CONSERVATION STATUS OF THE FEDERALLY ENDANGERED GOLDEN-CHEEKED WARBLER

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I. Agency Description

At the Texas A&M Institute of Renewable Natural Resources, we conduct problem-driven research addressing today's challenging wildlife and habitat management questions. Our mission is to solve complex natural resource issues through discovery, engagement, innovation, and land stewardship. The Institute's capacity to conduct interdisciplinary research is a result of our team's broad range of capabilities and expertise, and is enhanced by our strong partnerships and collaborations with universities, government agencies, nongovernmental organizations, and other stakeholders. We are invested in generating reliable science that can be used to promote sustainable wildlife populations through sound management and policy decisions.

II. Executive Summary

The Golden-cheeked Warbler (*Setophaga chrysoparia*; hereafter warbler), a small, insectivorous, migratory songbird that breeds exclusively in mixed oak-juniper (*Quercus-Juniperus*) woodland of central Texas (Pulich 1976, Ladd and Gass 1999), was emergency listed in 1990 as federally endangered (USFWS 1990). At the time of its listing, research conducted on a small number of study sites located in the eastern portion of the warbler's breeding range suggested that there was ~1,270 mi^2 of potential warbler habitat in Texas supporting 13,800 warbler territories (Wahl et al. 1990; USFWS 1992). The USFWS (USFWS 1992) then developed warbler recovery criteria under the notion that there were few warblers existing in spatially structured populations across small, disjunct patches of warbler habitat. After ~25 years of research, recent and comprehensive studies indicate that there is ~5 times more warbler breeding habitat (~6,480 mi^2) and that there are ~19 times more warblers (263,339 males; 95% CI = 223,927–302,620) than assumed at the time of the emergency listing decision (Collier et al. 2012, Mathewson et al. 2012). In addition, molecular work suggests there is no genetic basis for managing warblers as separate population entities (Lindsay et al. 2008). Collectively, these studies indicate that recovery criteria were based on a fundamental misunderstanding of the existing abundance and population structure of the species, and a re-examination of the warbler's federally endangered listing status is strongly warranted by the USFWS.

III. Background

The U.S. Fish and Wildlife Service (USFWS) listed the Golden-cheeked Warbler (*Setophaga chrysoparia*; hereafter warbler), a small, insectivorous, migratory songbird that breeds exclusively in mixed oak-juniper (*Quercus-Juniperus*) woodland of central Texas (Pulich 1976, Ladd and Gass 1999), as federally endangered in 1990. During the breeding season (March–July), warblers require shredded bark from mature Ashe juniper for nest material and a combination of Ashe juniper, oaks, and associated hardwoods for nesting and foraging (Pulich 1976, Ladd and Gass 1999). Most warblers leave the breeding grounds in late July and migrate through Mexico and Central America to their wintering grounds in southern Mexico, Guatemala, Honduras, El Salvador, and Nicaragua, where they remain until spring migration begins in late February (Pulich 1976, Ladd and Gass 1999). Primary concerns at the time of the emergency listing decision included habitat loss and fragmentation, urban encroachment, lack of oak recruitment, and brood parasitism by brown-headed cowbirds (*Molothrus ater*) (USFWS 1990).

Recovery goals and most subsequent research efforts operated under the assumptions that warblers are rare and exist within spatially separated populations (Morrison et al. 2012). However, more recent research suggests (1) there is more warble breeding habitat and the species is more abundant than previously assumed, (2) woodland patches are not separated or isolated by large distances, (3) warblers occupy and successfully breed across a much wider range of habitat conditions than initially identified, and (4) gene flow is panmictic. As such, criteria for species recovery and recommendations for management are based on a limited understanding of the species at the time of their inception, warranting further review of the warbler's federally endangered status in the future. As part of that effort, this report summarizes the abbreviated history and current knowledge of warbler habitat distribution, population trends, potential threats, and existing regulatory mechanisms for the species and provides a biological foundation for future conservation measures.

IV. Federal Listing History

- Emergency listed as federally endangered May 1990; final rule published December 1990
- Recovery Plan published by USFWS September 1992
- USFW announced 5-year Status Review and solicited new information April 2006
- Spotlight Species Action Plan posted to the Federal Register by USFWS August 2009
- Scientific Evaluation for the 5-year Status Review published November 2010
- Scientific Evaluation for the 5-year Status Review published August 2014

V. Criteria for Species Recovery (USFWS 1992)

- Sufficient breeding habitat protection to ensure continued existence of at least one viable, self-sustaining population in each of the eight regions outlined in the plan
- Potential for gene flow across regions between demographically self-sustaining populations needed for long-term viability
- Sufficient and sustainable non-breeding habitat to support the breeding populations
- All existing warblers populations on public lands protected and managed to ensure their continued existence
- All criteria met for 10 consecutive years

VI. Habitat and Population

Breeding Habitat Estimates

At the time of its listing, research conducted on a small number of study sites located in the eastern portion of the warbler's breeding range suggested that there was ~1,270 mi^2 of potential warbler habitat in Texas (Wahl et al. 1990; USFWS 1992). Since that time, there have been numerous attempts to update the warbler breeding habitat estimate (Table 1). Results have been highly variable due to differences in land cover classification techniques, source imagery (year collected, image quality, resolution), post-hoc adjustments (minimum patch size requirements, estimated conversion rates, personal opinion), counties included as part of the warbler's breeding range, access to private land for surveys, and actual change in

ground cover over time, among others (Table 1). However, more recent estimates based on randomly sampled patches on public and private land across the warbler's breeding range, congruent satellite imagery, and biological covariates known to influence warbler occurrence identified ~6480 mi^2 of potential warbler breeding habitat (Collier et al. 2012). This estimate falls within the range of potential warbler breeding habitat identified by others since the listing decision (~2,130–6,840 mi^2; Table 1). However, the Collier et al. (2012) habitat model provided the first probabilistic predictions for the likelihood of patch occupancy by warblers and was constructed using data and statistical procedures that were appropriate for the scale and scope of the project (Collier et al. 2012). Information obtained from Collier et al. (2012) indicates that there is ~5 times more warbler breeding habitat than identified at the time of the warbler's listing, that there are a large number of warbler habitat patches across their breeding range, and that these patches are not separated by large distances.

Table 1. Summary of Golden-cheeked Warbler breeding habitat and population estimates.

Reference	Total potential habitat	Habitat delineation method	Density estimate	Density method	Total population	Population method	Advantages	Limitations
Pulich 1976	502 mi^2	Used Soil Conservation Service definition of ''virgin Ashe juniper'' (stands 20–40 ft trees >75 years old), reduced by author; no imagery used	"good" = 0.125 pairs/ha; "average" = 0.05 pairs/ha; "marginal = 0.03 pairs/ha	Spot-mapping with marked population in Dallas, Bosque, Kendall counties; Census surveys conducted in 1962 and 1974	1962: 15,630 individuals; 1974: 14,950 individuals	Calculated proportion of total habitat for each of 3 habitat quality ranks (23%, 31%, and 46%, respectively), multiplied by respective density estimates	First comprehensive field-based study	Site-specific estimates from a small number of sites applied to entire range; Narrow habitat definition; Assumed constant density across the warbler's breeding range; Projected density within 3 qualitative habitat assessment ranks
Wahl et al. 1990	Uncorrected: 1305 mi^2; Corrected for habitat changes post-imagery collection: 915 mi^2; Habitat in patches >50 ha: 124–412 mi2	Corrected values for habitat loss and patch size; 1974, 1976, and 1981 Landsat imagery, unsupervised and supervised classification from known breeding locations (see Shaw 1989); 1989 value is corrected for estimated habitat loss	0.149 pairs/ha	Median estimate for 16 sites in 11 counties determined primarily by 1-mile transect method (Emlen 1971); surveys conducted in 1987, 1988	Carrying capacity: 4,822–16,016 pairs	Median density estimate projected to total potential habitat estimates after corrections	First attempt to use remote sensing for warbler habitat mapping	Assumed constant density across the warbler's breeding range; Imagery for habitat map did not include all portions of the breeding range; Used asynchronous remote imagery to define habitat; Corrected based on assumed habitat change and warbler-habitat relationships (e.g., patches <0.02 mi^2 unoccupied); Site-specific estimates applied range-wide; Data collected primarily on public lands
USFWS 1992	1272 mi^2 (Adapted from Wahl et al. 1990; estimates included counties with >3.8 mi^2 of potential warbler habitat)	Used Wahl et al. (1990) habitat total estimate for 1989 adjusted for estimated habitat loss; included the assumption that 34% of patches <0.02 mi^2 are occupied	Estimates from Pulich (1976) for good, average, and marginal	Estimates for each of 3 habitat ranks from Pulich (1976)	13,800 territories	Followed Pulich (1976) proportions of habitat quality assuming same proportions apply to habitat delineated by Wahl et al. (1990); not corrected for patch size	See above	See above
Rowell et al. 1995	Method 1 (derived from generalized locations containing typical warbler habitat): 450 mi^2; Method 2 (derived using limited warbler detecions - included patches <0.2 mi^2): 2108 mi^2	1990–1992 Landsat, Ashe juniper-deciduous woodlands with >75% canopy cover and patches >0.02 mi^2; Method 1: unsupervised classification of polygons; Method 2: supervised classification from point locations	0.3 individuals/ha	Estimates from Wahl et al. (1990)	Carrying capacity: 64,520 individuals	Projected density to total habitat from Method 2 for patches >0.02 mi^2 because less variation in spectral reflectance compared to Method 1	Based on improved imagery from a narrow period of time; Habitat classifications based on larger warbler occurance data sets	Did not conduct range-wide field surveys; Vegetation data used to drive classification collected at few study sites; Assumed constant density across the warbler's breeding range; Corrected based on assumed warbler-habitat relationships (e.g., patches <0.02 mi^2 unoccupied; estimated at 40% of theri total area classified as potential habitat)

Reference	Total potential habitat	Habitat delineation method	Density estimate	Density method	Total population	Population method	Advantages	Limitations
Diamond and True 1998	1986: 6379 mi^2; 1996-1997: 6472 mi^2	1986 and 1996–1997 Landsat; land cover classified as Ashe juniper, or mixed juniperoak forest/woodland, or mixed or primarily deciduous forest	NA	NA	NA	NA	Clearly identified limitations	Occupancy within potential habitat unknown; classification accuracy questioned
Rappole et al. 2003	2484 mi^2	Used Diamond and True (1998) classification but removed patches 0.02 mi^2	0.188 territorial males/ha; 89% pairing success	Estimates from 167 males from monitored population on Fort Hood, Coryell and Bell counties from 1992 to 1996 (Jette et al. 1998)	228,426 (95% CI: 227,142–229,710) individuals	Adjusted mean density of males by 89% pairing success to estimate number of females	More inclusive habitat classification (included patches >0.02 mi^2)	Site-specific estimates from a small number of sites applied to entire range; Assumed constant density across the warbler's breeding range; Excluded ~112 mi^2 of potential warbler habitat; Adjusted based on pairing success at small number of study sites
DeBoer and Diamond 2006	2921 mi^2	Grouped forest cover types based on NLCD data; Included only patches >246 ft from edge; Conducted occupancy surveys in 2002	NA	NA	NA	NA	Used metrics obtained at local and landscape scales; Collected data on 36 patches of privately owned land and 13 patches of publicly owned land	Limited field sampling across the range; Does not incorporate interpatch heterogeneity
Diamond 2007	Model C: 6841 mi^2; Model D: 6648 mi^2	Evergreen/forest/woodland or deciduous forest/woodland within 100 m of evergreen. Model C: adjusted for edge; Model D: with reduction for low canopy cover and addition for high canopy cover	NA	NA	NA	NA	Compared multiple models	Narrow habitat definition and included qualitative classification of habitat "quality"; Limted field data; unclear methodology
SWCA 2007	2132 mi^2	2004 digital imagery; >50% canopy closure composed of large Ashe juniper and deciduous trees; patches >0.02 mi^2	"high" = 0.22 pair/ha; "low" = 0.025 pair/ha	‘‘High’’ estimate from long-term monitoring study on Fort Hood, Bell and Coryell counties (Peak 2003); ‘‘low’’ estimate from surveys Government Canyon SNA, Bexar Co. (USFWS 2004)	Estimated using the SWCAhabitat model: 13,931–116,565 pairs; Adjusted estimate based on personal opinion: 20,445–26,978 pairs	Adjusted estimate based on assumptions of density with goal of deriving a ‘‘satisfactory minimum population estimate’’	Considered several landscape-scale metrics: density of woodland, proportions of Ashe juniper and deciduous trees, size of trees, patch size, land use	Site-specific estimates from a small number of sites applied to entire range; Inclued ony high quality habitat, therefore narrow definition of warbler habitat and not based on quality as it relates to productivity; Personal opinion used to adjust population estimates downward "We looked at the results of this application and did not like it."
Loomis Austin 2008	6484 mi^2	2001 NLCD average canopy cover in a 7 x 7 cell (cell = 98 ft) neighborhood; potential habitat = all areas within 3 cells of areas with at least 50% mean canopy cover	NA	NA	NA	NA	Broad range in canopy cover considered potential habitat	Included qualitative classification of habitat "quality" based on canopy cover metrics; Limited field data collected small number of sites over long period of time (2001–2008); unclear methodology

Reference	Total potential habitat	Habitat delineation method	Density estimate	Density method	Total population	Population method	Advantages	Limitations
Collier et al. 2012	6479 mi^2	2007 and 2008 Landsat 5; unsupervised classification; used NLCD to remove any cover types mis-classified as woodland and pixels identified as woodland, but with <30% canopy cover; used road layer to further define habitat patches	NA	NA	NA	NA	Data collection and statitical procedures were appropriate for the scale and scope of the project (patches were randomly sampled across the warbler's breeding range, imagery was current to the study); Included data collected public and private land; Used biological co-variates know to influence warbler occurrence; High predictive accuracy; Provided probabilitstic prediction of the likelihood of patch occupancy	Did not incorporate interpatch heterogeneity
Mathewson et al. 2012	6479 mi^2	2007 and 2008 Landsat 5; unsupervised classification; used NLCD to remove any cover types mis-classified as woodland and pixels identified as woodland, but with <30% canopy cover; used road layer to further define habitat patches. (Collier et al. 2012)	mean patch-specific density: 0.23 males/ha	Abundance point counts done in 301 patches, such that each patch surveyed was given a density estimate	263,339 (95% CI: 223,927–302,620) singing males	Used predicted patch-specific density estimates as a function of predicted patch-specific occupancy probability and based on 1,000 simulated realizations of population distribution	Data collection and statitical procedures were appropriate for the scale and scope of the project (patches were randomly sampled across the warbler's breeding range, imagery was current to the study); Included data collected within 306 patches on public and private land; More conservative estimate than would have been projected by including detection probability	2009 population estimate; Cannot be applied to local-scale; Patch-specific, so does not incorporate interpatch heterogeneity

Winter and Migratory Habitat Estimates

Warblers winter in pine-oak forests of southern Mexico, Guatemala, Honduras, El Salvador, Nicaragua, and possibly Costa Rica at elevations between ~2,600 and 8,500 ft (Komar et al. 2011). Infrequently, warblers may also be found in pine, cloud or broadleaf forests, scrub habitat or agricultural areas (Rappole et al. 2000, Potosem and Muñoz 2007, McCrary et al. 2009). Using U.S. Geological Survey (USGS) data and Landsat imagery, Rappole et al. (2003) estimated ~2,600 mi^2 of potential pine oak-habitat on the wintering grounds (excluding Nicaragua). However, the authors acknowledged that known detections fell into a USGS land cover class of "evergreen needleleaf forest", which they did not include in their initial analyses and could add ~1,700 mi^2 to their estimate of potential winter habitat, resulting in ~4,300 mi^2 of potential winter habitat. Alliance for the Conservation of Mesoamerican Pine-Oak Forests (ACMPOF) estimated ~7,500 mi^2 of potential warbler wintering habitat (ACMPOF 2008). Parks and protected areas exist along the migration route. However, data regarding warbler use of those areas during migration is lacking.

Breeding Population Estimates

Population estimates extrapolated from research conducted on a small number of study sites located in the eastern portion of the warbler's breeding range suggested that there were 13,800 warbler territories in Texas at the time of the warbler's emergency listing as federally endangered (Wahl et al. 1990; USFWS 1992). Subsequent population estimates based on improved imagery (though still quantified using a small number of site-specific observations, qualitative definitions of warbler habitat quality based on personal opinion, and assumptions of constant density across the warblers breeding range) indicated that there were ~13,000–230,000 individuals (Table 1). Most recently, Mathewson et al. (2012) estimated the warbler population size using models of patch-specific densities derived from randomly located range-wide abundance surveys, then developed a predictive equation that related biological metrics to patch-scale density. They found that patch-specific occupancy probability (which is a function of patch size and landscape composition; Collier et al. 2012) was the best predictor of patch-specific densities, and estimated the population of male warblers at 263,339 (95% CI = 223,927–302,620). Without accounting for detection probability, which would have increased the overall population estimate, this indicates that there are ~19 times more warblers than assumed at the time of the emergency listing decision.

The most recent warbler status review suggests that the Mathewson et al. (2012) model may have over-predicted warbler density estimates, and, therefore, resulted in inflated population estimates (USFWS 2014). More specifically, the USFWS (2014) noted concerns that patch-specific territory density estimates with known warbler numbers are lower than predicted by the range-wide estimates. This is a misapplication of the model results, which the authors explained should only be applied at the range-wide scale. Mathewson et al. (2012) used data and statistical procedures that were appropriate for the scale and scope of the project (i.e., patches were randomly sampled on public and private land across the warbler's breeding range, imagery was current to the study). In addition, their overall estimates align with other habitat and population estimates when assumptions regarding habitat quality are removed (Table 1). Furthermore, the territory density estimates derived by Mathewson et al. (2012) were well within the range of most available information for the species (Table 2). It is also important to note that relationships between warbler density and patch-scale metrics used by Mathewson et al. (2012) to predict abundance across the species' range were consistent with patch-scale metrics previously shown to affect warbler

density at local scales (Magness et al 2006, Baccus et al. 2007). While the Mathewson et al. (2012) model should not be used at the local scale, which again was acknowledged by the authors in their peer-reviewed manuscript, their work provided patch-specific predictions of warbler density across the species' breeding range and represents the best available warbler breeding population estimate.

Table 2. Summary of patch-specific Golden-cheeked Warbler territory density estimates.

Source	Density (males/ha)	Location	Survey method
Pulich 1976	0.03–0.13	Dallas, Bosque, Kendall counties	Census
Kroll 1980	0.12–0.20	Bosque county	Territory mapping
Wahl et al. 1990	0.08-0.63	Rangewide	1.6 km Emlen strip census
Jette 1998	1992–1996; 0.14–0.28	Fort Hood (Coryell County)	Territory mapping
Peak 2003	1999–2003; Site 1: 0.10–0.22, Site 2: 0.25–0.37	Fort Hood (Coryell County)	# males / size of study site
Peak and Lusk 2009	2003–2009; 0.21–0.29	Fort Hood (Coryell County)	# males / size of study site
Peak and Grigsby 2011, 2012, 2013	2011–2013; 0.27–0.32	Fort Hood (Coryell County)	# males / size of study site
City of Austin & Travis County	1999–2013; 0.17–0.44	BCP (Travis County)	Territory mapping
Cooksey & Edwards 2008	1991–2008; 0.04–0.20	Camp Bullis (Bexar County)	Point counts along transects
Mathewson et al. 2012	0.23	Rangewide	Point counts at random points in patches

Winter Population Estimates

Estimates of the warbler population on the winter range vary substantially. Rappole et al. (2003) estimated a winter habitat carrying capacity of 34,425 birds, using their estimate of density (0.05 birds/ha) and an estimate of ha of pine-oak above ~4000 ft (~2,600 mi^2; see above). When the "evergreen needleaf" class was included, their winter population estimates increased to 56,674 birds. Using the habitat estimate from ACMPOF (2008) and their own warbler density estimate (0.3 birds/ha), Komar et al. (2011) estimated a total warbler population of 585,000 birds, with 345,000 adult males, although the authors admit that the amount of habitat is likely overestimated. Komar et al. (2011) detected decreased warbler abundance in each year of their range-wide study of wintering warblers (2007–2010), suggesting potential declines in the overall warbler populations, insufficient sampling, or observer bias.

Survival

Using data collected from a small portion of the warbler's breeding range (Fort Hood Military Reservation, Coryell and Bell counties, TX) and assuming metapopulation dynamics (but see Lindsay et al. 2008 below), Alldredge et al (2004) developed the population viability model used to guide conservation decisions by the USFWS. Results of their analyses suggest that the probability of warbler extinction over the next 100 years is low as long as enough habitat exists to support $\geq$3,000 breeding pairs in each of the eight defined recovery regions. The total amount of available warbler habitat exceeds this threshold (Mathewson et al. 2012) and Hatfield et al. (2012) recently suggested that recovery region boundaries should be reestablished to reflect warbler biology as opposed to watershed boundaries. Under this paradigm, recovery metrics would not include estimates of abundance across the 8 recovery regions, which currently require a minimum of 3,000 males per recovery region, since these initial estimates were based off small-scale studies, we now know that density varies widely across the warbler's breeding range, and warblers do not exist as a metapopulation (detailed below).

In a more recent analysis, Duarte et al. (2014) used data (again collected at Fort Hood) and found adult survival rates slightly lower than those initially used by Alldredge et al. (2004) (mean apparent survival for Duarte et al. 2014 = 0.47 and mean apparent survival for Alldredge et al. 2004 = 0.56). However, Duarte et al. (2014) additionally recognized that warbler survival rates coincided with those obtained for other closely related warbler species and acknowledged that their calculations should not be used to simulate range-wide population dynamics. Duarte et al. (2014) found no evidence that survival at this study location exhibits spatial or temporal variation and there are no known studies that address range-wide variation in warbler survival rates. Such information would be necessary to infer broad-scale population dynamics and set informed conservation targets identified by Alldrege et al. (2004) and used by USFWS.

Productivity

Pairing success is generally high (typically >70%) and studies suggest that estimates of this metric depend on factors such as tree species composition (Marshall et al. 2013), male age (Jette et al. 1998), and warbler territory density (Farrell et al. 2012). Territory success (proportion of territories that successfully fledge young) is also relatively high (typically >50%) and exhibits similar trends with tree species composition (Marshall et al. 2013), male age (Pruett 2014), and warbler territory density (Farrell et al.

2013). Fecundity is difficult to compare across years due to inconsistencies in measuring, reporting, and that warblers split broods (biasing fledging counts low), but estimates of fecundity are consistently high on the Fort Hood Military Reservation (1.13–2.06 young per territory; Anders 2000) and City of Austin properties (1.82–3.04 young per territory; COA 2010, 2011, 2012, 2013).

While warbler management guidelines identify large-tracts of oak-juniper woodland with >70% cover as high quality breeding habitat, more recent research indicates that relationships between woodland stand characteristics and fledging success vary regionally (Campomizzi et al. 2012). In the Limestone Cut Plain Ecoregion, where most warbler research has been conducted, the predicted probability of warbler fledging success increased with increasing patch size, decreasing patch edge to area ratio, and increasing percent cover. This coincides with site-specific nest survival data obtained at the Fort Hood Military Reservation and in the Austin area (Stake 2003, Peak 2007, Reidy et al. 2009b, Peak and Thompson 2014). However, these relationships are not consistent across Ecoregions (Campomizzi et al. 2012) and warblers will fledge young in areas with <20% canopy cover, especially in the southern portion of their breeding range (Klassen et al. 2012). Furthermore, there is experimental song playback evidence that warblers can be drawn into previously unoccupied woodland stands with less canopy cover and successfully fledge young outside the habitat conditions typically considered suitable for the species (Farrell et al. 2012).

Genetics

Athrey et al. (2011) examined temporal changes in genetic variation using 134 samples collected from 1890–2008 at locations in Travis, Bexar, and Kerr counties, Texas. They divided the samples into historic (1890–1915) and contemporary (2005) time periods and found reduced allelic richness (20% decline) and heterozygosity (13% decline) in the contemporary samples compared to the historic samples. Athrey et al. (2011) suggested that habitat fragmentation in the 20th century resulted in reduced gene flow and increased spatial structuring of the warbler population. However, previous research using DNA collected from 109 individuals at seven study sites across the warblers' range in 2004 and 2005 found no evidence of genetic bottlenecks or genetic differentiation (Lindsay et al. 2008). The latter results indicate that current allelic richness and heterozygosity are relatively high and similar to those of other warbler species, and suggests that there is no genetic basis for managing warblers as separate population entities (i.e., there is no genetic basis for assuming metapopulation dynamics; Lindsay et al. 2008).

VII. Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes

There is no evidence that the warbler has been subject to overuse for commercial, recreational, scientific, or educational purposes. Birds of many species are captured for the pet trade or killed for recreational hunting on the wintering grounds, but it is unlikely that these activities pose a threat to the warbler's continued existence. Research that includes mist nesting and banding of warblers is organized and regulated by the USFWS, TPWD, and BBL and these activities rarely cause harm to individuals.

VIII. Disease, Predation, and Brood Parasitism

In 2012, avian pox was confirmed on Balcones Canyonlands Preserve (Austin, TX) properties after several warblers were reported with swollen and bleeding feet, legs, and lesions on the face, legs and feet. City of Austin researchers recommended exercising care when handling the birds in those locations to

minimize the spread of the infection. This appears to be an isolated event and there are no other disease detection records for this species.

Documented warbler predators (adults and young) include snakes, birds, mammals, red-imported fire ants (*Solenopsis invicta*) (Stake et al. 2004, Reidy et al. 2008, Reidy et al. 2009a). Brood parasitism varies annually, but is uncommon and represents a small risk to overall warbler nest survival (Groce et al. 2010).

IX. Natural or Manmade Factors

Habitat Loss

From 1992–2001, Groce et al. (2010) examined National Land Cover data (NLCD) and estimated a net loss of ~450 mi^2 (~6%) of woodland within the warbler's breeding range during that time period. The highest conversion rates were identified near urban areas and were attributed to development and population growth. More recent Texas Land Trends analyses support this trend, as most land conversion that occurred between 1997–2012 occurred with population expansion in the states 25 fastest growing counties (txlandtrends.org). Duarte et al. (2013) used Landsat imagery to quantify range-wide changes in golden-cheeked warbler breeding habitat over a 10-year period between 1999–2000 and 2010–2011. They identified a total ~8,570 mi^2 of potential golden-cheeked warbler habitat in 1999–2000 (more than any other estimates of potential warbler habitat; see above) and ~6,090 mi^2 in 2010–2011 (similar to other estimates of potential warbler habitat; see above). They determined that the degree of fragmentation and loss was uneven across the range with the greatest reductions in mean patch size the southern portion of the warblers' range.

ACMPOF (2008) estimated that 74% of the original pine-oak forest cover remains on the warbler's wintering grounds in Mexico and Central America; ~7% of the existing habitat is located in protected areas. Primary conversion threats include unsustainable forestry practices that are incompatible with conservation, forest fires, and commercial logging (ACMPOF 2008). Parks and protected areas exist along the migration route, but no data exists regarding the amount of potential stopover habitat. Similarly, many conservation groups and NGOs work in the region, but there is no data to quantify the scope of their efforts.

Habitat Fragmentation

Fragmentation of existing breeding habitat represented a major concern at the time of the warbler's listing. Range-wide studies conducted during the breeding season indicate that the predicted probability of occupancy increases from north to south with increasing patch size and mean percentage of woodland cover in the surrounding landscape (Collier et al. 2012). Site-specific research conducted by Butcher et al. (2010) found that warblers establish territories in patches as small as ~0.01 mi^2 in rural landscapes. Follow-up research conducted in the Austin area found that minimum patch size requirements for territory establishment were larger (~0.05 mi^2; Robinson 2013). Combined, the Collier et al. (2012), Butcher et al. (2010), and Robinson (2013) studies emphasize the importance of large and small patches to sustain the warbler population on its breeding ground.

Range-wide, warbler density also increased from north to south, which ecologically represents increasing patch size and mean percentage of woodland cover in the surrounding landscape (Mathewson et al. 2012). This coincides with site-specific research (Magnesss et al. 2006, Baccus et al. 2007, Peak and Thompson

2013). Though again, small patches do support warblers and the importance of these smaller areas should not be discounted. Patch size can also influence avian reproduction. Coldren (1998) found that pairing and fledging success increased with increased patch size. Minimum patch size for reproductive success is 0.06–0.07 mi^2 in a rural landscape (Butcher et al. 2010) and ~0.08 mi^2 in an urban environment (Arnold et al. 1996). However, in a range-wide study that included productivity data from 1,382 territories, Campomizzi et al. (2012) did not find consistent relationships between territory success and patch size or patch edge-to-area ratio across their breeding range.

Habitat Degradation

In a study conducted in the western portion of the warbler's breeding range, Stewart et al. (2014b) found that the presence of oak wilt (a defoliating tree disease caused by the fungus *Ceratocytis fagacearum*) did not affect warbler territory placement, but pairing success for males whose territories included some proportion of oak wilt had 27% lower pairing success. With that said, Stewart et al. (2014b) found no difference in fledging success between territories in oak wilt affected and unaffected forests. In a similar study conducted in the eastern portion of the warbler's breeding range, Appel and Camilli (2010) examined post-breeding habitat use in warblers in relation to oak wilt and found no difference in the use of affected and unaffected forest. Studies suggest that oak wilt is more likely to occur outside warbler habitat (Appel and Camilli 2010, Stewart et al. 2014a); Stewart et al. (2014a) found that oak wilt occurred in 4.1% of their study area and predicted that the amount of habitat affected will double by 2018 as the disease spreads.

Deer can limit oak survival when the saplings are browsed (Russell and Fowler 2002, 2004). However, there is no direct evidence to suggest that herbivory by native or non-native browsers is contributing to reduced habitat (or habitat suitability) for the warbler. Murray et al. (2013) investigated local declines in Texas red oak (*Q. buckleyi*) at Balcones Canyonlands National Wildlife Refuge, but concluded that fire suppression and drought were likely the cause of reduced oak density. Similarly, Yao et al. (2012) suggested fire could have a dual effect on warbler habitat (such that reduced tree density could reduce suitability), but oak recruitment is typically high following moderate to high intensity fires.

Management Practices

At the time of listing, it was assumed that any Ashe juniper removal from warbler habitat would have a negative effect on the species. However, Marshall et al. (2012) found that a higher proportion of territories successfully fledged young in areas where understory juniper was thinned when compared to untreated control sites. Warbler territory density was also similar between the thinned sites and control sites, which suggests that the pattern of higher productivity in the treated areas did not result from density dependent mechanisms.

Climate Change

A combination of long-term fire suppression and drought exacerbated by climate change could increase the risk of wildfires and restrict warbler breeding habitat (EPA 2009), but whether this will influence the long-term survival of the species is unknown.

Noise

In the original listing decision, road construction noise and activity was cited as a potential threat to the warbler. Lackey et al. (2012) found similar warbler abundance, pairing success, and fledging success across road noise only sites, road construction sites, and control sites, and there was no relationship between warbler reproductive success and distance from the roadway. Similarly, warblers at the Fort Hood Military Reservation occupied and breed in patches exposed to active military activity and there is no correlation between warbler reproductive success and noise level (Lopez et al. 2012). Both studies suggest that warblers habituate to anthropogenic noise disturbance.

X. Regulatory Mechanisms

Direct take of warblers is prohibited by the Migratory Bird Treaty Act of 1918 and by the Texas Parks and Wildlife Department. Listing of the warbler as federally endangered by the USFWS provided protection for warbler breeding habitat on public and private land. In addition, there are several conservation-based programs that preserve existing warbler habitat on private land. These include:

- 160 Habitat Conservation Plans and one Safe Harbor Agreement supported by the USFWS
- The Recovery Credit System (RCS), a voluntary natural resource management program developed by the Texas Department of Agriculture provides technical guidance and assistance to private landowners near the Fort Hood Military Reservation with qualifying lands that support warbler habitat. The goal of this program is to mitigate adverse impacts to habitat on the installation that result from military training activities. Since July 2006, the total investment for implementation of the RCS is $1,954,666 and the cost-share for the 20 participating landowner's cost share is $451,295. Contract terms range from 10–25 years and the program protects ~3.4 mi^2 of warbler breeding habitat on private land.
- The *Black-capped Vireo and Golden-cheeked Warbler Habitat Identification/Treatment Criteria for the NRCS Brush Management Consultation* was developed by the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS). This program provides technical guidance for brush clearing to avoid warbler breeding habitat on properties with NRCS contracts.
- The Alliance for the Conservation of Mesoamerican Pine-Oak Forests in was established in 2003. This voluntary international cooperative partnership includes members from many national nongovernmental organizations in Mexico, Guatemala, El Salvador; Honduras, Nicaragua, and the U.S. (including the Nature Conservancy, Texas Parks and Wildlife Department, and the Zoo Conservation Outreach Program). The organization's conservation plan, published in 2008, directs management and preservation actions in the pine-oak ecoregion on Central America, where most warbler wintering habitat is located.

XI. Conclusion

At the time of the Golden-cheeked Warbler's emergency listing as federally endangered in 1990, research conducted on a small number of study sites located in the eastern portion of the warbler's breeding range suggested that there was ~1,270 mi^2 of potential warbler habitat in Texas supporting 13,800 warbler territories (Wahl et al. 1990; USFWS 1992). The USFWS (USFWS 1992) then developed warbler recovery criteria under the notion that there were few warblers existing in spatially structured

populations across small, disjunct patches of warbler habitat. Specifically, the warbler recovery criteria require:

- Sufficient breeding habitat protection to ensure continued existence of at least one viable, self-sustaining population in each of the eight regions outlined in the plan
- Potential for gene flow across regions between demographically self-sustaining populations needed for long-term viability
- Sufficient and sustainable non-breeding habitat to support the breeding populations
- All existing warblers populations on public lands protected and managed to ensure their continued existence
- All criteria met for 10 consecutive years

After ~25 years of research, recent and comprehensive studies indicate that there is ~5 times more warbler breeding habitat (~6,480 mi^2) and that there are ~19 times more warblers (263,339 males; 95% CI = 223,927–302,620) than assumed at the time of the emergency listing decision (Collier et al. 2012, Mathewson et al. 2012). Regardless of the actual warbler population size, it is clear that there are substantially more warblers than assumed at the time of listing (Mathewson et al. 2012), the available warbler breeding habitat is much more widely distributed than initially thought (Collier et al. 2012), and that breeding warblers inhabit a much wider range of habitat conditions than identified during early studies (e.g., Klassen et al. 2012). In addition, there is no genetic evidence that warblers have demographically self-sustaining populations, and thus, there is no basis for managing warblers as separate population entities across the recovery regions (Lindsay et al. 2008). Scientific studies also fail to support the notion that the spatial extent of wintering habitat is a limiting factor for this migratory species. Finally, maintaining warbler populations on public lands is certainly a part of warbler conservation. However, this criterion was developed under the assumption that there was limited warbler breeding habitat and that the remaining warbler breeding habitat was highly fragmented and separated by large distances, which recent studies no longer support. Long-term and comprehensive research conducted over the last 25 years offers a different perspective on the species, strongly warranting a re-examination of the warbler's federally endangered listing status by the USFWS.

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