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Identifying western yellow-billed cuckoo breeding habitat with a dual modelling approach

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ABSTRACT

The western population of the yellow-billed cuckoo (*Coccyzus americanus*) was recently listed as threatened under the federal Endangered Species Act. Yellow-billed cuckoo conservation efforts require the identification of features and area requirements associated with high quality, riparian forest habitat at spatial scales that range from nest microhabitat to landscape, as well as lower-suitability areas that can be enhanced or restored. Spatially explicit models inform conservation efforts by increasing ecological understanding of a target species, especially at landscape scales. Previous yellow-billed cuckoo modelling efforts derived plant-community maps from aerial photography, an expensive and oftentimes inconsistent approach. Satellite models can remotely map vegetation features (e.g., vegetation density, heterogeneity in vegetation density or structure) across large areas with near perfect repeatability, but they usually cannot identify plant communities. We used aerial photos and satellite imagery, and a hierarchical spatial scale approach, to identify yellow-billed cuckoo breeding habitat along the Lower Colorado River and its tributaries. Aerial-photo and satellite models identified several key features associated with yellow-billed cuckoo breeding locations: (1) a 4.5 ha core area of dense cottonwood-willow vegetation, (2) a large native, heterogeneously dense forest (72 ha) around the core area, and (3) moderately rough topography. The odds of yellow-billed cuckoo occurrence decreased rapidly as the amount of tamarisk cover increased or when cottonwood-willow vegetation was limited. We achieved model accuracies of 75–80% in the project area the following year after updating the imagery and location data. The two model types had very similar probability maps, largely predicting the same areas as high quality habitat. While each model provided unique information, a dual-modelling approach provided a more complete picture of yellow-billed cuckoo habitat requirements and will be useful for management and conservation activities.

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1. Introduction

The western population of the yellow-billed cuckoo (*Coccyzus americanus*) (hereafter "cuckoo") is a species of conservation concern and was recently listed as threatened under the federal Endangered Species Act (U.S. Fish and Wildlife Service (USFWS), 2014). The cuckoo is a Neotropical migrant that breeds in the western portions of the United States, Canada, and Mexico, where it nests in low to moderate elevation (328–6,902 ft; 100–2,104 m) riparian woodlands (Hughes, 1999). The riparian habitats upon which they depend are dynamic and can undergo repeated cycles of establishment, growth, and destruction (Paxton et al., 2007). Anthropogenic alterations of watersheds and riparian systems are degrading and destroying its habitat range-wide, while habitat fragmentation results in small isolated populations of cuckoos that contribute to its vulnerability. The cuckoo is included in several habitat conservation plans, including the Lower Colorado River Multi-Species Conservation Program's (LCR MSCP, 2004), which

Abbreviations: BWR, Bill Williams River; LCR, Lower Colorado River; LCR MSCP, Lower Colorado River Multi-Species Conservation Program; NDVI, Normalized Difference Vegetation Index; SD, standard deviation; SDM, species distribution model; TRI, terrain ruggedness index; USFWS, U.S. Fish and Wildlife Service.

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aims to minimize and mitigate the effects of projects or actions on cuckoos.

Conservation of the cuckoo requires detailed information about its breeding habitat requirements at multiple spatial scales. Currently, most information indicates the importance of specific, finite, patch-level vegetation-community composition and structure, generally consisting of multi-structured or multi-layered riparian vegetation with substantial canopy cover provided by native riparian trees, particularly willows (*Salix* spp.) and cottonwoods (*Populus* spp.; Corman and Wise-Gervais, 2005; Girvetz and Greco, 2009; Johnson et al., 2010). There is evidence that consideration of patch-level habitat variables alone does not adequately describe cuckoo breeding habitat nor the potential effects of landscape-level habitat characteristics and processes (Girvetz and Greco, 2009; Greco, 2013; Johnson, 2009). Habitat features such as vegetation communities boundaries, patch size, patch shape, patch fragmentation and patch connectivity can have different influences when measured at different scales (Bissonnette, 1997; Givetz and Greco, 2009).

Understanding the spatial scales at which organisms respond to environmental factors and processes is especially essential for sustaining species of conservation concern and threatened habitats. Recognizing the need for assessing species' habitat needs at multiple spatial scales, in conjunction with the availability of remotely sensed measures of vegetation and landscape composition, has prompted ecologists to model habitat associations with hierarchical approaches that incorporate predictor variables measured at multiple spatial scales (Girvetz and Greco, 2009; Meyer and Thuiller, 2006; Saab, 1999; Scott et al., 2002; Wiens 1989). These approaches often combine variables of vegetation structure or composition that are measured at a relatively fine scale (e.g. <1 ha), and landscape variables (e.g. percent cover within a given area or patch configuration) measured at considerably broader spatial scales (e.g. entire watershed; Meyer and Thuiller, 2006). Comparing the relative strength of predictor variables measured at different spatial scales may be one tool for understanding the appropriate scale of measurement (Holland et al., 2004) and, ultimately, management actions. Through the identification of habitat features at multiple spatial scales, spatially explicit models increase our ecological understanding of a target species while providing site-specific habitat maps (Hatten and Paradzick, 2003; Paxton et al., 2007).

Previous efforts to spatially model cuckoo habitat used maps of vegetation communities obtained from orthorectified aerial photography (hereafter "aerial-photo models"). While aerial-photo models are comparatively easy to interpret, they are expensive to obtain and difficult to accurately reproduce due to classification errors, subjectivity, and the lack of standardized methods (Cherrill and McClean, 1995; Hearn et al., 2011). In contrast, vegetation maps created from Landsat imagery (hereafter "satellite models") can characterize vegetation features across broad areas with the normalized difference vegetation index [NDVI] with near perfect repeatability (Hatten et al., 2010). However, satellite models usually lack the ability to identify specific plant communities and can be difficult to translate into target habitat conditions for conservation purposes (Paxton et al., 2007). Thus, the goal of the project is an important consideration when selecting imagery for classification purposes. When projecting habitat models across very large geographic areas, Landsat imagery is ideal (Hatten, 2016); when classifying vegetation at species or community levels, higher resolution imagery is preferred (Carter et al., 2009; Xun and Wang, 2015).

The goal of our study was to characterize and map cuckoo breeding habitat along the Lower Colorado River (LCR) with a dual modelling approach, at multiple spatial scales. We used aerial-photo and satellite models to accomplish five objectives; (1) identify factors associated with high-quality habitat, (2) develop species distribution models, (3) map habitat quality throughout the study area, (4) identify areas where habitat restoration will be most effective, and (5) increase our understanding of cuckoo breeding habitat by comparing and contrasting the two modelling techniques. To facilitate the modelling process, we developed a conceptual model of cuckoo breeding habitat that identified habitat features hypothesized to be important (Fig. 1). Specifically, we hypothesized that cuckoo habitat selection is influenced by riparian patch size and fragmentation, vegetation density and structure, and plant community and patch location in relation to land cover (e.g. agriculture, urban development, surface water).

2. Materials and methods

2.1. Study area

The study area consists of riparian habitats within the LCR MSCP boundaries, which we refer to as the LCR. It includes areas up to and including the full-pool elevations of Lake Mead, Lake Mohave, Lake Havasu, and the historical floodplain of the Colorado River from Lake Mead to the United States–Mexico Southerly International Boundary, a distance of about 644 river km (400 mi; Fig. 2). Yellow-billed cuckoos were once considered abundant throughout the study area's riparian floodplain (Grinnell and Miller, 1944; Stephens, 1903), when the Colorado River flowed unimpeded and was a highly dynamic system. Since the late 1800s, the riparian ecosystem of the LCR has undergone dramatic changes. Dam construction and irrigation practices between 1909 and 1966 inundated floodplains and altered hydrology, resulting in destruction and modification of native riparian woodland. Dams also enabled the conversion of floodplains to agricultural uses and dam operations contributed to the replacement of native riparian vegetation with non-native plants, most notably tamarisk (*Tamarix* spp.; Ohmart et al., 1988; Rosenberg et al., 1991; Shafroth et al., 2002).

The LCR in Arizona and California supported an estimated 180–240 yellow-billed cuckoo pairs in 1976–77, a number that declined by an estimated 80–93% by 1986 (Laymon and Halterman, 1987a; Rosenberg et al., 1991). In 1998, no cuckoos were found in California on the southwestern portion of the study area in sites that were occupied in 1976–77 (Halterman, 1998). Declines in cuckoo abundance coincided with habitat loss due to high water levels and inundation of long duration in 1983–84, and 1986 (Laymon and Halterman, 1987b; Ohmart et al., 1988; Rosenberg et al., 1991).

The Bill Williams River (BWR) is a tributary of the Colorado River, and due to water releases from Alamo Dam ~60 km upstream of its confluence with the Colorado River, the BWR has had the most continuous, native-dominated riparian habitat along the LCR. Since the 1960s, the largest known population of cuckoos has been in the BWR and our surveys confirmed that it continued to support the largest cuckoo population in the LCR (Johnson et al., 2007, 2008; Rosenberg et al., 1991). More recently, surveys have shown that cuckoos continue to be more abundant in the native-dominated habitat of the BWR, in addition to LCR MSCP restoration habitat (McNeil et al., 2013).

2.2. Modelling overview

The major difference between the satellite and aerial-photo models was resolution – the satellite model used Landsat Thematic Mapper (TM) imagery, which has 30×30 m pixel-to-ground resolution, while the aerial-photo model used imagery with a 3×3 m pixel-to-ground resolution, to create land cover maps. We used Landsat TM imagery to provide coarse-scale information about riparian vegetation features such as structure, lushness, and spatial arrangement (Hatten et al., 2010). In contrast, we used higher res-

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