad hoc way were too deep for it to have very high suitability. This may be because the points selected were not representative of the whole area, or because the relationship is flawed at this scale.

There were some modifications made to SI_1, the percent open water variable. This variable may be measured at a scale that makes the relationship in this model too strict. Many areas of what are believed to be highly suitable marsh were modeled as 100% land. That is because this model considers any emergent vegetation as land. Thus, even though a cell may be suitable at the smaller spatial scale of an alligator, it can appear to have no value to the HSI model. To correct this, the model has been changed so that the minimum value of the SI drops to 0.1 rather than 0 for a cell comprised of 100% land.

There were also some modifications made to SI_2, the variable for water depth relative to the marsh surface, as a result of this testing exercise. Even though 25 cm water depth above marsh surface is considered a maximum for any suitability due to the potential for flooding of alligator nests, strict use of this value will make large tracts of actually suitable land have no value. The model was therefore modified so that instead of going to 0 at the outer range of the suitable equation, it goes to 0.1. Use of water depth specifically during nesting season was also considered, but upon seeing the output it became apparent that the hydrologic model did not operate on an appropriate scale for this use.

3.0 Habitat Suitability Index Model for American Alligator

The overall equation for the HSI of alligators in a model cell is the geometric mean of five suitability variables, each scaled from 0–1, where 1 is the most suitable (Table 1). Solving the HSI equation produces a value that is between 0 and 1 that represents the total suitability of the cell.

$$\mathrm{HSI} = (SI_1 \times SI_2 \times SI_3 \times SI_4 \times SI_5)^{1/5}$$

Table 1: Description and Source for the Five HSI Variables Used in the Alligator HSI Model.

Variable	Description	Source
SI1	Percent Open Water	Modified from Newsom et al. (1987) and Nyman (2012)
SI2	Relative Water Depth	Modified from Nyman (2012)
SI3	Habitat Type	Modified from Newsom et al. (1987) and Nyman (2012)
SI4	Edge	Same as Nyman (2012)
SI5	Salinity	Same as Nyman (2012)

3.1 Applicability of the Model

This model is intended to estimate the suitability of habitat for alligators in general, and does not specifically target alligator productivity (Shinde et al., 2013) or any specific life stage. This model identifies factors that are likely to be important for reproduction (i.e., nesting), foraging, physiology, and predator avoidance. Thus, the model does not explicitly focus on any one process, but broadly describes the general needs of the species.

Geographically the model is only intended to apply to coastal Louisiana. Elements of the model may be appropriate outside this area, but many of the factors, especially the relationship between habitat type and suitability are based strictly on an analysis of data from south Louisiana.

It should also be noted that this model only produces an estimate of the potential suitability of the habitat based on the available knowledge for alligators in southern Louisiana. The actual realized abundances of alligators across the spatial coverage of the model may not match the hypothesized suitability because of many factors outside those of the model, including harvest of alligators, and natural and anthropogenic disturbances.

3.2 Response and Input Variables

V_1: Percent open water

This variable represents the proportion of the cell that is open water relative to emergent land. The values for the suitability are 1 at proportions of water 20–40%, and fall linearly to 0 above that range and linearly to 0.1 below that range (Figure 2).

$$SI_1 = \begin{cases} ((4.5 * V_1)/100) + 0.1 & \text{for } V_1 < 20 \\ 1.0 & \text{for } 20 \le V_1 \le 40 \\ ((-1.667 * V_1)/100) + 1.667 & \text{for } V_1 > 40 \end{cases}$$

Rationale: Alligators need both emergent land and open water in order to thrive (Newsom et al., 1987). Nesting of alligators depends on the presence of emergent vegetation (Joanen, 1969; Hunt & Ogden, 1991; Elsey et al., 2008). Basking for thermoregulation would not be possible in costal marsh without emergent land (Chabreck, 1965; Asa et al., 1998). And although most alligator foraging takes place in water (Watanabe et al., 2013), alligators do occasionally forage for prey on land (Dinets, 2010).

Determining the ideal ratio of land and water for alligator habitat suitability is difficult. The only source available to report on the ratio is a personal communication with Ted Joanen in Newsom et al. (1987). Joanen proposed that the most suitable habitat for alligator nesting in coastal marshes of Louisiana had 20–40% open water. This expert opinion appears to be the only one available for the model. The relationship presented here is similar to that used by Newsom et al. (1987) with the exception that suitability for this variable does not go to 0 for 100% land (0% open water) in a cell. Preliminary tests of the model indicated that vegetation models operate at a scale such that extensive areas of marsh with only small bodies of water would appear to have no open water and thus no value for alligators. This seems unlikely at the scale at which an alligator might operate, so to compensate, the cell retains 10% suitability even at 0% water for the percent open water variable. Cells that do not contain one of the marsh types or cypress swamp habitat will have no value anyway (see variable SI_3), so the overall HSI model should not assign value to areas with no water unless the land is a wetland type.

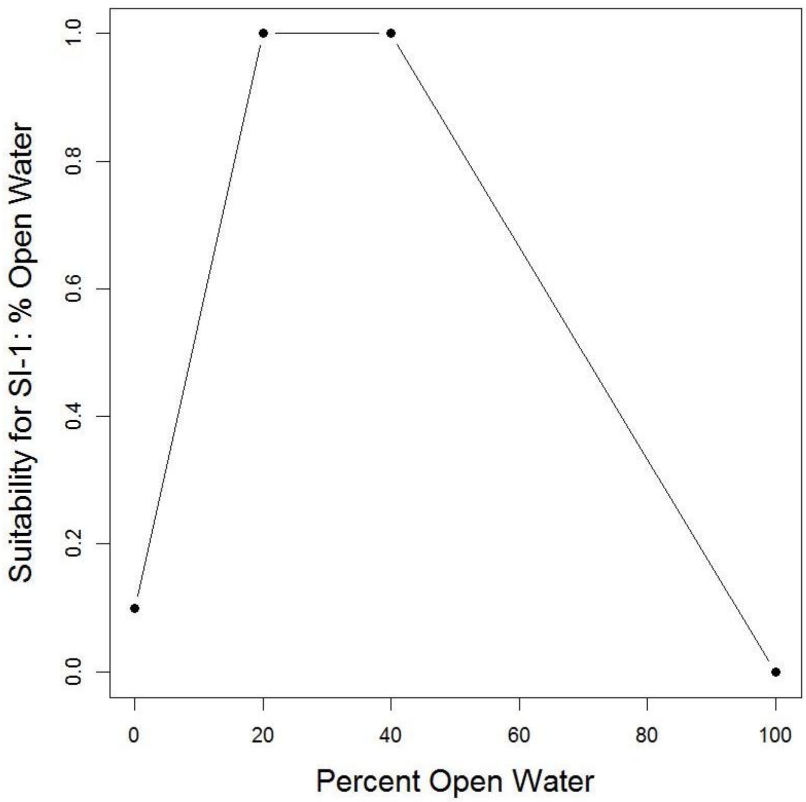

Figure 2: Relationship Between the Percent of the Cell that is Open Water and Suitability for Alligators Under Variable SI_1.

V_2: Water depth relative to marsh surface

This variable describes the average water depth in the cell relative to the marsh surface over the calendar year. The SI peaks at 1 when the average water depth is 15 cm below marsh elevation and declines to 0.1 at 55 cm below marsh elevation and at 25 cm above marsh elevation. The formula for the SI calculation is below and is shown in Figure 3.

$SI_2 = 0.1$	for $V_2 \leq -0.55$ m
$(2.25 * V_2) + 1.3375$	for -0.55 m $< V_2 < -0.15$ m
1.0	for $V_2 = -0.15$ m
$(-2.25 * V_2) + 0.6625$	for -0.15 m $< V_2 < 0.25$ m
0.1	for $V_2 \geq 0.25$ m

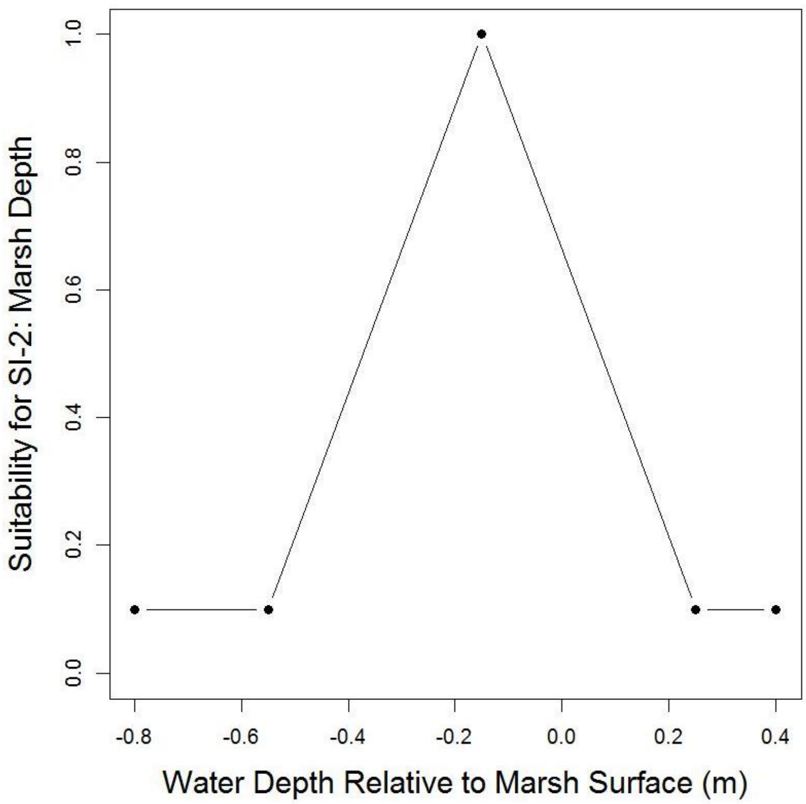

Figure 3: Relationship Between the Average Water Depth Relative to the Marsh Surface Elevation for the Previous 12 Months and SI_2 for Alligators.

Rationale: Alligator prey abundance and availability are related to hydrology. If water depth is too high, prey will be dispersed and hard to obtain, but if water depth is too low, prey abundance will decline as it is eventually consumed. Water depth can affect alligator body condition positively or negatively over a period of several weeks (Fujisaki et al., 2009). Fujisaki et al. (2009) found that high water conditions prior to alligator capture were correlated with lower alligator body conditions. Likewise, drought conditions have been shown to increase alligator stress (Lance et al., 2010) and to decrease the hatching rate of alligator eggs (Eversole et al., 2013). Extremely low water levels can also lead to poor body condition (Fujisaki et al., 2009). Although alligators are adapted to a cyclical fluctuating environment, habitat is most suitable when the water depths in an area are not too low and not too high.

Nesting success also depends heavily on water levels. In low water conditions, depredation of alligator eggs in nests by mammalian predators increases, but in high water years, the risk of nest flooding increases (Joanen, 1969; Kushlan & Jacobsen, 1990; Hunt & Ogden, 1991; Saalfeld et al., 2012). If water conditions are high at the start of the nesting season, alligators may be able to respond by building nest mounds higher, but if water levels increase due to heavy rains or water management after nests are built, many of the nests will likely be destroyed by high water (Kushlan & Jacobsen, 1990).

Modeling the ideal conditions for water depth on the marsh across the coastal region of south Louisiana is difficult. No data are available on the relationship between water depths and alligator abundance, body condition, or nest success across a spatial or temporal range of water depth values in the area. Similar data from the Florida Everglades (Fujisaki et al., 2009;

Shinde et al., 2013) are unlikely to be useful in coastal Louisiana as the marsh habitat is very different. Water level data from intermediate and brackish marsh in a study by Nyman et al. (2009) found that a healthy marsh with good value for wildlife had an annual average water depth of about 15 cm below the marsh surface. Joanen (1969) presented data on alligator nest heights indicating that the average height of the bottom of the egg cavity was 25.4 cm above the marsh surface. Therefore 25 cm seems like a reasonable upper bound on the range of suitable water depths relative to marsh surface even though this primarily affects nesting. If we take -15 cm depth as the center of the range, then we can consider the range of suitability to span 40 cm on either side of that value. Thus, our range of suitability for average water depths relative to marsh surface would be from -55 cm to 25 cm.

Nyman (2012) centered the range of suitable depths on -15 cm as here, but he used a much narrower range of suitability from -30 to 0. This may, in fact, represent the most suitable or core of the range of values, but there is little evidence to support this relationship across all of coastal Louisiana. The wider range included here makes it possible for many more areas to still be considered somewhat suitable for alligators in terms of relative water depths. Also, this wider range includes almost the entire range of mean daily water depths from both study sites in Nyman et al. (2009). The shape of the relationship chosen here is a simple linear one from 0.1 at the minimum and maximum values to 1 at the proposed most suitable depth. This could easily be redrawn as a logistic curve or some other relationship if there were data to support such a hypothesis. As it is, this variable in the HSI model represents a simple way to give the greatest weight to average water depths roughly in the middle of what is considered the range of depths suitable for alligators. This variable would benefit from more targeted research to determine how this relationship varies across habitats and time.

Using the water depth during the nesting season (15 June –15 September; Joanen & McNease, 1975) was considered. For instance, a cutoff could be introduced where a cell would have a SI of 0 if water depths in a cell rise above the height of the eggs in the nests. There are, however, at least two problems with this approach. First, the scale at which the hydrologic models work is not the same as the alligator nest, and based on preliminary testing, water levels considered too high for nesting were frequently simulated in areas where nests are known to be successful. Also, due to the way the models estimate water depth, there are occasional spikes in water depth in the model output that may not actually be experienced at the nest site. Using an average of water depths during the nesting season may resolve that issue, but then it becomes difficult to assign suitability for an average depth. Therefore, the nesting season was not directly used as the time period for the marsh water depth input. It was also determined during the testing phase that, because of the scaling issue, areas known to be productive for alligators had average water depths outside the range of high suitability in some years. Rather than give those cells an SI value of 0, a value of 0.1 was assigned. This compromise assigns some value to a cell even in very dry or very wet years, but maintains the peak depths for alligator HSI.

V_3: Habitat type

This variable describes the SI value for a cell based on the values of each habitat type and their proportions within the cell. Intermediate marsh has the highest value, and is given a SI of 1, whereas bare ground, saline marsh, submerged aquatic vegetation, and open water have a SI of 0. The values for each habitat are given below and in Figure 4.

For a given cell:

SI_3 = (0.551 * proportion bald cypress swamp) + (0.713 * proportion fresh marsh) + (1.0 * proportion intermediate marsh) + (0.408 * proportion brackish marsh)

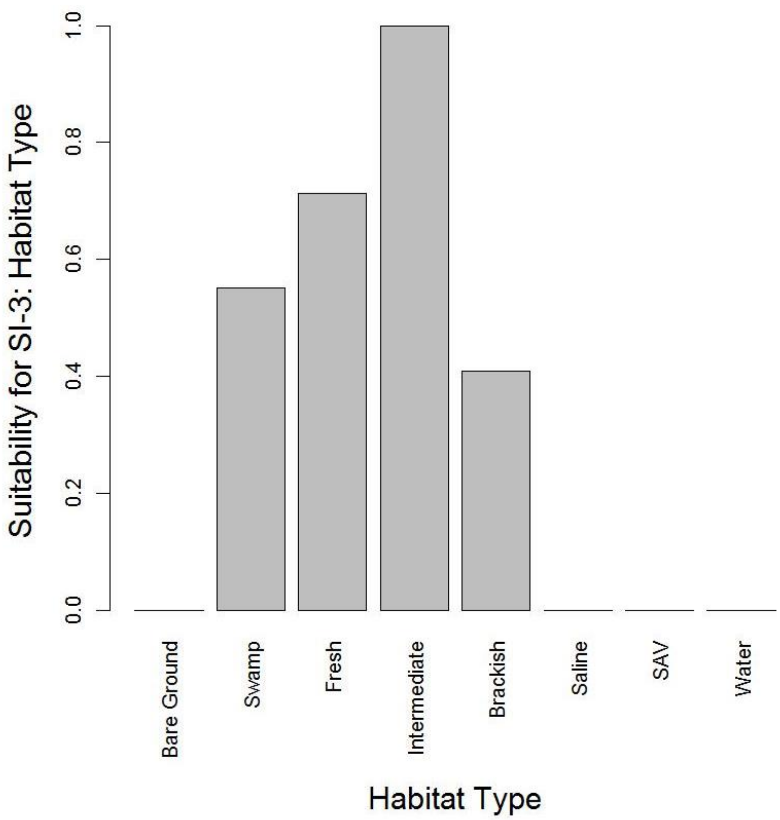

Figure 4: Values for the Suitability of Major Habitat Types (SI_3) Used by Alligators in the HSI Model.

Rationale: This variable concerns the relative suitability of the major habitat types in coastal Louisiana. Some data on microhabitat associations of individual alligators are available from the literature (Webb et al., 2009; Carter, 2010), but few published reports comparing abundance or suitability of the major habitat types in coastal Louisiana exist. It is well documented that the most productive habitats for alligators in coastal Louisiana are the fresh and intermediate marsh (McNease & Joanen, 1978; Newsom et al., 1987), but gathering data on the relative suitability of marsh and other habitats is difficult. Night spotlight counts, for instance, are known to be variable based on water level and habitat conditions (Woodward et al., 1996; Carter, 2010; Fujisaki et al., 2011), but there are no extensive night count survey data for coastal Louisiana. LDWF does conduct annual nest surveys throughout coastal Louisiana across three major marsh habitat categories: fresh marsh, intermediate marsh, and brackish marsh.

The annual LDWF alligator nest surveys are conducted from a helicopter. The number of nests observed and the area of each habitat surveyed are recorded, making it is possible to determine the relative proportion of nests in each type of marsh habitat. For this model, the helicopter transect data for coastal Louisiana were sorted by habitat type. The surveys are conducted in fresh, intermediate, and brackish marsh, as well as a habitat type labeled transitional. Transitional habitat represents brackish marsh that is declining in quality (LDWF, 2013), and was not used in this analysis, primarily because it represented a very small portion of the data. The density of nests observed (nests/acre surveyed) was determined for each site and for each year by habitat (LDWF, unpublished data). The proportion of the total area of each habitat that was surveyed at each site was also determined, and a weighted average of nest densities by habitat across sites and years (2003–2013) was computed with the proportion of the area surveyed as the weighting factor. These densities were normalized to a 0–1 scale such that the maximum value was 1.

No helicopter survey data exist for the cypress-tupelo swamp habitat. To determine relative habitat suitability for this habitat, the approach of Nyman (2012) was followed. The SI for cypress-tupelo swamp was assigned a value proportional to the number of harvest tags issued by LDWF per acre of habitat. In 2011 and 2012, the two most recent years for which tag data are available, the same number of tags per acre were issued in each habitat type. The average number of tags per acre in the marsh habitat types was compared to the number of tags per acre issued in the cypress-tupelo swamp habitat. All were normalized to a 0–1 scale to determine the scaled value for cypress-tupelo swamp.

The values used in the model are the averaged and scaled values from the nest surveys for the three types of marsh habitat, with the scaled value for cypress-tupelo swamp from the tag allotments added. The outcome of this is slightly different from the previous version of the alligator HSI model (Nyman, 2012). Following the tag allotments only, as was done in Nyman (2012), the habitat with the highest value would be fresh marsh. However, by examining the quantitative data from the helicopter surveys, it was determined that the intermediate marsh actually had the highest density of nests. Nyman (2012) noted that the 2007 Coastal Master Plan alligator HSI model also had intermediate marsh as the habitat with the highest suitability value, following the pattern found in McNease and Joanen (1978).

The approach taken to determine relative suitability of each habitat for alligators in the current model is basically a compromise between the 2007 and 2012 Coastal Master Plans. Where quantitative data are available (i.e., the three marsh types), they are used. Tag allotments are used as a surrogate for quantitative data in cypress-tupelo swamp in order to include this important habitat type. It should be noted that the SI values for brackish marsh and cypress-tupelo swamp are similar between this model and Nyman (2012). The main difference is that in this version the intermediate marsh gets the highest SI followed closely by fresh marsh.

To determine the overall SI for habitat of a cell, the proportion of each habitat type is multiplied by its corresponding scaled SI value and then these values are summed. As in Nyman (2012), bare ground, open water, submerged aquatic vegetation, and saline marshes are given a SI value of 0. This does not mean to imply that these habitats have no value to alligators and that alligators will never use them. Clearly open water is important for alligators (see SI_1 and SI_4). However, these habitats have low value, and if an entire cell were comprised of one or more of these low value habitats with no marsh or cypress/tupelo swamp habitat, then the cell would indeed be considered unsuitable for alligators. Thus, these habitats contribute no value to the potential suitability of a cell.

V_4: Edge

In their HSI model, Newsom et al. (1987) used categories of interspersion (low, medium, high) as a surrogate for edge. Nyman (2012) developed a relationship based on an edge variable produced as output from the Wetland Morphology modeling group in the 2012 Coastal Master Plan. This output was scaled such that the median value had a SI value of 0.5 and values at the 90th percentile and above had a value of 1.0. This allows for a more continuously variable effect of edge as it increases toward the highest values, rather than the categorical approach of Newsom et al. (1987).

In the current model, the methodology used by Nyman (2012) was followed with one exception. The minimum value for 0 edge was set to an HSI of 0.05, rather than 0. Although edge is important for alligators, making an edge value of 0 have no suitability is too restrictive given the scale and accuracy of the edge variable. Edge values from all cells were calculated and the 90th percentile was found to be 22. The relationship for HSI and edge is given below and in Figure 5.

$SI_4 = 0.05 + 0.95*(V_4/22.0)$ for $0 \leq V_4 \leq 22$
1.0 for $V_4 > 22$

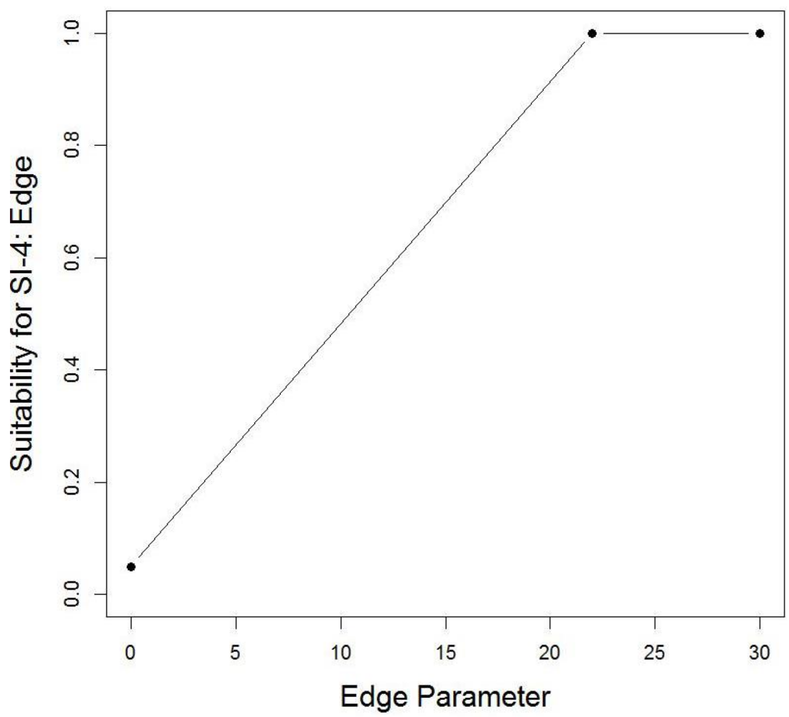

Figure 5: Effect of the Edge Input Parameter (SI_4) on the Suitability for Alligators.

Rationale: Alligators have been shown to benefit from an interspersion of emergent land with open water (McNease & Joanen, 1974; Newson et al., 1987; Webb et al., 2009). Areas with extensive edge are the primary places used by hatchling and juvenile alligators (McNease & Joanen, 1974), and nests are most frequently placed near the edge of the marsh with close access to water (Joanen, 1969).

Aside from reproduction, marsh edges are important areas for alligator foraging. High concentrations of small nekton and other prey are found along marsh edges (Peterson & Turner, 1994; La Peyre et al., 2007; Rehm & Baldassarre, 2007; O'Connell & Nyman, 2010). Thus, marsh edges are important for juvenile and adult alligators.

V_5: Salinity

This variable describes the relationship between average annual water salinity in the cell (measured in ppt) and the habitat suitability for alligators. SI is 1 at 0 ppt and declines to 0 at 10 ppt (Figure 6).

$SI_5 = (-0.1 * V_5) +1$ for $0 \leq V_5 \leq 10$
0.0 for $V_5 > 10$

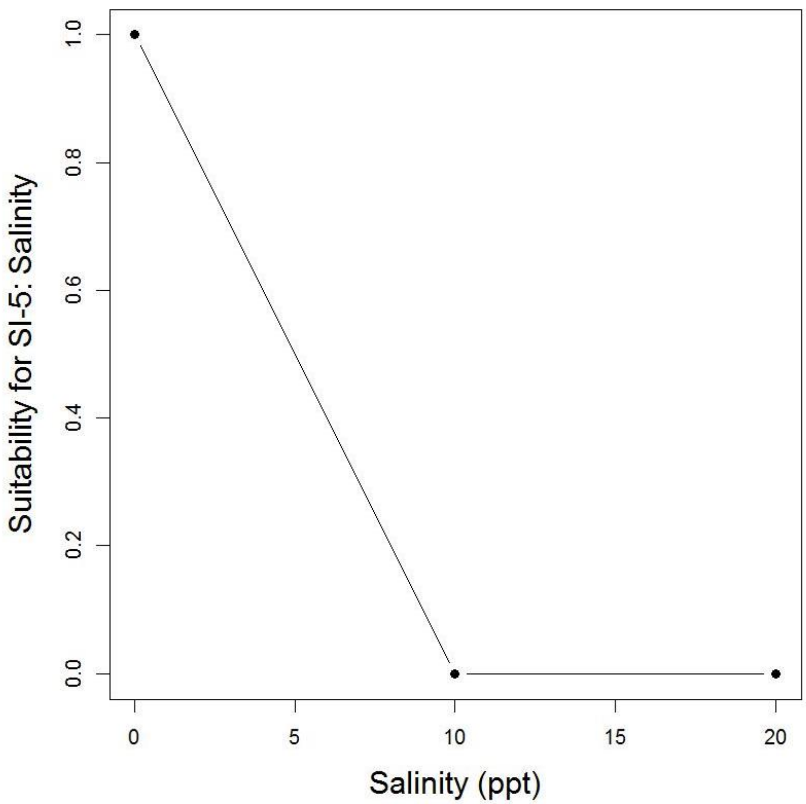

Figure 6: Effect of Salinity (SI_5) on the HSI for Alligators.

Rationale: The alligator is primarily a freshwater reptile, although they can tolerate salinity in estuarine situations. Like other crocodilians, alligators primarily obtain salt from water either intentionally ingested or inadvertently during feeding (Mazzotti & Dunson, 1989). They may be able to excrete some salt, but without a source of fresh water, alligators lose the ability to osmoregulate. Alligators may occasionally spend time in areas of pure seawater (Elsey, 2005), but they cannot persist for long in these environments. Rootes et al. (1991) found that alligators had slower growth rates leading to a longer time to reach sexual maturity in an estuarine marsh compared to freshwater sites in Louisiana. Thus, it is reasonable to assume that habitat quality for alligators declines as salinity increases.

In coastal Louisiana, 10 ppt is considered a threshold above which alligators cannot reproduce (Joanen & McNease, 1972; Newsom et al., 1987). Joanen (1969) found alligators nesting in marsh with salinities up to 8.3 ppt. Certainly some alligators may occasionally use habitats of higher salinity, but they cannot persist without returning to fresh water to drink, and reproduction will not occur there. In fact, in their HSI model for alligators, Newsom et al. (1987) did not consider any habitats above 10 ppt. In this model, following the example of Nyman (2012), SI is highest at 0 ppt and declines linearly to 0 at 10 ppt.

4.0 Model Verification and Future Improvements

A verification exercise was conducted to ensure the distributions and patterns of HSI scores across the coast were realistic relative to current knowledge of the distribution of alligators. In order to generate HSI scores across the coast, the HSI models were run using calibrated and validated Integrated Compartment Model (ICM) spin-up data to produce a single value per ICM grid cell. Given the nature of a coast wide model, the ICM spin-up data may not reflect 'real-world' conditions in all areas of the coast. For example, some areas known to have wetland vegetation were classified as non-wetland habitat resulting in low HSI scores when high scores would otherwise be expected. In these instances, no improvements could be made to the HSI as these issues reside in other ICM subroutines (i.e., vegetation). As a result, the accuracy of the verification exercise is contingent on these inconsistencies.

High scores for suitability of alligators were observed in areas of marsh and wetlands that are generally known to have high alligator density. Much of the coastal zone had average salinities too high to be considered suitable for alligators, but excluding those cells and with consideration of the issue of vegetation classification in the ICM input data, the model appears to be performing as expected.

This version of an alligator HSI model is built upon work done in the past, mostly by Newsom et al. (1987) and Nyman (2012). It incorporates recommendations for improvement made by Nyman (2012), but there are still areas that could be further refined. The most important improvements could probably be made in the relationship between water depth and alligator suitability. This is especially important because land managers may have a high degree of control over water depth in impounded areas. Other areas may be controlled such that flooding can be limited during certain times of year (e.g., nesting season). Further refinements to the model would probably require the collection of field data. Fortunately, the current model offers a good place to begin to form hypotheses to test. Studies that provide more information in variability of nest heights and flooding rates of nests in the different habitats of coastal Louisiana would be valuable. It would also be very useful to have better estimates of how low water level affects alligator suitability. These relationships are much better defined for the Everglades (Shinde et al., 2013) than they are in coastal Louisiana.

Another area for improvement would be to gather data that could be used to better inform the habitat type suitability for alligators. Data on actual alligator abundance rather than just nest density would be useful, especially in the cypress swamp areas where so little data exist on nesting. An approach such as systematic night spotlight counts of alligators may serve this purpose (Woodward et al., 1996). Of course, it is important to make a distinction between the abundance of alligators and the density of nests in terms of suitability. This model does not focus explicitly on nesting for suitability, but reproduction is a significant part of the justification for the variables.

Finally, if more detail about alligator populations in Louisiana, not just habitat suitability, is desired, future models should consider going to either a spatially-explicit based modeling approach (Green et al., 2014) or to an alligator production model (Shinde et al., 2013). While these approaches are much more expensive in terms of time to develop and computer resources, they can address issues such as the spatial arrangement of cells and changes over time in the same area. Most importantly, these types of models can produce an estimate of the effect of management on the alligator population, not just the suitability of habitat. If this level of detail is sought for alligators in Louisiana, then these types of models could be developed.

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