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Habitat Modeling and Conservation of the Western Chicken Turtle (*Deirochelys reticularia miaria*)

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***Abstract*.—The Western Chicken Turtle (*Deirochelys reticularia miaria*) is considered rare and declining throughout its range, although no population surveys have been conducted range-wide. Uncertainty regarding population status and perceived threats to habitat convinced the U.S. Fish and Wildlife Service to consider Endangered Species Act protection for the subspecies. The goal of this study was to inform the listing process by describing the biological and conservation requirements for Western Chicken Turtles. We modeled potentially suitable habitat throughout the range of the subspecies and quantified current and future threats to that habitat in Texas, USA. Potentially suitable habitats with the highest probability of occurrence were concentrated in southeast Texas and southwest Louisiana, especially where low elevation wetlands were in high density. Wetland loss and fragmentation in urban and urbanizing rural areas, particularly around Houston, represent the greatest current and future threats to habitat in Texas. Population surveys targeting potentially suitable habitat indicate that this subspecies is rare. From 4 February to 6 July 2015, we conducted 1,491 visual observation and road-cruising surveys across 107 counties, and recorded 2,458 aquatic trap nights at five sites near historical localities. Between 15 April and 5 May 2015, each survey method produced a single Western Chicken Turtle observation (n = 3). Current population threats from commercial harvest and export appear insignificant for this subspecies, although continued monitoring of wild populations is recommended. We also recommend expanded wetland protection policies for areas identified as high quality habitat that are under the greatest threat.**

Key Words.—ephemeral wetlands; fragmentation; habitat perforation; harvest; terrestrial; urbanization

Introduction

Populations of wetland species are declining worldwide due to habitat loss (Gibbons et al. 2000; Stuart et al. 2004; Millennium Ecosystem Assessment 2005). The most common conservation practice implemented to protect such species is wetland preservation (Quesnelle et al. 2015). For example, the goal of the No Net Loss wetland policy of the U.S. federal government is to maintain individual or groups of wetlands or to maintain the total amount of wetlands at a regional scale (U.S. Environmental Protection Agency [USEPA] 2002). One problem with this policy is that it does not protect the landscape surrounding wetlands, which implicitly assumes the species only needs wetlands to persist (Bauer et al. 2010). This assumption is certainly not true for all wetland species experiencing declines, especially amphibians and reptiles (Gibbons 2003; Semlitsch and Bodie 2003). Indeed, landscape matrix quality can be more important than overall wetland amount for many amphibian and reptile wetland species (Quesnelle et al. 2015). Because many wetland species also require terrestrial resources, policies that only restore and create wetlands may not result in recovery of declining amphibian and reptile populations. With these policy limitations in mind, here we characterize the current status of Western Chicken Turtle (*Deirochelys reticularia miaria*) habitat and identify current and future threats to habitat and populations in Texas, USA, to frame the development of a conservation plan for the species.

Chicken Turtles (*D. reticularia*) are semi-aquatic members of the Emydidae family that inhabit shallow, ephemeral bodies of water and adjacent terrestrial habitats throughout the southeastern U.S. (Buhlmann 1995; Buhlmann et al. 2008; Ernst and Lovich 2009). They are unique among emydids because of their carnivorous diets, pharyngeal feeding, short life spans, fast growth rates, cool season nesting, and terrestrial affinity (Gibbons 1969; Bennett et al. 1970; Gibbons and Greene 1978; Gibbons et al. 1983; Gibbons 1987). This species is separated into three subspecies based on geographic variation in morphology (Swartz 1956). The Western Chicken Turtle (*D. r. miaria*) occurs west of the Mississippi River in Louisiana, Arkansas, Missouri, Oklahoma, and Texas, and exhibits dark, seam-following marks on a yellow plastron that the Eastern (*D. r. reticularia*) and Florida Chicken Turtles (*D. r. chrysea*) typically lack (Buhlmann et al. 2008). In addition to these morphological differences, phylogenetic comparisons suggest a deep split between Western Chicken Turtles and the other two subspecies (Walker and Avise 1998; Hilzinger 2009).

The ecology of the Western Chicken Turtle is poorly understood compared to its eastern counterparts (McKnight 2014), but biological uniformity across subspecies is often assumed. This assumption is questionable given the variability in habitat type, availability, and connectivity, as well as the variable climate across the range of the species (Kawecki and Ebert 2004). Moreover, diet and reproductive characteristics of species are frequently tailored to local environmental conditions (Stearns 1992). For example, past research has shown that Eastern and Florida Chicken Turtles are strict carnivores, feeding primarily on aquatic insects and crayfish (Jackson 1996; Demuth and Buhlmann 1997). However, recent research suggests that Western Chicken Turtles are more omnivorous, feeding on plants in addition to aquatic insects and crayfish (McKnight et al. 2015a). Additionally, recent observations indicate that Western Chicken Turtles exhibit a discrete nesting season rather than the bimodal nesting season observed in the other two subspecies (McKnight et al. 2015b). Western females are unique in that they develop follicles from March to July, are gravid from April to July, and nest from May to July. During this time, other subspecies are generally not reproductively active (Buhlmann et al. 2008).

The Western Chicken Turtle is also assumed to be rare and declining throughout its range, although no formal survey has been conducted range-wide (Buhlman et al. 2008), and our current understanding of population trends is limited. In Arkansas, Dinkelacker and Hilzinger (2014) conducted a three-year capture-recapture study and estimated a positive population growth rate for Western Chicken Turtles. In another recent capture-recapture study in Oklahoma, McKnight (2014) estimated recapture rates and annual adult survival of 100% over two years. Although the duration of these studies was short, the positive population growth rate and high adult annual survival observed contradicts the perception of population decline in Western Chicken Turtles. Instead, these studies suggest chicken turtle populations are less dense than those of other turtle species within the same community (Congdon et al. 1986), which could give the appearance of decline. For example, population densities based on observed and estimated population size for the Arkansas population were 3.7 turtles/ha and 5.6 turtles/ha, respectively, which is similar to densities observed in other regions of the distribution of the species (Dinkelacker and Hilzinger 2014). Populations of 3–5 turtles/ha are considered normal in Florida, and populations of 10 turtles/ha are considered high (Ewert et al. 2006). However, an estimate of 17.7 turtles/ha was reported as normal for a population of Eastern Chicken Turtles in South Carolina (Congdon et al. 1986).

Resolving this uncertainty in the population status of Western Chicken Turtles is critical given the many perceived threats to this subspecies and lack of laws to protect its habitat. Although data were lacking for Western Chicken Turtles prior to this study, substantial alteration or loss of freshwater wetland habitats to agriculture and urban development in the southeastern U.S. has caused declines in populations of similar amphibians and reptiles (Buhlmann et al. 2009; U.S. Fish and Wildlife Service [USFWS] 2011). The Western Chicken Turtle is thought to have suffered even greater declines from alteration or loss of habitat than other species, because the ephemeral, depressional wetlands that make up its habitat are frequently classified as non-adjacent, geographically isolated wetlands (GIWs; Leibowitz 2015). To be considered a waterway of the U.S. and protected by the Clean Water Act (CWA), wetlands must be shown to be connected to or have a significant nexus with traditional navigable waters (TNW; USEPA 2015). However, such connections are difficult to identify using traditional national wetland databases (e.g., National Wetland Inventory, National Hydrography Dataset) or maps generated from other remote sensing products (Leibowitz 2015) because they often occur as infrequent surface events or are obscured as subsurface groundwater flowpaths (USEPA 2015). Thus, site visits to determine connections between GIWs and TNWs must coincide with events generating surface water or groundwater connectivity. As a result, many Western Chicken Turtle habitat patches receive no protection.

A more important point about the conservation of Western Chicken Turtles is that hydrologic connectivity of GIWs may not capture the biological connectivity of the wetland habitats of the species. As ephemeral wetlands dry, Western Chicken Turtles depend upon terrestrial upland habitats that provide refuge and act as corridors to other ephemeral wetlands that could be hydrologically unconnected and not eligible for protection. Radio telemetry data indicate that these movements among drying wetlands are 250 m on average, but could be as long as 8 km in certain landscapes (McKnight 2014). Thus, even perfect detection of connectivity between GIWs and TNWs does not guarantee that all Western Chicken Turtle habitat will be protected. Additionally, these long terrestrial movements suggest that Western Chicken Turtle populations could be particularly sensitive to freshwater wetland habitat loss and fragmentation.

Despite perceived declines in Western Chicken Turtle populations and threats to its habitat, there has been little formal protection directed at the subspecies other than a state designation as endangered by Missouri, USA (Buhlmann et al. 2008). In the USA, Arkansas, Louisiana, Oklahoma, and Texas regulate, but do not prohibit, take of all native amphibians and reptiles, including the Western Chicken Turtle. This lack of formal protection at the state level, along with the general uncertainty regarding its biology, distribution, and range-wide abundance, has prompted a petition to list the subspecies as threatened or endangered under the U.S. Endangered Species Act. The subsequent 90-day finding by the USFWS states that listing the subspecies as threatened or endangered may be warranted (USFWS 2011), and further information on current and future threats to Western Chicken Turtle populations and habitat throughout its range are required to help make a final ruling on listing. The objectives of our research are to fill key gaps in our understanding of the habitat, biological, and conservation needs of this subspecies by: (1) modeling potentially suitable Western Chicken Turtle habitat; (2) identifying and quantifying current and future threats to habitat in Texas; (3) characterizing historical and current distribution patterns and population trends in Texas; and (4) summarizing recent commercial, recreational, scientific, and educational collection or harvest data. The conclusions on threats and recommendations on management of Western Chicken Turtle habitat and populations generated from this research will provide a foundation for the development of a conservation plan for the subspecies.

Materials and Methods

Study area.—We modeled potentially suitable Western Chicken Turtle habitat across states in the USA with documented historical locality data for the species. These states included Texas, Oklahoma, Arkansas, and Louisiana. Following model development, we characterized Western Chicken Turtle habitat alteration across 115 counties in east and south Texas. From north to south, this region includes a mix of oak woodlands, prairies, and pine forests, which transitions into gulf coast prairies and marshes and then to scrub and brush country at the Mexico border.

Modeling of potentially suitable habitat.—We used a species distribution model to generate maps of habitat that could potentially support Western Chicken Turtles (Phillips et al. 2006; Phillips and Dudík 2008). This approach, based on Labay et al. (2011), generates a continuous probability distribution of species occurrence from presence-only datasets and a suite of environmental predictor variables (Phillips et al. 2006). Our presence-only dataset was comprised of 205 georeferenced historic localities for this species gathered from the VertNet database (VertNet Western Chicken Turtle [*Deirochelys reticularia miaria*] Database. Available from http://vertnet.org/. [Accessed 22 October 2014]). This dataset included specimen localities from Texas (n = 110), Arkansas (n = 5), Louisiana (n = 81), and Oklahoma (n = 9) that were documented between 1892 and 2009 (Mean year documented = 1957, Median year documented = 1962; Fig. 1). Our suite of spatial environmental predictor variables included elevation, aspect, slope, compound topographic index (U.S. Geological Service [USGS] 2014a), dominant soil order (e.g., mollisols, vertisols), surface soil texture, which used relative particle size to estimate the percentage of sand in the soil (Gridded Soil Survey Geographic Database; U.S. Department of Agriculture [USDA] 2014a), wetland density (Dahl 2011) and type based on National Wetland Inventory classification (e.g., freshwater, estuarine, emergent vegetation, forested; Cowardin et al. 1979; USFWS 2014), and 19 climate variables (WorldClim 2014; Appendix Tables A1 and A2).

We used the Maxent modeling algorithm following default parameterization recommendations (Phillips and Dudík 2008; Elith et al. 2011) where models were cross-validated with 10 replicates generating a raster map of relative estimates of probability of occurrence (30-arc second resolution ~ 900 m). To reduce urban sampling bias, which is common in datasets created from natural history collections, we added samples to the background following protocols outlined in Elith et al. (2011; refer to Implications for Modelling). We used a modeled probability of occurrence threshold of $P > 50\%$, not as an ecological occurrence classification (Liu et al. 2005), but rather to symbolize model results given the perceived rarity of the chicken turtle (Fig. 1). To focus subsequent landscape condition and fragmentation analyses, we selected counties with the most favorable potential habitat by calculating the mean probability of occurrence for the county (Appendix Fig. A1).

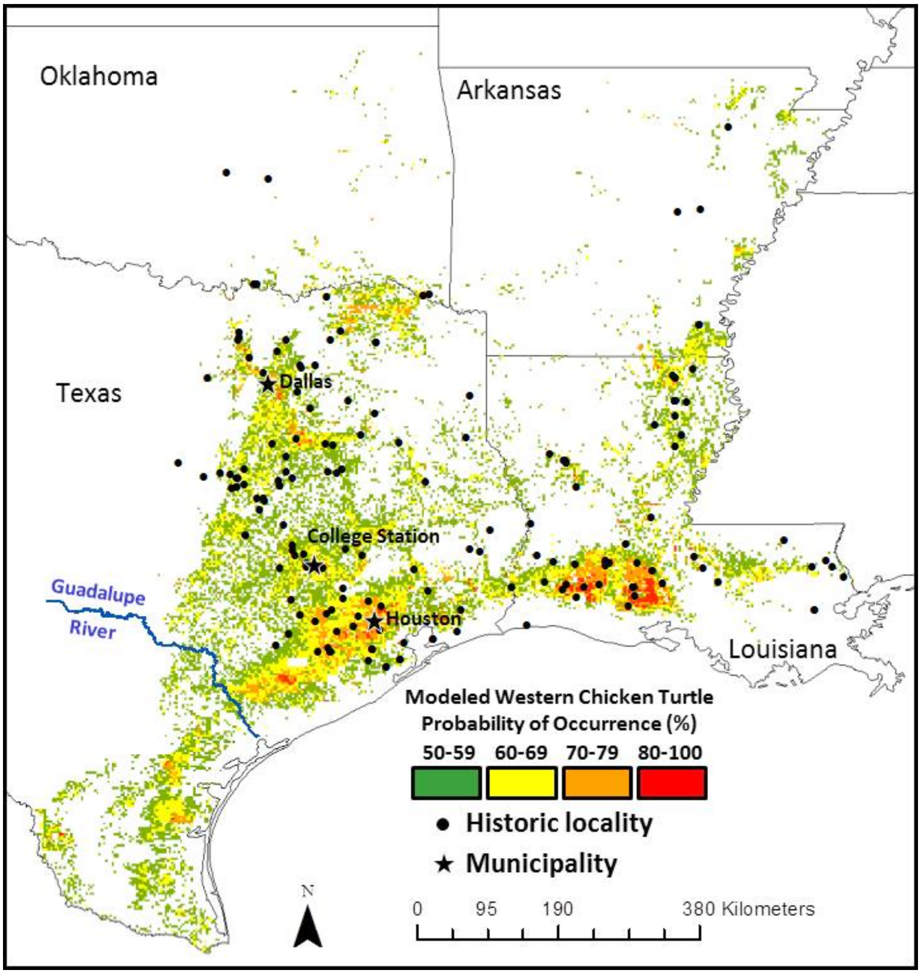

Figure 1. Modeled probability of occurrence for Western Chicken Turtles using a species distribution model. Historical turtle localities are shown as solid circles. The Guadalupe River is the inferred southern boundary for this subspecies based on the distribution of historic localities, the decrease in precipitation to the west in Texas, and the progression from Gulf Coast Prairies and Marshes in the Southeast Texas to the unfavorable Tamaulipan Scrub in South Texas.

Current threats to habitat.—To evaluate current anthropogenic threats to habitat modeled within the range of the species in Texas, we investigated recent land use changes using the National Land Cover Database (NLCD; Jin et al. 2013; USGS 2014b). The NLCD is a 30-m resolution satellite imagery-derived land cover dataset for the conterminous United States that is considered suitable to investigate temporal trends of changes in land use at a regional scale (Carle 2011). The NLCD divides Landsat imagery into 16 land-cover classes (Vogelmann et al. 1998; Jin et al. 2013), which we combined into four groups: wetlands (classes 11, 90, and 95), urban (classes 21, 22, 23, 24, and 31), agriculture (81 and 82), and forests (41, 42, 43, 51, and 52). Using these groups, we identified areas of wetland loss, urban and agricultural expansion, and forest loss from 2001 to 2011 following, in part, the approaches of Jantz et al. (2005), Carle (2011), and Johnston (2013). Briefly, we considered the baseline suitable habitat condition to be defined by the habitat model where modeled probability of occurrence (P) > 50%. We then refined the baseline layer by overlaying landscape alteration from 2001 NLCD urban and agricultural classes and roads, medians, and right-of-ways (Texas Department of Transportation [TxDOT] 2014) and reclassifying intersecting pixels as unsuitable habitat. We used this layer to establish a 2001 pre-alteration baseline. We then subtracted 2001–2011 landscape changes from urban and agricultural expansion, wetland loss, and forest loss from the baseline to create a layer of current, altered habitat. We resampled all layers to the same extent and 10-m resolution.

We compiled the results of this analysis for counties with mean modeled probability of occurrence (P_{mean}) > 50%. Within these high-priority counties, we also identified habitat most at risk of alteration, by quantifying land cover changes for pixels with modeled probability of occurrence (P) > 50%. To help identify and rank counties with both the highest quality potential habitat and the highest risk of alteration, we introduced a Habitat Alteration Index (*HAI*). The *HAI* was calculated by:

$$HAI = \frac{(\sum \text{landscape alteration} \times P_{mean})}{1000}, \qquad \text{Equation 1}$$

where landscape alteration is the sum of wetland loss, urban expansion, exurban expansion, agricultural expansion, and forest loss (km^2). We calculated *HAI* for counties with Pmean > 50% in two ways: (1) for all disturbed land in a county; and (2) for disturbed land found only in pixels with $P > 50\%$.

In addition to identifying areas where landscape alteration occurred, we also quantified areas of focused core habitat loss and then characterized the spatial pattern of habitat fragmentation. First, we compared our maps of baseline and altered habitat and quantitatively identified areas with intense current fragmentation scenarios using the Optimized Hot Spot Analysis tool in ArcGIS 10.2. This analysis was done by resampling our 10-m resolution analysis to a 1-km^2 grid, which made the calculation of Getis-Ord Gi* (Getis and Ord 1992) spatial statistics computationally tractable (i.e., the computer we used was not able to complete the analysis at 10-m resolution due to processor limitations). We then evaluated landscape changes using the approach of Soille and Vogt (2007), implemented in GIS using GUIDOS toolbox (Vogt et al. 2009). Briefly, we surrounded areas of altered habitat with a 100-m edge distance and assumed that the species did not use this formerly suitable habitat because of its proximity to altered landscape. While we do not know the sensitivity of Western Chicken Turtles to edge effects, analogous studies (Goodrich et al. 2004; Neel et al. 2004; McGarigal et al. 2005; Howell et al. 2006; Svobodová et al. 2011) used a conservative 100 m edge distance. Next, we used morphological spatial pattern analysis (MSPA) to calculate several landscape alteration metrics, including bridges and loops. We defined bridges as areas of suitable habitat that connected two or more core habitat areas (i.e., corridors), and loops as areas of suitable habitat that extended out from a core area and return to that same core area. We assessed core habitat, bridge, and loop changes between pre-alteration, recent alteration, and future alteration (see below) scenarios to quantify loss of core habitat and changes in connectivity between core habitat areas.

Future threats to habitat.—We mapped and quantified future urban expansion beyond the urban fringe from 2010 to 2050 using the Theobald (2005) database of forecasted increases in housing density. We considered urban areas in the Theobald dataset to include: commercial and industrial institutions, > 10 units/ac, 5–9.9 units/ac, 2–4.9 units/ac, 0.5–1.6 ac/unit, and 1.7–4.9 ac/unit. We selected these housing density classes because visual inspection of the 2010 dataset most closely agrees with patterns of urban development observed in current aerial photography (USDA 2014b) and developed land classes in the NLCD dataset. Areas of possible future wetland loss from urban expansion were identified by overlaying maps of future urbanized areas with wetlands from the 2011 NLCD dataset. The *HAI* was also used to identify where high-quality Western Chicken Turtle habitats were most altered by forecasted future urbanization. We characterized the spatial pattern of future habitat fragmentation by removing future urbanized areas from the map of current habitat and using MSPA to quantify future habitat fragmentation. We used the same MPSA, Optimized Hot Spot Analysis tool (ArcGIS 10.2), and Getis-Ord Gi* (Getis and Ord 1992) spatial analyses as described in the current threats section to quantify future habitat alteration.

Distribution and population trends.—Because most of the study area is private land, we primarily used road-cruising and visual observations to conduct distribution surveys within modeled suitable habitat. We used road-cruising surveys along public roadways passing through modeled suitable habitat areas. We conducted visual observation surveys using binoculars and spotting scopes at locations with wetlands in proximity to public roadways. Most surveys were conducted under sunny conditions to increase the chances of observing basking turtles, but we also conducted some surveys under cloudy conditions following rain events to capture turtles migrating across roads. We identified and recorded all turtles found, alive or dead, to species.

Where access to private lands within the study area was granted, we were able to conduct trapping surveys. Trapping sites included the Katy Prairie Conservancy (KPC; Waller and Harris counties), Lake Waco Wetlands (LWW; Baylor University, McLennan County), and John Bunker Sands Wetland Center (JBSWC; Kaufman County). We sampled Western Chicken Turtle populations at these sites and two additional public sites at Gus Engeling Wildlife Management Area (GEWMA; Texas Parks and Wildlife Department; Anderson County) and Jesse H. Jones Park and Nature Reserve (JJPNR; Harris County). We used a combination of aquatic traps and nets (e.g., hoop nets, crayfish traps) with leaders that have been shown to be effective at capturing and re-capturing Western Chicken Turtles in other parts of the range of the species (Adams and Saenz 2011; Dinkelacker and Hilzinger 2014; McKnight 2014; McKnight et al. 2015). Our strategy was to saturate wetland areas with traps wherever traps could be set. This means that some hoop nets had leads and some did not depending on what the specific area of habitat would allow. This also means that some wetland areas did not have hoop nets with leads due to water depth, but instead were saturated with crawfish traps. Regardless of species, we weighed, determined sex, measured carapace and plastron length, and individually marked all turtles captured.

Collection and harvest data.—We acquired international exportation data from the USFWS for all freshwater turtles exported from states within the Western Chicken Turtle range between 1999 and March of 2015. The Law Enforcement Management Information System (LEMIS) returned records including the following fields: record ID, genus, species, wildlife description, quantity, units, country of origin, country of export, purpose, source, shipping date, and port of export. We also acquired harvest data for all freshwater turtles for 2005 through 2015 as reported by permitted non-game dealers to the Texas Parks and Wildlife Department (TPWD). Before 2008 in this data set, Texas allowed the collection of Western Chicken Turtles from the wild with a non-game collector permit. After 2008, regulations imposed by TPWD limited collection and possession from the wild to just four species of turtles (*Chelydra serpentina*, *Trachemys scripta*, *Apalone spinifera*, and *Apalone muticus*). TPWD also prohibited all collection from public waters (Prestridge et al. 2011). Those permitted were required to file annually with TPWD. Data provided by TPWD included collection by county, possession by year, purchases by year, and sales by year.

Results

Modeling of potentially suitable habitat.—Our map of potentially suitable Western Chicken Turtle habitat generally included most of Texas east of the Interstate Highway 35, which parallels the Balcones Escarpment, southwestern Louisiana, and to a lesser extent eastern and northern Louisiana (Fig. 1). Arkansas and Oklahoma contained sparsely distributed potentially suitable habitats. Mapping of potentially suitable habitat suggested that Western Chicken Turtles preferred lower elevations, elevated and consistent rainfall year round (especially in the summer), and proximity to freshwater wetlands. Lower elevation, which corresponded well with streams and associated wetlands the species is thought to prefer (Buhlmann et al. 2009), was the most important variable in the Maxent model explaining 70.1% of the variation in the modeled distribution of the species. Wetland density was the second most important factor explaining 12.8% of the variation, followed by soil order, soil texture, aspect, slope, and compound topographic index explaining 6.5, 4.4, 4.3, 1.2, and 0.7%, respectively. Although wetland type was not included in the model, we did observe a positive association between Western Chicken Turtle historical localities and freshwater wetlands shown as a percentage of each wetland type within a buffer area of a certain km radius (i.e., 1-km, 5-km, 10-km, and nearest; Cowardin et al. 1979; USFWS 2014; Appendix Table A3).

Current threats to habitat.—Recent land use changes have altered 2,300 km^2 of predicted suitable habitat and over 500 km^2 of wetlands in the Texas range of the species (Figs. 2A). Habitat alteration was caused by forest loss, urbanization, agricultural expansion, and wetland conversion (about 40%, about 39%, about 17%, and about 4%, respectively; Appendix Table A4). Alteration of core habitat, defined as one or more 10-m resolution pixels of unaltered landscape surrounded on all sides by 100-m buffer cells of unaltered landscape, was most intense in and around the Houston metropolitan region (336 km^2, respectively). Here also 36 km^2 of connective bridge corridors were lost, indicating a decrease in migration pathways between habitat patches. However, bridge corridors increased in some parts of the Houston area, indicating that landscape alteration was perforating formerly pristine habitat, but migration pathways still remained.

Conversion of over 500 km^2 of wetlands in the 115-county study area to other land classes included about 137 km^2 to urbanization and about 37 km^2 to agricultural expansion, and was greatest in the Houston area (95 km^2; Appendix Table A4). Also in the 115-county study area, recent urban expansion occurred primarily around major metropolitan areas and totaled about 2,170 km^2; however, the effects of urbanization on habitat varied spatially. Total crop expansion in the 115-county study area was 872 km^2, which converted 385 km^2 of potentially suitable habitat. Recent loss of forested lands in the 115-county area was 4,794 km^2, resulting in conversion of 921 km^2 of potential habitat. We summarized the effects of recent landscape alteration on habitat using *HAI* and found the greatest alteration of high-quality potential habitat was around the Houston, Dallas, and College Station metropolitan areas (Appendix Fig. A2A).

Our habitat fragmentation analysis found that the greatest intensity of current core habitat loss occurred in the Houston metropolitan area (Appendix Fig. A3A). Conversely, clusters of pristine, unaltered core habitat were found to the southwest of Houston and northeast of Waco (Appendix Fig. A3B). Few unaltered core habitat areas remained around Houston.

Future threats to habitat.—Forecasted future urbanization through 2050 is predicted to alter about

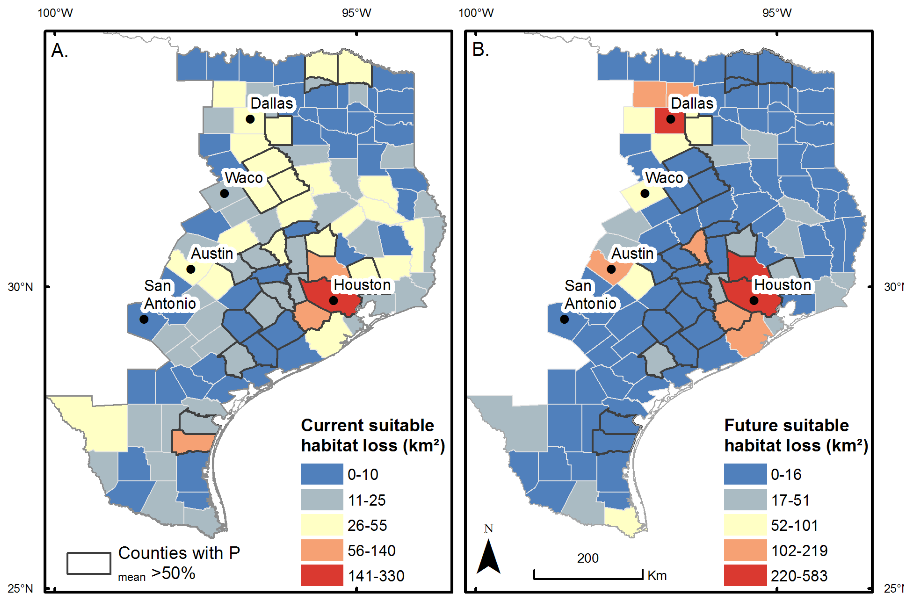

FIGURE 2. Suitable habitat loss in Texas by county. (A) Current suitable habitat losses aggregated at the county level and classified using natural breaks. (B) Future suitable habitat losses from forecasted urbanization aggregated at the county level and classified using natural breaks.

11,900 km^2 of landscape and convert 3,514 km^2 of suitable habitat (Fig. 2B, Appendix Table A4). Urbanization, and resulting wetland conversion, will likely be highest around the Houston, Dallas, and College Station metropolitan areas (Figs. 2B, Appendix Table A4). This trend is also borne out in our future *HAI* calculations (Appendix Fig. A2B). Future urbanization and the loss of migration pathways is likely to be most intense in and around Houston followed by the Dallas and College Station metropolitan areas (Appendix Fig. A3C).

Distribution and population trends.—From 4 February to 6 July 2015, we conducted 1,491 visual observation and road-cruising distribution surveys across 107 Texas counties (Fig. 3). During these surveys, we observed 1,255 individual turtles representing 13 turtle species. Both visual observation and road-cruising distribution survey methods resulted in one Western Chicken Turtle observation each (Fig. 3). On 15 April 2015, we observed through binoculars one Western Chicken Turtle basking on a log in Falls County. The next month, on 5 May 2015, we found another Western Chicken Turtle dead on the road in Waller County. At the point of observation, ditches on either side of the road contained moving water approximately 30 cm deep and 70% vegetative cover comprised of three species: Swamp Smartweed (*Persicaria hydropiperoides*), Creeping Primrose-willow (*Ludwigia repens*), and Green Flatsedge (*Cyperus virens*). This dead Western Chicken Turtle was preserved and catalogued in the Biodiversity Research and Teaching Collections at Texas A&M University.

We sampled Western Chicken Turtle populations at KPC, LWW, JBSWC, GEWMA, and JJPNR during the same survey interval. Across all five sites, we recorded 2,458 trap nights using all aquatic trapping methods combined. The number of site specific traps nights were 1,068 (KPC), 258 (LWW), 400 (JBSWC), 708 (GEWMA), and 24 (JJPNR). This trapping effort yielded 656 individual turtle captures representing nine turtle species, including one female Western Chicken Turtle captured in a pluvial wetland 2 May 2015 at KPC in Harris County (Fig. 3). The wetland contained palustrine shrub vegetation in the center (e.g., Rattlebush, *Sesbania drummondii* and Creeping Primrose-willow) with palustrine emergent vegetation on the fringe (e.g., Swamp Smartweed and Square-stem Spikerush, *Eleocharis quadrangulata*).

Collection and harvest data.—International exports of live Western Chicken Turtles from the USA were rare, with only 26 export events from January 1999 to March 2015. Of these, 25 individuals were shipped from the state of Texas, and four were marked as collected from the wild (no source location given). Additionally, only three companies accounted for 100% of the international export of live specimens and all exports left the country from the Dallas-Fort Worth airport. US Global Exotics, an exporter based in Arlington, Texas, accounted for 84% of the trade in Western Chicken Turtles, but was closed down in 2009 after being charged with multiple violations of the Lacey Act (Ashley et al. 2014).

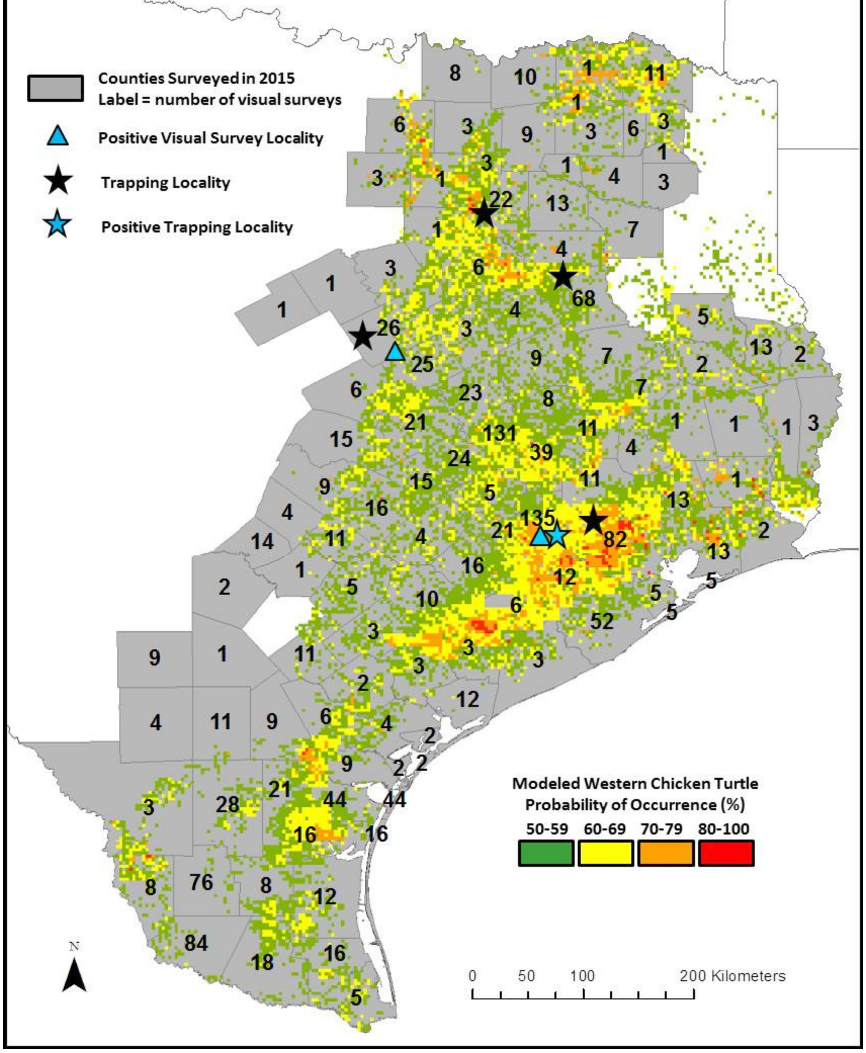

Figure 3. Map depicting Western Chicken Turtle population survey effort across 107 counties (gray shading) in Texas. Modeled probability of occurrence is identical to Fig. 1. Blue shapes identify localities with Western Chicken Turtle detections in 2015. Numbers in each county reflect the total number of visual and road-cruising surveys conducted between 4 February and 6 July 2015.

Annual reports to TPWD from permittees indicated that a single collector harvested five individuals from the wild in 2007 and 2008. Since then, harvesting of Western Chicken Turtles from the wild, or the reporting of it, has ceased. From 2009 to 2012, annual reports showed that a single permitted collector possessed a single Western Chicken Turtle. No captive colonies were actively producing offspring in captivity for sale in the state during the years reported (2008–2012).

Discussion

Our model of potentially suitable Western Chicken Turtle habitat indicates that southeastern Texas and southwestern Louisiana have the greatest amount of habitat with the highest probability of occurrence. Texas is predicted to have the most potentially suitable habitat; however, we believe the modern southern boundary for Western Chicken Turtles in the state occurs somewhere along the Guadalupe River. Although the model of potentially suitable habitat extends along the Gulf Coast southwest of the Guadalupe River, this point represents a change in ecoregion from favorable habitat with high wetland density in Gulf Coast Prairies and Marshes to unfavorable Tamaulipan Scrub. This point also reflects a sharp hydro-climatic gradient from favorable habitats in the east to habitats in the west with an unfavorable decline in precipitation and a reduction in the number of permanent streams. The strongest evidence for the establishment of this line as the southern boundary for the subspecies is the distribution of historic localities, which do not occur south and west of the Guadalupe

River. Continued surveys in that area are necessary to verify this boundary, but by establishing the Guadalupe River as the modern southern boundary for Western Chicken Turtles, we hope to frame the implementation of conservation strategies for the subspecies where they can be most effective (i.e., northeast of the Guadalupe River).

Western Chicken Turtle habitat in Texas is currently threatened, and most likely will continue to be threatened, by wetland loss and fragmentation caused by urbanization. From 2001 to 2011, loss of wetlands occurred in prime habitat in and around Houston, which is a continuation of a decades-long trend (Brody et al. 2008). The Houston metropolitan area also has the greatest amount of higher quality habitat in the study area and a high density of historic localities. The Dallas metropolitan area also has elevated urbanization, but habitat quality is lower. This difference between quality of habitat and intensity of habitat alteration is borne out in the *HAI*, which confirms the intensity of habitat alteration in and around Houston and, less so, around Dallas and College Station. We expect this trend in habitat loss due to urbanization in the Texas part of the range of the subspecies to continue into the future, as urbanization continues to occur in high-quality habitat near Houston, College Station, and Dallas, reducing the number of migration pathways between remaining freshwater wetlands.

Our observations suggest that the Western Chicken Turtle is extremely rare in Texas. Distribution-wide surveys (n = 1,491; 107 counties) and trapping (n = 2,458 trap nights; five populations) yielded only three individuals. Some researchers have speculated that the perception that the subspecies is rare and declining throughout its range could be partially an artifact of sampling bias (McKnight 2014; Donald McKnight, pers. comm.). Given the discrete seasonal activity pattern of this subspecies (mainly March to June; Dinkelacker and Hilzinger 2014; McKnight 2015a), it is possible that traditional turtle sampling techniques may give the erroneous impression of rarity or population declines. For example, typical trapping techniques deployed during warmer months (e.g., June to August) may be ineffective when the subspecies is aestivating below ground. Similarly, given the terrestrial affinity of this subspecies, employing only aquatic turtle trapping techniques at locations with large numbers of sympatric emydids might also give the impression of rarity or population decline in this subspecies. To minimize potential temporal sample bias, we conducted our surveys and trapping from February to July when the subspecies is known to be seasonally active (Dinkelacker and Hilzinger 2014; McKnight 2015a). We also employed aquatic trapping and terrestrial road-cruising survey methods for this subspecies to avoid any possible methodological sample bias. Our observations of three individuals using three sample methods (i.e., visual observation, road-cruising, and trapping) gives some indication that our sampling results are not biased, although higher capture rates would have provided greater confidence.

Western Chicken Turtle population threats from commercial wild harvest and export appear insignificant. According to annual reports submitted to TPWD by non-game wildlife permittees, commercial take of all freshwater turtles in Texas has decreased since regulatory changes were imposed by TPWD in late 2007. However, it is unclear if this decrease is due to a decline in turtle numbers or availability, under-reporting of harvest, or a lull in commercial activity. This last point requires continued monitoring as commercial activity for freshwater turtles is driven by global market demands and could increase quickly and unexpectedly. Any increase in harvest pressure on other species of freshwater turtles that share habitat with Western Chicken Turtles could threaten the small population sizes of this subspecies simply from high rates of bycatch. From January 1999 to March of 2015, for example, 749 shipments, including 682,680 (82,004 from the wild) live specimens of *Trachemys scripta* spp., were exported from states within the Western Chicken Turtle range. There is no information on bycatch rates for non-target, similar-looking species of turtles included in these large volume shipments of freshwater turtles. Harvest of Western Chicken Turtles and other freshwater turtle species should be continually monitored and investigated given the susceptibility of turtle populations in general to harvest-related declines.

Wetland loss and fragmentation in urban and urbanizing rural areas is likely the most important current and future anthropogenic threat to Western Chicken Turtle habitats and populations in Texas, but there are very few conservation mechanisms available to slow, stop, regulate, or limit this trend. Current federal wetland regulations do not protect wetland-terrestrial upland habitat that Western Chicken Turtles require. The U.S. Clean Water Act only protects wetlands that have been proven to be hydrologically connected to traditional navigable waters, which is difficult to determine. This species relies heavily on terrestrial upland habitats that provide refuges and act as corridors to wetlands that could be hydrologically unconnected and thus not eligible for federal protection. One solution to this problem is to expand the definition of hydrologic connectivity to also include biological connectivity of wetlands. This revision would better reflect the aquatic and terrestrial needs of Western Chicken Turtles, as well as other wetland species. Indeed, the population distribution of many amphibian and reptile wetland species is more strongly related to landscape matrix quality than overall wetland amount, likely due to requirements of the species for terrestrial resources (Quesnelle et al. 2015). Our map of current clusters of unaltered habitat identifies reasonable starting points for implementing this expanded wetland policy northeast of the Guadalupe River.

Future research characterizing the status of Western Chicken Turtle habitats and populations in Texas and beyond should continue to evaluate the distribution, density, abundance, and long-term population trends of the subspecies. Additional research on commercial trading activities is also needed to help understand trends in global market demands for freshwater turtles and evaluate the accuracy of reporting on those trade activities. Finally, research investigating the effects of large scale watershed management on Western Chicken Turtle habitats and populations could shed light on more regional conservation solutions for the subspecies. For example, we did not evaluate how reservoir operation may have reduced available habitat by decreasing the frequency and intensity of high pulse flows needed to seasonally inundate riverine wetlands that the subspecies requires. Increasing our understanding of how to manage reservoirs in the range of the subspecies to restore seasonally inundated riverine wetlands might improve the long-term viability of this subspecies. This research could also benefit other species of conservation need, such as the Paddlefish (*Polyodon spathula*; Paukert and Fisher 2001), which requires high pulse flow for reproduction and has been the topic of recent research of modifying environmental flows in east Texas to recover the species (e.g., Caddo Lake Institute Paddlefish Experiment; Trungale and Smith 2015). Successful conservation of Western Chicken Turtles depends on continued research and management actions designed to increase our understanding of the subspecies and the wetland habitats it requires.

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APPENDICES.

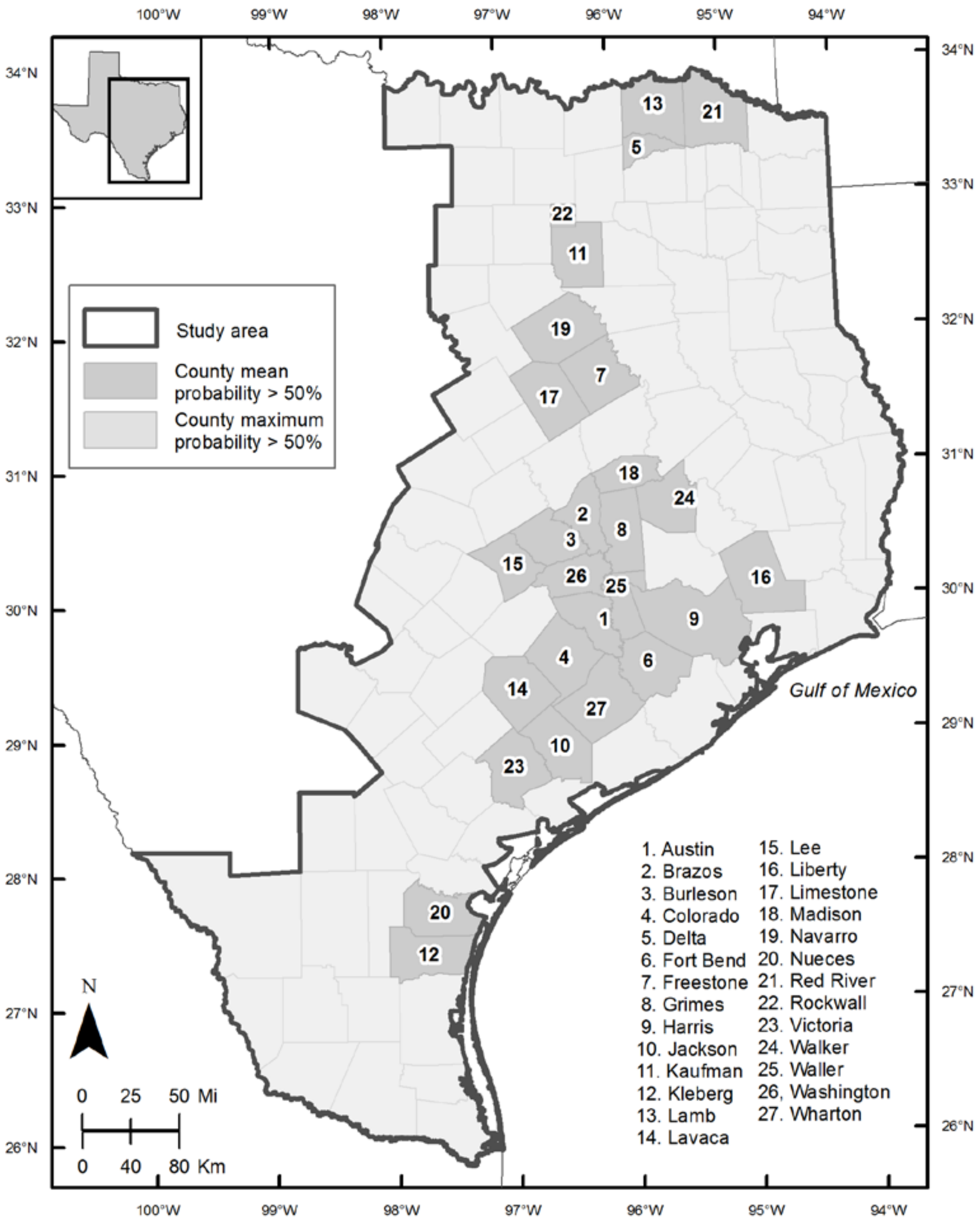

FIGURE A1. Texas, USA, counties with mean modeled probability of occurrence > 50%. We assessed current and future threats to Western Chicken Turtle habitat in Texas for: (1) 115 counties with maximum modeled probability occurrence >50% (counties with light gray shading) and (2) 27 counties with the most likely potentially suitable habitat with mean modeled probability of occurrence >50% (counties with darker gray shading and black outline). Numbers refer to county names.

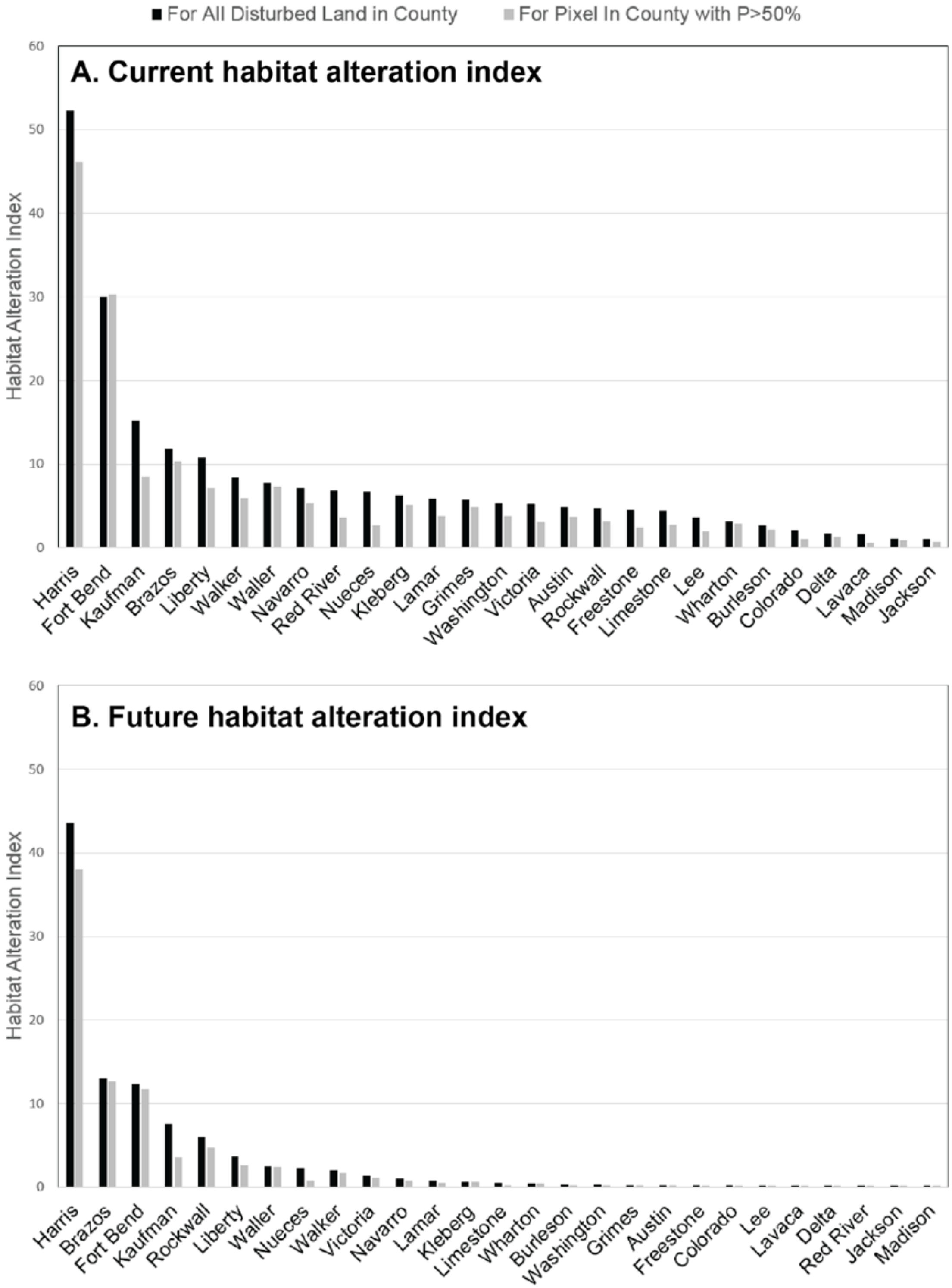

FIGURE A2. Current and future habitat alteration index for Texas counties with P_{mean} >50%. Counties are sorted from highest (left) to lowest (right) habitat alteration index so that counties with better-quality turtle habitat and the greatest current and future threats to their habitat are indicated. (A) Current habitat alteration index (*HAI*). (B) Future habitat alteration index (*HAI*).

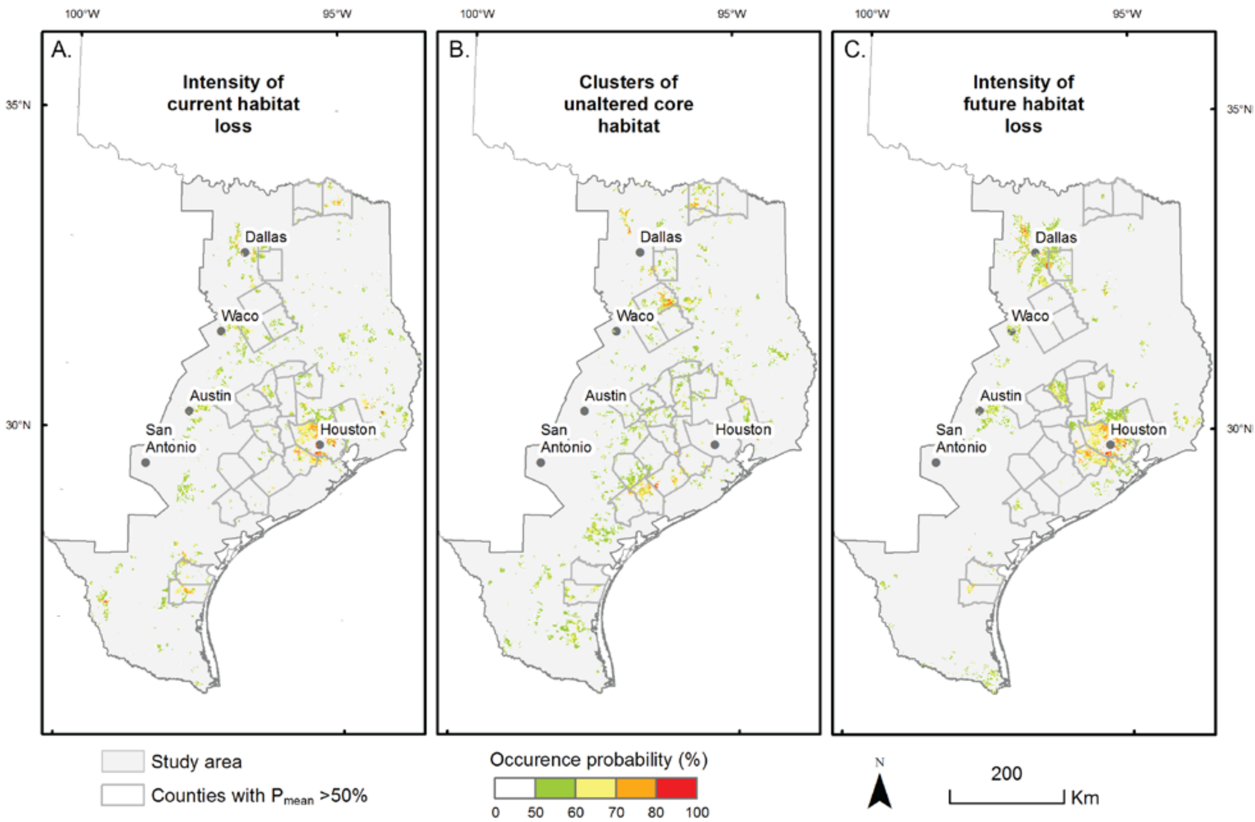

FIGURE A3. Intensity of (A) current habitat loss, (B) clusters of unaltered current core habitat, and (C) intensity of future habitat loss in Texas. Alteration intensity was identified with the *Gi** statistic and ranked according to the habitat model (i.e., red is better habitat than green). The Houston metropolitan region is experiencing focused loss of high-quality habitat from urban expansion and few clusters of unaltered core habitat remain. Conversely, rural areas have more remaining clusters of unaltered core habitat, which may serve to focus conservation efforts. Our analysis indicates additional high-quality habitat in the Houston metropolitan region will continue to be converted in the future to other uses.

TABLE A1. Features used as predictor variables for Maxent Species Distribution Modeling following the approach of Labay et al. (2011). References are 1 = 30-arc second digital elevation model (USGS 2014), 2 = WordClim (2014), and 3 = SSURGO (USDA 2014). Note: † indicates only these variables were used for final Maxent model run, in addition to wetland density (after Dahl 2011) and dominant soil order.

Category	Description	Maxent Variable	Source
Topological	Altitude†	alt	1
	Aspect†	aspect	
	Slope†	slope	
	Compound topographic index = *(ln (accumulated flow/tan[slope]))* †	cti	
Climate	Annual mean temperature	bio_1	2
	Mean diurnal range = *(monthly mean (max temp - min temp))*	bio_2	
	Isothermality = *(bio_2/bio_7)(*100)*	bio_3	
	Temperature seasonality = *(standard deviation *100)*	bio_4	
	Maximum temperature of warmest month	bio_5	
	Minimum temperature of coldest month	bio_6	
	Temperature annual range *(bio_5 – bio_6)*	bio_7	
	Mean Temperature of wettest quarter	bio_8	
	Mean Temperature of driest quarter	bio_9	
	Mean Temperature of warmest quarter	bio_10	
	Mean Temperature of coldest quarter	bio_11	
	Annual precipitation	bio_12	
	Precipitation of wettest month	bio_13	
	Precipitation of driest month	bio_14	
	Precipitation seasonality *(coefficient of variation)*	bio_15	
	Precipitation of wettest quarter	bio_16	
	Precipitation of driest quarter	bio_17	
	Precipitation of warmest quarter	bio_18	
	Precipitation of coldest quarter	bio_19	
Soils	Average percent sand in soil (from surface texture) †	wct_surftext	3

TABLE A2. Wetland (and deep water) classes found in the study areas. The approach followed the classification of Cowardin et al. (1979), which included biological, chemical, geomorphological, hydrological, and physical characteristics.

Type	Generalized Description
Riverine	River and streams
Lake	Lakes, reservoirs, and large ponds
Freshwater Pond	Marshes, wet meadows, swamps, and small shallow ponds.
Freshwater Emergent Wetland	Wetlands dominated by erect, rooted, herbaceous hydrophytes. Persistent; non-persistent.
Freshwater Forested/Shrub Wetland	Forested: Wetlands dominated by woody vegetation 6 m or taller. Shrub: Wetlands dominated by woody vegetation less than 6 m tall. Deciduous; evergreen; dead woody plants.
Estuarine and Marine Wetland	Tidal waters of coastal rivers and embayments, salty tidal marshes, mangrove swamps, tidal flats, and coastland.
Estuarine and Marine Deep Water	Tidal waters of coastal rivers and embayments, salty tidal marshes, mangrove swamps, tidal flats, and open water.

TABLE A3. Proximity of Western Chicken Turtle localities to wetland type, shown as percentage of wetlands within a buffer area of a certain km radius (i.e., 1-km, 5-km, 10-km, and nearest) in five states in the southern USA. The highest three values for each buffer are shaded (blue for Texas; light gray for all four states assessed).

Wetland Type	Texas				Arkansas, Louisiana, Oklahoma, Texas			
	1-km	5-km	10-km	*Nearest*	1-km	5-km	10-km	*Nearest*
Estuarine and Marine Deep Water	0.2	0.5	0.0	*0*	0.2	0.5	0.8	*0*
Estuarine and Marine Wetland	1.3	0.1	0.0	*2*	1.2	0.6	0.5	*1*
Freshwater Emergent Wetland	3.5	3.1	0.7	*22*	2.3	1.9	1.7	*13*
Freshwater/Forested Shrub Wetland	3.6	3.9	0.6	*14*	6.9	8.8	8.7	*38*
Freshwater Pond	1.0	0.7	2.1	*57*	0.7	0.6	0.6	*38*
Lake	2.5	1.4	0.0	*3*	2.9	2.7	2.1	*5*
Riverine	0.6	0.3	0.0	*3*	0.7	0.5	0.6	*5*
Total wetland area %	12.7	10.3	3.6		14.9	15.5	14.9	
Mean		8.8				15.1		
Standard deviation		4.7				0.4		

TABLE A4. Habitat alteration summary for counties in Texas, USA. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%. Refer to Fig. A1 for county locations.

***All values are in km²																									
		Alteration Regimes			Wetland Loss			Forest Loss			Suitable Habitat Loss						Core Habitat Loss				Bridge Change		Loop Change	
County ID	**COUNTY**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**All Current**	**Urban**	**Ag**	**All Current**	**Wetland Conversion**	**Forest Conversion**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**Future**	**Current**	**Future**	**Current**	**Future**
1	Anderson	4	4	16	5	-	1	67	2	4	30	2	21	3	4	11	39	-	2	1	15	-4	1	-
2	Angelina	5	-	57	3	-	-	97	4	-	30	1	27	1	-	19	43	-	-	3	12	-6	6	-3
3	Austin	2	1	4	1	-	-	17	-	1	14	-	10	2	1	3	6	-	-	-	-2	-1	-2	-
4	Bastrop	7	26	160	1	-	-	54	4	23	26	-	11	2	12	62	27	-	5	13	7	-28	-2	-4
5	Bee	1	4	7	-	-	-	29	-	3	8	-	6	-	1	2	9	-	-	1	3	-1	-	-
6	Bell	41	22	367	2	1	-	30	18	1	10	-	1	1	8	29	8	-	2	7	3	-6	-3	-3
7	Bexar	148	22	802	3	2	-	168	117	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Bowie	10	4	34	16	-	-	79	8	3	2	1	2	-	-	-	4	-	-	-	2	-	1	-
9	Brazoria	55	2	274	22	10	-	19	10	1	42	1	3	38	-	101	7	2	-	14	-1	-21	-2	-12
10	Brazos	29	1	225	2	1	-	28	15	1	40	1	9	29	1	219	24	4	-	51	6	-83	-5	-15
11	Brooks	3	2	3	1	-	-	35	1	1	15	-	12	2	1	2	37	1	-	-	19	-2	4	-
12	Burleson	1	4	6	-	-	-	17	-	4	11	-	8	-	3	4	19	-	1	-	9	-4	-	-
13	Caldwell	1	23	16	1	-	-	37	-	17	16	-	5	1	10	5	14	-	3	-	4	-1	-1	-
14	Calhoun	3	1	3	5	1	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Cameron	20	1	231	9	1	-	12	3	1	12	1	3	7	-	89	6	-	-	17	4	-21	1	-6
16	Camp	1	2	4	2	-	-	15	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	Cass	1	2	12	6	-	-	144	1	2	1	-	1	-	-	-	1	-	-	-	-	-	-	-
18	Chambers	16	6	14	14	4	6	5	3	-	13	1	2	10	-	8	9	2	-	1	1	-1	1	-1
19	Cherokee	2	1	30	2	-	-	80	1	1	20	1	19	-	-	9	34	-	-	1	12	-4	2	-1
20	Collin	103	3	730	4	-	-	13	9	-	24	3	2	19	1	204	20	2	-	65	9	-36	-	-12
21	Colorado	1	1	4	1	-	-	26	-	1	13	1	11	-	1	2	14	-	-	-	6	-1	-	-
22	Cooke	1	2	20	1	-	-	4	-	-	-	-	-	-	-	1	-	-	-	-	-	-1	-	-
23	Dallas	89	1	437	3	2	-	28	22	-	54	1	3	49	1	219	22	5	-	58	2	-37	-2	-14

TABLE A4 (CONTINUED).

***All values are in km²																								
		Alteration Regimes			Wetland Loss			Forest Loss			Suitable Habitat Loss						Core Habitat Loss				Bridge Change		Loop Change	
County ID	**COUNTY**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**All Current**	**Urban**	**Ag**	**All Current**	**Wetland Conversion**	**Forest Conversion**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**Future**	**Current**	**Future**	**Current**	**Future**
24	Delta	-	13	1	4	-	1	9	-	7	12	3	2	-	8	-	18	-	3	-	2	-	3	-
25	Denton	96	3	690	2	1	-	13	10	-	41	-	1	40	1	159	19	9	-	49	-2	-22	-	-14
26	DeWitt	1	11	2	-	-	-	32	-	9	15	-	10	1	4	1	17	-	1	-	10	-	-2	-
27	Duval	3	5	5	1	-	-	70	2	4	13	-	12	-	1	1	28	-	-	-	14	-	3	-
28	Ellis	28	30	245	3	-	-	9	3	2	25	2	2	4	17	87	25	-	6	16	8	-31	1	-6
29	Falls	-	42	4	1	-	1	10	-	4	23	-	2	-	20	2	17	-	6	-	-	-1	-	-
30	Fannin	1	18	12	1	-	-	9	-	1	2	-	1	-	1	-	3	-	-	-	2	-	-	-
31	Fayette	1	4	5	-	-	-	15	1	3	8	-	5	1	2	2	8	-	1	-	4	-1	-2	-
32	Fort Bend	129	1	183	18	15	-	27	19	1	137	3	7	126	1	175	16	7	-	27	-11	-38	-8	-16
33	Franklin	-	4	8	1	-	-	9	-	4	2	-	1	-	-	2	3	-	-	-	1	-3	-	1
34	Freestone	18	5	4	3	1	1	44	4	2	34	1	20	10	3	2	30	1	1	-	13	-	-4	-1
35	Galveston	36	-	109	13	8	-	13	11	-	12	-	1	11	-	44	3	1	-	5	-	-9	-1	-4
36	Goliad	3	3	2	-	-	-	15	1	3	8	-	6	1	1	1	14	-	-	-	7	-	-1	-
37	Gonzales	1	15	3	-	-	-	44	-	13	19	-	13	-	6	2	18	-	2	-	5	-1	-	-
38	Grayson	7	1	73	2	-	-	6	2	-	-	-	-	-	-	2	1	-	-	-	1	-1	-	-
39	Gregg	15	-	45	1	1	-	20	11	-	1	-	1	-	-	-	2	-	-	-	1	-	1	-
40	Grimes	3	1	5	-	-	-	23	2	1	22	-	17	3	1	3	38	1	1	-	16	-2	-	-
41	Guadalupe	18	30	131	1	-	-	53	7	23	3	-	1	-	2	5	3	-	1	1	1	-1	1	-1
42	Hardin	5	-	31	10	2	-	92	3	-	41	3	34	4	-	14	78	1	-	1	26	-6	9	-2
43	Harris	327	2	668	51	43	1	161	132	1	330	5	26	297	1	583	122	51	-	178	-25	-91	-15	-57
44	Harrison	16	3	28	7	1	-	112	12	2	3	-	3	-	-	1	5	-	-	-	2	-	-	-
45	Hays	26	7	497	1	-	-	38	14	3	2	-	1	-	1	14	3	-	-	4	2	-5	-	-
46	Henderson	4	6	59	5	-	1	34	1	5	15	1	9	2	3	30	21	-	1	3	8	-6	3	-5

TABLE A4 (CONTINUED).

***All values are in km²																								
		Alteration Regimes			Wetland Loss			Forest Loss			Suitable Habitat Loss						Core Habitat Loss				Bridge Change		Loop Change	
County ID	COUNTY	Urban	Ag	Future	All Current	Urban	Ag	All Current	Urban	Ag	All Current	Wetland Conversion	Forest Conversion	Urban	Ag	Future	All Current	Urban	Ag	Future	Current	Future	Current	Future
47	Hidalgo	78	4	145	4	1	-	38	5	3	18	1	12	4	2	18	45	-	1	1	21	-5	5	-1
48	Hill	-	21	11	2	-	-	3	-	-	5	-	-	-	5	1	6	-	2	-	3	-	-	-
49	Hopkins	1	9	3	5	-	-	15	-	9	7	3	1	-	3	1	11	-	1	-	4	-	1	-
50	Houston	2	1	4	3	-	1	67	1	1	18	-	17	1	-	1	26	-	-	-	7	-	5	-
51	Hunt	6	13	54	1	-	-	10	-	4	3	-	1	1	2	4	5	-	1	-	1	-1	2	-
52	Jackson	1	1	1	1	-	-	7	-	1	7	-	5	1	1	1	9	-	-	-	5	-	-1	-
53	Jasper	1	-	19	15	-	-	106	1	-	27	5	22	-	-	2	69	-	-	-	31	-1	4	-
54	Jefferson	21	2	50	22	9	1	5	2	-	11	2	2	7	-	18	8	-	-	4	1	-2	2	-2
55	Jim Hogg	2	-	3	-	-	-	23	-	-	1	-	1	-	-	-	2	-	-	-	1	-	1	-
56	Jim Wells	2	6	11	1	-	-	29	1	5	18	-	13	1	4	5	15	-	1	-	5	-3	-	-
57	Johnson	19	15	408	1	-	-	17	2	-	1	-	-	-	1	1	1	-	-	-	-	-1	-	-
58	Karnes	3	14	2	-	-	-	54	1	7	22	-	13	1	8	-	23	-	3	-	11	-	-2	-
59	Kaufman	22	7	151	1	-	-	10	1	4	28	1	3	18	6	72	14	2	2	15	1	-19	-	-8
60	Kenedy	5	1	-	8	-	-	37	1	-	9	1	7	-	-	-	31	-	-	-	18	-	5	-
61	Kleberg	3	37	11	3	-	-	47	1	21	56	1	15	2	37	10	61	-	25	1	8	-4	-	-1
62	Lamar	3	38	14	2	-	1	25	1	14	30	1	6	3	21	9	29	-	7	1	6	-2	2	-1
63	Lavaca	2	2	2	-	-	-	10	1	2	7	-	4	1	1	1	13	-	-	-	8	-	-1	-
64	Lee	3	6	3	2	-	-	27	2	5	16	1	11	1	3	2	11	-	1	-	-2	-	-	-
65	Leon	4	5	3	2	-	-	54	2	4	26	1	21	2	3	2	30	-	1	-	9	-1	-	-
66	Liberty	5	-	69	14	1	-	45	2	-	39	7	28	4	-	49	78	-	-	12	29	-21	10	-
67	Limestone	8	35	11	1	-	-	26	3	4	39	-	9	4	26	5	39	1	10	-	10	-1	-3	-1
68	Live Oak	3	6	8	1	-	-	55	1	4	6	-	5	-	1	4	10	-	-	-	6	-5	-	1
69	Madison	-	-	-	-	-	-	7	-	-	5	-	4	-	-	-	4	-	-	-	2	-	-	-

TABLE A4 (CONTINUED).

***All values are in km²																									
		Alteration Regimes			Wetland Loss			Forest Loss			Suitable Habitat Loss						Core Habitat Loss				Bridge Change		Loop Change	
County ID	COUNTY	Urban	Ag	Future	All Current	Urban	Ag	All Current	Urban	Ag	All Current	Wetland Conversion	Forest Conversion	Urban	Ag	Future	All Current	Urban	Ag	Future	Current	Future	Current	Future
70	Marion	-	1	8	5	-	-	83	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-
71	Matagorda	2	2	14	5	-	1	12	-	1	6	-	4	1	1	3	3	-	-	-	2	-2	-	-
72	McLennan	19	29	163	3	1	-	7	2	1	22	1	1	8	12	58	15	1	3	8	6	-12	-5	-9
73	McMullen	4	7	3	1	-	-	60	2	6	1	-	1	-	-	-	1	-	-	-	-	-	1	-
74	Milam	1	23	4	2	-	-	45	1	15	32	1	17	1	14	2	37	-	5	-	13	-	-3	-1
75	Montague	3	-	10	4	-	-	10	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
76	Montgomery	120	-	915	19	14	-	147	85	-	106	3	31	71	-	494	136	38	-	183	36	-118	7	-35
77	Morris	-	1	6	4	-	-	17	-	1	3	1	2	-	-	-	5	-	-	-	2	-	-	-
78	Nacogdoches	3	-	39	2	-	-	104	2	-	30	-	29	-	-	5	51	-	-	1	16	-2	6	1
79	Navarro	1	33	17	4	-	1	11	-	2	37	2	7	1	28	13	41	-	10	2	11	-7	1	-
80	Newton	1	-	9	16	-	-	97	-	-	15	3	11	1	-	2	40	-	-	-	17	-2	6	1
81	Nueces	22	2	45	3	-	-	19	4	1	15	1	7	6	1	15	13	-	-	2	10	-4	-1	-2
82	Orange	7	-	39	12	3	-	8	2	-	16	6	5	5	-	27	35	1	-	3	19	-15	4	-1
83	Panola	2	2	9	4	-	-	79	1	1	14	-	13	-	-	1	21	-	-	-	5	-1	3	1
84	Polk	3	-	42	4	-	-	94	2	-	24	1	23	1	-	16	44	-	-	2	18	-8	4	-2
85	Rains	-	4	3	1	-	-	6	-	4	1	-	-	-	1	1	1	-	-	-	-	-	-	-
86	Red River	-	38	1	15	-	4	71	-	32	44	4	16	-	24	1	50	-	7	-	7	-	4	-
87	Refugio	1	2	1	1	-	-	6	1	1	3	-	2	1	-	1	5	-	-	-	4	-	-1	-
88	Robertson	10	6	4	1	-	-	41	4	6	18	-	12	3	2	2	20	-	1	-	10	-2	-5	-
89	Rockwall	21	-	116	-	-	-	4	3	-	17	-	1	16	-	91	7	3	-	18	-1	-21	-	-8
90	Rusk	3	3	23	5	-	1	58	1	1	4	1	3	-	-	1	6	-	-	-	1	-	1	-
91	Sabine	-	1	6	6	-	-	45	-	1	11	2	9	-	-	1	26	-	-	-	11	-1	6	-
92	San Augustine	-	-	3	1	-	-	45	-	-	9	-	9	-	-	2	21	-	-	-	13	-1	5	-

TABLE A4 (CONTINUED).

***All values are in km²																									
		Alteration Regimes			Wetland Loss			Forest Loss			Suitable Habitat Loss						Core Habitat Loss				Bridge Change		Loop Change	
County ID	**COUNTY**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**All Current**	**Urban**	**Ag**	**All Current**	**Wetland Conversion**	**Forest Conversion**	**Urban**	**Ag**	**Future**	**All Current**	**Urban**	**Ag**	**Future**	**Current**	**Future**	**Current**	**Future**
93	San Jacinto	2	-	26	1	-	-	39	1	-	7	1	5	1	-	10	16	-	-	2	9	-9	2	-
94	San Patricio	6	3	41	4	-	-	17	1	2	11	-	7	1	2	10	10	-	1	1	6	-7	-2	1
95	Shelby	2	-	10	4	-	-	59	1	-	8	1	7	-	-	2	14	-	-	-	8	-1	4	-
96	Smith	27	7	220	9	3	2	51	17	5	4	-	2	2	-	19	4	-	-	4	2	-4	-	-3
97	Starr	7	15	96	1	-	-	50	2	9	6	-	3	1	2	8	10	-	1	1	2	-4	3	-
98	Tarrant	157	2	529	1	1	-	24	18	-	17	1	1	15	-	51	7	1	-	16	1	-7	-	-3
99	Titus	4	6	18	6	-	-	22	2	5	12	2	6	2	1	7	14	-	-	1	5	-2	1	-
100	Travis	107	22	1,036	4	2	-	106	61	15	36	-	6	18	12	150	32	3	6	51	6	-33	-1	-12
101	Trinity	1	-	13	1	-	-	51	-	-	29	1	28	1	-	11	57	-	-	3	20	-4	6	-2
102	Tyler	1	-	12	6	-	-	93	1	-	8	-	7	-	-	1	16	-	-	-	6	-1	1	-
103	Upshur	2	7	17	4	-	-	54	1	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
104	Van Zandt	1	9	12	1	-	-	15	-	8	2	-	1	-	1	2	1	-	-	-	-	-	-	-1
105	Victoria	7	1	27	2	-	-	10	2	1	11	1	5	5	1	21	8	-	-	2	4	-7	-1	-2
106	Walker	4	1	36	2	-	1	64	2	-	41	1	37	3	-	31	75	-	-	6	28	-16	6	-1
107	Waller	6	2	41	1	-	-	11	1	2	16	1	8	6	2	40	12	1	1	7	6	-13	-2	-2
108	Washington	2	2	6	-	-	-	10	1	1	8	-	6	1	1	3	7	-	-	-	1	-1	-	-1
109	Webb	41	25	203	5	1	-	239	21	21	42	1	22	5	15	40	78	1	8	19	37	-8	4	-4
110	Wharton	2	2	7	1	-	1	7	-	1	9	-	5	2	2	6	4	-	-	-	2	-1	-3	-2
111	Willacy	1	-	4	3	-	-	8	-	-	3	-	2	-	-	-	6	-	-	-	3	-	2	-
112	Williamson	81	20	735	2	1	1	62	32	5	12	-	3	-	8	29	8	-	2	3	-	-6	-1	-5
113	Wilson	3	20	30	-	-	-	68	2	17	16	-	5	-	11	-	15	-	6	-	1	-	-1	-
114	Wood	2	11	22	2	-	-	26	1	10	2	-	1	-	-	2	2	-	-	-	1	-1	1	-
115	Zapata	9	3	34	1	-	-	58	5	1	25	-	19	4	1	8	75	2	-	2	49	-3	-1	-1
	Totals	**2,173**	**872**	**11,902**	**500**	**137**	**37**	**4,794**	**766**	**443**	**2,300**	**96**	**921**	**898**	**385**	**3,514**	**2,423**	**148**	**147**	**895**	**781**	**-867**	**70**	**-282**