FINAL REPORT

HABITAT MODELING AND CONSERVATION OF THE WESTERN CHICKEN TURTLE (*DEIROCHELYS RETICULARIA MIARIA*) IN TEXAS

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Western Chicken Turtle (female) from Harris County, Texas photo credit: Toby J. Hibbitts

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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 U.S. Fish and Wildlife Service to consider Endangered Species Act protections for the subspecies. The goal of this study was to determine biological and conservation requirements for Western Chicken Turtles in Texas. We modeled potentially suitable habitat and quantified current and future threats to habitat state-wide. Suitable habitats occupied East Texas, especially where low altitude wetlands occurred in high density. Wetland loss and fragmentation in urban and urbanizing rural areas, particularly around Houston, represented the greatest current and future threats to habitat. Population surveys targeting potentially suitable habitats indicate 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 5 sites near historical localities. Between 15 April and 5 May 2015, each survey method produced a single Western Chicken Turtle observation (n = 3). The only live-caught specimen (female) was delivered to Houston Zoo for future captive breeding and head starting research. Current population threats from commercial harvest and export appear insignificant for this subspecies, although continued monitoring of wild populations is recommended. We also recommend a combination of expanded wetland protection policies, captive breeding, and head start programs for conservation of Western Chicken Turtles in areas identified here as having high quality habitat under greatest threat.

Key Words.—captive breeding; ephemeral wetlands; fragmentation; habitat perforation; harvest; head start; terrestrial; urbanization

INTRODUCTION

Wetland species' populations 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 federal "no net loss" wetland policy is to maintain individual or groups of wetlands or to maintain the total amount of wetlands at a regional scale (U.S. National Wetlands Mitigation Action Plan). One problem with this policy is that it does not protect the landscape surrounding wetlands, which implicitly assumes the species only needs wetlands (Bauer et al. 2010). This is certainly not true for all wetland species experiencing declines, especially amphibians and reptiles (Gibbons 2003; Semlitsch and Bodie 2003). Indeed, landscape matrix quality is more important than overall wetland amount for many amphibian and reptile wetland species (Quesnelle et al. 2015). Because many species also require terrestrial resources, policies which 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*) habitats and populations in Texas and identify current and future threats to their persistence in order 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 United States (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 (Swartz 1956; Gibbons 1969; Bennett et al. 1970; Jackson 1974; Jackson 1978; Gibbons and Greene 1978; Gibbons et al. 1983; Gibbons 1987; Buhlmann 1995; Jackson 1996; Demuth and Buhlmann 1997; Buhlmann et al. 2009). This species is separated into three subspecies based on geographic variation in morphology (Schwartz 1956). The Western Chicken Turtle (*D. r. miaria*) occurs west of the Mississippi River in Louisiana, Arkansas, Missouri, Oklahoma, and Texas, and possesses dark, seam-following marks on a yellow plastron which 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, but biological uniformity across subspecies is often assumed (McKnight 2014). This assumption is questionable given the variability in habitat type, availability, connectivity as well as climate across the species' range (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. 2015). 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. 2015). 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 observed a positive population growth rate for Western Chicken Turtles. In another recent capture-recapture study in Oklahoma, McKnight (2014) observed 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 species' distribution (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). Alternatively, 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 extremely urgent 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 United States has caused declines in populations of similar amphibians and reptiles (Buhlmann et al. 2009; FWS 2011). The Western Chicken Turtle is thought to have suffered even greater declines from alteration or loss of habitat than these 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 water of the U.S. and protected by the Clean Water Act, such wetlands must be shown to be connected to or have a significant nexus with traditional navigable waters (TNWs) (CWA; 40 CFR 230.3; 80 FR 37054). 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. 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 habitats likely 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 species' wetland habitats. As ephemeral wetlands dry, Western Chicken Turtles depend upon terrestrial upland habitats that provide refuges 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 habitats 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 (Buhlmann et al. 2008). 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, 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 US Endangered Species Act (ESA 1973). The subsequent 90-day finding produced by the US Fish and Wildlife Service (FWS) states that listing the subspecies as threatened or endangered may be warranted (FWS 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 in Texas by: (1) modeling potentially suitable Western Chicken Turtle habitat; (2) identifying and quantifying current threats to this habitat; (3) assessing future habitat conditions based upon the presence of risk factors; (4) characterizing historical and current distribution patterns and population trends; (5) summarizing recent commercial, recreational, scientific, and educational collection or harvest data; and (6) evaluating the feasibility of captive breeding and head start programs for conservation of the subspecies. The conclusions on threats and recommendations on management of Western Chicken Turtle habitat and populations in Texas generated from this research will provide a foundation for the development of a conservation plan for the species.

MATERIALS AND METHODS

Study area.—We studied Western Chicken Turtles 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 may potentially support Western Chicken Turtles (see work flow Fig. 1; Phillips et al. 2006; Phillips and Dudík 2008). This approach, based upon Labay et al. (2011), is ideal for small, presence-only datasets (Phillips et al. 2006) and generated a continuous probability distribution of occurrence using presence-only data (e.g., know turtle distribution; TAMU 2014) and a suite of environmental predictor variables (WorldClim 2014). We also included a wetland density map based upon Dahl (2011; Appendix Fig. 1, Appendix Table 1). An urban sampling bias was reduced by adding samples to the background (refer to: Elith et al. 2011; Implications for modelling). We implemented Maxent following default parameterization recommendations (Phillips and Dudík 2008; Elith et al. 2011) with models cross-validated with 10 replicates generating a grid of relative estimates of probability of occurrence. We assumed that pixels with modeled probability of occurrence (P) >50% are considered potentially suitable habitat. This threshold is somewhat arbitrary, and we use it here as a conservative approach to quantify all potentially suitable habitat given the rare nature of the Chicken Turtle. Further, we selected counties with the most favorable potential habitat by calculating the mean probability of occurrence for the county. We also evaluated the proximity of historic localities to wetlands and sandy soil (refer to Appendix 1 for approach).

Current threats to habitat.—To evaluate current anthropogenic threats within the species' modeled Texas range, we investigated recent land use changes using the National Land Cover Database (NLCD; Jin et al. 2013; Appendix Tables 1 and 2, USGS 2014). 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). We considered counties with mean modeled probability of occurrence (P_{mean}) >50% to be habitat most likely to support the species and, therefore, warranted a focused assessment of recent anthropogenic threats. Within these high-priority counties we identified habitat most at risk of alteration, by assessing land cover changes for pixels with modeled probability of occurrence (P) >50%. Additional details on our approach to evaluate current threats using the NLCD are provided in Appendix 1.

To provide conservation biologists with another tool to 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 P_{mean} >50% in two ways: (1) for all disturbed land in a county; and (2) for disturbed land found only in pixels with P>50%.

We also removed areas of recent landscape alterations (2001–2011) from the baseline, un-altered potentially suitable modeled habitat to quantitatively evaluate current habitat alteration and fragmentation using morphological spatial pattern analysis (MSPA). We considered the baseline suitable habitat condition to be defined by the habitat model where modeled probability of occurrence (P) >50%. We refined the baseline layer by overlaying landscape alteration from 2001 NLCD urban and agricultural classes and roads, medians, and right-of-ways (TxDOT 2014) and reclassifying intersecting pixels as unsuitable habitat. We used this layer to establish a 2001 pre-alteration fragmentation 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 compared our maps of baseline and altered habitat to calculated metrics of current landscape fragmentation and mapped these metrics spatially. Additional details on the habitat alteration and fragmentation approach are provided in Appendix 1.

Future threats to habitat.—We assessed future threats to and fragmentation of Western Chicken Turtle habitat caused by forecasted urbanization (2010–2050) using the same approach we used for current threats. 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/acre, 5–9.9 units/acre, 2–4.9 units/acre, 0.5–1.6 acre/unit, and 1.7–4.9

acre/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 2014) and developed land classes in the NLCD dataset. Forecasted housing development using these Theobald classes also resulted in the most qualitatively plausible pattern of 2050 housing development, given recent trends in urban expansion. 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 which counties with high-quality Western Chicken Turtle habitat were most altered by forecasted future urbanization. We assessed future habitat fragmentation by removing future urbanized areas from a map of current habitat and using MSPA to quantify future habitat fragmentation.

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. Road-cruising surveys were conducted along public roadways passing through modeled suitable habitat areas. Visual observation surveys using binoculars and spotting scopes were conducted 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 some surveys were also conducted under cloudy conditions following rain events to capture turtles migrating across roads. All turtles observed, alive or dead, were identified to species and recorded.

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 (Waller and Harris Counties), Lake Waco Wetlands (Baylor University, McLennan County), and John Bunker Sands Wetland Center (Kaufman County). Western Chicken Turtle populations were sampled at these sites and two additional public sites at Gus Engeling Wildlife Management Area (Texas Parks and Wildlife Department, TPWD; Anderson County) and Jesse H. Jones Park and Nature Reserve (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 species' range (Dinkelacker and Hilzinger 2014; McKnight 2014; McKnight et al. 2015). All turtles captured, regardless of species, were weighed, sexed, measured (e.g., carapace and plastron length), and individually marked for identification upon recapture. Each captured Western Chicken Turtle was also considered for inclusion in a captive breeding and head start program managed by the Houston Zoo (see *Captive breeding and head starting*).

Collection and harvest data.—We acquired international exportation data from FWS 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 Texas Parks and Wildlife Department (TPWD). Data provided by TPWD included collection by county, possession by year, purchases by year, and sales by year.

Captive breeding and head starting.—In collaboration with amphibian and reptile curators at the Houston Zoo, we developed a plan to deliver and house a subset of the Western Chicken

Turtles captured during our distribution and population surveys. Following a precautionary quarantine period, wild caught Western Chicken Turtles were kept in medium sized aquatic Waterland tubs (246 liters; ¾ water, ¼ land, with submersible filtration) in a mostly shaded area. Different sex ratios were to be evaluated in terms of captive breeding potential for future head starting conservation objectives.

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 (Figs. 2 and 3; Table 1). Potentially suitable habitat included river basins from the Guadalupe River east to the Louisiana border and also includes most of the Gulf Coastal Plains.

Mapping of potentially suitable habitat suggested that Western Chicken Turtles in Texas preferred lower altitudes, elevated and consistent rainfall, and proximity to freshwater wetlands (Appendix Table 4). The species did not appear to require especially sandy soil, but few historic localities had clay-rich soils (Appendix Table 5). The turtle prefers high freshwater wetland density, but not a specific type of wetland (i.e., estuary, pond, shrub wetland, pond/lake; Appendix Table 6). Few historic localities or modeled potentially suitable habitat included brackish wetlands near the coast. Habitat modeling also showed that the species favored elevated—and consistent—precipitation year round (especially in the summer). This was consistent with historic localities in humid east Texas and Louisiana. Another notable finding was low modeled probability of occurrence in proximity to East Texas National Forests, although historical records from these forests exist (Adams and Saenz 2011). The jackknife test of input feature importance (Appendix Fig. 2) indicated lower altitude was the most important factor influencing the species' modeled distribution. Wetland density was the second most important factor, which was consistent with visual inspection of wetland density maps (Dahl 2011; Appendix Fig. 1). Generalized soil order (i.e., sandy, clayey) also strongly influenced the modeled Western Chicken Turtle distribution. Soil texture (i.e., percent sand) was only somewhat important.

Current threats to habitat.**—**Recent land use changes have altered 2,300 km^2 of suitable habitat and over 500 km^2 of wetlands in the species' Texas range (Figs. 4 and 5). Alteration was caused by forest loss, urbanization, agricultural expansion, and wetland conversion (~40%, ~39%, ~17%, and ~4%, respectively; Appendix Table 7; Appendix Figs. 4–17). Alteration of core habitat was most intense in and around Houston (Montgomery, Harris, and Liberty counties, 136, 122, and 78 km^2, respectively). Our analysis showed that Harris and Liberty counties lost 25 and 11 km^2 (respectively) of connective bridge corridors, indicating a decrease in migration pathways between habitat patches. However, in Montgomery County, bridge corridors increased, 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 ~137 km^2 to urbanization and ~37 km^2 to agricultural expansion. Overall, the three counties with the highest wetland loss were Harris, Jefferson, and Brazoria (51, 22, and 22 km^2, respectively). Urban expansion was the most important cause of wetland conversion in Houston-area Harris, Fort Bend, Montgomery, and Brazoria counties (43, 15, 14, and 10 km^2, respectively). In the entire study area, recent urban expansion occurred primarily around major metropolitan areas and totaled ~2,170 km^2; however, the effects of urbanization on habitat varied spatially. For example, urbanization in Harris and Tarrant counties caused 297 and 15 km^2 of suitable habitat loss, respectively. Fort Bend County had the fourth highest urbanization and second highest suitable habitat loss (126 km^2). Conversely, highly urbanized Bexar County did not have any habitat loss because it is located at the western edge of the species' historic range.

Total crop expansion in the 115-county study area was 872 km^2 and Kleberg County had the highest habitat loss (37 km^2) from agricultural expansion. Falls, Red River, Lamar, Kleberg, Limestone, and Navarro counties all had recent crop expansion >30 km^2 with >20 km^2 of it resulting in suitable habitat lost. With the exception of Falls County, all of these counties had suitable Western Chicken Turtle habitat (P_{mean} >50%).

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. The largest amount of forested area loss (i.e., mesquite) was near Laredo (Webb County, 239 km^2). However, because this county is located ~300 km southwest of the species' western-most historic range, no suitable habitat was lost. Of the counties with the most suitable modeled habitat (i.e., P_{mean}>50%), Walker, Liberty, and Harris counties had the most habitat conversion from forest loss (37, 28, and 26 km^2; respectively). The five counties with the greatest suitable habitat conversion from forest loss were Walker, Hardin, Montgomery, Nacogdoches, and Liberty (37, 34, 31, 29, and 28 km^2; respectively).

We summarized the effects of recent landscape alteration on habitat using HAI (Fig. 6A) and found Harris, Fort Bend, Brazos, Kaufman, Waller, and Liberty counties were the most altered large potential habitat areas (*HAI*=46, 30, 10, 9, 7, and 7, respectively). These counties are all highly urbanized and included economically-important Houston, Dallas, and College Station metropolitan areas.

Our habitat fragmentation analysis (Figs.7 and 8) found that the greatest intensity of recent core habitat loss occurred in the Houston metropolitan area (Harris County, ~1,800 km^2; Fig. 7). The second highest intensity of core habitat loss (~300 km^2) occurred in Karnes County where oil and gas development in the Eagle Ford Shale Play likely caused agriculture and forest conversion. Other core habitat fragmentation was caused by agricultural expansion in the Blackland Prairie (i.e., southeast of Waco) or a combination of urban and agricultural expansion (i.e., Austin and Dallas). Conversely, Colorado, Wharton, Jackson, and Lavaca counties had clusters of pristine, unaltered core habitat (Fig. 8). Very little unaltered core habitat remained in Houston (Harris County); however, a few parts of Fort Bend County still had not yet been urbanized. The largest contiguous area of unaltered core habitat (~510 km^2) close to Houston is located in Liberty County and a portion Chambers County.

Future threats to habitat.—Forecasted future urbanization through 2050 (Figs. 4 and 9; Appendix Figs. 18–21; Appendix Table 7) may alter ~11,900 km^2 of landscape and convert 3,514 km^2 of suitable habitat. Urbanization may be highest in Travis (1,036 km^2), Montgomery (915 km^2), and Bexar (802 km^2) counties; however, the most important future habitat alteration may occur near Houston (Harris, Brazos, and Fort Bend counties, 583, 219, and 175 km^2; respectively). Urbanization around Houston will convert the most wetland area (Harris, Montgomery, Brazoria, and Fort Bend counties, 194, 159, 108, and 67 km^2; respectively).

Urbanization around Dallas (Rockwall County) and College Station (Brazos County) will also cause important future wetland loss.

Future habitat alteration from urbanization will be most intense around the Houston and College Station metropolitan areas. Our calculation of future HAI is highest in Harris, Brazos, and Fort Bend counties (Fig. 6B; 38, 13, and 12, respectively).

Future urbanization may result in 895 km^2 of core habitat alteration, with the most occurring in Montgomery, Harris, and Collin counties (183, 178, and 65 km^2; respectively). Houston-area Harris, Brazos, and Fort Bend counties may have the highest alteration of core habitat (178, 51, and 27 km^2; respectively) with 322 km^2 in the P_{mean}>50% counties with the best habitat. Future loss of migration pathways was most intense around Houston (Harris, Montgomery, Harris, Brazos, and Fort Bend counties had 118, 91, 83, and 38 km^2 of connective bridge corridor loss, respectively). The greatest intensity of future habitat fragmentation may occur in and around the Houston (~3,052 km^2) and Dallas (~1,784 km^2) metropolitan areas (Fig. 10). Habitat loss intensity may also be elevated near College Station. Small clusters of intense core habitat loss are also widely distributed throughout the study area.

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. 11). 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 (blue triangles Fig. 11). On 15 April 2015, one Western Chicken Turtle basking on a log was observed through binoculars in Falls County. The next month, on 5 May 2015, another Western Chicken Turtle was found dead on the road in Waller County. 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 the 5 sites described above during the same survey interval. Across all 5 sites, we recorded a total of 2,458 trap nights using all aquatic trapping methods combined (Table 2). This trapping effort yielded 656 individual turtle captures representing 9 turtle species, including one female Western Chicken Turtle captured on 2 May 2015 in Harris County (blue star Fig. 11). This female was delivered to the Houston Zoo to help evaluate the feasibility of captive breeding and head starting for Western Chicken Turtles.

Collection and harvest data.**—**International exports of live Western Chicken Turtles from the US were rare (Table 3), 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 placed out of business in 2009 after being charged with multiple violations of the Lacey Act.

Before 2008, Texas allowed the collection of Western Chicken Turtles from the wild with a non-game collector permit. Since 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). However, with a hunting license, it is still legal to possess up to six specimens collected from the wild for personal use, but TWPD does not report these data. Currently, non-game collector permits are available for $63, and all applications for permits are generally accepted. Those permitted are required to file annually with TPWD. There are no seasons or bag limits for species permissible to collect.

Annual reports to TPWD from permittees indicated that a single collector harvested five individuals from the wild in 2007 and 2008 (Table 4). Since then, harvesting of Western Chicken Turtles from the wild, or the reporting of it, has ceased. Annual reports showed that very few permitted collectors possessed Western Chicken Turtles (Table 5), and no captive colonies were actively producing offspring in captivity for sale in the state during the years reported (2008–2012).

Captive breeding and head starting.—One Western Chicken Turtle female was collected live and transferred to the Houston Zoo on May 15, 2015. The specimen passed through quarantine without problems and has been kept outdoors at the Houston Zoo in an aquatic Waterland Tub™ with water changes performed once a week. The individual has been fed a rotating diet of earthworms, crickets, defrosted smelt, Mazuri® aquatic turtle pellets and defrosted shrimp three times per week. Behaviorally, the specimen has spent approximately 75% of the time in water and the remaining 25% basking. Because only a single female was captured during this study, evaluation of captive breeding and head starting protocols for Western Chicken Turtles is on-going.

DISCUSSION

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, important loss of wetlands occurred in prime habitat in and around Houston (Fig. 4; Appendix Fig. 8), which is a continuation of a decades-long trend (Brody et al. 2008). Houston-area Fort Bend and Harris counties also have the best quality habitat in the study area (P_{mean}=67% and 65%; Table 1) and a high density of historic localities (Fig. 2). Dallas-area Kaufman and Rockwall counties also have elevated urbanization, but habitat quality is lower (P_{mean}=~50%). This difference between quality of habitat and intensity of habitat alteration is borne out in the HAI (Fig. 7), which confirms the intensity of habitat alteration in and around Houston (HAI: 7–46) and, less so, around Dallas (HAI: 3–9) and College Station (HAI=10).

We expect this trend in habitat loss due to urbanization in the Texas part of the species' range to continue (Fig. 4; Appendix Fig. 18), as urbanization occurs in high-quality habitat near Houston, College Station, and Dallas. Crop expansion and forest loss (e.g., Appendix Fig. 11) were significant land-change processes; however, HAI in these counties—with the exception of those near urban areas—indicates these processes are less important causes of habitat loss. We expect the most intense future concentrated core habitat alteration (Fig. 10) to occur in and around the Houston (clusters as large as ~3,050 km²) and Dallas (clusters as large as ~1,780 km²) metropolitan areas. Future Harris County landscape alteration is so intense that bridge corridors are decreasing, resulting in fewer 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 species is rare and declining throughout its range could be an artifact of sampling bias (McKnight 2014; personal communication). Given the discrete seasonal activity pattern of this subspecies (mainly March–June; Dinkelacker and Hilzinger 2014; McKnight 2014), 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–August) may be ineffective when the subspecies is estivating 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 2014). 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 different sample methods (i.e., visual observation, road-cruising, trapping) indicates our sampling results are not biased.

In light of current and forecasted future trends in habitat degradation, continued surveys for Western Chicken Turtles are recommended. Our sampling methods potentially provide a standardized survey protocol for this subspecies. We particularly recommend surveys be conducted near the major metropolitan areas of Houston, College Station, and Dallas, which are at greatest risk of habitat loss. Surveys of populations in other parts of the range will provide a means to evaluate the success of our methods across a gradient of modeled probability of occurrence. To this end, the map of current clusters of unaltered habitat (Fig. 8), can be used to guide researchers to the largest contiguous tracks of highest quality habitat.

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.

With just one female in captivity at the Houston Zoo, our evaluation of the feasibility of captive breeding and head starting for Western Chicken Turtles is incomplete. We made attempts to locate other individuals in captivity to increase the Houston Zoo population, but no captive colonies of Western Chicken Turtles existed within institutions belonging to the

Association of Zoos and Aquariums (AZA). In our search, we did find that captive breeding of the species has been successful at one AZA facility, the Tennessee Aquarium, but those individuals were Florida Chicken Turtles with reportedly different reproductive requirements (Buhlmann et al. 2008; McKnight et al. 2015). Head starting is often paired with captive breeding programs for turtles, and it may be a successful strategy for increasing recruitment in Western Chicken Turtle populations. In an Arkansas study, 18 of 21 (86%) wild-collected eggs incubated in moist vermiculite at 29ºC for 68 days were successfully hatched, released, and then recaptured the following year (Dinkelacker and Hilzinger 2014). This high survivorship for head started juveniles may indicate that Western Chicken Turtles might depend more on high recruitment than on adult survival to maintain wild populations. Evaluation of captive breeding and head starting protocols for Western Chicken Turtles remains an important topic for future research, because it could be an important recovery strategy for future conservation efforts and provide a platform for future research on the subspecies' biological and habitat needs.

CONCLUSIONS

The Western Chicken Turtle favors wetlands and nearby uplands. 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. We recommend a combination of strategies to conserve this subspecies, including (1) expanded wetland habitat protection policies; (2) captive breeding; and (3) head start programs in the best-quality habitat areas under the greatest threat. Conservation efforts should be focused where they are likely to be most effective within the species' range. Our analysis of current habitat threats and condition suggest that the modern southern boundary for Western Chicken Turtles occurs somewhere along the Guadalupe River (Fig. 12). The establishment of this line is supported by the distribution of historic localities, which do not occur south and west of the Guadalupe River, and our current distribution surveys (n = 396), which did not detect the species south of the Guadalupe River. While 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. By establishing the Guadalupe River as the modern southern boundary for Western Chicken Turtles, we hope to frame the implementation of effective conservation strategies for the species.

Current federal wetland regulations do not protect wetland-terrestrial upland habitat that Western Chicken Turtles prefer. The Clean Water Act (CWA; 40 CFR 230.3; 80 FR 37054) 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 species' requirements for terrestrial resources (Quesnelle et al. 2015). The map of current clusters of unaltered habitat (Fig. 8) identifies reasonable starting points for implementing this expanded wetland policy (north and east of the Guadalupe River).

Even if policies are changed to enhance wetland protection, areas with little remaining wetland habitat (Fig. 7) may require captive breeding and head starting to restore populations of the species. The increased recruitment from these conservation activities will help ensure long-term persistence of the subspecies in the region as a series of populations occupying protected habitat remnants. For example, Harris and Waller Counties contain several sites protected from anthropogenic alteration where the species has been recently observed that may be candidates for reintroduction with individuals from a captive propagation program. Despite these counties being under greatest risk of current and future anthropogenic alteration, they contain a large portion of high quality Western Chicken Turtle habitat. As such, they represent favorable starting points for future head start programs designed to maintain persistence of Western Chicken Turtle populations.

FUTURE RESEARCH

Future research characterizing the status of Western Chicken Turtle habitats and populations in Texas should continue to evaluate the species' distribution, density, abundance, and long-term population trends using the survey protocols established here. Data and individual turtles captured during these surveys could be used to fully evaluate the feasibility of captive breeding and head starting as conservation strategies for Western Chicken Turtles. 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 species. 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 the species prefers. Increasing our understanding of how to manage reservoirs in the species' Texas range to restore seasonally inundated riverine wetlands might improve the species' long-term viability. 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). Successful conservation of Western Chicken Turtles depends on continued research and management actions designed to increase our understanding of the species and the wetland habitats it prefers.

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FIGURES

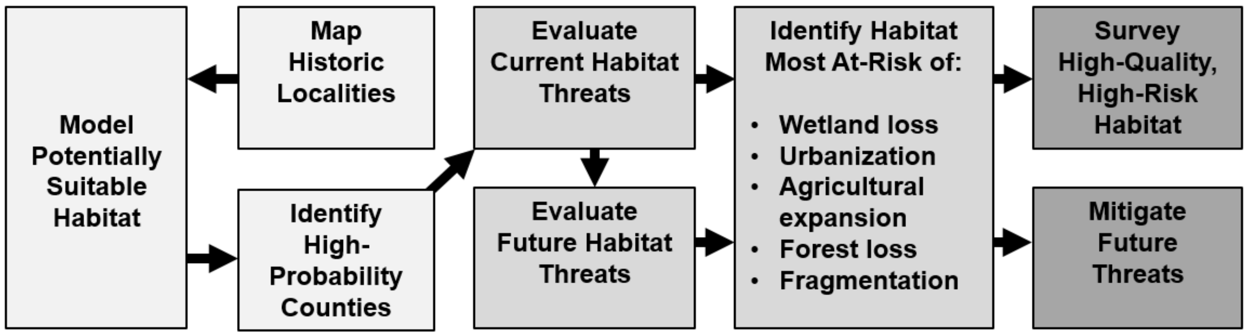

FIGURE 1. Habitat assessment framework for Western Chicken Turtles. We used a habitat assessment approach with three generalized components: (1) model potentially suitable habitat (light gray), (2) evaluate current and future threats that are risks to potentially suitable habitat (medium gray), and (3) direct surveys to high-quality, high-risk habitat to characterize current distribution patterns and population trends and also propose strategies to conserve the species by mitigating future threats (i.e., captive breeding; dark gray).

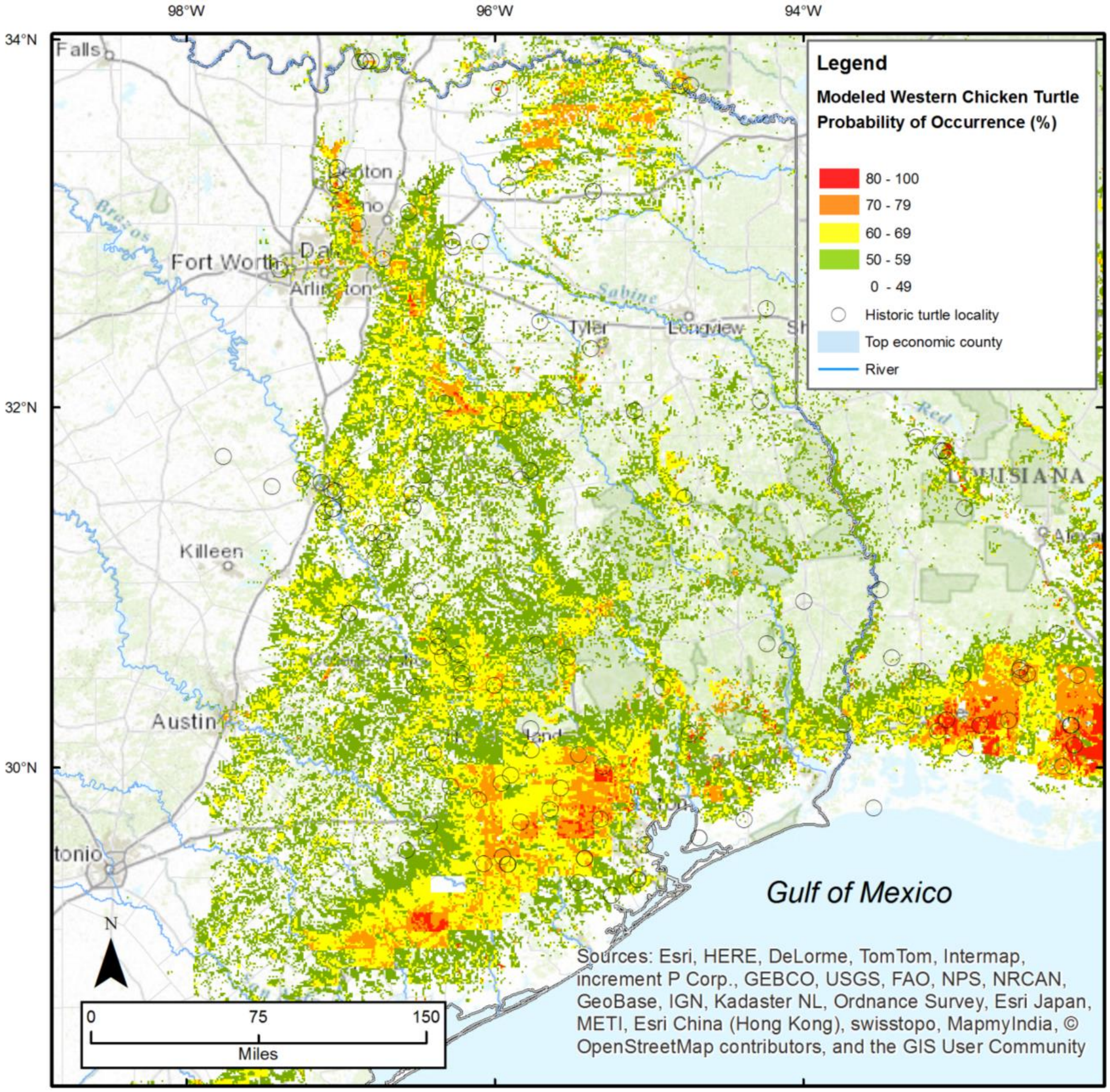

FIGURE 2. Modeled probability of occurrence for Western Chicken Turtle using a species distribution model. Only probability of occurrence >50% is shown and relative probability of occurrence increases from green to yellow to red. The model results do not represent actual current turtle localities, but potentially suitable habitat—based on model inputs—which is likely to support the target species. Historical turtle localities are shown as hollow circles.

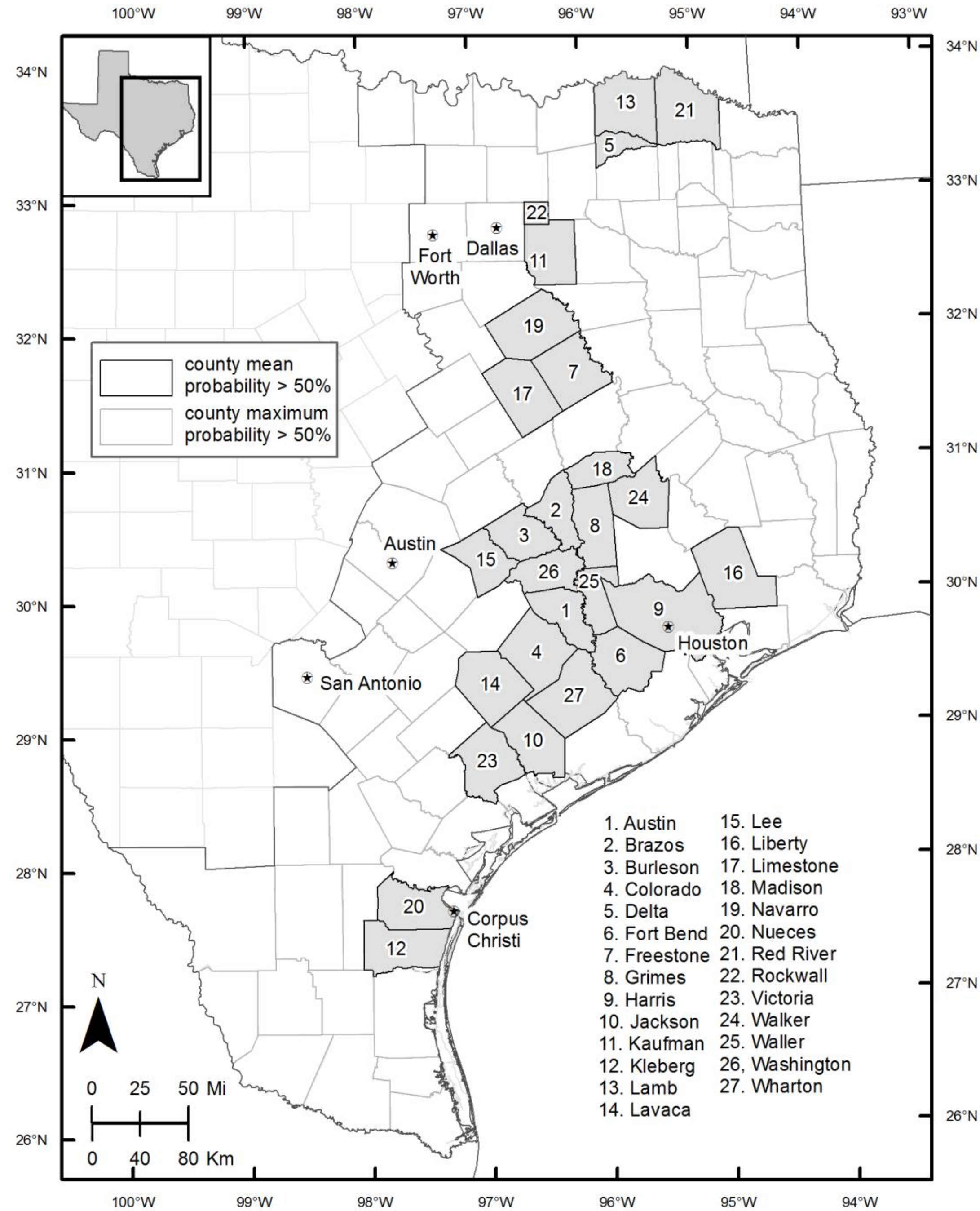

FIGURE 3. Counties with mean modeled probability of occurrence >50%. We assessed current and future threats to Western Chicken Turtle habitat in Texas for: (1) 115 counties with maximum modeled probability occurrence >50% (polygons with light gray outline) and (2) 27 counties with the most likely potentially suitable habitat with mean modeled probability of occurrence >50% (light gray polygons with black outline). Numbers refer to county names.

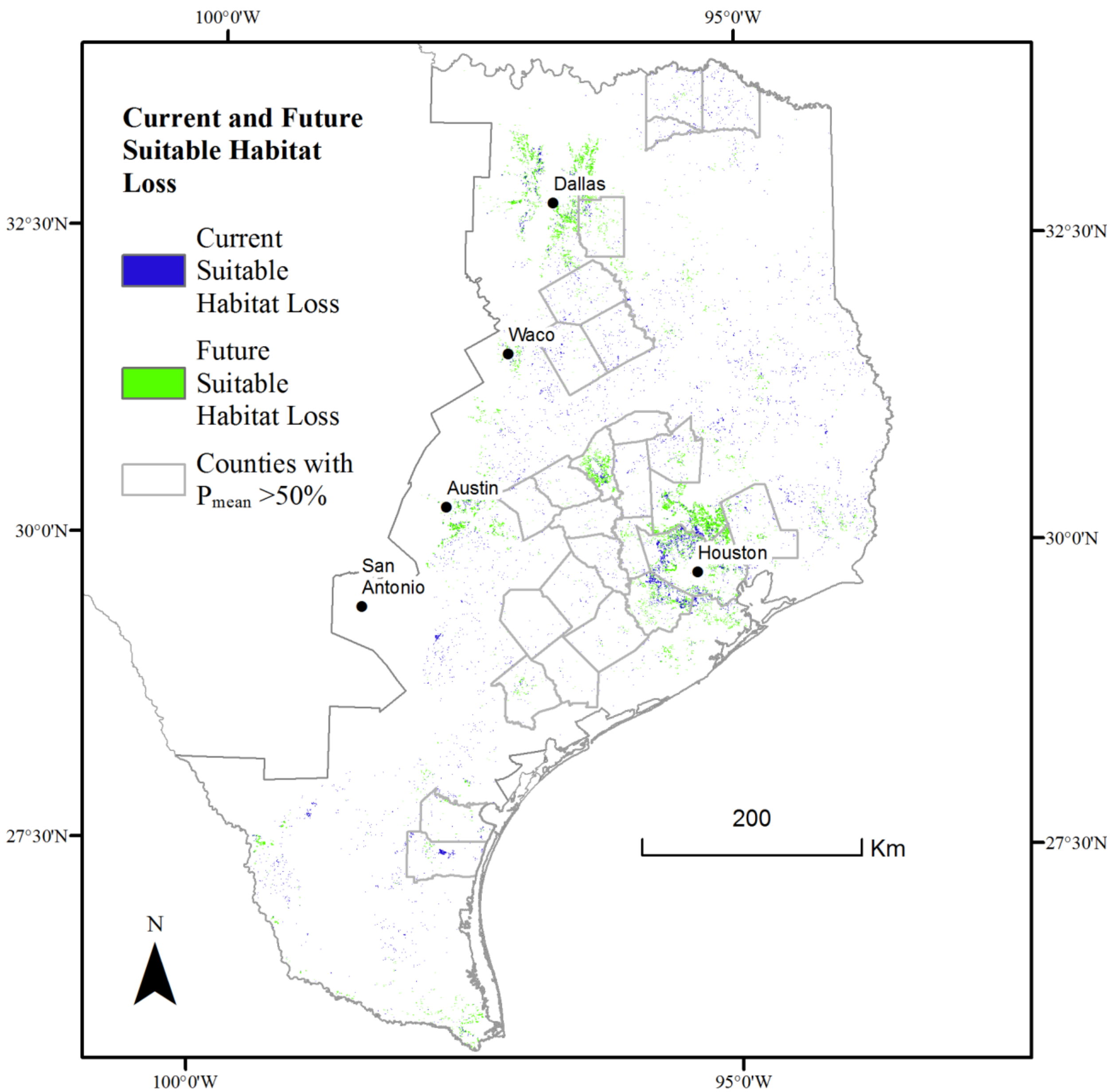

FIGURE 4. Current and future suitable habitat loss. Wetland and forest conversion as well as urban and agricultural expansion were the major causes of current habitat loss. Urban expansion (Theobald 2005) was the major cause of future habitat loss.

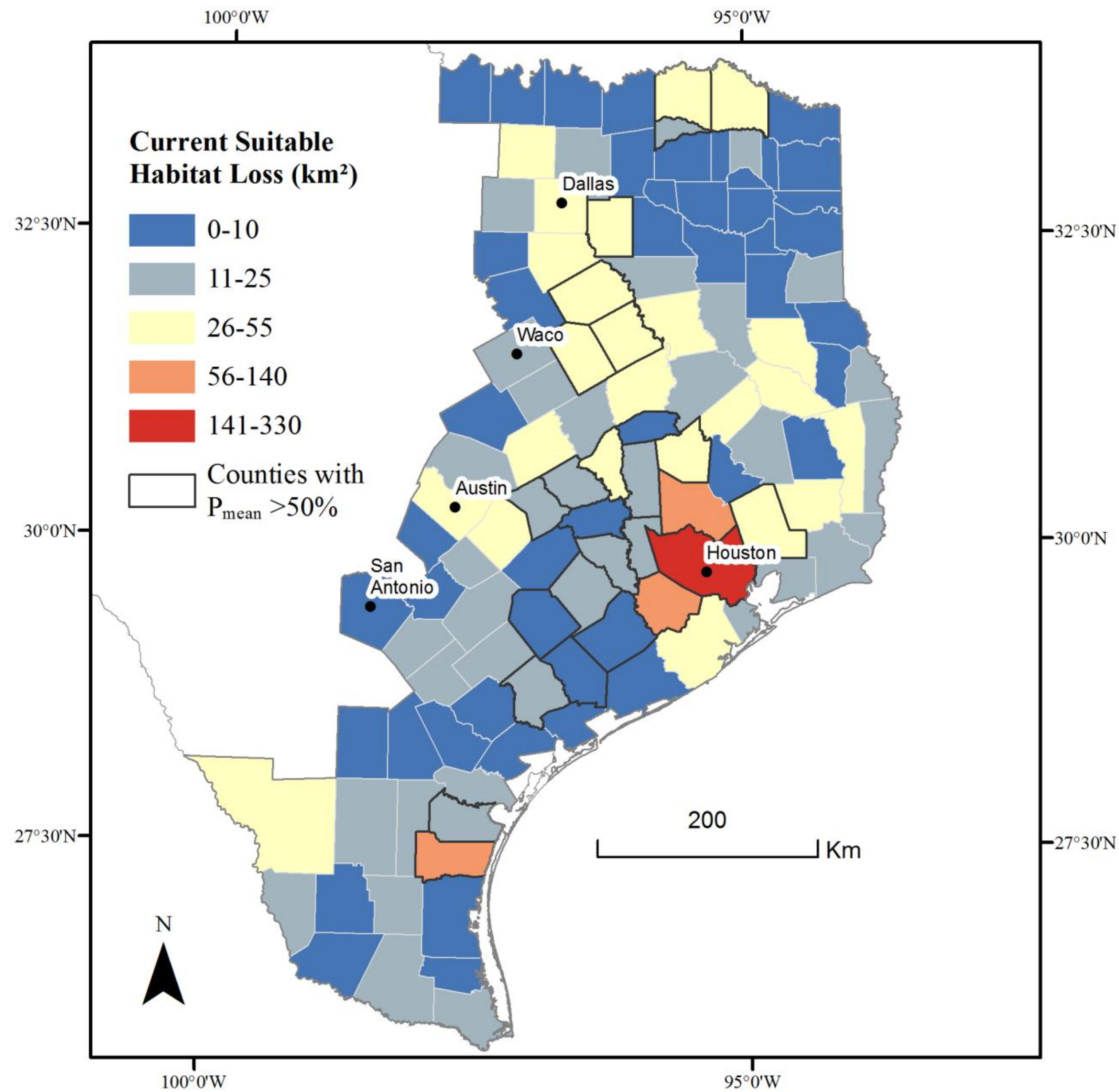

FIGURE 5. Current suitable habitat loss by county. Suitable habitat losses aggregated at the county level and classified using natural breaks (Jenks 1967).

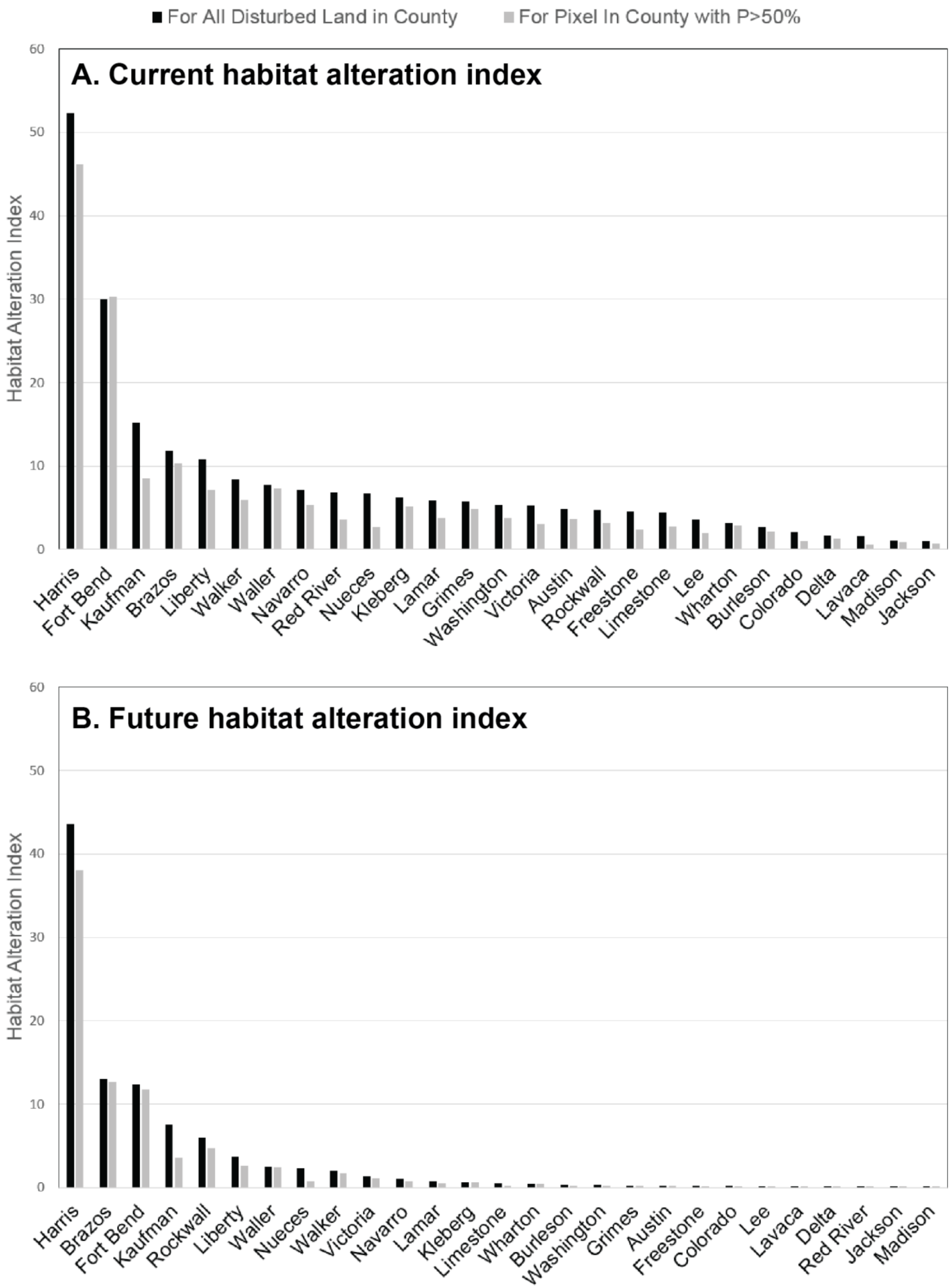

FIGURE 6. Current and future habitat alteration index for counties with P_{mean} >50%. (A) Current habitat alteration index (*HAI*). (B) Future habitat alteration index (*HAI*).

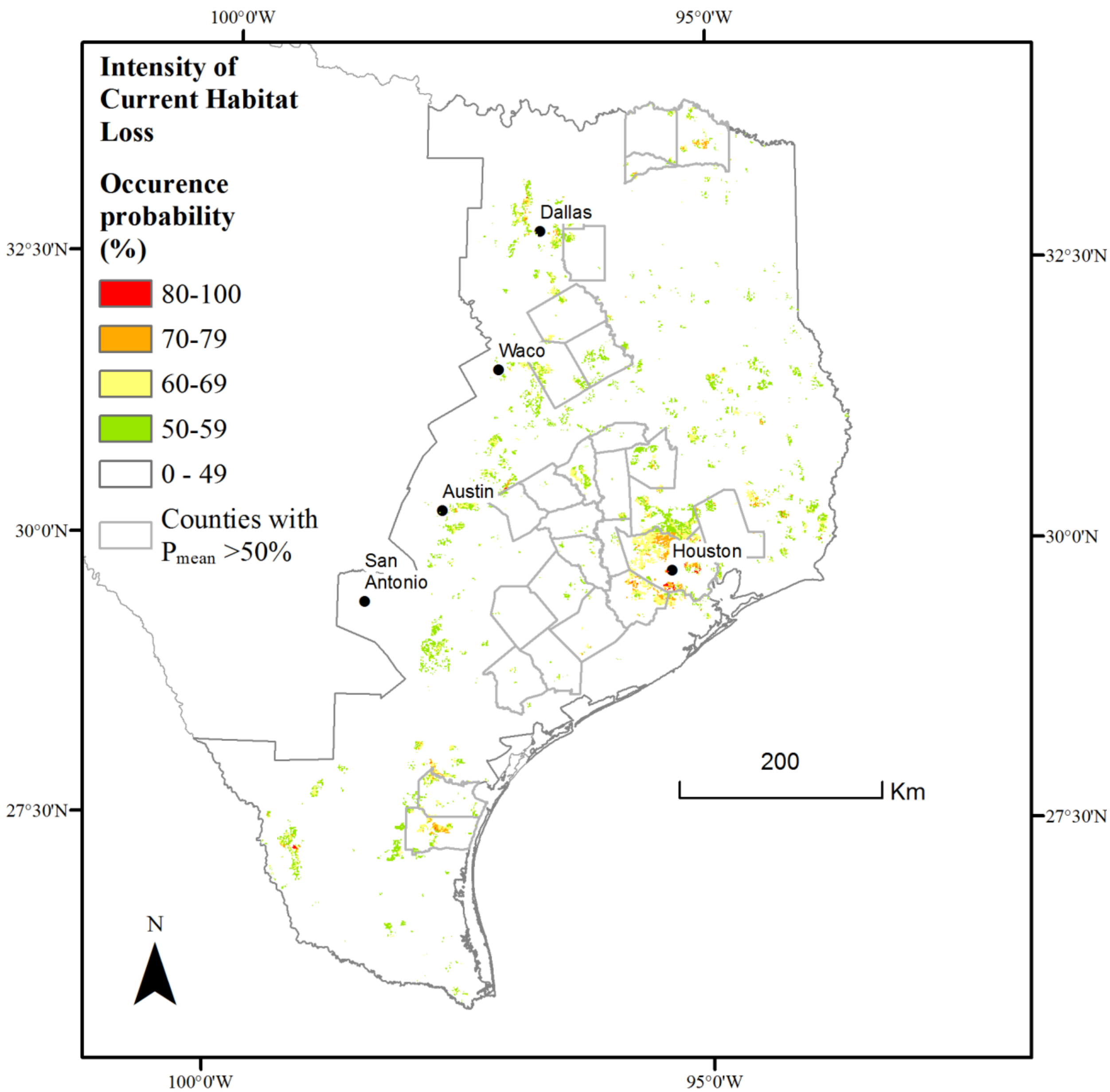

FIGURE 7. Current habitat loss intensity. Intensity of current habitat loss identified with the *Gi** statistic (Getis and Ord 1992) and the underlying modeled lost habitat.

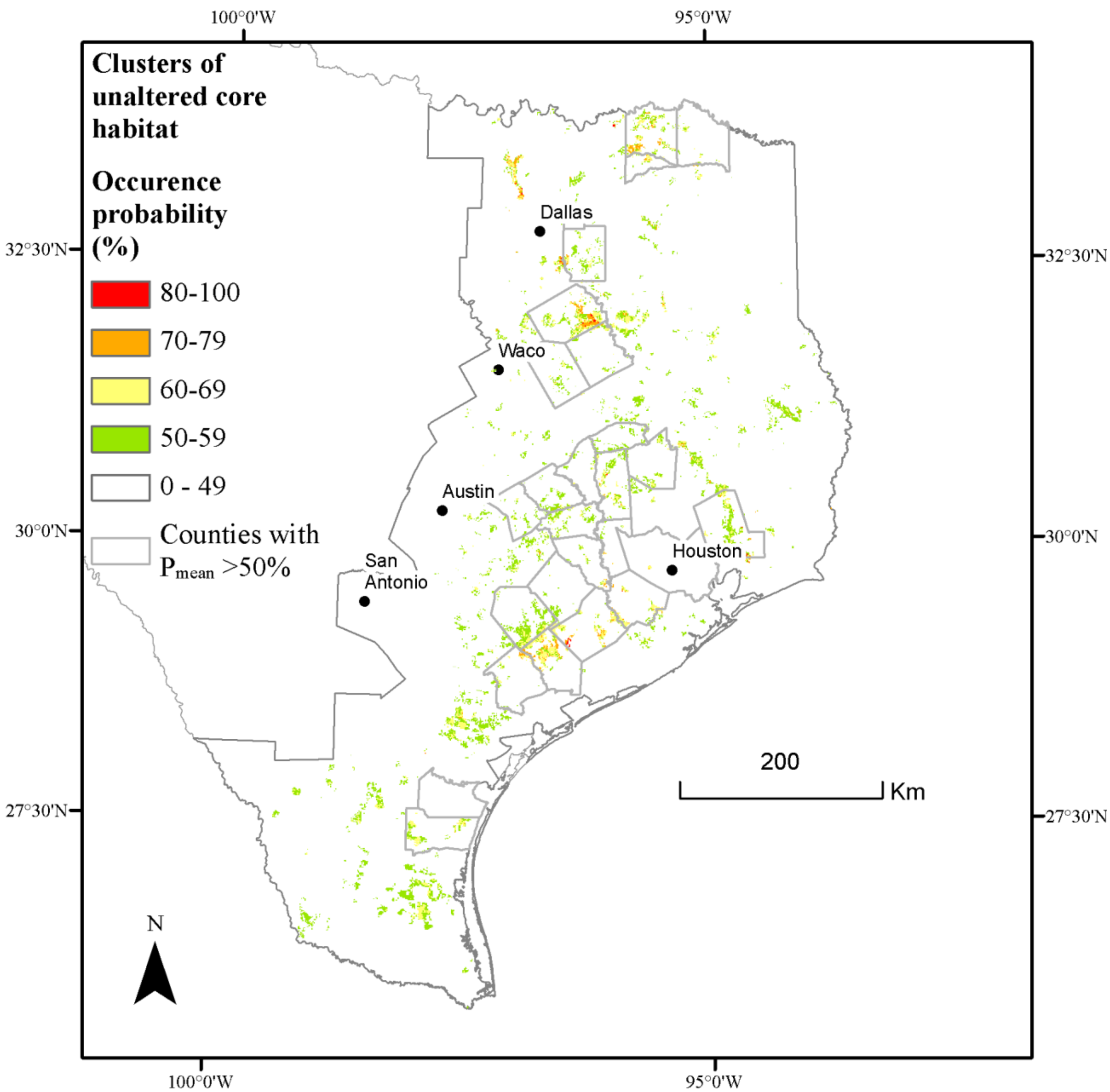

FIGURE 8. Current clusters of unaltered core habitat. Clustered areas with a relatively low amount of core habitat loss with underlying modeled habitat may serve to focus conservation efforts.

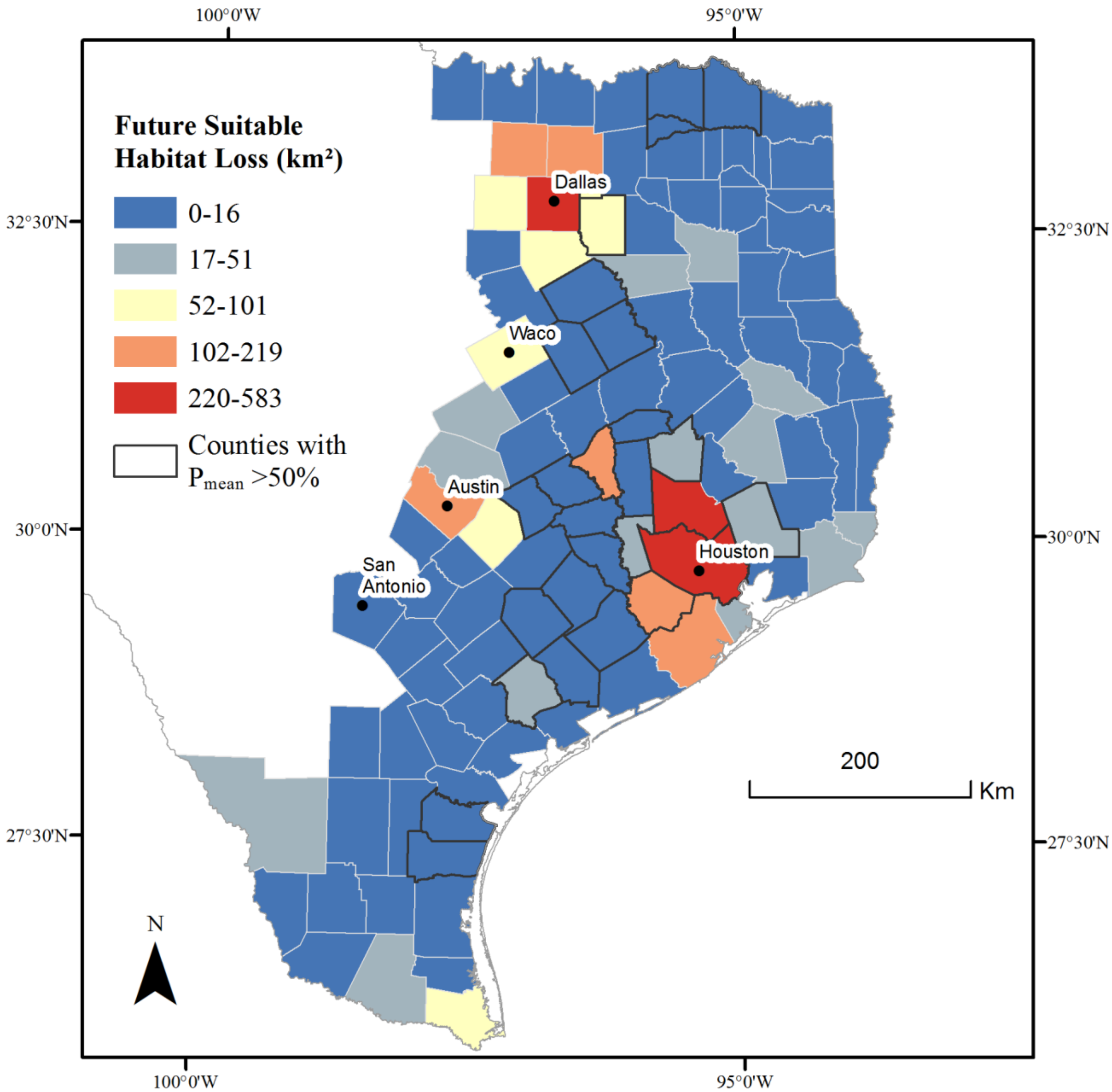

FIGURE 9. Future suitable habitat loss from urban expansion. Future suitable habitat losses from forecasted urbanization (Theobald 2005) aggregated at the county level and classified using natural breaks (Jenks 1967).

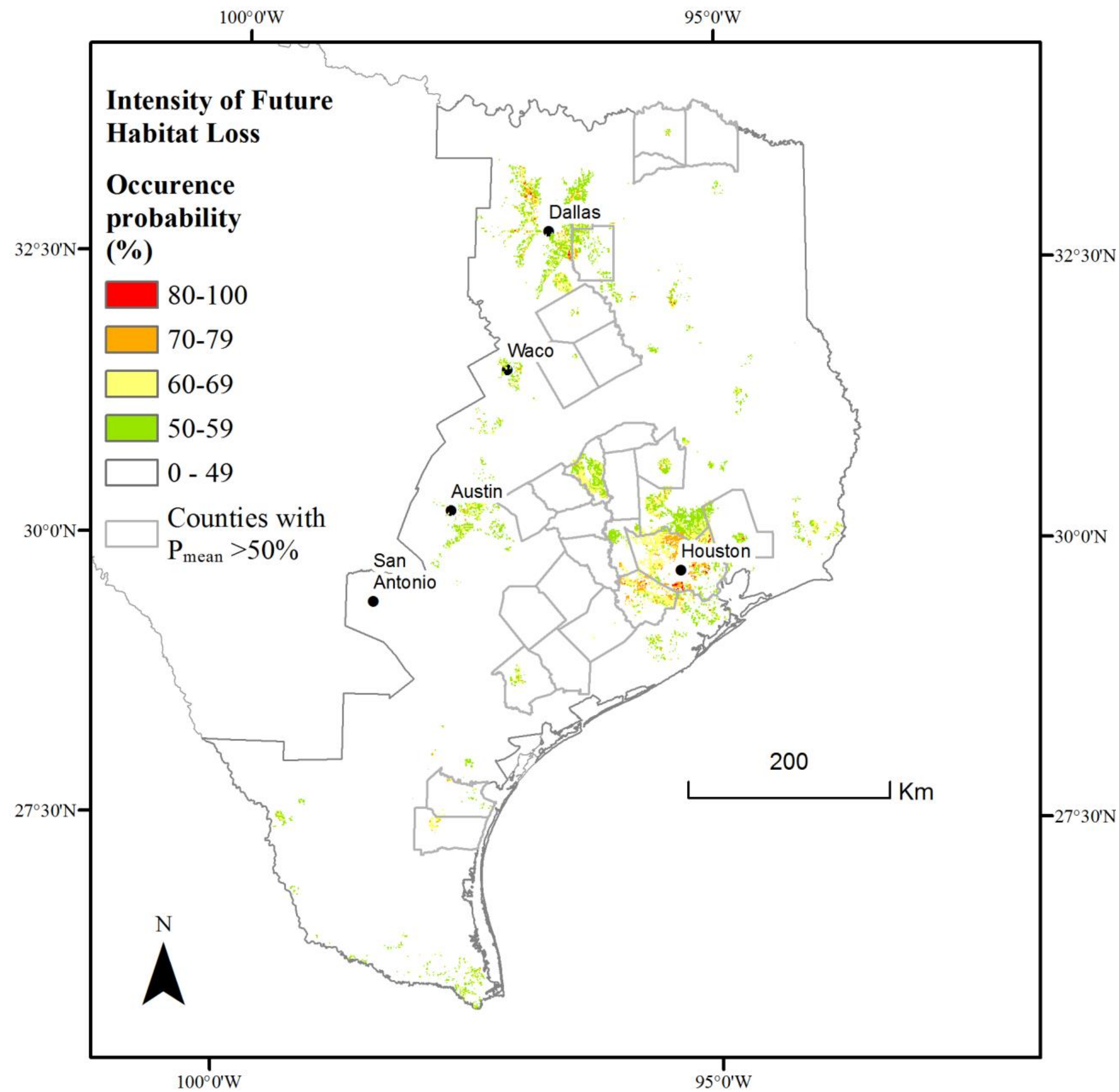

FIGURE 10. Future habitat loss intensity from 2010 to 2050. Intensity of future habitat loss identified with the *Gi** statistic (Getis and Ord 1992) and the underlying modeled lost habitat.

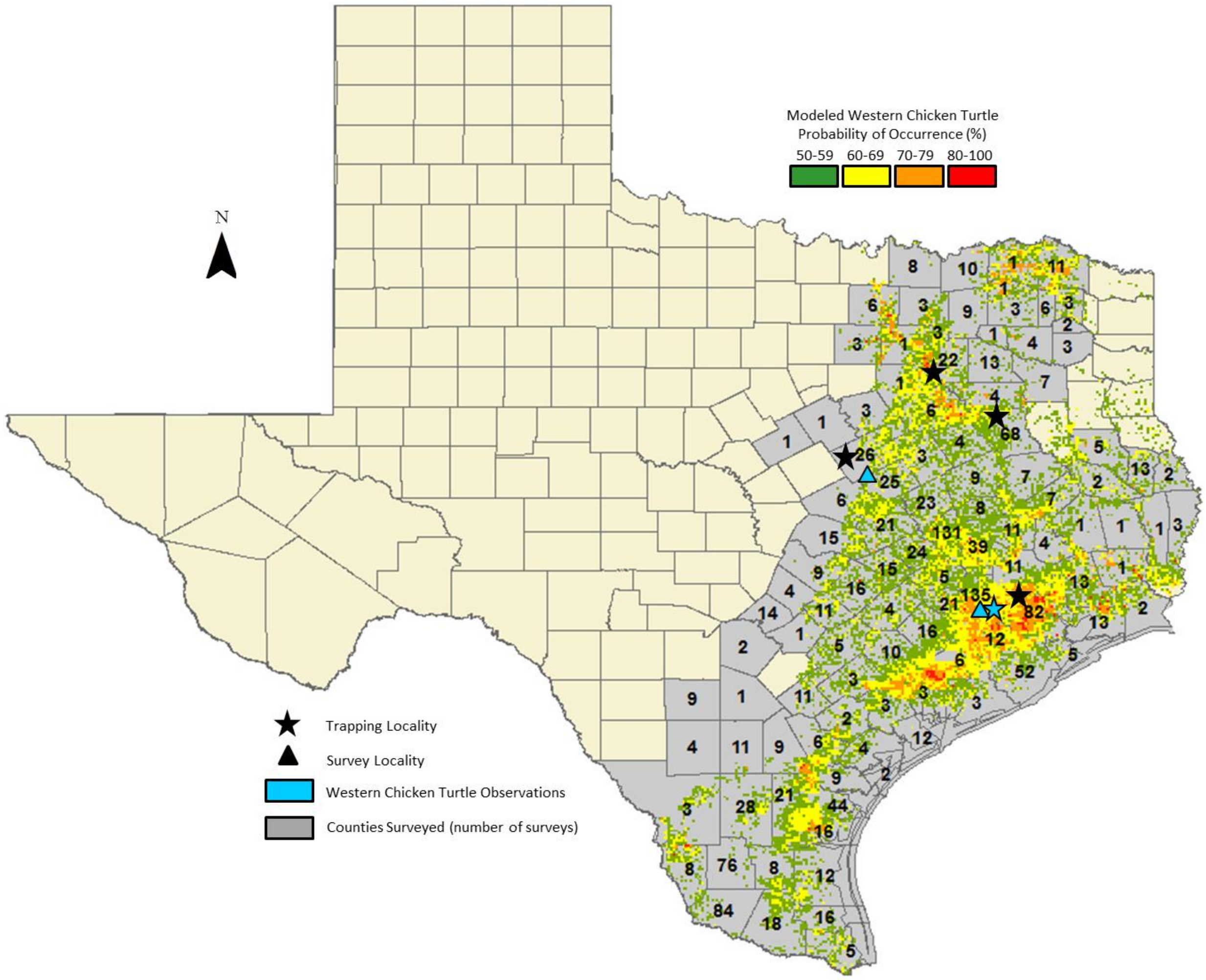

FIGURE 11. Map depicting Western Chicken Turtle distribution and population survey effort across 107 counties (gray shading) in Texas. Numbers in each county reflect the total number of distribution surveys conducted between February 4 and July 6, 2015. As in Figure 2, modeled probability of occurrence >50% is shown and relative probability of occurrence increases from green to yellow to red. Triangles and stars identify survey and trapping localities, respectively. Blue triangles and stars identify localities where Western Chicken Turtles were observed.

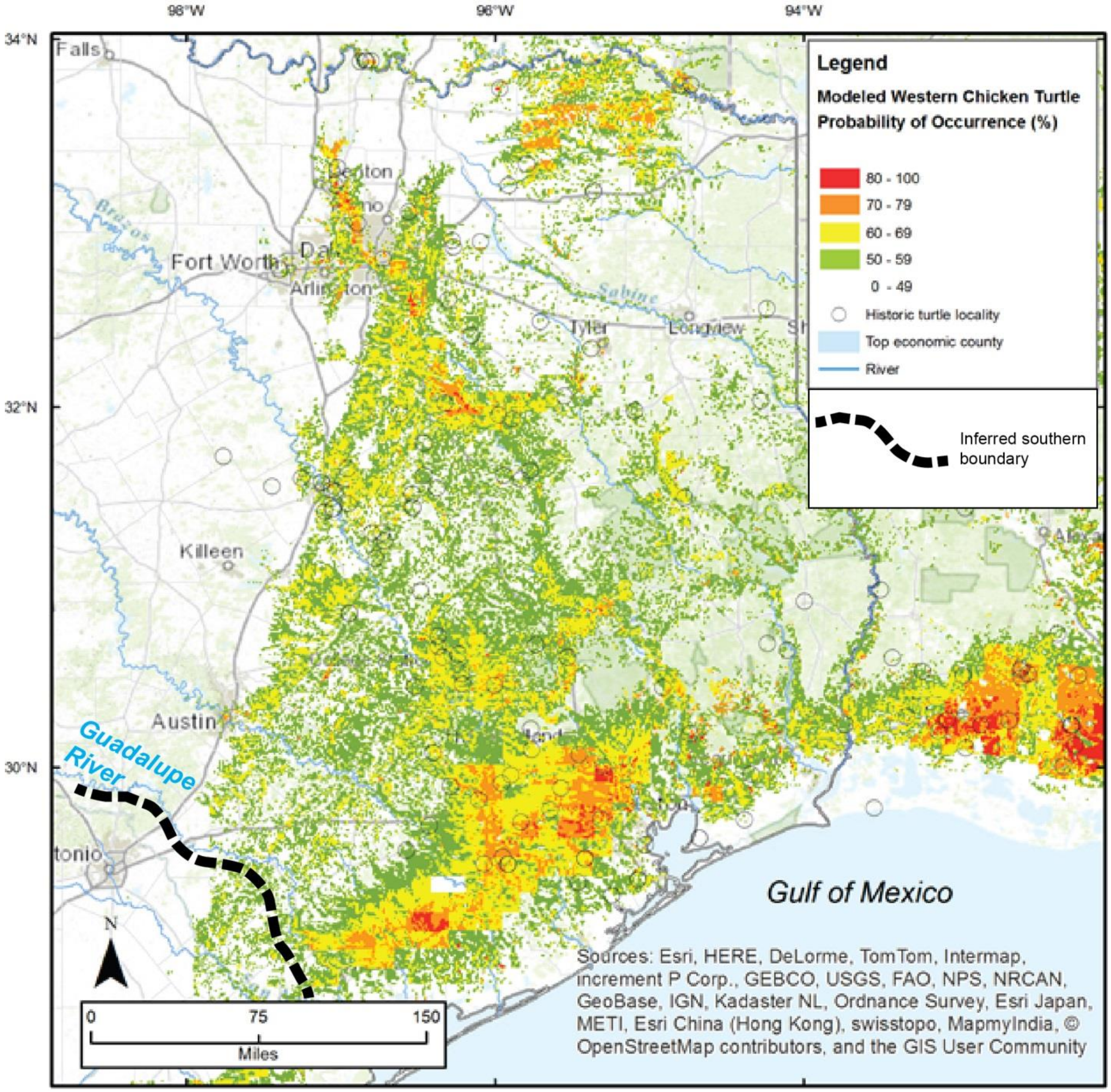

FIGURE 12. Inferred southern boundary for Western Chicken Turtle. We base our delineation of the inferred southern species boundary on the modeling of potentially suitable habitat, the distribution of historic localities (which are northeast of the Guadalupe River), the decrease in precipitation to the west in Texas, and the progression from Gulf Coast Prairies and Marshes in the Southeast Texas to the unfavorable Tamaulipan Scrub in South Texas.

TABLE 1. Counties in Western Chicken Turtle habitat with mean modeled probability of occurrence >50%.

County	County Area (km2)	P_{mean}	Comments
Fort Bend	2,294	67	Houston exurban area; high wetland density
Harris	4,528	65	Houston metropolitan area; high wetland density
Wharton	2,834	63	Gulf Coastal Plains: Colorado River basin
Waller	1,341	62	Houston exurban area
Jackson	2,203	60	Gulf Coastal Plains: Guadalupe River basin
Grimes	2,078	59	College Station exurban area
Kleberg	2,343	59	Gulf Coastal Plains, 50 km south-southwest of Corpus Christi
Austin	1,700	58	Brazos River basin
Navarro	2,813	58	Trinity River tributaries
Brazos	1,529	58	College Station metropolitan area; Brazos River basin
Washington	1,609	55	Brazos River basin
Walker	2,075	55	San Jacinto River basin
Liberty	3,041	54	Trinity River basin
Burleson	1,756	53	Brazos River basin
Delta	720	52	Sulphur River basin
Lamar	2,636	52	Red River basin
Nueces	2,223	52	Corpus Christi metropolitan area; Gulf Coastal Plains; Nueces River basin
Rockwall	385	52	Dallas metropolitan area; Trinity River basin
Madison	1,222	51	Brazos and Trinity River basins
Victoria	2,300	51	Victoria metropolitan area; Gulf Coastal Plains; Guadalupe River basin
Freestone	2,311	51	Trinity River basin
Limestone	2,417	51	Brazos River basin
Colorado	2,522	51	Colorado River basin
Red River	2,740	51	Red River basin
Lavaca	2,515	51	Navidad River basin
Lee	1,656	50	Brazos River basin (Yegua Creek)
Kaufman	2,092	50	Dallas exurban area; Trinity River basin
Total	57,881		

TABLE 2. Western Chicken Turtle population trapping effort and success across 5 sites from 4 February to 6 July 2015. All trapping methods are combined (hoop nets, crayfish traps).

Site	Trap Nights	Individuals Captured	Species Captured	Western Chicken Turtles Captured
Gus Engeling Wildlife Management Area	708	221	5	0
Katy Prairie Conservancy	1068	269	5	1
Lake Waco Wetlands (Baylor University)	258	17	3	0
Jesse H. Jones Park and Nature Reserve	400	136	6	0
John Bunker Sands Wetland Center	24	13	1	0
Total	2458	656	9	1

TABLE 3. International shipments of live Western Chicken Turtles as reported to US Fish and Wildlife Service through the Law Enforcement Management Information System (LEMIS).

Year	Number of Exporters	Total Shipments	Number of Turtles		Total
			Captive	Wild Caught	
2000	1	1		1	1
2001	1	1	2	0	2
2002					
2003					
2004	2	4	10	0	10
2005	2	2	9	1	10
2006	1	7	28	0	28
2007	1	3	7	0	7
2008	1	6	33	0	33
2009	1	2	0	2	2
Total		26	89	4	93

TABLE 4. Texas Parks and Wildlife Department harvest data for Western Chicken Turtles collected from the wild by permitted collectors.

Year	Number of Collectors	Total Collected
2007	1	4
2008	1	1

TABLE 5. Texas Parks and Wildlife Department reports by non-game dealers for those possessing Western Chicken Turtles under permit 2008-2012.

Year	Dealers	Start total	Collected	Purchased	Born	Gift	Sold	Processed	Donated	Died or Lost	End total
2008	1	4	0	0	0	0	0	0	0	0	4
2009	2	1	0	0	0	0	0	0	0	0	1
2010	2	1	0	0	0	0	0	0	0	0	1
2011	1	1	0	0	0	0	0	0	0	0	1
2012	1	1	0	0	0	0	0	0	0	0	1

Appendix: HABITAT MODELING AND CONSERVATION OF THE WESTERN CHICKEN TURTLE (*DEIROCHELYS RETICULARIA MIARIA*) IN TEXAS

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Materials and Methods

***Modeling of potentially suitable habitat.*—**The habitat model we presented in the paper has been corrected for sample bias that was apparent in earlier model runs. Our first model run used several climate coverages, including a suite of precipitation and temperature features (WorldClim 2014). These inputs resulted in modeled habitat with unrealistically strong north-south and east-west gradients that correlated with temperature and precipitation gradients. Historic localities also had bias towards urban areas with universities where surveyors worked. This also yielded modeled habitat with an urban bias. A subsequent model run omitted climate coverages, but kept topographic-related features (i.e., altitude, slope, aspect, compound topological index), which yielded similarly unsatisfactory results. Thus, our final habitat model, which we presented in the paper, reduced sample bias by using special rarefication to add samples to the background (refer to: Elith et al. 2011; Implications for modeling). The final model also added a wetland density map as an input to represent more faithfully the Western Chicken Turtle affinity for wetlands. We also used a generalized soil order map to include in the model regional-scale trends in soil quality, instead of only using site-specific soil texture/sand percent values.

***Proximity of Known Occurrences to Wetlands and Sandy Soil.*—**Western Chicken Turtles are thought to prefer habitat in close proximity to shallow, seasonally fluctuating wetlands (Buhlmann et al. 2009). Thus, in addition to modeling potentially suitable habitat with a species distribution model, we also evaluated the proximity of known turtle occurrences to wetlands and sandy soils. The species also estivates during hot months and may require sandy soil in which to construct its burrows (Buhlmann et al. 2009). Thus, potential current habitat was assessed based upon the proximity of wetlands and sandy soil to all currently available georeferenced historic localities in Texas (n=110), Arkansas (n=5), Louisiana (n=81), and Oklahoma (n=9). The Texas localities clustered along a generalized arc from near Dallas-Fort Worth, downstream along the Trinity River, across to Waco, downstream on the Brazos River, and then spreading out to the Texas-Louisiana border along the Gulf Coastal Plains. Localities in Oklahoma were on the Red and Canadian Rivers. Localities also clustered along the Mississippi River bottomlands in Arkansas downstream to Louisiana, where many localities were found in low-elevation swamp lands (Fig. 2).

We tested the hypothesis that the species prefers habitats near wetlands and sandy soil by assessing the occurrence of wetlands and sandy soil within 1-km, 5-km, and 10-km buffers of Western Chicken Turtle localities. These buffers around historic localities in Texas were intersected in a GIS environment with wetlands (FWS 2014b) and sandy soils listed in the SSURGO (USDA 2014) database. The National Wetlands Inventory classified wetlands (Appendix Tables 2 and 3) using a system developed by Cowardin et al. (1979) from 1980s-vintage aerial imagery (FWS 2014a). The turtles are thought not to prefer flowing water; however, riverine wetlands (FWS 2014b) were included in the analysis as to not exclude any potential habitat. Buffers were intersected with wetlands in ArcGIS to create wetlands within each buffer and calculate the percent buffer area occupied by each wetland type. The wetland type closest to a turtle locality was identified using a spatial join. Sandy soils were extracted from the SSURGO database, which included high-resolution (10-m) soil texture, minimum percent sand, and maximum percent sand. Sand percent was calculated as the average of the minimum and maximum sand percent. The average and mode of the percent sand value within each buffer was calculated using zonal statistics in ArcGIS.

Current conditions: Evaluation of current threats to habitat and populations.—The NLCD is 30-m resolution land cover data for the conterminous United States that divides Landsat imagery into 16 land-cover classes, including two wetlands classes (marsh and forest), four urban classes (plus one class for barren land), two classes for agriculture, and five classes for forests and shrubs (Jin et al. 2013). The NLCD constrains image classification using National Wetlands Inventory (NWI) wetlands (FWS 2014a), a digital elevation model, population density, and road datasets (Vogelmann et al. 1998). We combined NLCD classes into four groups (Appendix Table 3). Wetlands included classes 11, 90, and 95. Urbanization included classes 21, 22, 23, 24, and 31. Agricultural included 81 and 82. Forests included 41, 42, 43, 51, and 52. We identified where these four land cover groups changed in the study area from 2001–2011.

We identified areas of intense current and future fragmentation for input datasets resampled to 10-m resolution using the Optimized Hot Spot Analysis tool in ArcGIS 10.2. We used this tool to calculate Getis-Ord Gi* (Getis and Ord 1992) spatial statistics. Using a 1-km^2 fishnet, we identified areas of focused core habitat loss for current and future fragmentation scenarios. We assessed habitat fragmentation from current and future landscape alteration using morphological spatial pattern analysis (MSPA). We evaluated structural landscape changes using the approach of Soille and Vogt (2009). We implemented the analysis in GIS using GUIDOS toolbox, which is based on the approach of Vogt et al. (2007). We surrounded areas of altered habitat with a 100-m edge distance and assumed that the species did not utilize 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; Howell et al. 2006; Svobodová et al. 2010; Robson et al. 2011; McGarigal et al. 2005; Neel et al. 2004) used a conservative 100-m edge distance. We calculated several landscape alteration metrics, including bridges, which we defined as areas of suitable habitat that connected two or more core habitat areas. We defined 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 scenarios to quantify loss of core habitat and changes in connectivity between core habitat areas. This analysis identified portions of the species' habitat at risk of recent and future alteration.

RESULTS

Modeling of potentially suitable habitat.—Sample bias was greatly reduced, compared to previous model runs by using spatial rarefication of samples and by omitting temperature and precipitation layers. Modeled probability of occurrence no longer concentrated around cities and was spread out over a more realistic, larger area. Alteration analyses of potentially suitable habitat are presented in several maps (Appendix Figs. 3–21).

Proximity of known occurrences to wetlands and sandy soil.—This subspecies preferred habitat near a high density of freshwater wetlands, but did not appear to prefer a specific wetland type (i.e., estuary, pond, shrub wetland, pond/lake). Although a few historic Western Chicken Turtle localities were near the Gulf Coast, the subspecies appeared to favor freshwater wetlands over brackish or saline wetlands. Because Western Chicken Turtles estivate during hot months, it has been hypothesized that this subspecies may require sandy soil in which to construct its burrows (Buhlmann et al. 2009). Our research indicated Western Chicken Turtles do not appear to require especially sandy soil; however, historic localities did not appear to favor clay-rich, low-sand soils either.

The evaluation of historic Western Chicken Turtle localities with the percent sand in soil (Appendix Table 5) showed that regardless of distance, the percent sand was generally 40–50%. The nearest wetland type to Texas Western Chicken Turtle localities included (Appendix Table 6) freshwater ponds (57%), freshwater emergent wetlands (22%), and freshwater/forested shrub wetlands (14%). Within a 10-km buffer, these same three wetland types dominated the percent wetland area. In the 1-km and 5-km buffers, lakes substituted for ponds. While the target species was occasionally found near the coast, they overwhelmingly preferred freshwater wetlands. Similarly, few localities were associated with riverine wetlands (i.e., flowing streams and rivers). The total percent of buffer area comprised of wetlands decreased with increasing buffer distance from 12.7% (1-km) to 3.6% (10-km). When Arkansas, Louisiana, and Oklahoma were added to Texas, the percent of buffer area occupied by wetlands was higher (mean=15.1%) than the Texas-only case (mean=8.8%) and did not change appreciably with increasing buffer distance (standard deviation=0.4%).

Assumptions and limitations of approach.—Our approach to assess anthropogenic threats in Western Chicken Turtle habitat had several limitations, but was still valid given the regional-scale scope of the study. For example, the NLCD had some shortcomings when used to map wetland loss; however, the dataset was still considered effective when looking at temporal trends at a regional scale (Carle 2011). This analysis was regional in scale and included 115 counties. Thus, we consider any site-specific land classification errors to be averaged out at a county-level and to be negligible.

The Theobald housing dataset also had some important limitations. We initially ran the future urbanization analysis using commercial and industrial institutions, >10 units/acre, 5–9.9 units/acre, and 2–4.9 units/acre. However this only resulted in ~18 km^2 of urbanization from 2010 to 2050. Thus, we also included 0.5–1.6 acre/unit and 1.7–4.9 acre/unit to the analysis, which was more consistent with development at the urban fringe. While Harris County and other counties likely have county-specific datasets, none integrates county-level data across the species' range. Thus, the Theobald dataset was the best available dataset to forecast landscape-scale spatial trends urbanization.

We resampled all datasets to a 10-m resolution (100-m^2 cells) to conduct fragmentation analyses. The resampling allowed for better representation of spatial area, however, results were only as accurate as the least accurate dataset. Additional landscape alteration factors may play a role in changing future available habitat for Western Chicken Turtle; however, future landscape alteration and fragmentation were evaluated using only one dataset representing urban expansion beyond the urban fringe. We assumed that agriculture would not expand past current locations (which are limited by favorable soil quality), and we could not accurately forecast where forest loss would occur. We also assumed the modeled predicted occurrence of >50% to be suitable habitat for Western Chicken Turtle.

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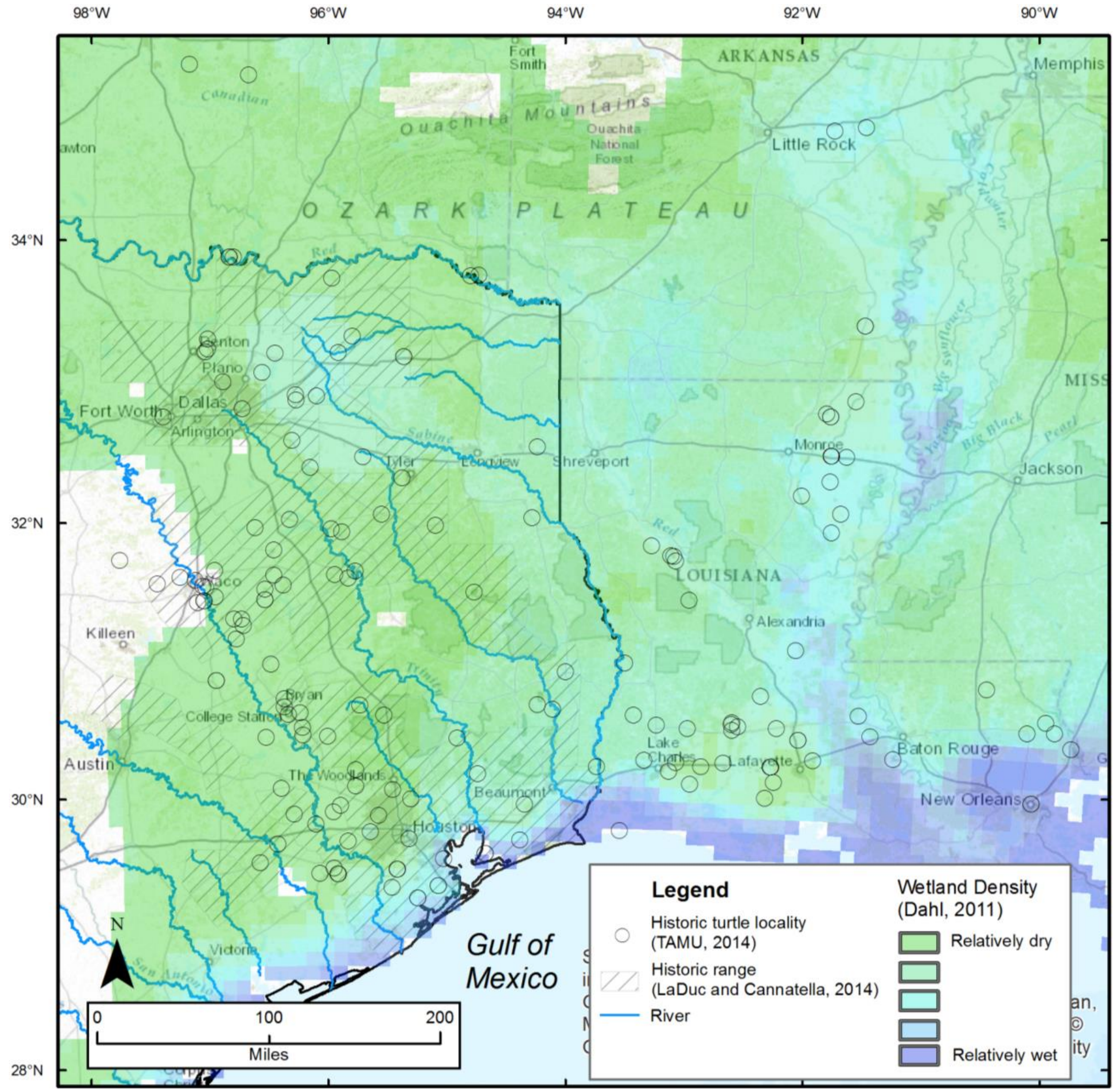
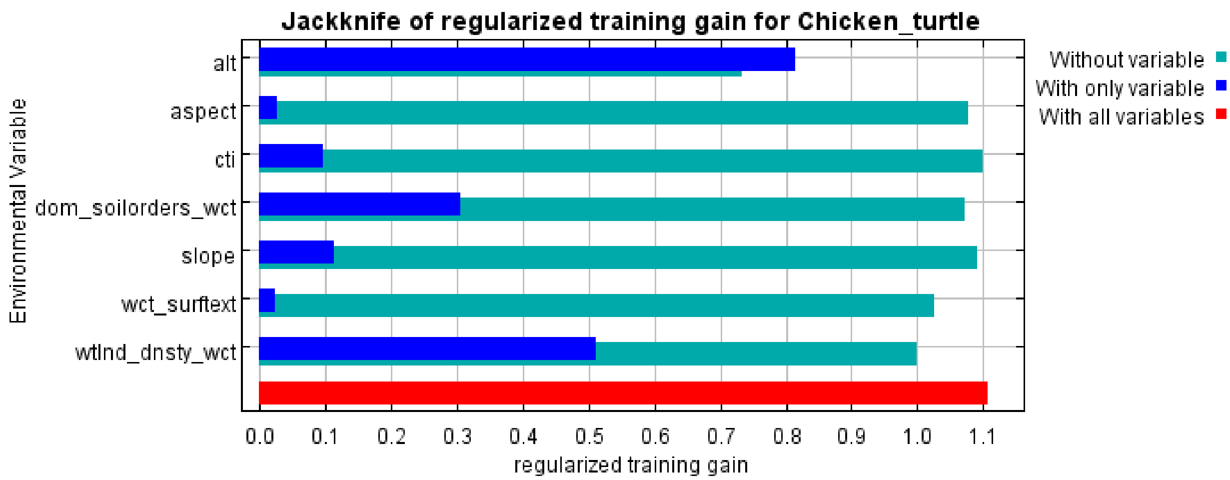
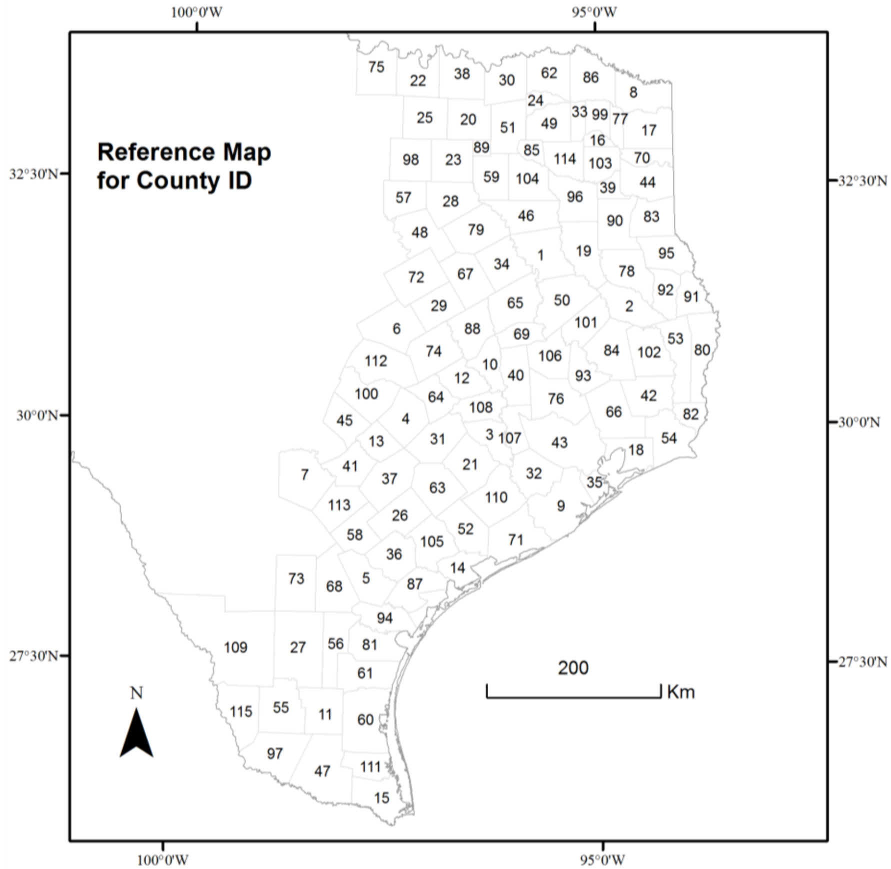


APPENDIX FIGURE 1. Wetland density map with historic Western Chicken Turtle localities. Data are from TAMU (2014; hollow circles), generalized historic range in Texas (LaDuc and Cannatella 2014; cross-hatched polygons), and relative wetland density (Dahl 2011; green to blue shading).

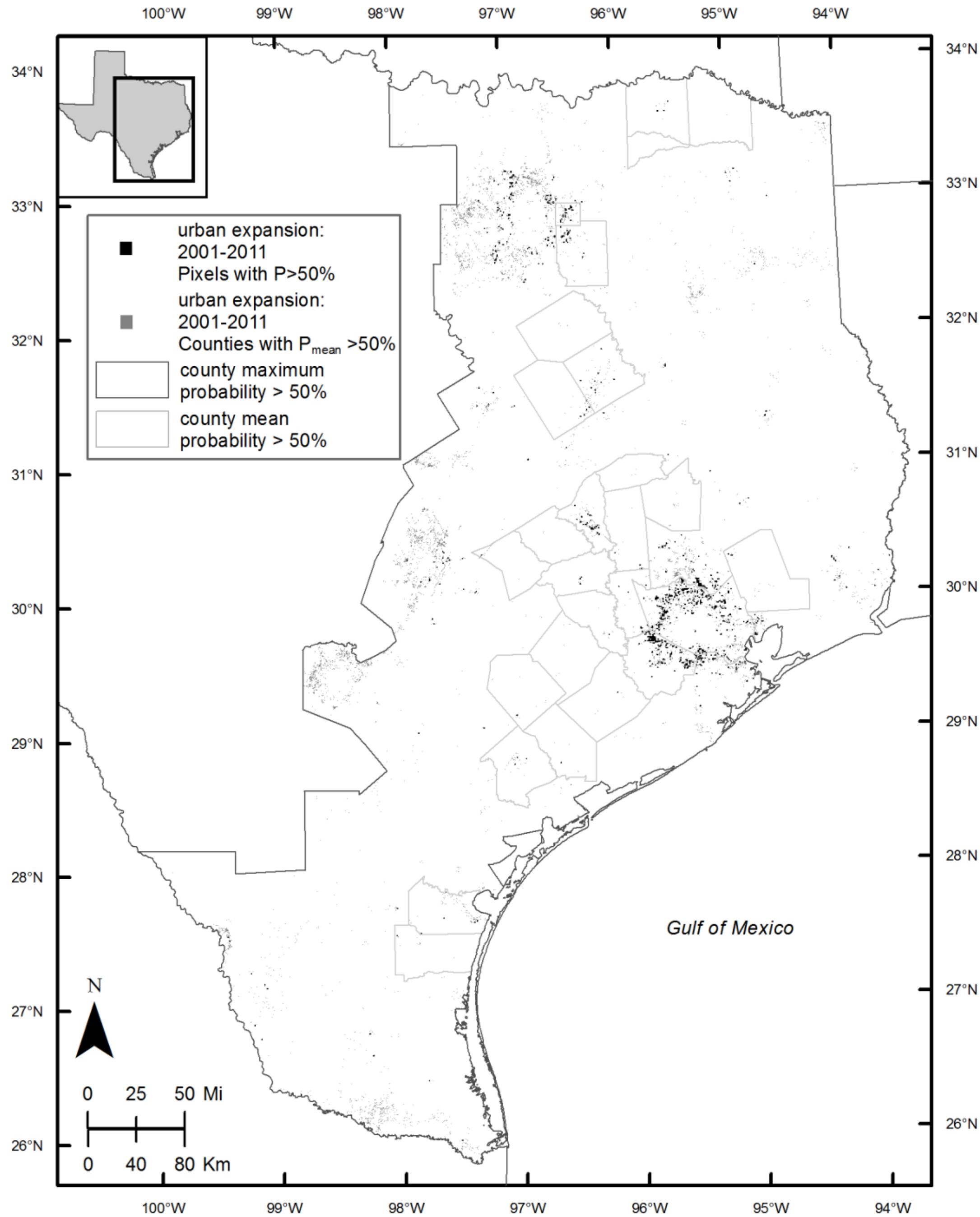


APPENDIX FIGURE 2. Jackknife test of input feature importance for Maxent species distribution model. Results indicate that altitude (alt) is the variable of highest gain when used in isolation for the model and decreases the gain the most when omitted from the model. Wetland density (wtlnd_dnsty_wct) is the second most important variable.

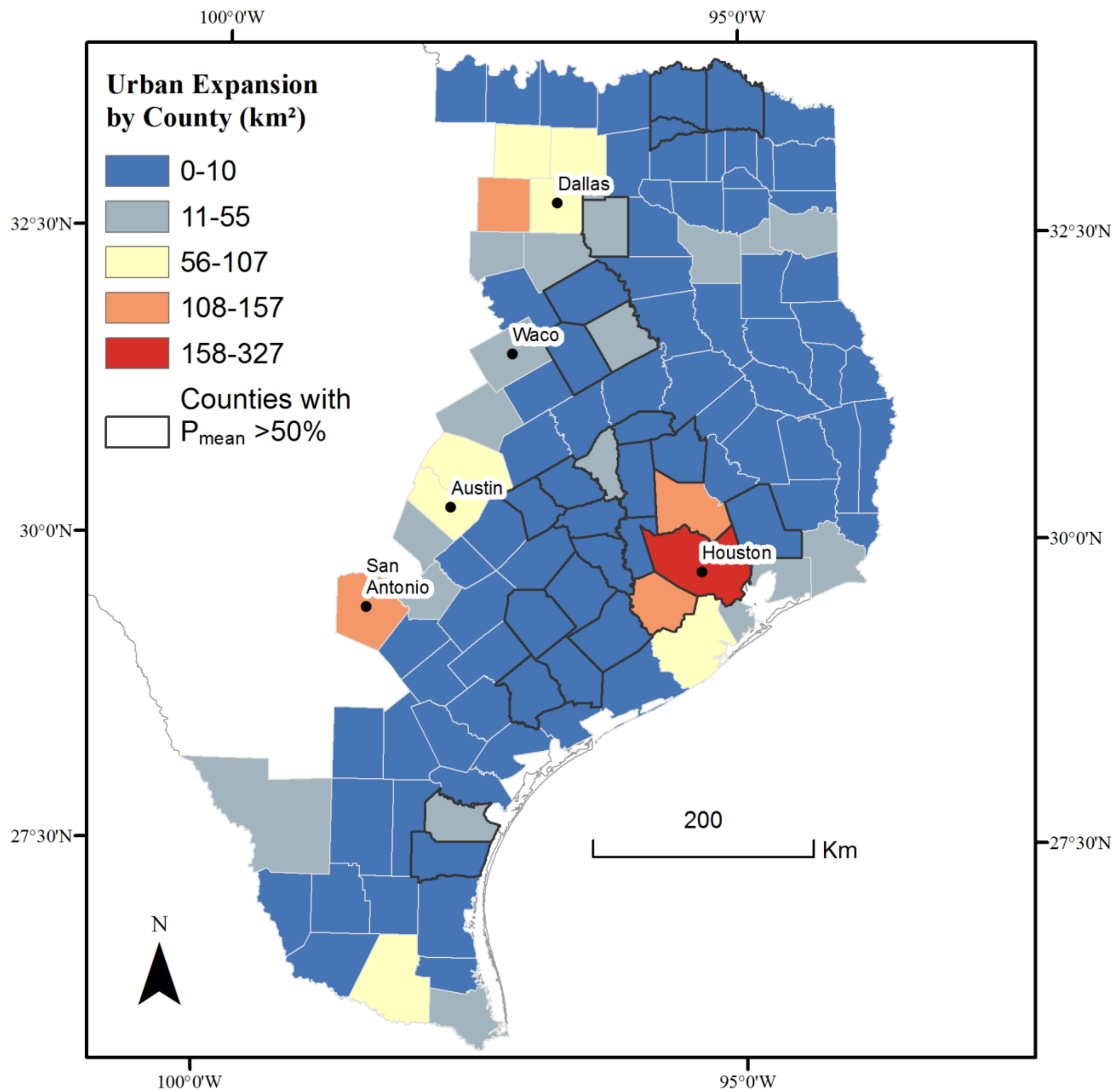


COUNTY	ID	COUNTY	ID	COUNTY	ID	COUNTY	ID
Anderson	1	Falls	29	Karnes	58	Refugio	87
Angelina	2	Fannin	30	Kaufman	59	Robertson	88
Austin	3	Fayette	31	Kenedy	60	Rockwall	89
Bastrop	4	Fort Bend	32	Kleberg	61	Rusk	90
Bee	5	Franklin	33	Lamar	62	Sabine	91
Bell	6	Freestone	34	Lavaca	63	San Augustine	92
Bexar	7	Galveston	35	Lee	64	San Jacinto	93
Bowie	8	Goliad	36	Leon	65	San Patricio	94
Brazoria	9	Gonzales	37	Liberty	66	Shelby	95
Brazos	10	Grayson	38	Limestone	67	Smith	96
Brooks	11	Gregg	39	Live Oak	68	Starr	97
Burleson	12	Grimes	40	Madison	69	Tarrant	98
Caldwell	13	Guadalupe	41	Marion	70	Titus	99
Calhoun	14	Hardin	42	Matagorda	71	Travis	100
Cameron	15	Harris	43	McLennan	72	Trinity	101
Camp	16	Harrison	44	McMullen	73	Tyler	102
Cass	17	Hays	45	Milam	74	Upshur	103
Chambers	18	Henderson	46	Montague	75	Van Zandt	104
Cherokee	19	Hidalgo	47	Montgomery	76	Victoria	105
Collin	20	Hill	48	Morris	77	Walker	106
Colorado	21	Hopkins	49	Nacogdoches	78	Waller	107
Cooke	22	Houston	50	Navarro	79	Washington	108
Dallas	23	Hunt	51	Newton	80	Webb	109
Delta	24	Jackson	52	Nueces	81	Wharton	110
Denton	25	Jasper	53	Orange	82	Willacy	111
DeWitt	26	Jefferson	54	Panola	83	Williamson	112
Duval	27	Jim Hogg	55	Polk	84	Wilson	113
Ellis	28	Jim Wells	56	Rains	85	Wood	114
		Johnson	57	Red River	86	Zapata	115

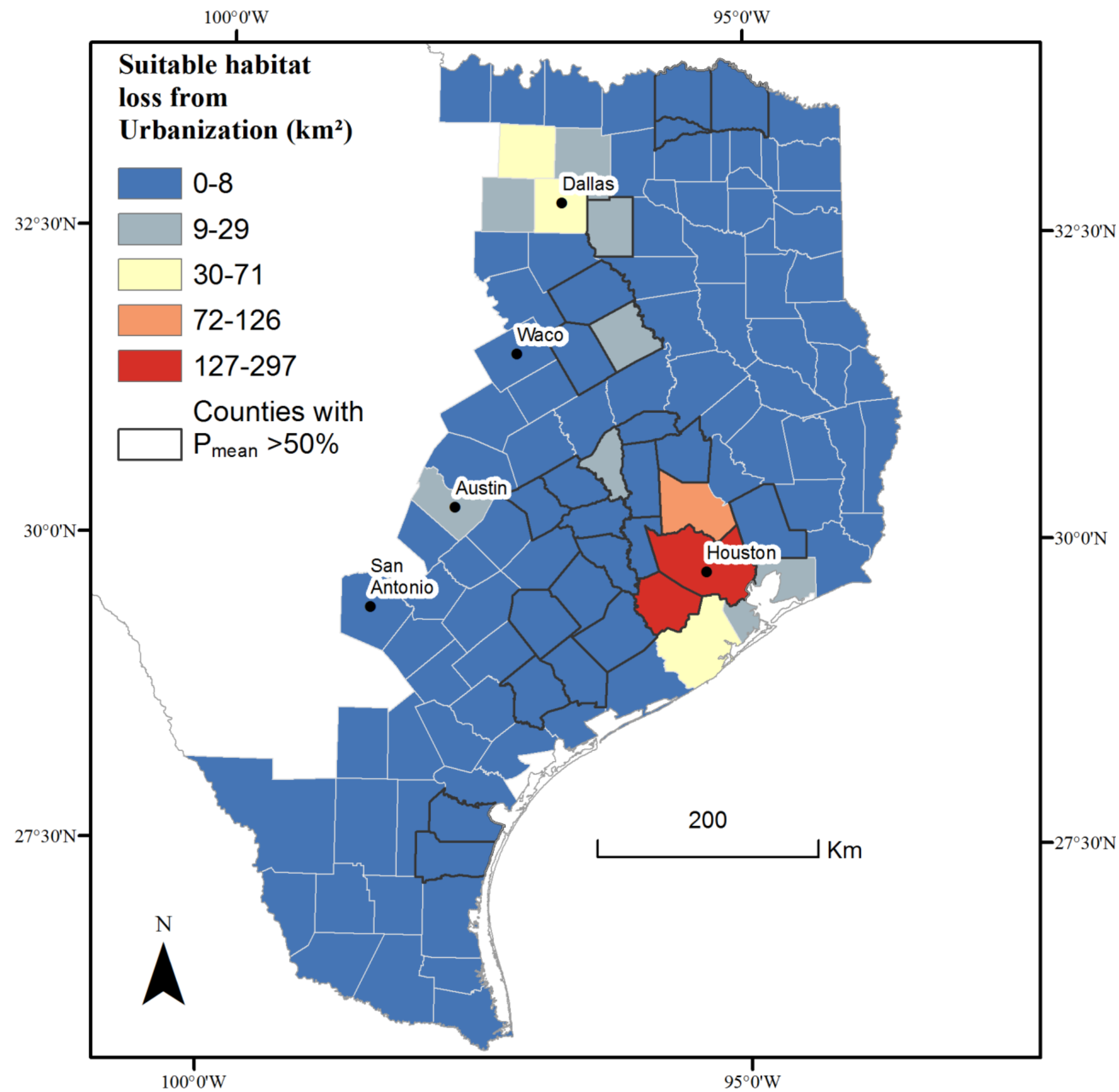
APPENDIX FIGURE 3. Reference map for county ID. This map can be used to cross reference values in subsequent tables.



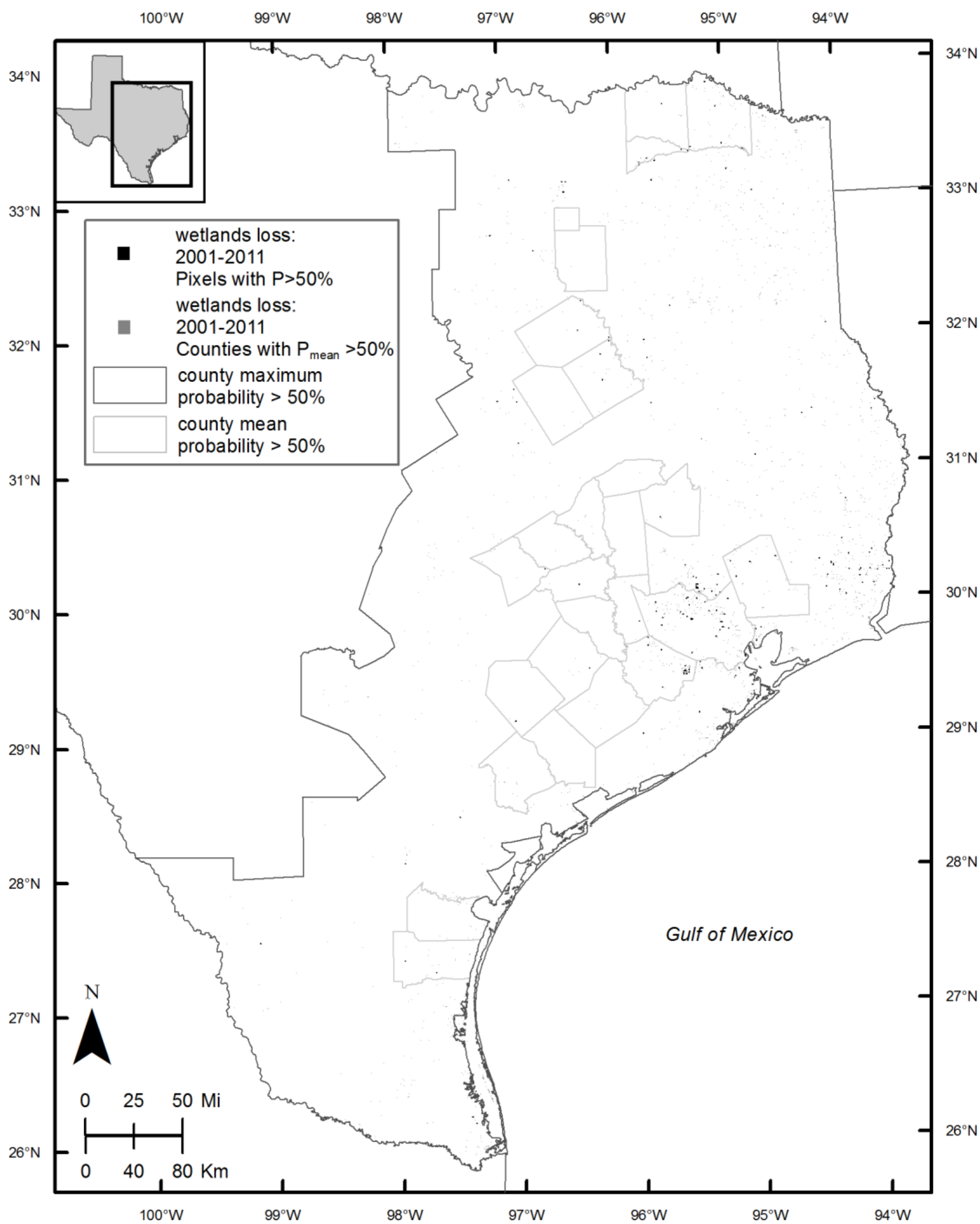
APPENDIX FIGURE 4. Current urban expansion from 2001 to 2011. Urban expansion was identified where the NLCD changed from any type of land cover to developed and barren land (classes 21, 22, 23, 24, and 31) for counties with maximum modeled probability occurrence, *Pmax*, >50% (light gray) and for pixels with modeled probability occurrence, *P* >50% (black).



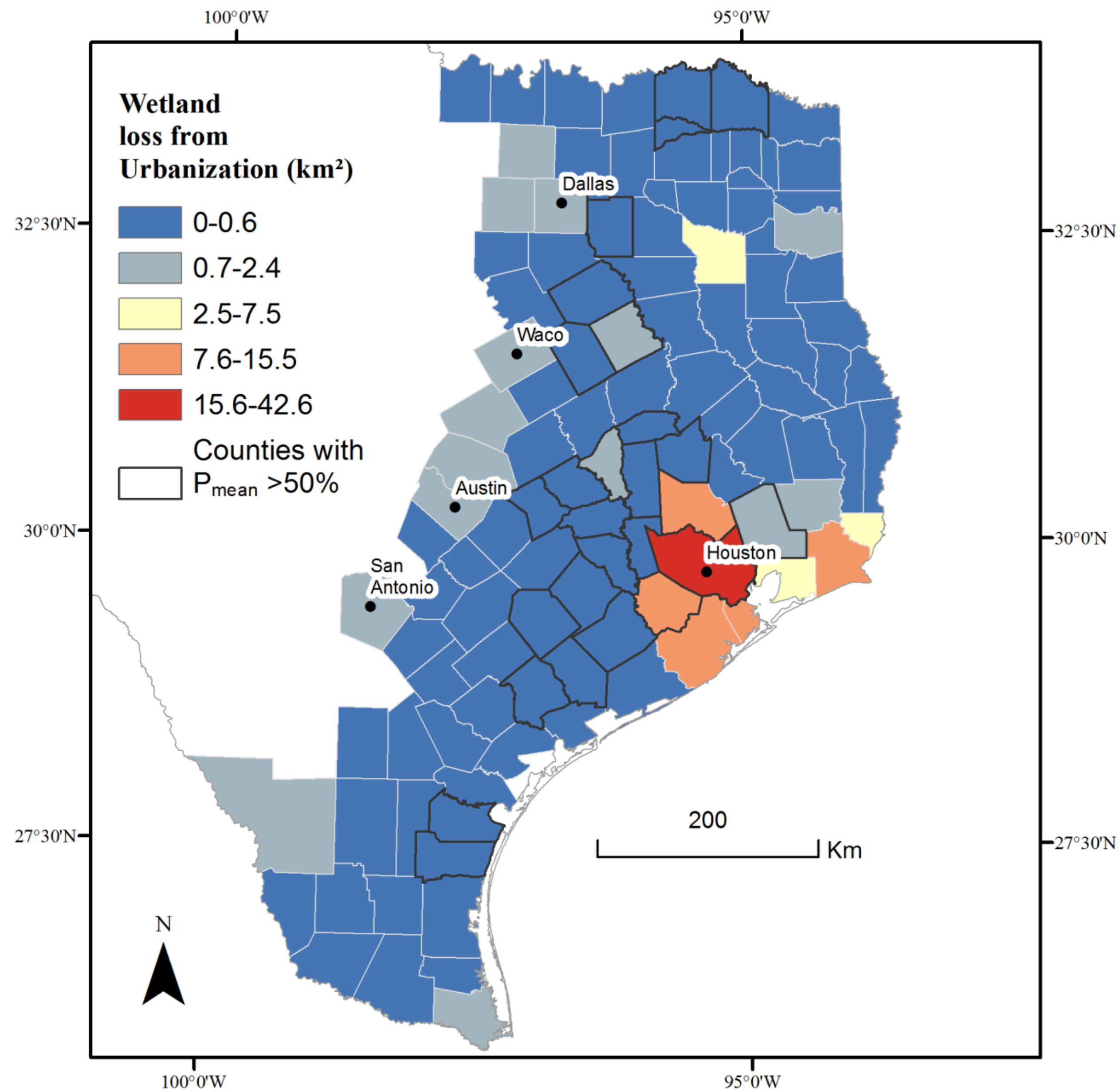
APPENDIX FIGURE 5. Current urban expansion by county from 2001 to 2011. Urban expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



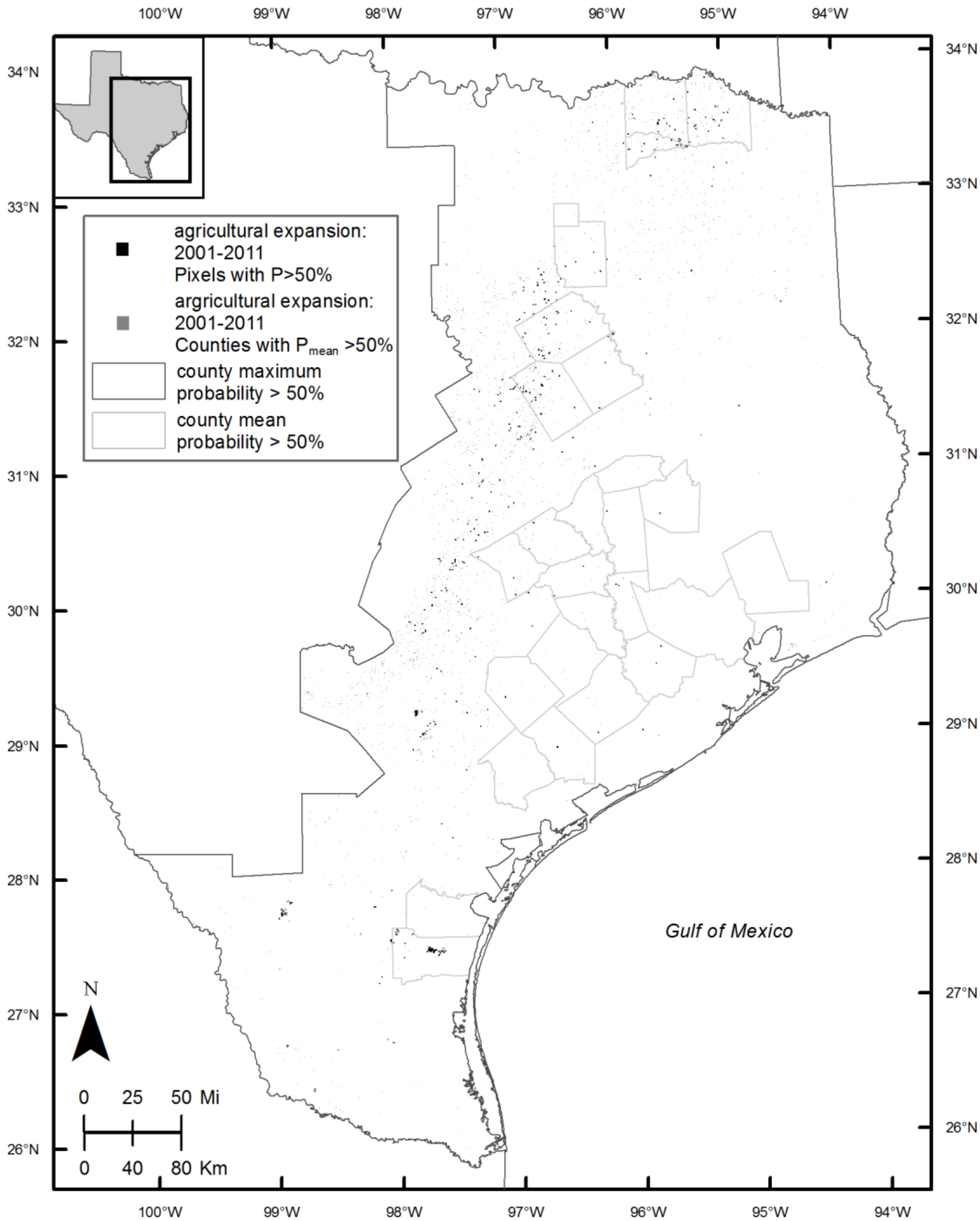
APPENDIX FIGURE 6. Current suitable habitat loss from urbanization by county from 2001 to 2011. Suitable habitat losses from urban expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



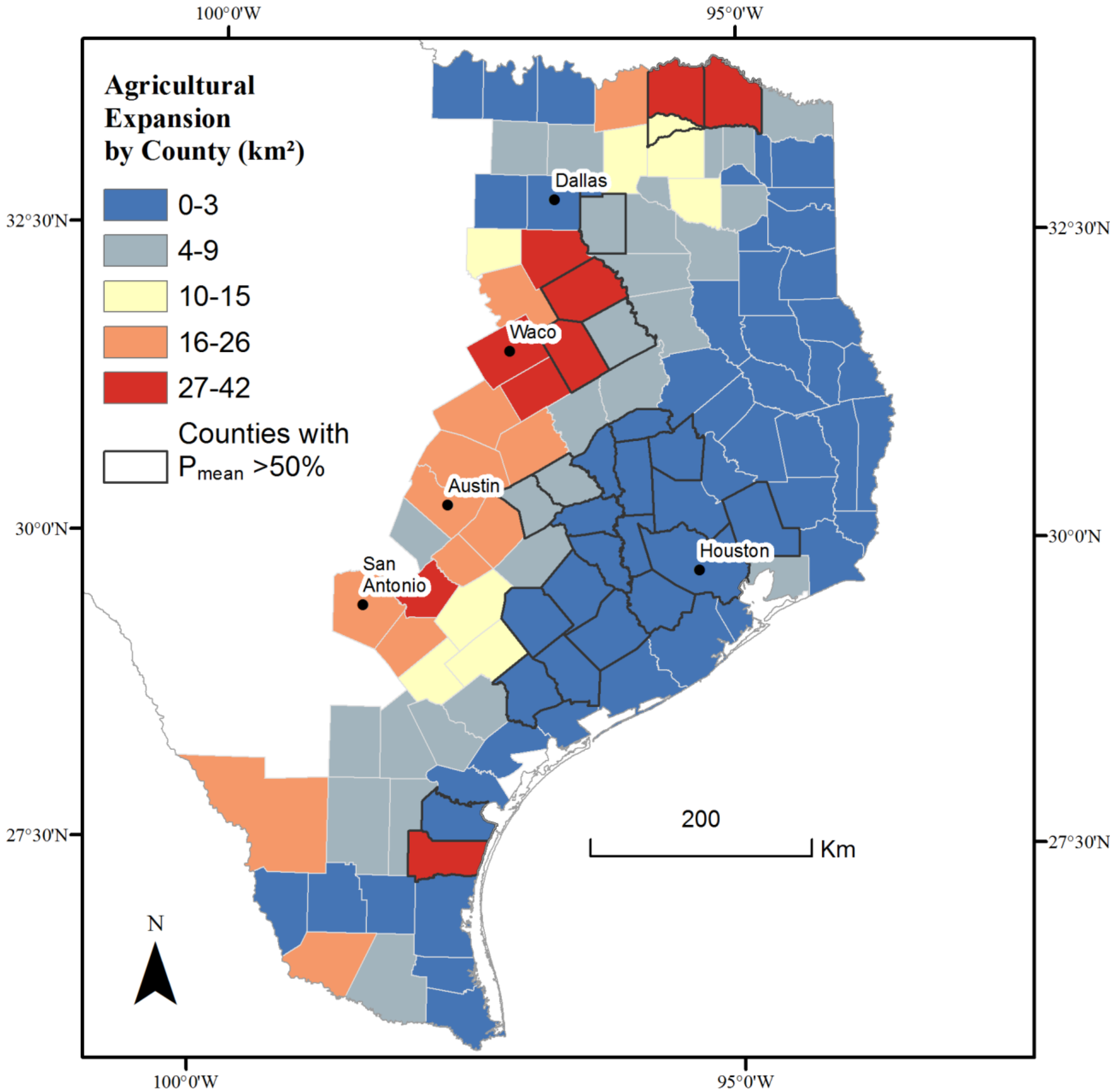
APPENDIX FIGURE 7. Current wetland loss from 2001 to 2011. Wetland loss was identified where the National Land Cover Database (NLCD) changed from woody and emergent herbaceous wetlands (classes 90 and 95) to any other type of land cover for counties with maximum modeled probability occurrence, P_{max} >50% (light gray) and for pixels with modeled probability occurrence, P >50% (black).



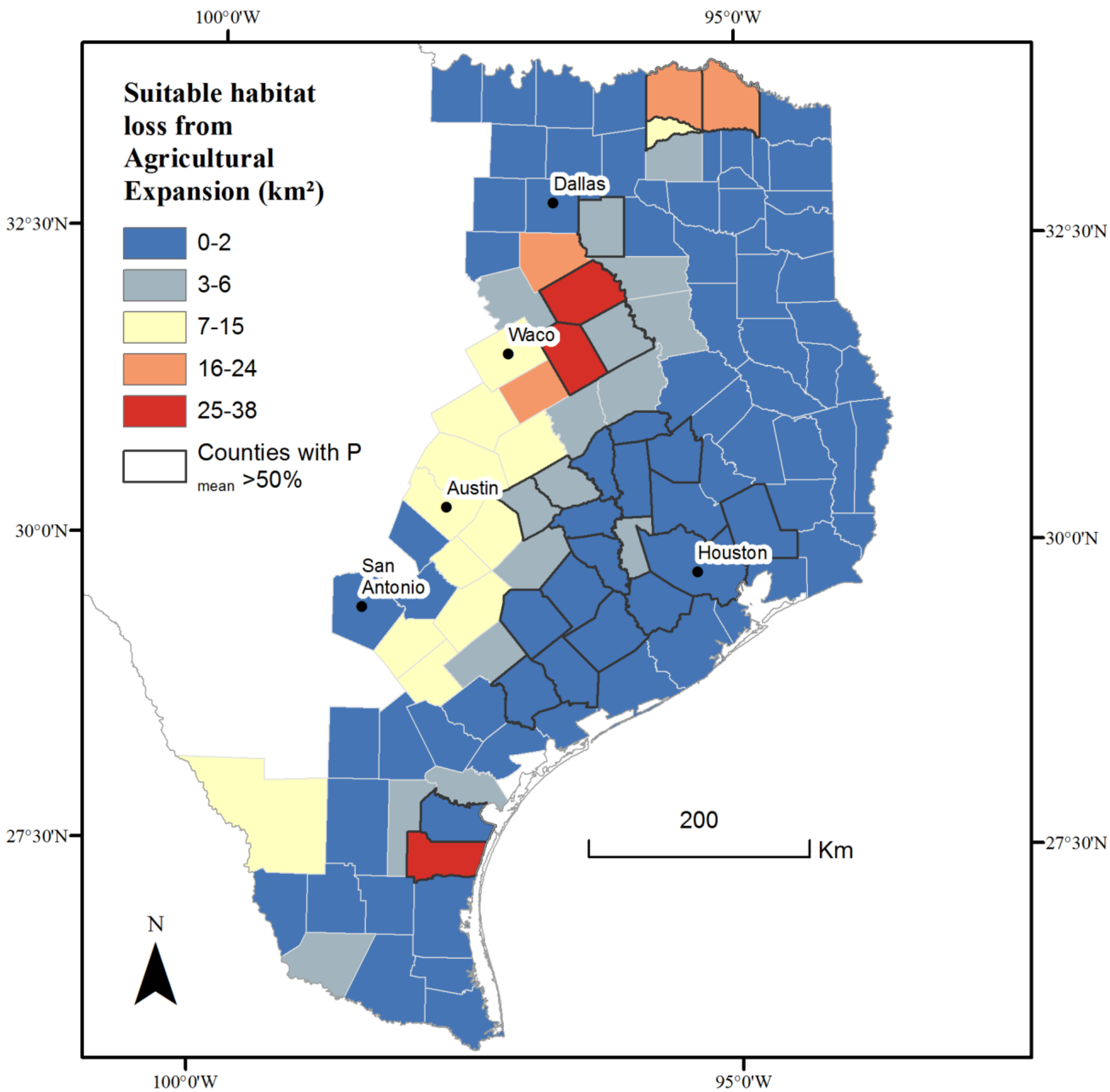
APPENDIX FIGURE 8. Current wetland loss from urbanization by county from 2001 to 2011. Wetland losses from urban expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



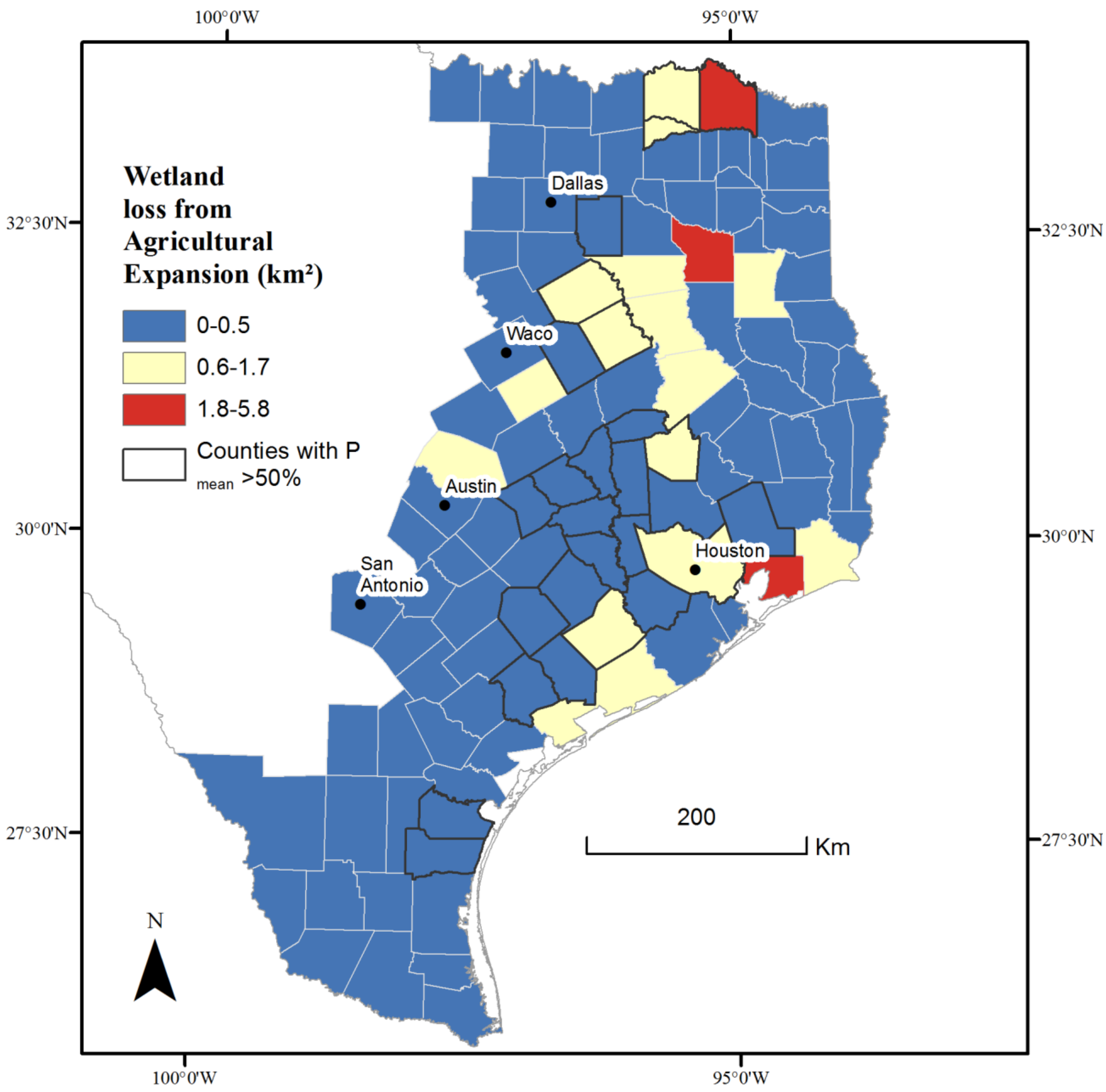
APPENDIX FIGURE 9. Current agricultural expansion from 2001 to 2011. Agricultural expansion was identified where the NLCD changed from any type of land cover to pasture/hay and cultivated crops (classes 81 and 82) f for counties with maximum modeled probability occurrence, P_{max} >50% (light gray) and for pixels with modeled probability occurrence, P >50% (black).



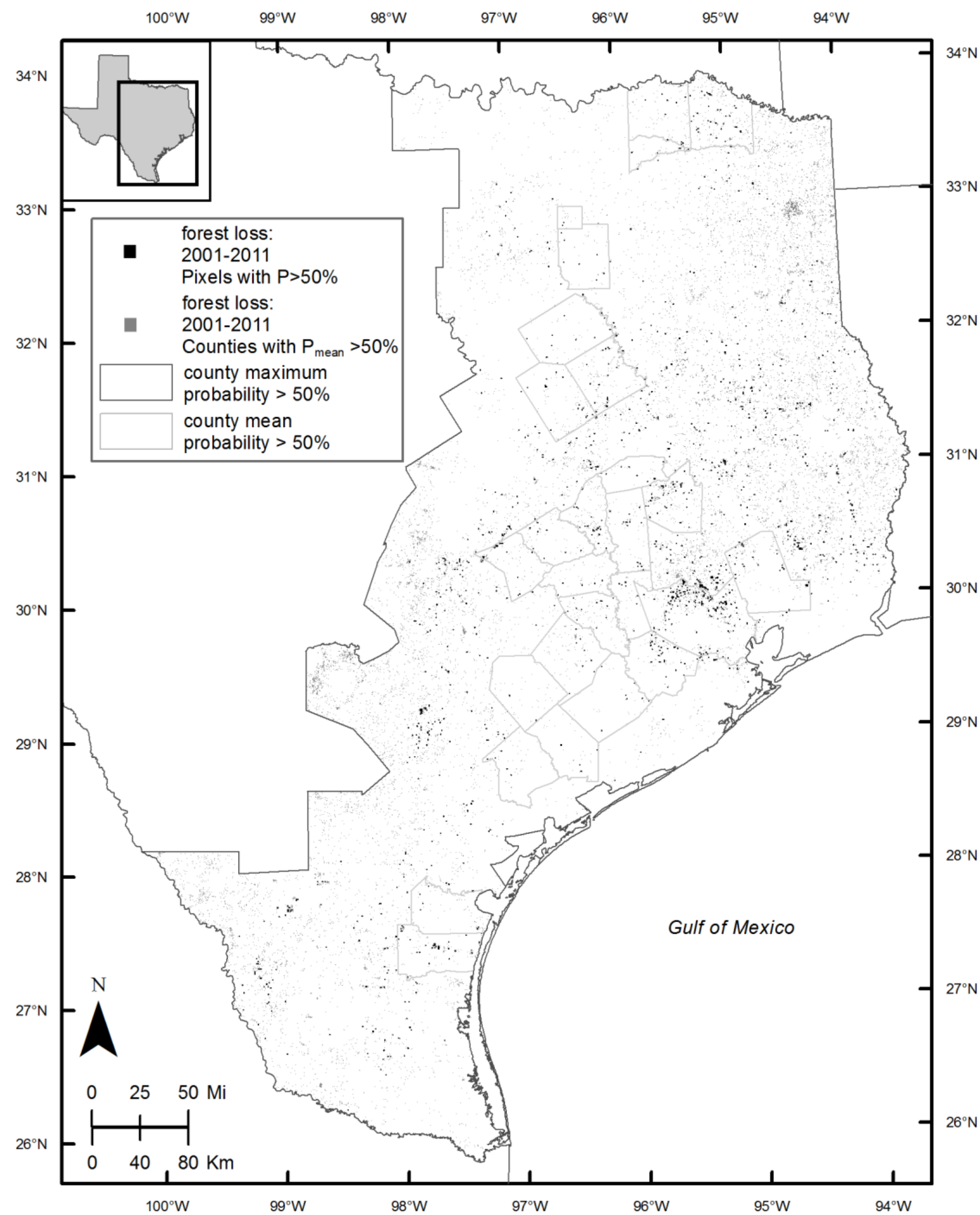
APPENDIX FIGURE 10. Current agricultural expansion by county from 2001 to 2011. Agricultural expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



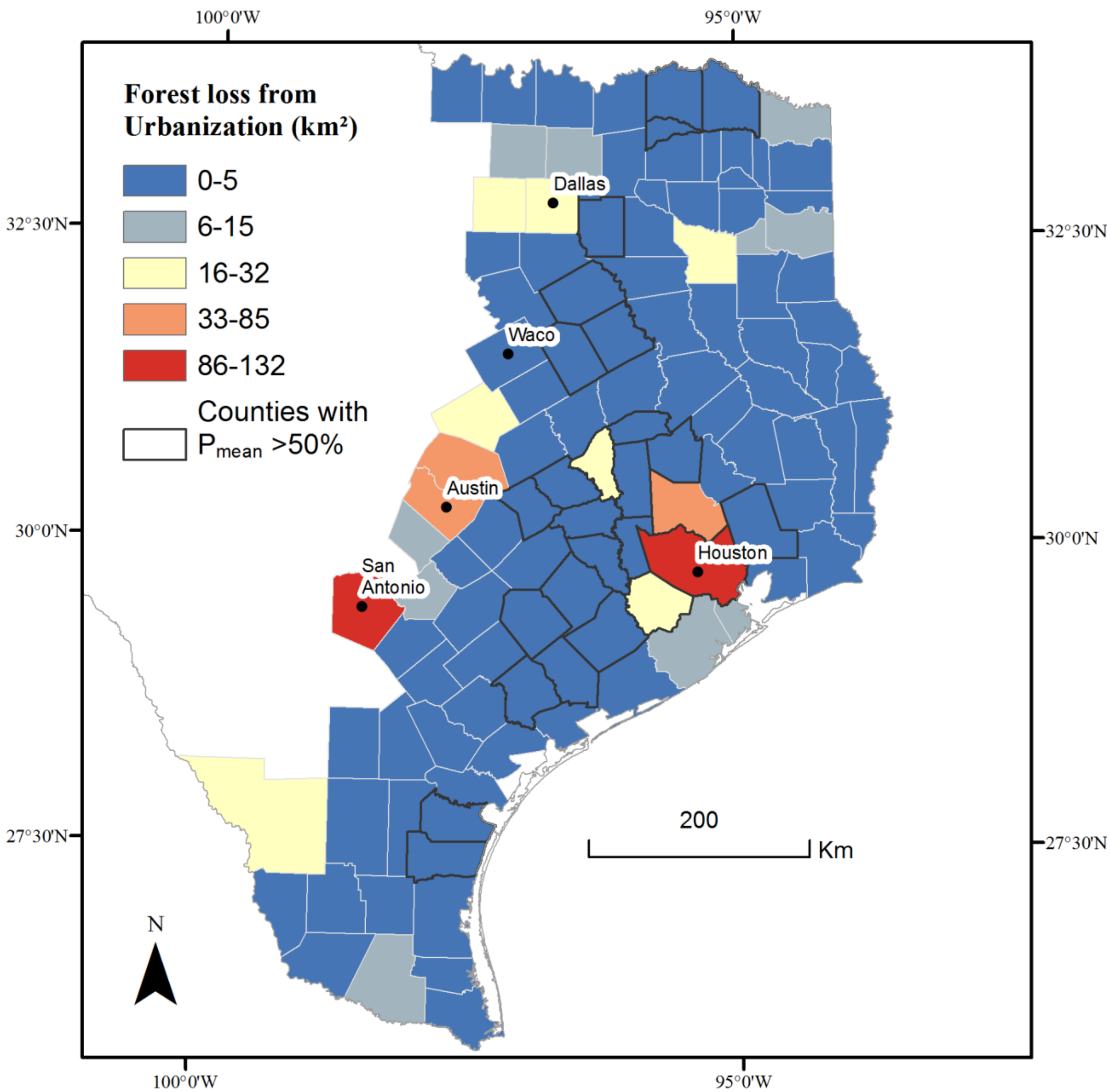
Appendix Figure 11. Current suitable habitat loss from agricultural expansion by county from 2001 to 2011. Suitable habitat losses from agricultural expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



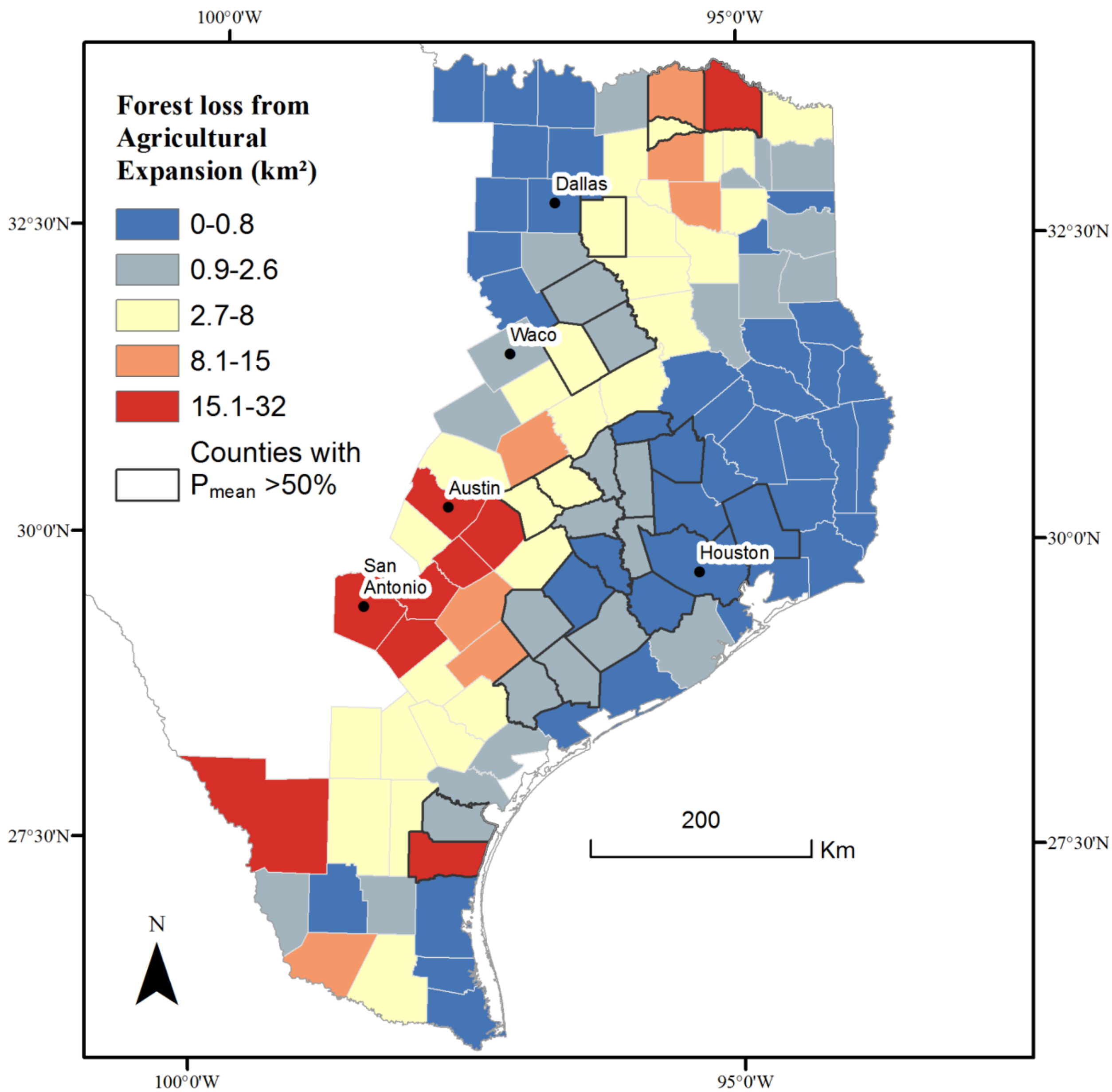
APPENDIX FIGURE 12. Current wetland loss from agricultural expansion by county from 2001 to 2011. Wetland losses from agricultural expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



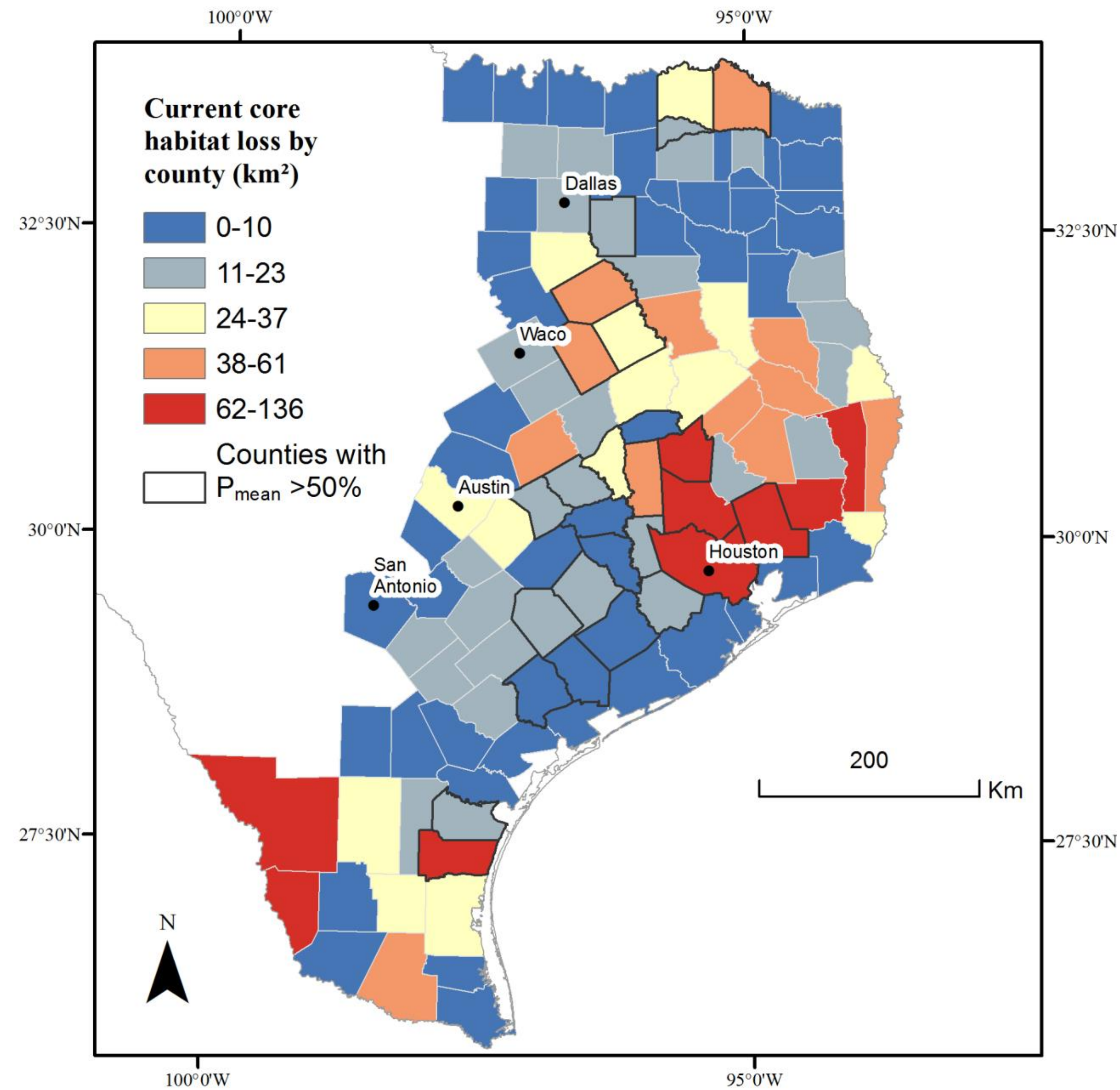
APPENDIX FIGURE 13. Current forest loss from 2001 to 2011. Forest loss was identified where the NLCD changed from deciduous, evergreen, and mixed forest, dwarf shrub, and shrub/scrub (classes 41, 42, 43, 51, and 52) to any other type of land cover for counties with maximum modeled probability occurrence, P_{max} >50% (light gray) and for pixels with modeled probability occurrence, P >50% (black).



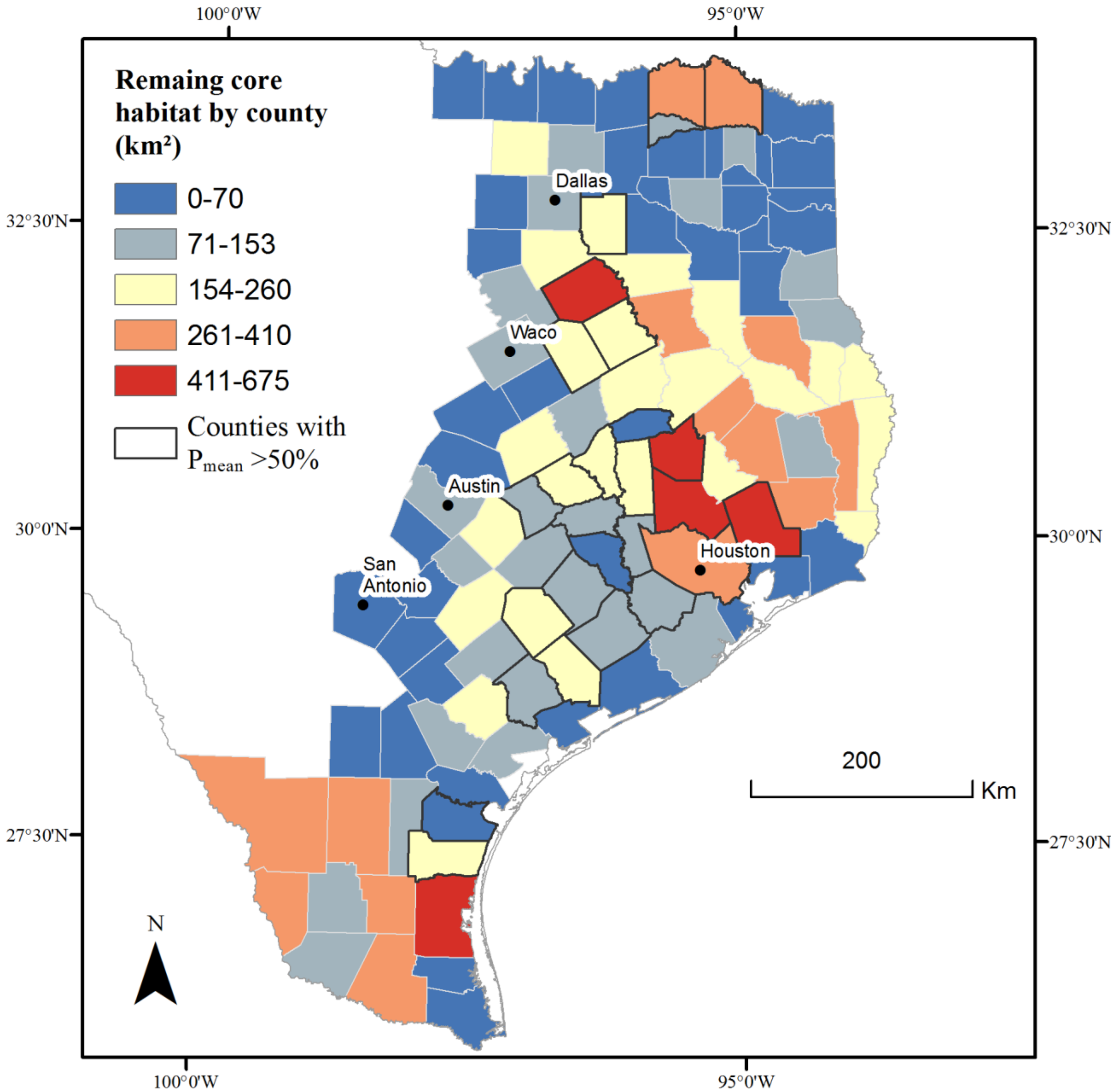
APPENDIX FIGURE 14. Current forest loss from urbanization by county from 2001 to 2011. Forest losses from urban expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



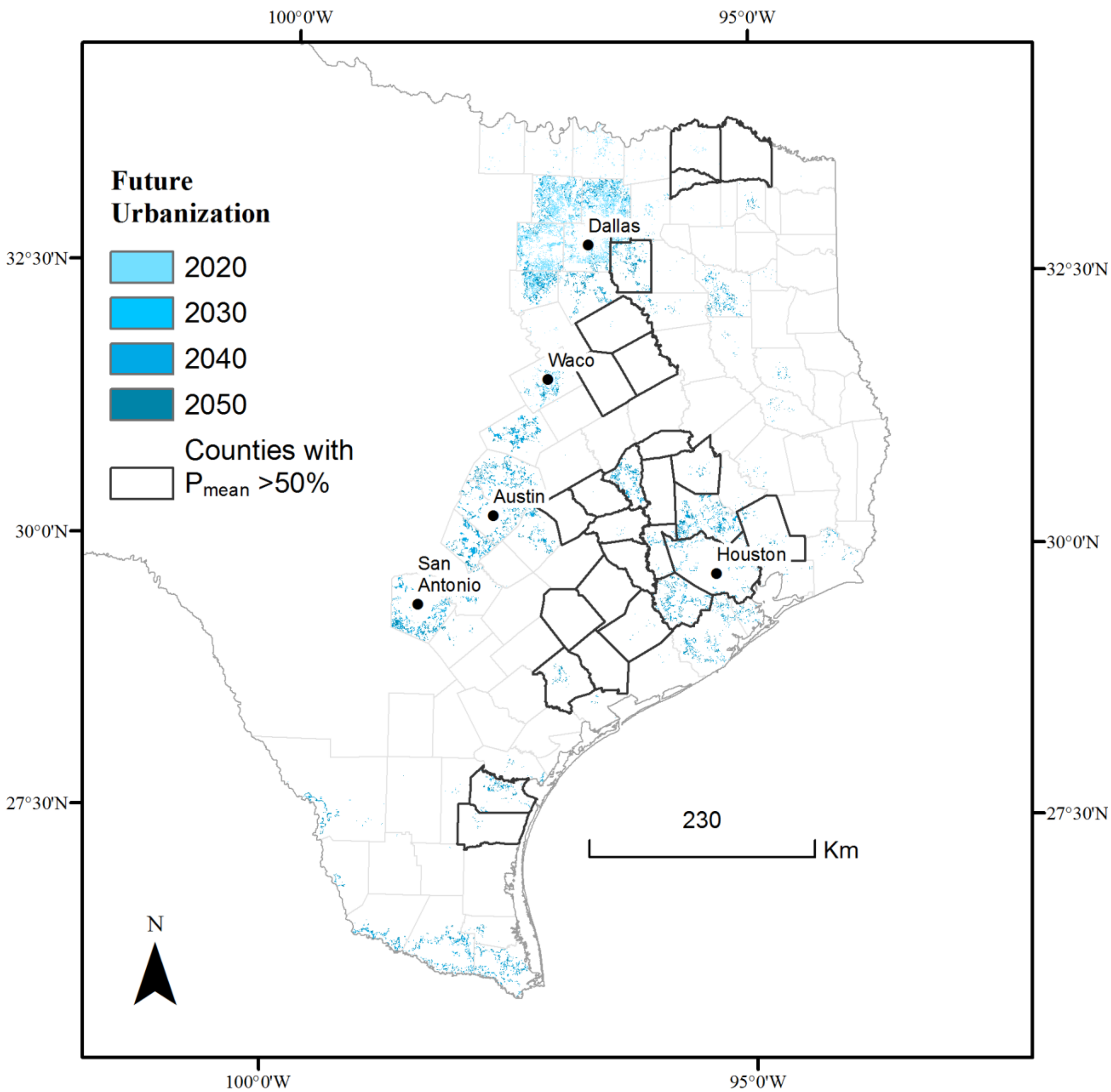
APPENDIX FIGURE 15. Current forest loss from agricultural expansion by county from 2001 to 2011. Forest losses from agricultural expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



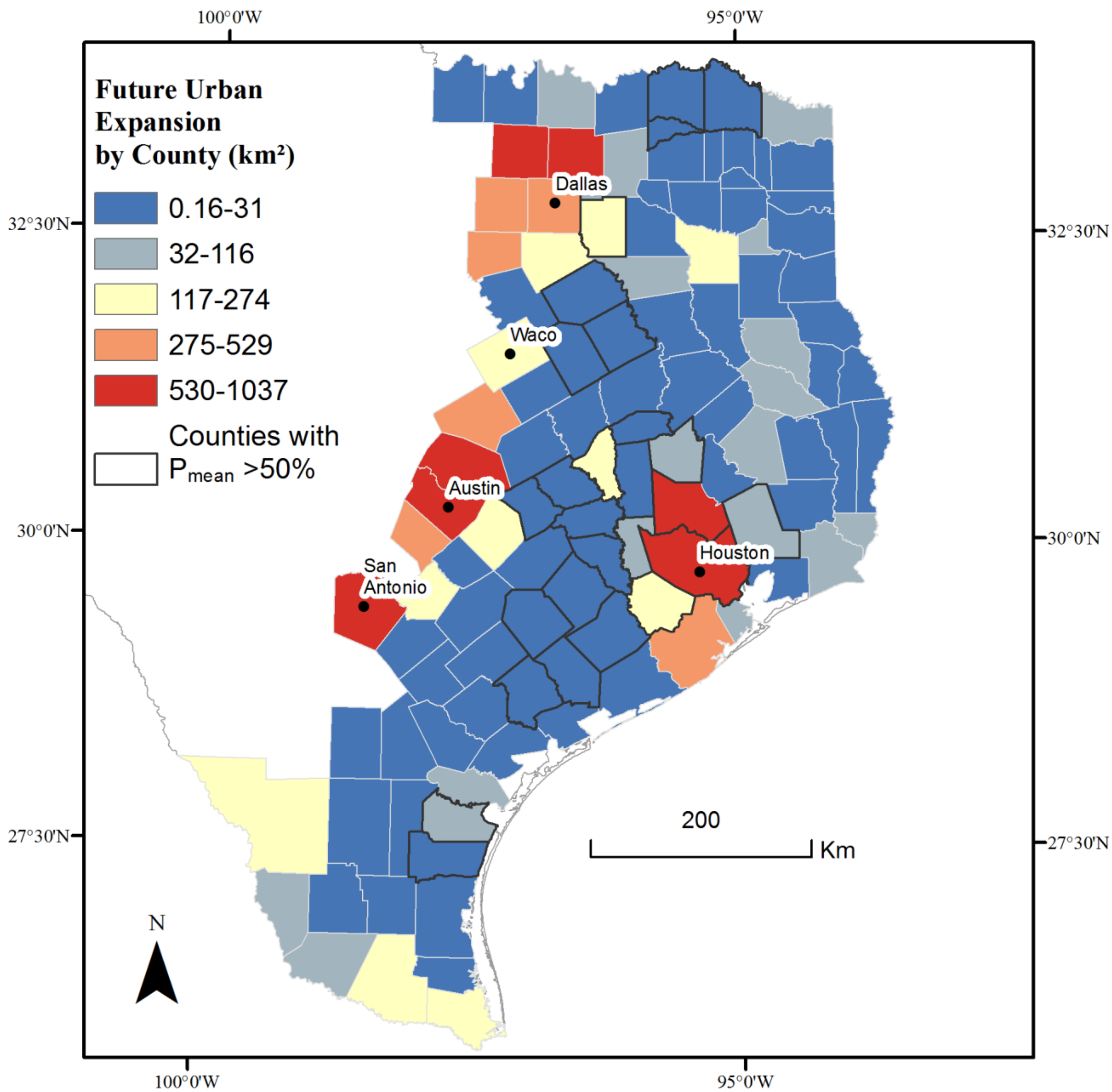
APPENDIX FIGURE 16. Current core habitat loss by county from 2001 to 2011. Current core habitat losses aggregated at the county level and classified using natural breaks (Jenks 1967).



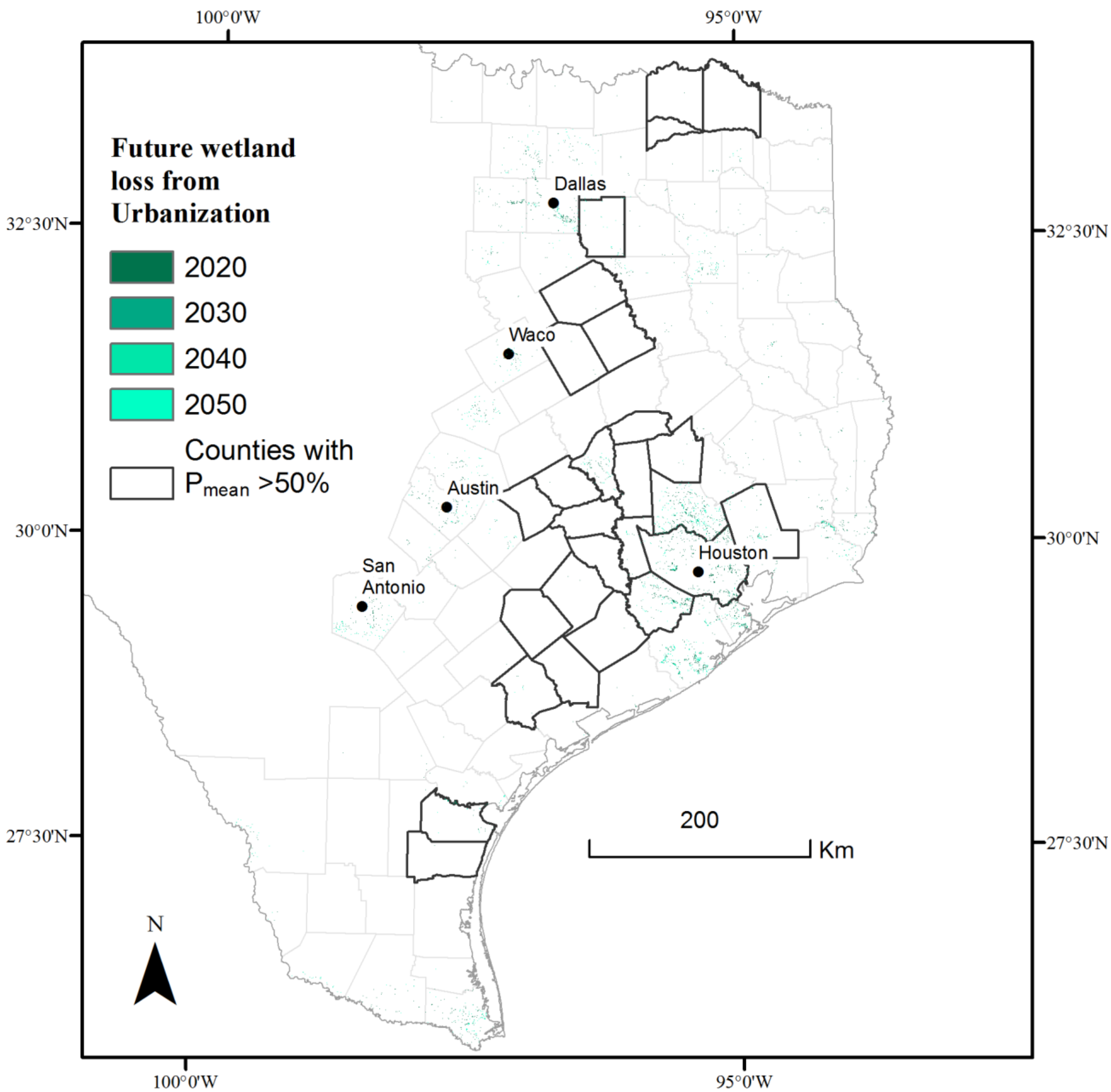
APPENDIX FIGURE 17. Current remaining core habitat by county. Remaining core habitat after current landscape alterations aggregated at the county level and classified using natural breaks (Jenks 1967).



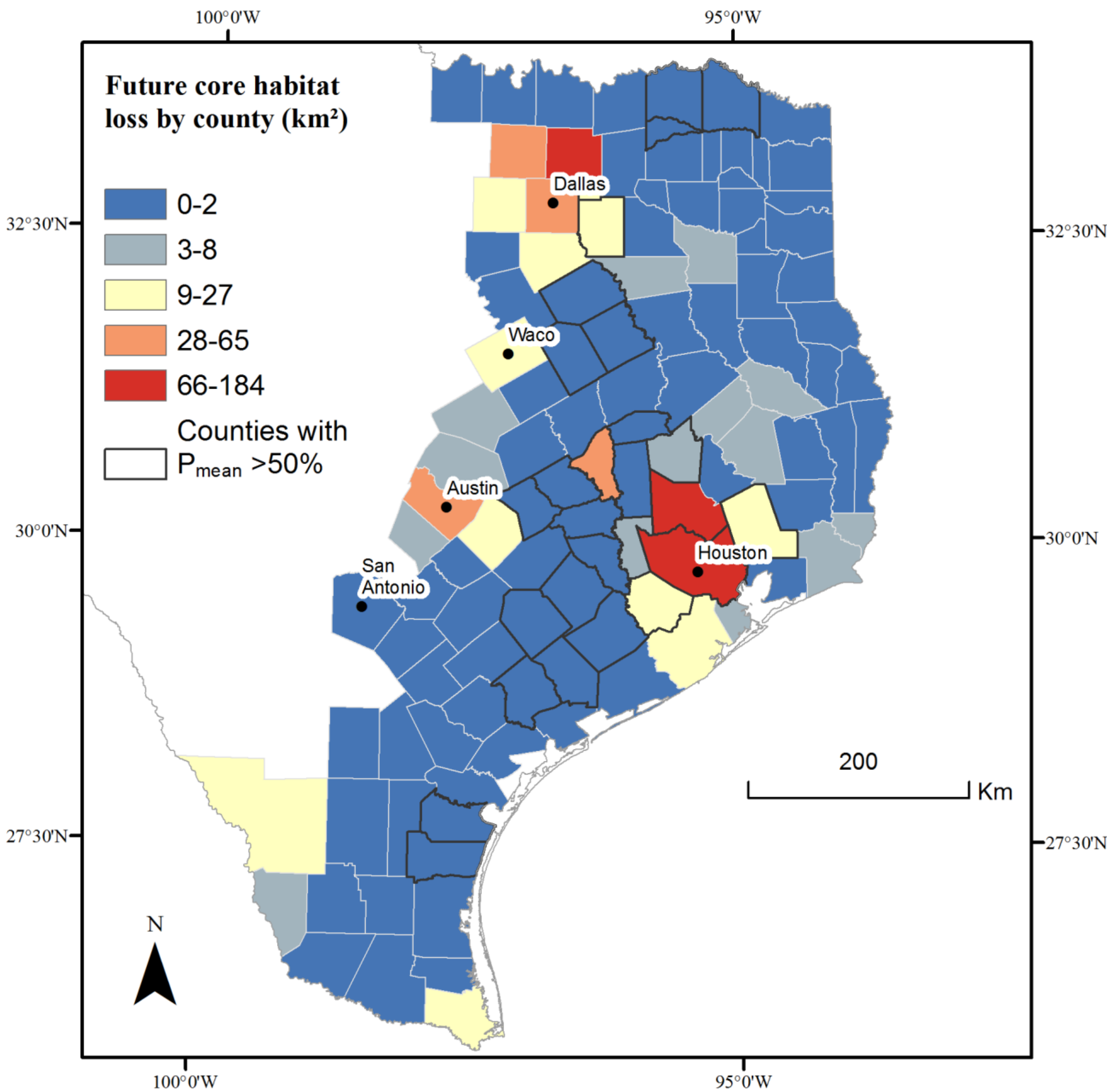
Appendix Figure 18. Future urban expansion beyond the urban fringe from 2010 to 2050. We forecast where land use changes from non-urbanized to urbanized using Theobald (2005) commercial and industrial institutions, >10 units/acre, 5–9.9 units/acre, 2–4.9 units/acre, 0.5–1.6 acre/unit, and 1.7–4.9 acre/unit.



Appendix Figure 19. Future urban expansion by county from 2010 to 2050. Forecasted urban expansion aggregated at the county level and classified using natural breaks (Jenks 1967).



APPENDIX FIGURE 20. Future wetland loss from urban expansion from 2010 to 2050. Forecasted where urbanization identified using Theobald (2005) intersects with 2011 National Land Cover Database (NLCD; Jin et al. 2013; USGS 2014a) classes 11, 90, 95.



APPENDIX FIGURE 21. Future core habitat loss by county from 2010 to 2050. Future core habitat losses aggregated at the county level and classified using natural breaks (Jenks 1967).

APPENDIX TABLE 1. Features used as predictor variables for Maxent Species Distribution Modeling. We followed the approach of Labay et al. (2011).

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 (sd *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

References: [1]30-arc second digital elevation model (USGS 2014b), [2]WordClim (2014), [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.

APPENDIX TABLE 2. 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 20 feet (6 meters) or taller. Shrub: Wetlands dominated by woody vegetation less than 20 feet (6 meters) 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.

APPENDIX TABLE 3. Changes in land use from 2001–2011 thought to threaten habitat. Changes in the National Land Cover Database (Jin et al. 2013; USGS 2014a) were used to assess risks to wetland habitat the species prefers.

Factor	From 2001 NLCD Class	To 2011 NLCD Class
Wetland Loss	11 Open water 90 Woody wetlands 95 Emergent herbaceous wetlands	*Any other class*
Urban Expansion	*Any class*	21 Developed, open space 22 Developed, low intensity 23 Developed, medium intensity 24 Developed, high intensity 31 Barren land (rock/sand/clay)
Agricultural Expansion	*Any class*	81 Pasture/hay 82 Cultivated crops
Forest Loss	41 Deciduous forest 42 Evergreen forest 43 Mixed forest 51 Dwarf shrub 52 Shrub/scrub	*Any other class*

APPENDIX TABLE 4. Heuristic estimate of relative contributions of environmental variables to Maxent model. The final habitat model presented in the paper uses the parameters listed in this table.

Variable	Percent Contribution
Altitude	70.1
Wetland density	12.8
Aspect	4.3
Dominant soil order	6.5
Soil surface texture	4.4
Slope	1.2
Compound topographic index	0.7

APPENDIX TABLE 5. Percent sand at turtle localities and also within 1-km, 5-km, and 10-km buffers.

	Distance to Locality: Texas				**Distance to Locality: Arkansas, Louisiana, Oklahoma, Texas**			
Percent Sand	At Site	1-km	5-km	10-km	At Site	1-km	5-km	10-km
Average	39	44	44	42	43	50	50	49
Mode	25	76	76	76	22	76	76	76

APPENDIX TABLE 6. Proximity of Western Chicken Turtle localities to wetland type (Cowardin et al. 1979; FWS 2014b). The highest three values for each buffer are shaded (blue for Texas; light green for all four states assessed).

	Texas				**Arkansas, Louisiana, Oklahoma, Texas**			
Wetland Type	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			

APPENDIX TABLE 7. Habitat alteration summary for Anderson to Dallas counties in Texas. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%.

***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

APPENDIX TABLE 7 (CONTINUED). Habitat alteration summary for Delta to Henderson counties in Texas. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%.

***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

APPENDIX TABLE 7 (CONTINUED). Habitat alteration summary for Hidalgo to Madison counties in Texas. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%.

***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	-	-	-

APPENDIX TABLE 7 (CONTINUED). Habitat alteration summary for Marion to San Augustin counties in Texas. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%.

***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	-

APPENDIX TABLE 7 (CONTINUED). Habitat alteration summary for San Jacinto to Zapata counties in Texas and 115-county study area alteration totals. Note: values are rounded to the nearest whole number, grey shading indicates a county with P_{mean} > 50%. Total values were calculated using unrounded numbers and then rounded to closest whole number.

***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**