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Special Section

Utilization of a Species Occupancy Model for Management and Conservation

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ABSTRACT Conserving habitat is increasingly challenging as human populations grow. Remote-sensing technology has provided a means to delineate species' habitat on large spatial scales. However, by combining habitat delineations with predictions of species' occurrence, habitat models can provide additional utility applications for conservation by allowing us to forecast how changing environmental and landscape conditions affect species' occurrence and distribution. We demonstrate how a spatially explicit habitat occupancy model for the golden-cheeked warbler (*Setophaga chrysoparia*) can be used as an impact assessment and conservation planning tool. We used predictions of patch-level occupancy rates and created several scenarios that simulated the removal or protection of warbler habitats. Resulting changes to habitat structure and availability were used to assess the resulting impacts of removal or protection on the occurrence probability for remaining habitat patches. By recalculating occupancy based on changes to habitat, our approach provides the ability to assess and compare impacts of location and orientation of development so that the least harmful option relative to predicted occurrence can be chosen. Potential applications of our modeling approach are many because our methods provide a useful tool for identifying potential impacts and assisting with mitigation efforts focused on the conservation and management of a species. © 2012 The Wildlife Society.

KEY WORDS conservation planning, golden-cheeked warbler, habitat, landscape management, mitigation, *Setophaga chrysoparia*, species distribution.

Implementation of successful management strategies require knowledge of animal distribution relative to environmental conditions and predictions of how animal populations will respond to direct and indirect environmental impacts (Kantrud and Stewart 1984, Wiens and Rotenberry 1985, Debinski and Brussard 1994, Colwell and Dodd 1995). Spatially explicit habitat models that predict the probability of species occurrence on broad spatial scales are useful tools for assessing potential impacts of land use or environmental changes, or for forecasting the outcome of management actions (Sagarin et al. 2006, Brotons et al. 2007). For species of conservation concern, the implications of habitat loss are often significant and loss can have long-term implications on population sustainability.

The golden-cheeked warbler (*Setophaga chrysoparia*; hereafter, "warbler") is a Neotropical migratory songbird that breeds exclusively in central Texas, USA, in mixed woodlands of mature Ashe juniper (*Juniperus ashei*), oak (*Quercus* spp.), and other deciduous species (Pulich 1976, Wahl et al. 1990). In 1990, the U.S. Fish and Wildlife Service (USFWS) listed the warbler as endangered, citing habitat loss and fragmentation as the primary threats to the species (USFWS 1990). Increasing infrastructure development (e.g., roads, utilities) within the warbler's limited breeding range creates networks of corridors that can deteriorate woodland habitat due to fragmentation (Peak 2007) and potentially inhibit exchange and dispersal of individuals between patches (Gobeil and Villard 2002, Goodwin and Fahrig 2002, Haynes and Cronin 2006, Richard and Armstrong 2010). However, the impacts of environmental or anthropogenic activities that could fragment potential habitat have typically been limited by our knowledge of the likelihood of warbler occurrence within those habitats. Any loss of habitat, either from natural phenomena (i.e., fire) or human activities, has the potential to impact the warbler due to the species' limited range.

Several warbler habitat classifications created in the past 20 years have provided estimates of range-wide habitat

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distribution (Wahl et al. 1990, Rowell et al. 1995, Rappole et al. 2003, DeBoer and Diamond 2006, Loomis-Austin, Inc. 2008) based on remotely sensed metrics and researcher-defined descriptions of warbler habitat. Several previous surveys also evaluated warbler occurrence and habitat associations, but these studies focused on a few public properties with known populations of warblers (Anders and Dearborn 2004, Peak 2007, Reidy et al. 2008), reducing the ability of the authors to extrapolate avian–habitat relationships across the breeding range. Two studies classified habitat quality across the range. DeBoer and Diamond (2006) used sample data from across the range to model habitat quality. However, their sample size was small ($n = 50$ patches), and several habitat metrics identified as relevant cannot be assessed remotely and, therefore, cannot be modeled or mapped at the range-wide scale. Diamond (2007) modeled habitat quality across the range, but estimates of quality were based on researchers' evaluation of quality, rather than using warbler occurrence data collected in the field to drive the development of a habitat model.

Here we demonstrate how a spatially explicit habitat model can be utilized as a tool for conservation planning and impact assessment. We used a patch-level habitat occupancy model for the warbler built on survey data collected on public and private properties across the warbler's breeding range in Texas (Collier et al. 2012). These patch occupancy predictions provided high accuracy in predicting warbler occurrence at the patch scale and were based on patch size and landscape composition (hereafter, "woodland composition") metrics combined with a north to south spatial gradient. Unlike previous models, which only delineate potential habitat, Collier et al. (2012) can categorize a habitat patch based on the probability of occupancy and, thus, can be used to predict the impacts of habitat loss or modification on warbler occupancy, rather than simply calculating the amount of habitat change. Herein, we illustrate the use of such a model by first showing the changes in predicted warbler occupancy based on simulated fragmentation or removal of habitat patches, and then showing how these effects can provide guidance for warbler conservation and management. Although we were able to sample across the entirety of the warbler's breeding range, occupancy models such as ours could also be developed for subsets of the range of most species.

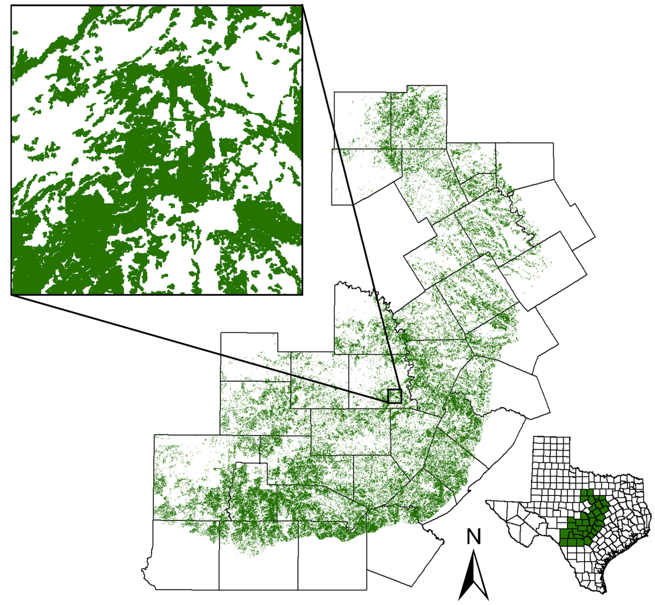

Figure 1. The 35-county breeding range of the golden-cheeked warbler (USFWS 1992) and the mixed-woodland habitat patches that create the potential habitat layer used in the model (Collier et al. 2012). Distinct patches of this cover type were used as the sample units.

METHODS

Occupancy Model

Collier et al. (2012) created a spatially explicit occupancy model for the warbler across its range in Texas. Collier et al. defined potential warbler habitat as mixed woodland patches delineated on 2007 and 2008 LANDSAT 5 imagery (Fig. 1; Collier et al. 2010). Collier et al. eliminated nonwoodland land-cover types (e.g., wetlands, cropland, urban areas, water) using the 2001 National Land Cover Data set (Homer et al. 2007), as well as pixels misclassified as woodland (canopy cover <30%). Collier et al. identified pixels that intersected paved or public roads using the Texas strategic mapping program, and removed those pixels from woodland classification, which defined breaks between some patches. As such, this delineation resulted in 63,616 distinct patches of potential habitat (mean patch size = 26.39 ha, range = 2.8–26,967 ha), equaling approximately 1.678 million ha, which were the sample units for the model (Fig. 1; Collier et al. 2010, 2012). Collier et al. used ArcGIS 9.3.1 to calculate patch size (ha) and woodland composition (percent of woodland within a 400-m radius of each pixel in the patch, averaged over the entire patch) for each patch of mixed woodland identified within the study area (modified from Magness et al. 2006). The model included these 2 metrics, plus an interaction between them, as well as spatial location (latitude and longitude) to assign an occurrence probability to each of the 63,616 patches of potential habitat. Predictions from Collier et al. (2012) can be visualized as a map depicting each habitat patch with an associated probability of occupancy, ranging from 0 to 1. We used these patch-specific estimates of warbler occurrence probability from Collier et al. (2012) as the foundation for our evaluation of natural and human-induced impacts on the golden-cheeked warbler across its breeding range in Texas.

Modeling Impacts

We used 2 hypothetical (Scenarios 1 and 2) and 2 real-life (Scenarios 3 and 4) scenarios of development activities and natural impacts to demonstrate the utility of the model for predicting impacts of habitat loss and fragmentation. Scenario 1 demonstrates how land managers can use the model predictions to determine where to protect warbler habitat. Scenario 2 details potential impacts on warbler habitat due to residential development outside of an urban area. Scenario 3 evaluates the impact of a large wildfire that occurred in April 2011 within the northern range of the warbler, while Scenario 4 demonstrates how model predictions can support selection of the best route for a power transmission corridor that minimizes impacts on habitat patches.

We used ArcGIS 9.3.1 to remove habitat from our delineation of habitat specific to Scenarios 2–4 and to evaluate the area of patches occurring within given boundaries. For Scenario 2, we deleted habitat patches that mimicked actual sizes and shapes of other developments in the region but do not represent actual locations of planned developments. For Scenarios 3 and 4 we obtained location information from an April 2011 wildfire and for a transmission corridor proposed by a utility company in Texas (Lower Colorado River Authority 2010). After removing habitat, we recalculated patch area and woodland composition for each scenario using the methods detailed in Collier et al. (2012). We then recalculated patch-specific occupancy probabilities for all patches using the new patch area and woodland composition values to evaluate the indirect impacts of habitat loss. We did not consider patch fragments ≤2 ha as potential habitat based on the approximate mean territory size of warblers (2.9 ha; Pulich 1976) and assigned them an occupancy probability of zero.

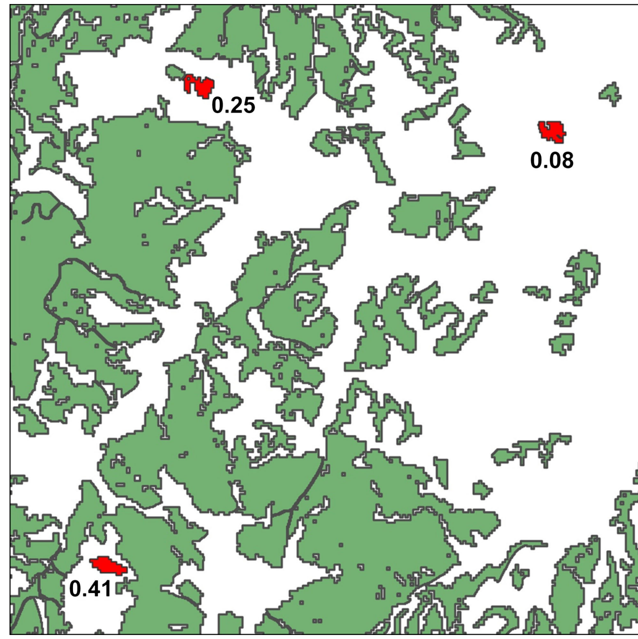

Figure 2. Predicted patch occupancy from Collier et al. (2012) for 3 patches of similar size (4.9–5.0 ha) and in the same geographic location (Kerr County, TX, USA), but with different landscape composition due to the proximity of other patches. Patches of the same size that are less isolated have a higher landscape composition and, therefore, a higher probability of occupancy.

MODEL UTILITY

Model Basics

The underlying occupancy model calculates predicted occupancy based on patch size, patch-specific woodland composition, and space; thus, some general trends in predicted patch occupancy emerged (Collier et al. 2012). First, as expected, larger patches generally have higher predicted occupancy rates than smaller patches. Second, because the model accounts for woodland composition, an increase or decrease in the amount of woodland in one habitat patch will affect the predicted occupancy of all other patches located within 400 m of the altered patch; therefore, patches that are more isolated from other patches of woodland habitat typically had lower occupancy rates (Fig. 2). Third, patch occupancy predictions and projections from Collier et al. (2012) incorporated spatial location across the range; thus, patches in the southern part of the range generally have higher occupancy probabilities than those in the north. Based on the characteristics included in the model, we can use the model to recalculate occupancy probability when habitat patches are lost or fragmented. Fragmentation of patches results not only in habitat loss (i.e., the habitat removed within the corridors that fragment the patch), but also reduces the size of patches and the woodland composition of surrounding patches, causing a decrease in probability of occupancy of the patch fragments (as illustrated below).

Scenarios

Scenario 1: Prioritizing regions for conservation.—Habitat delineation alone provides a minimal approach to determining levels of conservation importance among patches and properties because it ignores potential differences in occupancy probabilities among patches within property boundaries. Without assigning occupancy probabilities to habitat, a habitat distribution map would assume equal warbler occupancy to 2 properties (property A and B in Fig. 3a) that have approximately equal amounts of potential habitat (250.6 ha and 254.1 ha, respectively). Using the warbler occupancy model, property A has higher overall warbler occupancy probability, with 220.2 ha (88% of total

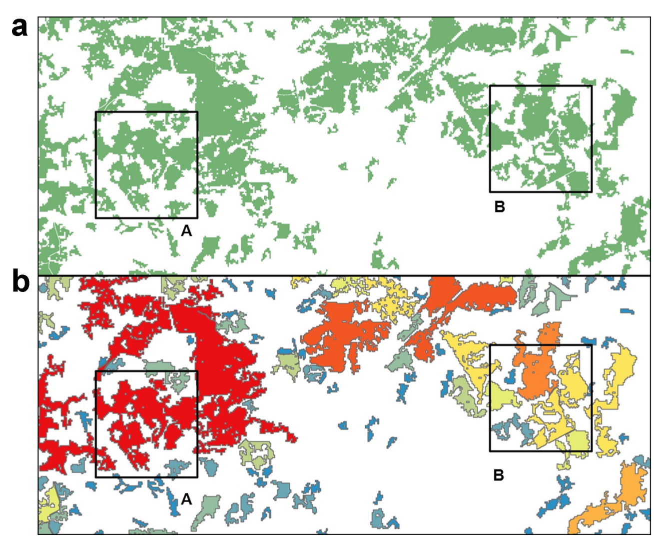

Figure 3. Demonstration of predicted occupancy wherein (a) 2 properties, A and B, contain approximately equal amount of potential golden-cheeked warbler habitat (250.6 ha and 254.1 ha, respectively) designated by green polygons, but (b) predicted patch occupancy from Collier et al. (2012) differed among patches in each property because of variation in patch-specific sizes and landscape composition. Warm colors in (b) represent higher predicted patch occupancy probabilities.

area) above 93% occupancy probability, than does property B (Fig. 3b). Property B only has 75.7 ha (30% of total area) above 70% probability of occupancy, and 176.8 ha above 50% probability of occupancy.

Scenario 2: Urban expansion.—Urban expansion is one of the major threats to woodland and, thus, warbler habitat (USFWS 1990); therefore, our next example evaluated impacts of potential urban development by simulating the fragmentation of a large habitat patch near San Antonio, Texas. We chose this patch due to its size, high occupancy probability, and relative proximity to a major city. We simulated removal of habitat by residential development by replicating the shape and size of neighborhoods, shopping centers, and connecting roads in the area and placing them over potential warbler habitat, delineated by our habitat classification. We determined the amount of habitat lost and the changes in probability of warbler occurrence using the occupancy model. Before the simulation, the total habitat within the patch was 5,104.8 ha with a predicted occupancy probability of 0.99 (Fig. 4). We simulated 1,093.2 ha of developed area, a 21.4% reduction in total habitat postdevelopment, which fragmented the original patch into 20 individual patches. The largest remaining patch was 1,139.6 ha and still had an occupancy probability of 0.97. Fifteen patches (1,095.1 ha) had an occupancy probability <0.9, of which 8 patches had an occupancy probability <0.8 (290.3 ha).

Scenario 3: Wildfire.—In April 2011, a major wildfire started west of Possum Kingdom Lake in Stephens County, Texas, and ultimately burned approximately 51,000 ha of land in Stephens, Palo Pinto, and Eastland counties (Fig. 5). Stephens and Palo Pinto counties comprise 2 of the 3 counties that make up the USFWS Recovery Region 1 for the warbler (Fig. 5). Because wildfires burn at different intensities across the burn area, we cannot assume all area within the fire scar was lost warbler habitat. However, we evaluated the impact of this fire on warbler habitat in terms of maximum potential habitat lost by running the simulation as if all habitat within the fire scar was lost, and addressing the potential effect on nearby patches and resulting patch fragments based on changes in probability of occupancy.

Prior to the wildfire, Recovery Region 1 contained approximately 114,550 ha of potential habitat, with 38,180 ha (33.3%) of the potential habitat having >50% probability of occupancy (Table 1). The fire caused a potential loss of 19,994 ha of habitat (17.5% of total habitat in the region); however, nearly 40% of the habitat with occupancy probability between 0.7 and 0.9 was potentially lost or affected by the fire. The region did not contain habitat with an occupancy probability >0.9 (Table 1).

Scenario 4: Transmission line corridor.—In September 2010, our habitat model (Collier et al. 2012) was used to assess the route of the Competitive Renewable Energy Zone (CREZ) transmission line from northern Schleicher County to the west side of Kendall County, Texas (Wilkins 2010, direct testimony, State Office of Administrative Hearings, SOAH Docket no. 473-10-5546, 28 Sep 2010, Austin, TX). We evaluated the impact of the planned 48.8-m-wide corridor transmission line and 2 proposed route alternatives, referred

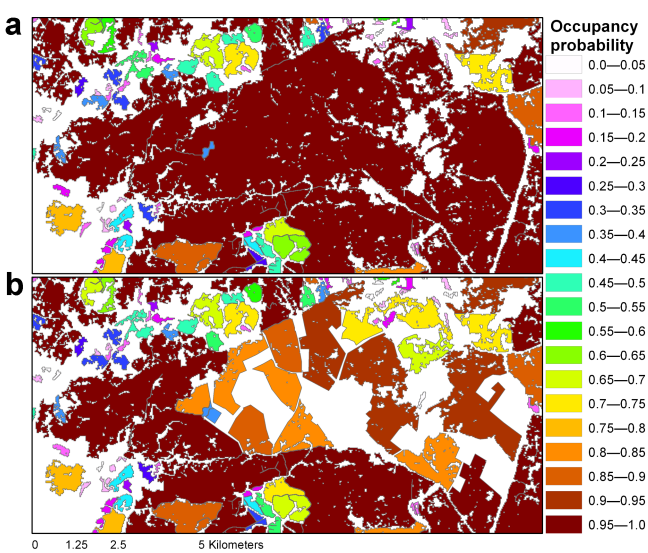

Figure 4. Demonstration of the effect of fragmentation of a patch of golden-cheeked warbler habitat. In this hypothetical example, we selected an area containing a large (5,129-ha) patch of potential habitat in Bexar County, Texas, USA (a), with a predicted probability of warbler occupancy of 0.99, based on the Collier et al. (2012) occupancy model. Warm colors represent higher predicted estimates of warbler occupancy and numbers are the patch-specific probability of occupancy. After 3,923 ha of potential habitat were removed from the area, the largest remaining patch was only 1,085 ha (b), but still had a 0.955 predicted occupancy. The other patches created had a predicted occupancy ranging from 0 (for the smallest patches) to 0.909.

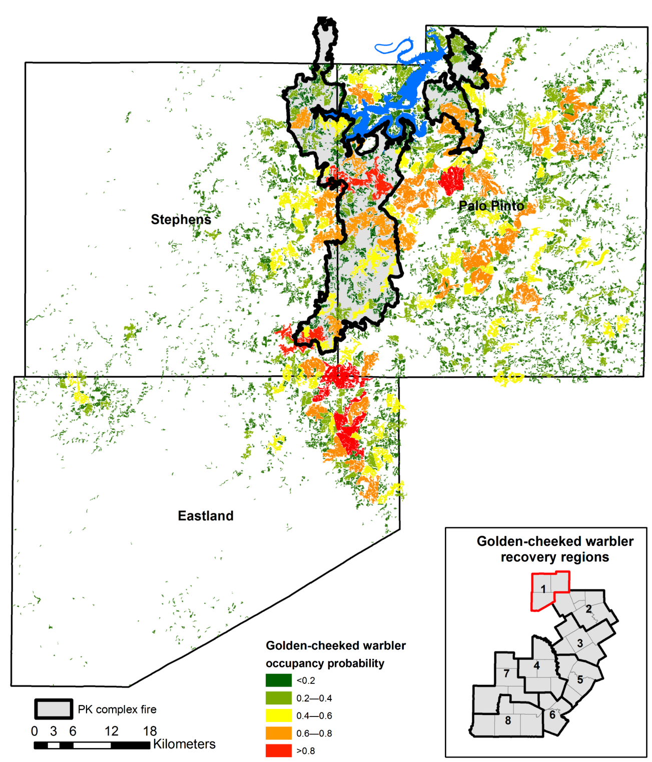

Figure 5. Extent and occupancy probability of golden-cheeked warbler habitat patches potentially impacted by the Possum Kingdom (PK), Stephens, Palo Pinto, and Eastland counties (TX, USA) complex fire in April 2011. The fire potentially eliminated 17.5% of the potential habitat available within Recovery Region 1.

Table 1. Summary of total golden-cheeked warbler habitat potentially lost within U.S. Fish and Wildlife Service Recovery Region 1 resulting from a wildfire in April 2011 west of Possum Kingdom Lake, Stephens County, Texas, USA. The amount of habitat falling within the fire scar accounted for 17.5% of the habitat in the region; however, nearly 40% of the habitat with occupancy probability >0.7 was potentially lost.

Occupancy probability	No. of patches		Sum (ha)		Change (ha)	Potential (% lost)
	Prefire	Postfire	Prefire	Postfire		
0.0–0.1	4,128	3,785	30,762.1	29,387.8	−1,374.3	4.5
0.1–0.2	264	207	13,515.5	11,143.6	−2,371.9	17.5
0.2–0.3	119	93	11,421.2	8,724.4	−2,696.8	23.6
0.3–0.4	62	52	9,411.3	7,754.8	−1,656.5	17.6
0.4–0.5	50	40	11,256.5	8,888.0	−2,368.4	21.0
0.5–0.6	19	19	6,423.9	6,437.8	13.9	−0.2
0.6–0.7	19	16	10,134.2	9,086.5	−1,047.6	10.3
0.7–0.8	17	11	13,605.7	8,227.5	−5,378.2	39.5
0.8–0.9	5	3	8,016.4	4,831.2	−3,185.2	39.7
0.9–1.0	0	0	0.0	0.0	0.0	n/a
Total	4,683	4,226	114,546.8	94,481.6	−20,065.0	17.5

to here as the northern route and southern route, with the intention of demonstrating which route option would have a lower impact on warbler habitat. The southern route follows Interstate 10 for much of its length while the northern route cuts a shorter, more direct path (Fig. 6). For this analysis, we removed all potential warbler habitat within the 48.8-m-wide transmission corridors for the length of both routes and calculated total habitat lost. Additionally, if patch fragments resulting from the development were ≤2 ha, we assumed that warblers would not occupy habitat patches of this size. Thus, we included the size of these patch fragments in the estimate of total habitat lost for each transmission line option. We then assessed the indirect impacts of the routes by recalculating patch occupancy probabilities for all patches that occurred within, or were intersected by, the transmission corridors.

The northern route traversed 18.5 km of potential habitat and would eliminate 87.5 ha. The southern route traversed 27.0 km of potential habitat with a total potential habitat loss of 125.1 ha. Fragments smaller than 2 ha accounted for 142 patches along the northern route, totaling 53 ha of potential habitat, and these <2-ha patches accounted for 176 patches along the southern route, totaling 54 ha of potential habitat. Combining these values with the amount of habitat that would be directly lost within the corridor meant that approximately 141 ha of potential habitat would be lost in the preferred route, and approximately 180 ha would be lost in the southern route, initially indicating that the preferred route would impact less of the warbler habitat.

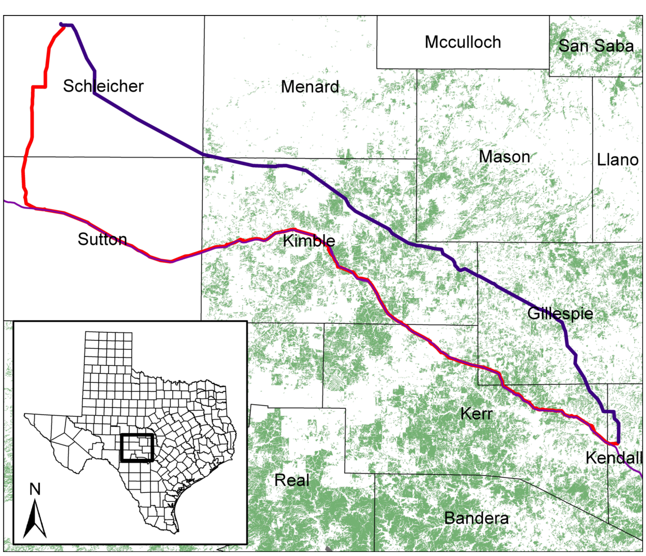

Figure 6. Two of many proposed routes for the CREZ transmission line from Schleicher County to Kendall County in central Texas, USA. The northern route is shown in blue and the southern route that parallels Interstate 10 for the majority of its length is shown in red.

Looking at only the patches that intersected each route, our assessment of habitat lost based on recalculated occupancy probabilities showed that habitat categorized as >0.9 occupancy probability was reduced by a greater amount in the northern route (487 ha) than the southern route (100 ha; Table 2; Fig. 7) due to a decrease in occupancy probability of the patches that remained after being fragmented by the corridors. However, the comparison changes depending on the occupancy probabilities of interest. For instance, the hectares lost in all probability categories >0.6 actually show a greater amount of loss in the southern route (385 ha) than the northern route (164 ha), but the hectares lost in probability categories >0.7 are approximately equal between the 2 routes.

DISCUSSION

Occupancy models allow land managers to identify not only the amount of habitat lost from proposed or actual activities or natural events, but also the probability that the habitat lost would be occupied by the species of interest. Further, the potential changes in probability of occupancy of nearby patches and any remaining fragments of patches can be calculated and mapped. As we demonstrated here using the golden-cheeked warbler, the ability to adapt the habitat model to realized and potential changes in habitat and then model the associated changes in occupancy probability within surrounding patches creates endless conservation applications. In our scenarios, we demonstrated how estimating only total habitat can result in misleading or incorrect conclusions regarding conservation value of different areas or assessment of fragmentation and other impacts on warbler habitat.

Table 2. Count of patches and total hectares within 10 golden-cheeked warbler occupancy probability classes both pre- and postimpact for 2 alternate Competitive Renewable Energy Zone routes in Texas, USA. Although the north route only directly eliminates 87.4 ha of habitat, 487.6 ha having a predicted occupancy >0.9 are either directly lost or result in a lowered predicted occupancy due to fragmentation. However, looking at the change in patches with occupancy probability >0.7, or even patches with occupancy probability >0.5, the 2 routes are similar.

	North					South				
	No. of patches		Sum (ha)			No. of patches		Sum (ha)		
Occupancy probability	Preimpact	Postimpact	Preimpact	Postimpact	Change (ha)	Preimpact	Postimpact	Preimpact	Postimpact	Change (ha)
<0.1	32	194	102.1	265.1	163.0	15	198	41.3	132.9	91.7
>0.1–0.2	23	22	178.5	166.1	−12.5	14	11	77.8	59.3	−18.5
>0.2–0.3	10	15	153.0	198.6	45.7	9	17	85.5	152.9	67.4
>0.3–0.4	9	8	183.0	164.4	−18.6	6	10	94.8	126.6	31.8
>0.4–0.5	7	7	210.8	157.9	−52.9	3	1	70.6	29.6	−41.1
>0.5–0.6	4	2	132.6	84.9	−47.7	2	6	50.2	179.4	129.2
>0.6–0.7	3	6	232.1	403.3	171.3	7	6	290.7	225.2	−65.5
>0.7–0.8	5	4	417.9	313.9	−104.0	3	1	158.3	47.9	−110.3
>0.8–0.9	5	5	828.6	1,084.5	255.9	8	7	773.2	663.7	−109.5
>0.9	4	3	1,578.2	1,090.6	−487.6	9	9	4,162.4	4,061.8	−100.6
Habitat removed (ha)					−87.4					−125.4

Additionally, assuming that the relationship between occurrence and density of warblers is similar to other species (Royle and Nichols 2003, Royle 2004), which is indicated by the findings of Mathewson et al. (2012), a decrease in predicted occupancy may have more impact than just a decrease in the probability that the patch will be occupied by a single bird. Implementation of the warbler occupancy model can guide land managers in selecting advantageous locations for conservation or management activities, evaluating least-cost configurations, locations, and pathways of developments or corridors, and assessing the impact of natural or human-induced habitat loss.

We presented a scenario in which assessments of occupancy probability can guide land managers in determining advantageous locations for conservation. In Scenario 1 we demonstrated how a planner or manager could determine where to prioritize conservation efforts. Without a calculated occupancy probability for each patch, the 2 areas in our scenario would appear to be of equal conservation importance; however, one property contained habitat patches with higher occupancy probability estimates. It is advantageous for land managers to seek optimal locations for conservation or habitat management practices. Many songbirds, including the golden-cheeked warbler, demonstrate high site fidelity on the breeding grounds in that breeding adults are more likely to return to areas or adjacent to areas that they breed at in previous years (Holmes and Sherry 1992, Jette et al. 1998). Furthermore, golden-cheeked warblers demonstrate conspecific attraction, wherein breeding birds use the presence of conspecifics to determine locations to settle for breeding (Campomizzi et al. 2008, Farrell 2011). These ecological phenomena of songbirds suggests that occupied areas are more likely to harbor birds in subsequent years; thus, conservation of habitat is likely more beneficial in areas with higher occupancy probabilities.

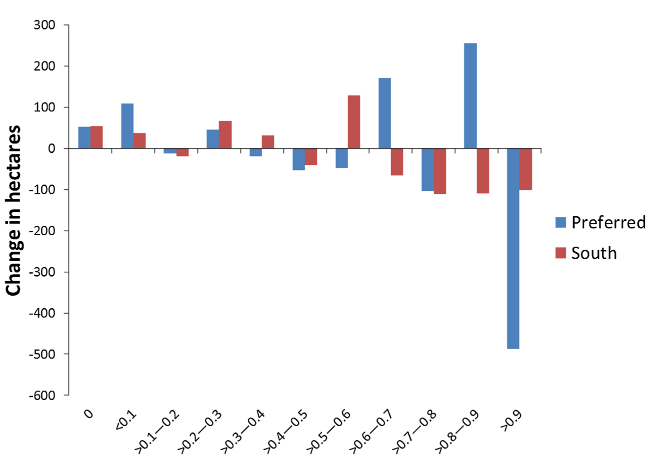

Figure 7. Change in hectares in each golden-cheeked warbler occupancy probability category for the preferred route and an alternate southern route in Texas, USA. More habitat is lost in the highest occupancy-probability category in the preferred route, indicating that the preferred route will have more of an impact on potential warbler habitat than the longer southern route.

We also demonstrated how the model can assess the impact of habitat loss and subsequent fragmentation of habitat, either after the loss of habitat has occurred (Scenario 3) or preemptively for proposed developments (Scenarios 2 and 4). In Scenario 3, we show that habitat loss due to a wildfire appeared to eliminate only 17.5% of the available habitat in Recovery Region 1, but it potentially eliminated nearly 40% of the habitat with a probability of occupancy >0.7. Therefore, the impact of this fire on the region may have a great impact on the recovery of the species, especially because recovery of the species defined by USFWS is dependent upon recovery in all individual recovery regions.

In Scenario 2, we demonstrate how fragmentation of a large patch can reduce the occupancy probabilities of resulting patch fragments. Although fragmentation of habitat is seldom desirable for the warbler, fragmentation of large patches may not always decrease the occupancy probability of resulting patches. For instance, if habitat fragmentation occurs in a large area of habitat and results in large patch fragments (≥160 ha), the predicted occupancies of the new patches may not decrease significantly from the original occupancy value, supporting the idea of a patch-size threshold (Butcher et al. 2010, Collier et al. 2010). We demonstrated this in

Scenario 2, wherein the predicted patch occupancy of the largest patch was not significantly reduced even though considerable habitat was removed. Although complete conservation of the largest patches may often be unreasonable due to financial, social, and logistical limitations, our findings suggest that the conservation of suitably sized and strategically placed patches may be more efficient for maintaining viable habitat (Zuidema et al. 1996).

In Scenario 4, the proposed CREZ routes illustrate how including information on occupancy probabilities when prioritizing location options for development provides greater insight into impacts to warbler habitat beyond simple calculations of the total amount of habitat that is removed for development. Based only on total habitat area, the northern route for the CREZ line would remove less total habitat than the southern route; however, total habitat area fails to account for differences in the sizes and distribution of habitat patches. In our example, the southern route followed the existing interstate corridor and habitat along this route was already fragmented into smaller sized patches, resulting in lower occupancy probabilities of these patches. Although more total habitat would be lost along the southern route, less high-occupancy habitat (>0.9) would be removed compared to habitat along the northern route. The northern route would bisect multiple large and contiguous patches of warbler habitat, increasing fragmentation of these patches and removing more high-occupancy habitat patches. However, both routes eliminated approximately the same amount of habitat with an occupancy probability >0.7. This exercise demonstrated the fallacy of evaluating impacts on habitat when considering only total habitat loss estimations. Similarly, the model could be used for assessing impacts of development of residential neighborhoods, shopping centers, infrastructure like roads and transmission lines, clearing for ranching, or natural disasters in which habitat would be lost.

Two main trends resulting from our model are demonstrated by our scenarios. First, concurring with previous work (Coldren 1998, DeBoer and Diamond 2006, Baccus et al. 2007, Butcher et al. 2010), our model showed the importance of large patches for maintaining high rates of warbler occupancy. Large patches harbor more potential habitat and also tend to have a higher predicted occupancy. Thus, there is less impact on predicted occupancy when habitat is removed along the edges of patches as opposed to bisecting patches. Second, the model showed that isolated patches had a lower probability of occupancy, indicating the importance of maintaining connectivity of habitat (through close proximity of patches) across the landscape, particularly in areas where habitat patches are small.

Although we were able to calculate changes in predicted occupancy on any spatial scale, as currently formulated, our model is most appropriately applied to broader spatial extents (e.g., network of patches) as opposed to a patch-by-patch or within-patch basis, and for determining the potential change in habitat area and occupancy between multiple management scenarios. As for any model, however, additional field sampling will allow for improvements in the underlying data base, as will field testing to continually improve model predictions, especially as applied to increasingly smaller spatial extents (Vaughan and Ormerod 2003).

Given the availability of 1) a range-wide map of a species' habitat, 2) remotely sensed, species-relevant habitat data, and 3) occupancy data from randomly sampled units across the habitat, our modeling technique can be applied to any species. Unlike static habitat maps, models like these have the dynamic ability to project the probability of occupancy throughout the range and also adapt to changes in the habitat. The dynamic nature of these models provides numerous applications for conservation of habitat and assessment of actual or potential impacts.

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