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# Status of the Yellow-billed Cuckoo along the Sacramento River in 2010

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## EXECUTIVE SUMMARY

The Yellow-billed Cuckoo is a state endangered species in California with breeding populations along the Sacramento River, Kern River, and Lower Colorado River. In 2010, from mid June until mid August, we conducted an extensive survey of the riparian habitat preferred by the cuckoo along the Sacramento River from Red Bluff to Colusa. We located 18 individual cuckoos using call playback surveys, spanning the entire study region. We performed an occupancy analysis using a range of territory sizes (15-75 ha) because territory size is not known for this population. Occupancy estimates predict that approximately 38 territories were occupied, depending on the size of territories. A population estimate derived from the occupancy estimate would be 38-76 cuckoos since each territory could be occupied by an individual or a pair. We did not find any significant relationships between cuckoo presence and various vegetation structure and composition measures. We believe that the Yellow-billed Cuckoo population has declined in the Sacramento Valley since the last survey during 2000, which is a cause for conservation concern for this important breeding area. Restoration of riparian habitat and further monitoring and research are needed to assist the recovery of the Sacramento Valley breeding population.

## INTRODUCTION

The western population of the Yellow-billed Cuckoo (*Coccyzus americanus*) in the United States is distinguished by its affinity for riparian habitat during the breeding season (Hughes 1999). Loss of riparian forests due to changing land use and alterations of river flow regime in the last 150 years have drastically reduced the amount of riparian forest in the landscape and hence the available breeding habitat for this neotropical migrant (Laymon and Halterman 1987). As a riparian obligate, the range of the species in the west has been severely restricted to remaining isolated riparian forest fragments. The western population of cuckoos once ranged from northern Mexico to the Canadian border, however now they only breed in significant numbers in California, Arizona, New Mexico and Texas (Gaines and Laymon 1984, Laymon and Halterman 1989, Hughes 1999). The species was listed as state endangered in California in 1988. The USFWS has designated the western population as a distinct population segment (DPS), which is a candidate for federal listing (US Fish and Wildlife Service 2001).

In California, the breeding range of the Yellow-billed Cuckoo once extended from the Mexican border, along the southern coast, and through the entire Central Valley (Grinnell and Miller 1944). They are now generally restricted to the Sacramento Valley, the Kern River, and the lower Colorado River with individuals occasionally reported in other areas (Laymon and Halterman 1987). The Sacramento Valley is believed to be a major population center for the species (Halterman et al. 2001). The Sacramento River also represents an area where cuckoo habitat potentially has increased. From 1996-2006 over 2000 ha of riparian was restored along the Sacramento River (Golet et al. 2008).

These restoration efforts represent new habitat that is potentially suitable for cuckoos and which did not exist, or was not mature enough for occupancy, during the last major survey effort in 2000.

Major survey efforts along the Sacramento River were conducted in 1972-73 (Gaines 1974, Gaines and Laymon 1984), 1977 (Gaines and Laymon 1984), 1987-90 (Laymon and Halterman 1989, Halterman 1991), and 1999-2000 (Halterman et al 2001). These surveys were done by foot and canoe, visiting suitable habitat patches, with each study varying in extent along the Red Bluff to Colusa stretch of the river. Focused cuckoo surveys were undertaken in 1998 (Greco 1999, Girvetz and Greco 2009), 2007 and 2008 (Hammond personal communication) along limited sections of the Sacramento River. The more focused surveys added to our knowledge of cuckoo habitat preferences and established that cuckoos will use restored habitat that was 4 years old (Hammond personal communication). These latter efforts were not aimed at estimating cuckoo population size.

The cuckoo's elusive nature requires broadcasting a recording of its call to illicit a playback response. Methods that rely on passively detecting individuals, such as point counts, do not adequately survey for cuckoos. For example, in 5551 individual sampling events during point count surveys conducted by PRBO from 1993 through 2004 in the Sacramento Valley without call playback, there were only 8 cuckoo detections. Call-playback surveys increase the probability of detecting cuckoos relative to unsolicited calls (Halterman 2009). The interpretation of cuckoo responses to playback surveys has changed over time. Prior to 2003 it was thought that sex and pairing status could be discerned by the type of call, but telemetry studies found that interpretation to be incorrect (Halterman 2009). Differences in the interpretation of older cuckoo surveys make multi-year comparisons challenging.

In 2010, we undertook a comprehensive survey of Yellow-billed Cuckoos in the riparian habitat along the Sacramento River. The objectives of the survey were, 1) to survey all riparian areas for the presence of Yellow-billed Cuckoos using the latest survey methods, 2) to estimate the size of the Sacramento River population, 3) to document nests of breeding cuckoos, 4) to identify habitat characteristics associated with breeding cuckoos, and 5) to compare our results to previous surveys of the river.

# METHODS

## Study Region

We defined the "study region" as the area along the Sacramento River between Red Bluff and Colusa (104 river miles) that was within 2 km of the main stem of the river (Figure 1). Our study region is the core of the cuckoo breeding range in the Sacramento Valley, as shown by the most recent large scale survey (Halterman et al. 2001). This section of the river passes through Tehama, Butte, Glenn, and Colusa counties from north to south. State Highway 32, which crosses the river at Hamilton City, roughly divides the study region in half. The habitat along the river consists of riparian scrub and riparian forest patches surrounded by an agricultural matrix. Other habitats include gravel bars, grasslands, and wetlands. Riparian forests in this region range from low willow (*Salix* sp.) dominated to tall Fremont cottonwood (*Populus fremontii*) dominated (all plant scientific names from USDA Plants Database, http://plants.usda.gov). California black walnut (*Juglans californica*), valley oak (*Quercus lobata*), California sycamore (*Platanus racemosa*), and boxelder (*Acer negundo*) are also present. The riparian forest understory varies from grass dominated to a well developed shrub layer. Riparian scrub consists of small trees (< 5m) and shrubs, with similar species composition as the riparian forest. In many cases, riparian scrub exists as part of the early successional stages of forest development. Restoration efforts in the region have resulted in an increase in the extent of riparian forest of different ages (Golet et al. 2008).

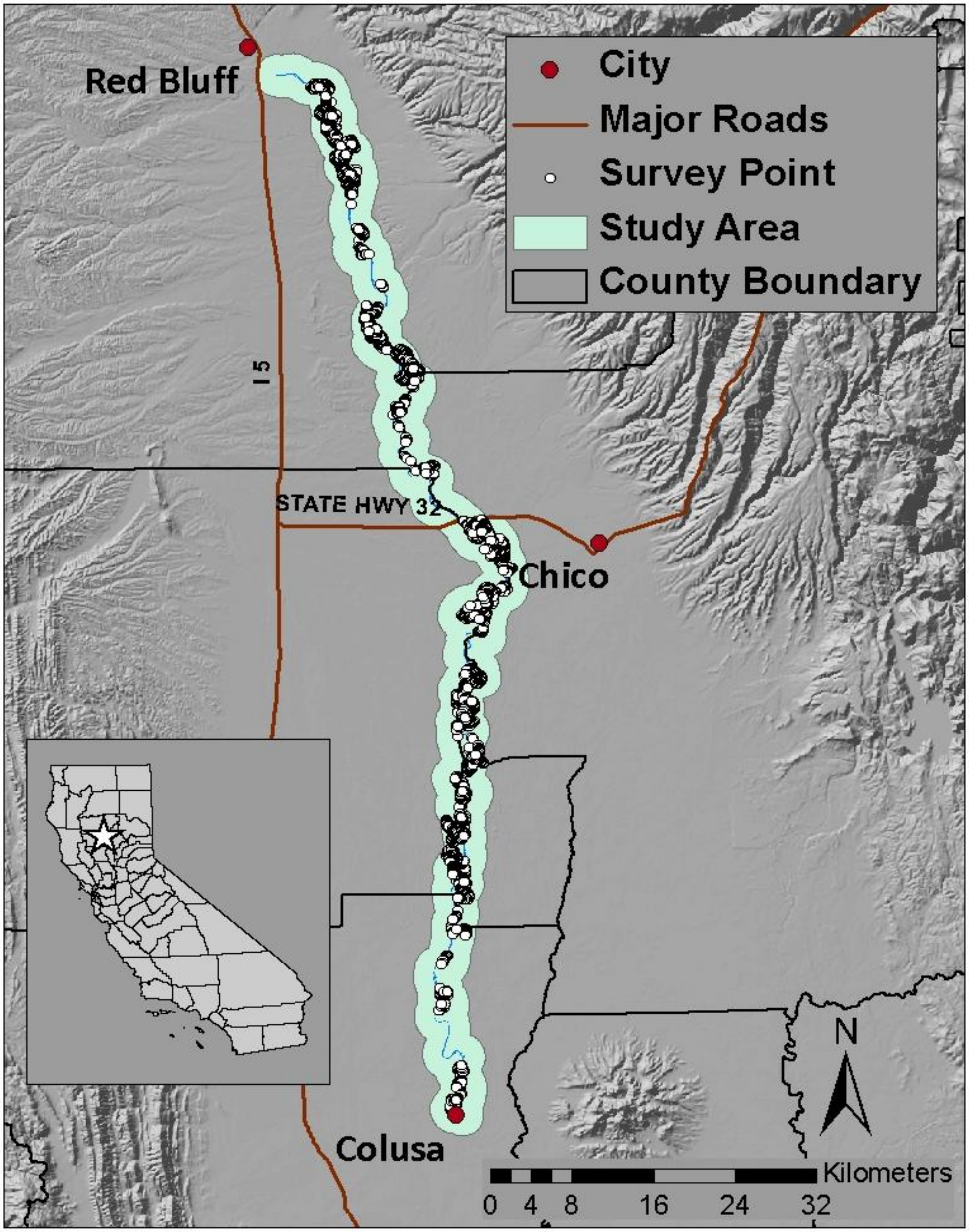


Figure 1. Map of study region, Sacramento Valley, California, including 2010 Yellow-billed Cuckoo survey points.

## Survey Sites

We selected survey sites (management units or isolated habitat patches) within the study region that met our criteria for potentially suitable cuckoo habitat using a combination of satellite imagery, aerial photos (flown in 2007), GIS analyses, and ground-truthing visits. We surveyed restored and remnant riparian forest. We considered mature riparian habitat to be suitable to cuckoos based on previous studies in the Sacramento Valley (Girvetz and Greco 2009), and in other regions. In remnant forests, we selected riparian areas with tall trees (> 4 m). If trees were 3-4 m tall and adjacent (within 50 m) to tall trees, we also included those in the survey. We surveyed restored areas if they were over 4 years old and if they had developed a canopy layer at least 4 m tall. Gravel bars, grasslands, and riparian areas with widely spaced trees (>50 m apart) were not included in the survey. Isolated, narrow stringers of riparian habitat less than 30 m wide also were not surveyed.

Survey routes, a series of survey points that can all be visited in one morning, were established within each survey site. In cases where the riparian habitat was narrow (less than 200 m wide) or the density of the understory plants prevented timely navigation, survey routes were established along the perimeter of the habitat. We prioritized surveying suitable habitat on public lands, but we also surveyed private lands that were immediately adjacent to the river. Areas only accessible from the river were surveyed from a boat or the riverbank. Where safe landing was possible, we surveyed the habitat along the high water line. For boat surveys we secured the boat and silenced the motor in order to conduct the survey.

## Playback Surveys

The call-playback survey method we used is specific to Yellow-billed Cuckoos and was developed and refined over the past decade (Halterman et al. 2001, Johnson et al. 2006, McNeil et al. 2010). The method was adopted by the Western Yellow-billed Cuckoo Working Group to facilitate compilation and comparison of data from the entire range.

Surveys began at sunrise and concluded by noon or when weather conditions (i.e. wind, rain, heat) decreased detectability. At a survey point, the surveyor first paused for one minute to listen for any spontaneously calling cuckoos and to record the GPS coordinates onto a standardized data form. Next, the recording was broadcast 5 times using a portable speaker, each call separated by one minute of silence. The recording is of a single cuckoo, from the Kern River, CA population (provided by Halterman), giving several "kuk" notes followed by several "kowlp" notes. If no cuckoos were detected, the surveyor moved 100 m and repeated the playback protocol. Surveys were done every 100 m in part because cuckoos can have a large territory and may not be detected in the portion of the territory in which the surveyor was conducting the playback. Additionally, 100-150 m may be the distance in which the surveyor is able to hear and detect the call of the cuckoo (Halterman 2009). Due to time constraints and safety, survey points were approximately 150-200 m apart when conducted from the boat. The increased distance among survey points conducted from the boat does not affect the detectability of cuckoos, but may reduce the amount of area surveyed. If a cuckoo was detected, the playback ceased and the relative location (distance and bearing) and behavioral notes (type of response, type of call, nesting activity) were recorded. Following a detection, the surveyor moved 300 m along the route before the call-playback was resumed to avoid detecting the same individual.

We attempted to survey each site four times during the breeding season (mid-June to late August). The first round was from June 14-29, the second round from June 30-July 15, the third round from July 15-29, and the fourth round from July 31-August 17. At least 12, but no more than 20 days, separated successive rounds for any single transect.

Our aim was to locate and visually observe all the cuckoos we detected with special attention to activity that indicated breeding (copulation, carrying nest material or food). Surveyors were instructed to spend time observing birds and looking for nests. Cuckoos are sensitive to disturbance around their nests (Halterman personal communication), so all attempts were made to minimize impacts (Martin and Geupel 1993) which included not lingering for excessive periods of time.

## Occupancy Analysis

Surveys used to quantify the abundance or population of a species traditionally regarded the actual count as the population size estimate. However, if the probability of detection for a species is less than certain ($p < 1.00$) that approach can underestimate population size because sites that contained the species, but in which no detections were made, are not accounted for (MacKenzie et al. 2005). This problem is especially relevant to population analyses of rare and elusive species (MacKenzie et al. 2005).

We used the occupancy modeling methods outlined by MacKenzie et al. (2005) and the program PRESENCE (Hines 2006) to estimate occupancy for Yellow-billed Cuckoos along the Sacramento River. Using presence and absence data collected during the repeated visits to an area, we can estimate the probability of detection and the proportion of areas occupied. We calculated occupancy estimates both by holding the probability of detection constant, as well as allowing it to vary among survey rounds.

In order to calculate occupancy we had to define the size of the "area" in which we were calculating occupancy. Ideally, the "area" used in cuckoo occupancy analyses would correspond to the size of a cuckoo territory. Although the protocol calls for surveying cuckoos every 100 m, it is thought that the size of a cuckoo territory is larger than a 100 m radius circle (3.1 ha). On the Kern River, Henneman (2009) defined the area of a cuckoo territory as a 300m radius circle (28.3 ha) in occupancy analyses based on nest searching efforts and local knowledge of the birds during that season. On the Middle Rio Grande in New Mexico, Johanson et al. (2007) selected a 500 m radius circle (78.5 ha) for cuckoo territories based on detection clumping patterns and local knowledge of the birds that year.

In a telemetry study along the San Pedro River, Arizona, Halterman (2009) found that home ranges during the breeding season varied by pairing status, sex, and the presence of a nest for 23 radio-tagged cuckoos. Using 95% kernel density estimates, the average home range varied from 15.8 ha (n=7 females) to 54.8 ha (n=7 unmated individuals) with an overall average of 38.6 ha (n=23). Because territory size in the Sacramento region is unknown, home range varied widely in the Arizona telemetry study (Halterman 2009), and the lack of consensus among studies using occupancy analyses (e.g. Henneman 2009 and McNeil et al. 2010), or other approaches (Johanson et al. 2007), we selected a range of potential territory sizes varying from 15 to 75 ha. These areas correspond to a circular territory with radius varying from 218-489 m. We calculated occupancy estimates for this range of territory sizes.

## GIS Analysis

We used ArcGIS 9.2 (ESRI 2006) to quantify the amount of habitat surveyed in 2010. We buffered survey points by 150 m which is a conservative estimate of the distance that the playback survey would elicit a response from a cuckoo. The multiple circles from the buffer were dissolved using GIS to form non-overlapping polygons. We then used GIS to remove any area of the polygon that overlapped with the main river channel. We consider the total area of the polygons minus any area that overlapped with open water to be the total area that we surveyed; this area equaled 5560 ha. We then used GIS to determine how many territories would fit into that area using the range of territory sizes of 15-75 ha. Occupancy estimates were calculated for each of the five territory sizes.

We also used data on land ownership and riparian restoration status (provided by The Nature Conservancy) and data on riparian habitat types (Geographical Information Center, California State University, Chico) to assess the amount and extent of riparian forest. The area of publicly and privately owned land was determined. The amount of riparian habitat within each of the landowner categories was also determined. We included the following vegetation categories in our riparian habitat assessment: black walnut (*Juglans californica),* boxelder (*Acer negundo*), California sycamore (*Platanus racemosa*), Fremont cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), mixed willow (*Salix* sp.), riparian scrub, and valley oak (*Quercus lobata*).

## Vegetation Features

To measure the vegetation characteristics of the survey routes we stopped every 300 m along the survey route and established the center of the vegetation plot within riparian habitat at a randomly chosen distance (between 12-50 m) perpendicular to the survey route. We also measured vegetation features at every point where a cuckoo was detected. The surveyor would go to the detection survey point, then follow the bearing and distance estimate to the location where the cuckoo was heard or seen, and then conduct the vegetation survey. We created an 11.3 m radius plot to measure tree related characteristics and a 5 m radius plot to measure characteristics of small trees and cover below 1.4 m. In cases where we could not directly survey the vegetation (e.g. boat surveys, extremely thick vegetation), we estimated as many vegetation characteristics as possible.

The height of the canopy, four convex spherical densiometer readings, and the tree species present along with the percent cover in each of four height categories (1.4-5 m, 5-15 m, 15-30 m, and greater than 30 m) were recorded within an 11.3 m radius plot. The number of trees within each of four DBH (diameter at breast height = 1.4 m) categories (0-<8 cm, 8-<23 cm, 23-38 cm, and greater than 38 cm) were counted. Proportions were also recorded for the amount and type of vegetative cover below 1.4 m. We determined if these vegetation variables were significant predictors of cuckoo presence by examining the slopes of individual variables in a logistic regression analysis.

## RESULTS

### Survey Sites

We selected 48 sites covered by a total of 68 survey routes, which were surveyed from June 14 through August 17, 2010 (Appendix 1). Several large sites required multiple routes to adequately cover the habitat. Four routes were surveyed by boat. There were 1400, 1559, 1525, and 1498 call points respectively for survey rounds one through four. Fewer points were surveyed during the first round because mechanical problems with the boat prevented us from accessing a few routes.

### Playback Surveys

A total of 24 Yellow-billed Cuckoo detections were made during the 2010 breeding season (Table 3, Figure 2), with the majority occurring in the second and third survey rounds (Table 1). Cuckoos were detected north (8 detections) and south (16 detections) of State Highway 32, which roughly divides the study region in half. The great majority of detections were the direct result of the call-playback, with only three resulting from the detection of a spontaneous call. Of the 24 detections, 17 were by call only, 6 were by call and visual, and one was visual.

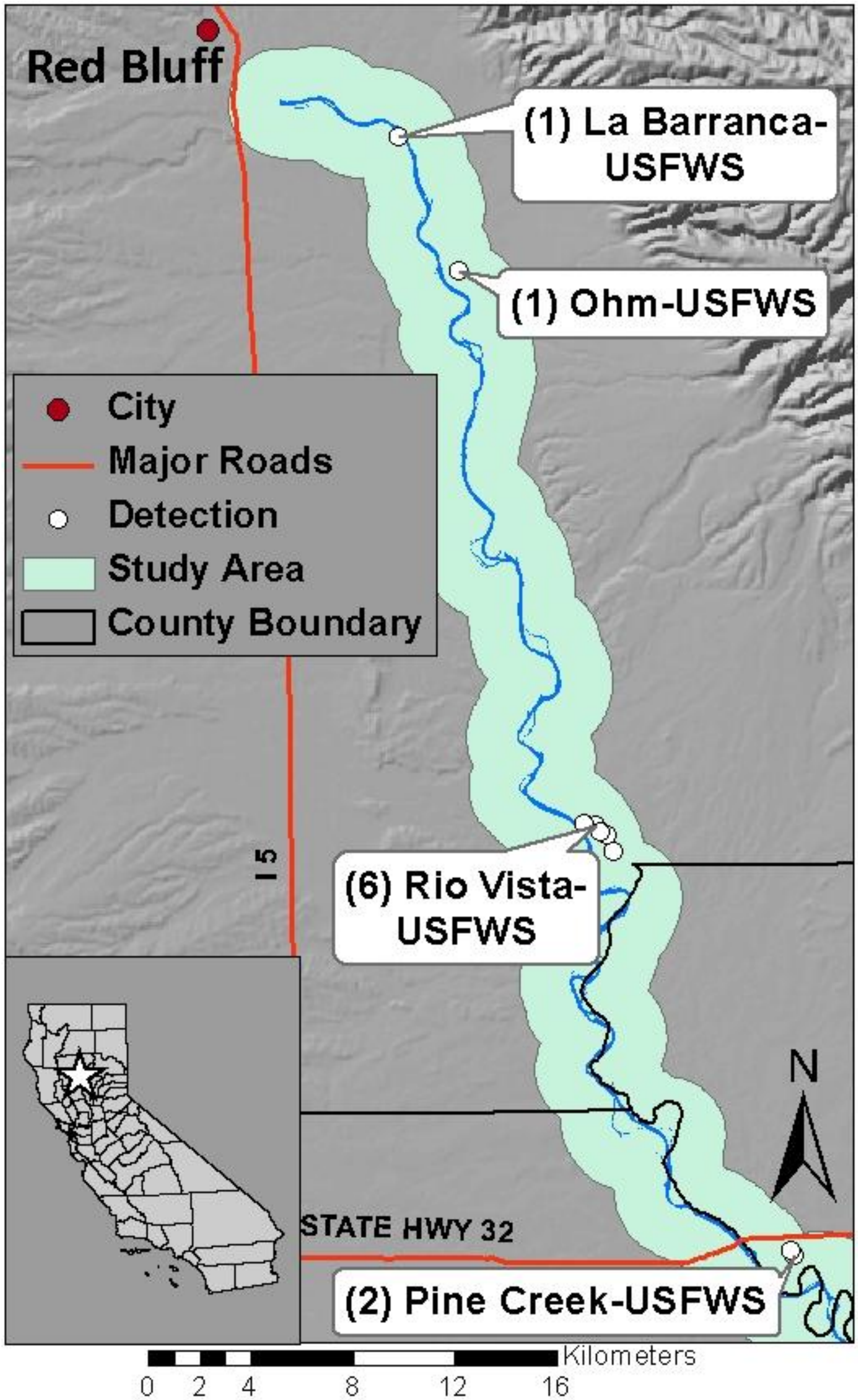


Figure 2a. Yellow-billed Cuckoo detection site names, owners and number of detections (in parentheses) from Red Bluff to Highway 32 (USFWS-US Fish and Wildlife Service). Due to the scale of the map some of the detections made in the same general area appear as one point.

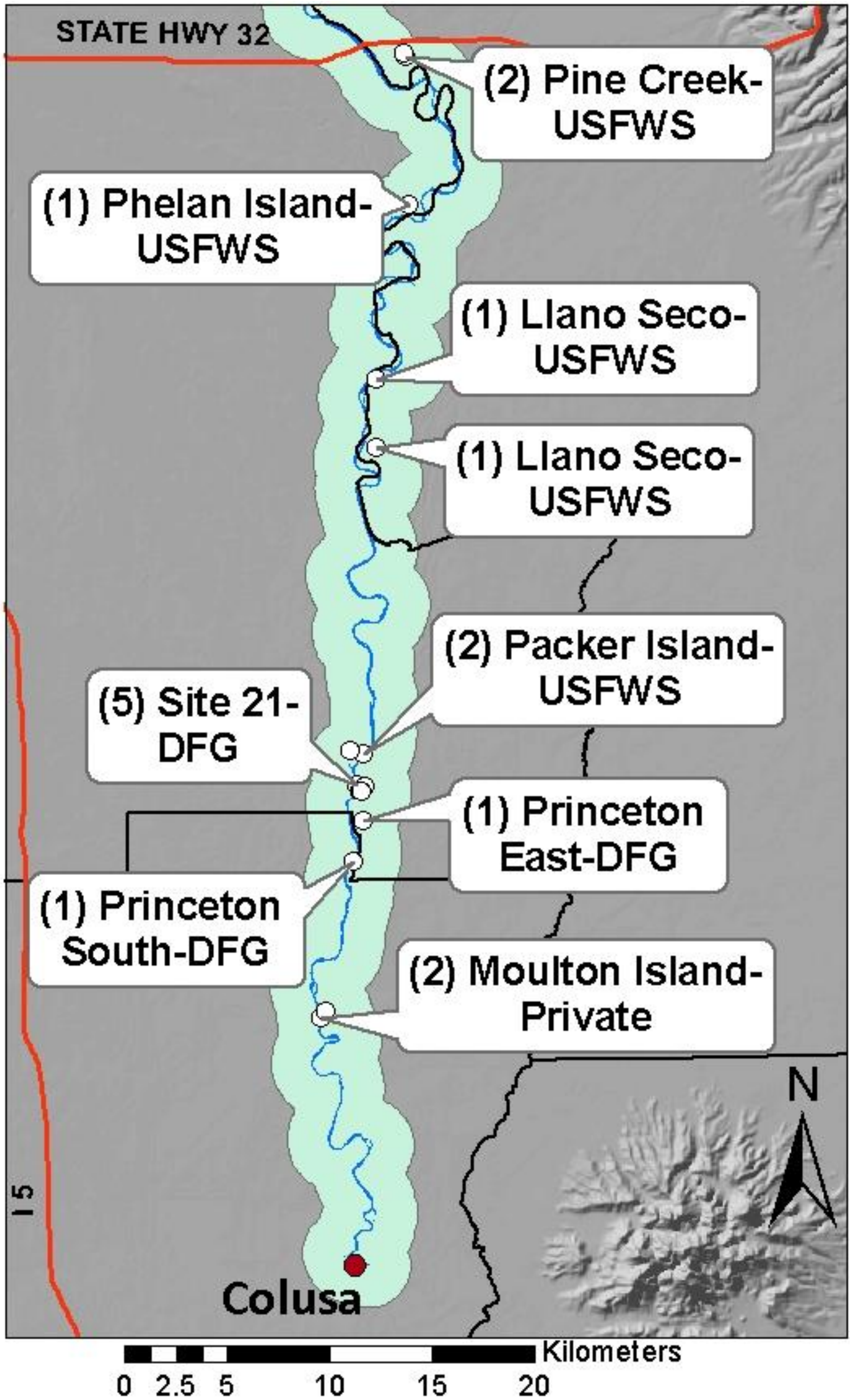


Figure 2b. Yellow-billed Cuckoo detection site names, owners and number of detections (in parentheses) from Highway 32 to Colusa. USFWS-US Fish and Wildlife Service, DFG-Department of Fish and Game. Due to the scale of the map some of the detections made in the same general area appear as one point.

Table 1. Yellow-billed Cuckoo detections during 2010 survey listed by round, then from north to south. The last detection was during vegetation surveys. Coordinates are NAD83 Zone 10. Method describes if the detection was directly following a playback or if the bird was detected before the playback was started.

| Location Name | UTM Coordinates | Date | Method | County | Landowner |
|---|---|---|---|---|---|
| Llano Seco | 586680, 4380969 | 29-Jun | Playback | Butte | USFWS |
| LaBarranca | 572627, 4443718 | 30-Jun | Playback | Tehama | USFWS |
| Pine Creek | 588102, 4400094 | 2-Jul | Playback | Butte | USFWS |
| Packer Island | 586053, 4366064 | 15-Jul | Playback | Glenn | USFWS |
| Site 21 | 585719, 4364538 | 15-Jul | Playback | Glenn | DFG |
| Site 21 | 586085, 4364430 | 15-Jul | Playback | Glenn | DFG |
| Site 21 | 586085, 4364430 | 15-Jul | Spontaneous | Glenn | DFG |
| Site 21 | 585908, 4364198 | 15-Jul | Playback | Glenn | DFG |
| Princeton South | 585551, 4360755 | 15-Jul | Playback | Colusa | DFG |
| Moulton Island | 583999, 4353151 | 15-Jul | Playback | Colusa | Private |
| East Ohm | 574982, 4438507 | 26-Jul | Playback | Tehama | USFWS |
| Rio Vista | 580346, 4416851 | 17-Jul | Playback | Tehama | USFWS |
| Rio Vista | 580346, 4416851 | 17-Jul | Spontaneous | Tehama | USFWS |
| Rio Vista | 580771, 4416516 | 19-Jul | Playback | Tehama | USFWS |
| Rio Vista | 581030, 4415883 | 19-Jul | Playback | Tehama | USFWS |
| Pine Creek | 588015, 4400259 | 17-Jul | Playback | Butte | USFWS |
| Phelan Island | 588222, 4392860 | 21-Jul | Playback | Glenn | USFWS |
| Moulton Island | 584180, 4353478 | 29-Jul | Playback | Colusa | Private |
| Rio Vista | 579906, 4416936 | 4-Aug | Playback | Tehama | USFWS |
| Llano Seco | 586637, 4384315 | 13-Aug | Playback | Butte | USFWS |
| Packer Island | 585408, 4366164 | 6-Aug | Playback | Glenn | USFWS |
| Site 21 | 585950, 4364208 | 17-Aug | Playback | Glenn | DFG |
| Princeton East | 586001, 4362725 | 5-Aug | Playback | Glenn | DFG |
| Rio Vista | 580527, 4416596 | 20-Aug | Spontaneous | Tehama | USFWS |

The number of detections can overestimate the number of individuals because the same individual may be encountered on multiple survey rounds. We estimated the number of individuals encountered throughout the season by examining each detection in relation to those in close proximity. Individuals detected on the same day were separated by the surveyor, who kept track of the cuckoo's movements to ensure that it was not double counted. Differentiating individuals among rounds is more difficult, but generally detections greater than 500 m apart are likely different birds and detections within 300 m are likely the same individual (Halterman et al 2001). Using these criteria we determined that we encountered 18 unique individuals. An alternate approach is to consider a bird breeding if it is detected during two of the four survey periods (Henneman 2009). If we use this approach then there were 5 breeding birds detected in our survey efforts.

After each cuckoo was detected, the surveyor attempted to locate the bird and observe any breeding behavior. On average, the surveyor spent 30 minutes searching or watching the individual, though the amount of time ranged from 6 to 70 minutes. No explicit breeding activity (e. g. nest material carry) was noted during these observations. In fact, most detections (17 of 24) were of birds that were only heard and not seen. Although we did not confirm breeding by direct observation, we are fairly confident that most of our detections were of breeding individuals since they were detected during the height of breeding season (July to early August, Table 1).

## Occupancy Analysis

Occupancy analysis requires repeated presence/absence surveys at a single location in order to determine the occupancy at that location. We wanted to define the occupancy in terms of the territory, but cuckoo territory size is not well known. Therefore we selected a range of cuckoo territory size areas varying from 15 to 75 ha. These correspond to ranges for western cuckoo territory size from telemetry data. A territory was considered occupied if a cuckoo was detected during at least one round. A naïve estimate (i.e. an estimate that does not account for detectability and therefore assumes a 100% detection rate) of occupancy was calculated directly from our results (Table 2).

Although we detected 18 individuals using the protocol, when using the larger territory sizes of 60 and 75 ha, some observations that we considered “separate individuals” had to be combined into one territory due to the proximity of the detections, so the number of occupied territories became 16 instead of 18 under these scenarios (Table 2).

Table 2. Cuckoo occupancy estimates for the Sacramento River during 2010 based on a range of potential territory sizes. Using the total amount of riparian habitat surveyed, we calculated the number of potential territories, the number of occupied territories, and the number of empty territories. These were used as inputs to determine the occupancy estimate (%) for each territory size. We multiplied the number of potential territories times the occupancy estimate (%) to determine the estimated number of occupied territories. The radius length of a circle for each territory size is shown for comparative purposes since that metric is often used by other researchers.

| Terr. size (ha) | Terr. radius (m) | # Potential terr. | Naïve # Occupied territories | # Empty territories | Occupancy estimate % | Occupancy estimate # terr. |
|---|---|---|---|---|---|---|
| 15 | 218.6 | 371 | 18 | 353 | 10.3 | 38.2 |
| 30 | 309.1 | 185 | 18 | 167 | 20.6 | 38.1 |
| 45 | 378.6 | 124 | 18 | 106 | 30.7 | 38.1 |
| 60 | 437.1 | 93 | 16 | 77 | 34.0 | 31.6 |
| 75 | 488.7 | 74 | 16 | 58 | 42.8 | 31.7 |

Occupancy estimates were lowest when the territory size was the smallest, and highest with the largest territory size (Table 2, Figure 3). As the territory size increases, there was a corresponding decrease in the number of potential territories. Our observed occupied territories were widely spread geographically and therefore their number changes very little as the territory size increases. The expected result would then be increasing occupancy with increasing territory size, which was what our results show.

The occupancy analysis suggests that with a territory size of 15 ha, approximately 10.3% of the 371 potential territories (or about 38 territories) are occupied by cuckoos (Table 2); 38 territories are also estimated at territory sizes of 30-45 ha. This is more than double the number of territories we actually observed occupied; this result occurs because cuckoo detection probability was estimated at less than 0.25 per survey round, so the analysis projects undetected territories.  At territory sizes of 60 or 75 ha, the occupancy estimated number of territories drops to approximately 32.

When the probability of detection is considered constant throughout the survey, its estimated value only varies slightly as the territory size increases (Figure 4). Allowing the estimated probability of detection to vary among rounds, we see that it is highest in rounds 2 and 3, followed by round 4, and lastly by round 1. This pattern holds as territory size increases. We used AIC values to choose which model had the most support to estimate occupancy (Burnham and Anderson 2002). Using AIC values is a method for comparing a number of models to assess which of them is the best supported by the data. We considered a model in which the probability of detectability was constant among survey rounds, as well as a model in which detectability varied among survey rounds. The model in which the probability of detection varied among rounds had the most support for each of the territory sizes we considered (Appendix 2).

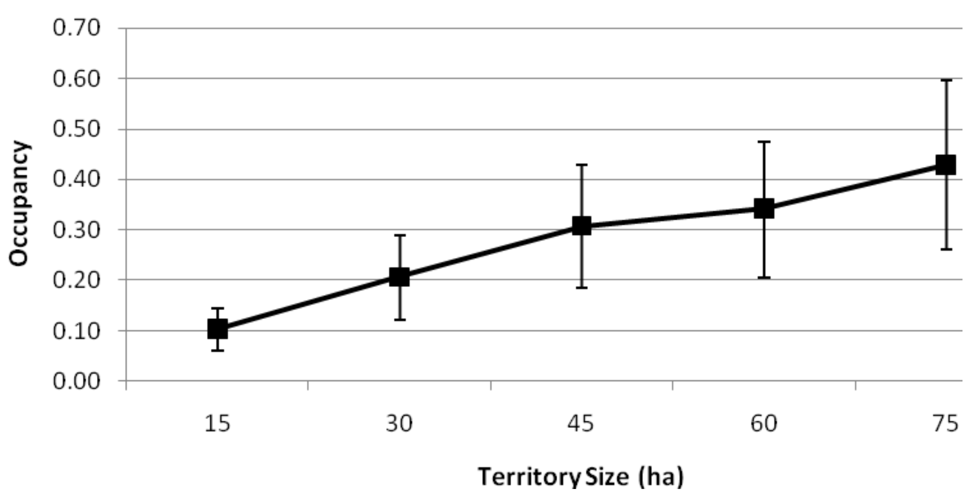


Figure 3. Estimates of the proportion of occupied Yellow-billed Cuckoo territories along the Sacramento River. Estimates generated with probability of detection allowed to vary among survey rounds. Error bars represent one standard error.

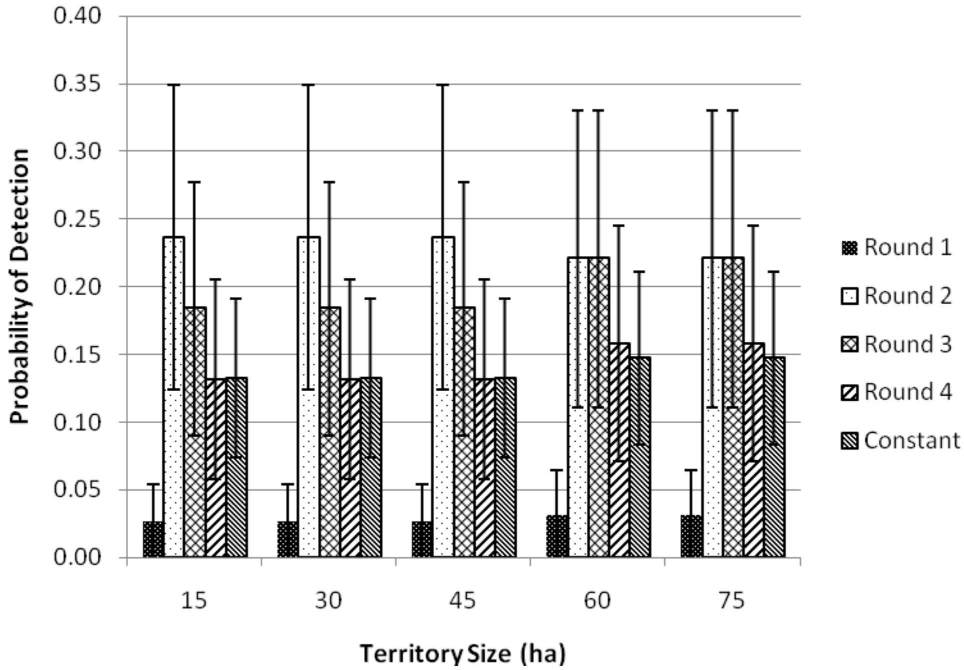


Figure 4. Probability of detection estimates for Yellow-billed Cuckoo along the Sacramento River when allowed to vary among survey rounds or held constant throughout the survey period. Estimates were calculated for each territory size. Error bars represent one standard error.

## GIS Analysis

The study area was calculated to be 58,894 ha, most of which is privately owned (Table 3). Federal and state agencies, along with non-governmental organizations (NGOs), own a combined 18.6% of the study area, with the remainder as private lands. With the riparian vegetation layer we can narrow the scope to habitats that may support Yellow-billed Cuckoos. For this analysis, we restricted the habitat types to those consisting of forests and scrub, excluding wetlands, grasslands, open water, and gravel bars. Of the total study area, only 13.5% (7,925 ha) consists of this forested riparian habitat. When evaluating the ownership of the riparian habitat, the majority (71.8%) is owned by federal and state agencies, and NGOs (Table 3).

Table 3. Study area ownership analysis.

| Owner | Total Area (ha) | % of Total | Riparian Habitat (ha) | % of Riparian Habitat |
|---|---|---|---|---|
| Bureau of Land Management | 158 | 0.3% | 140 | 1.8% |
| US Fish and Wildlife Service | 4345 | 7.4% | 2636 | 33.3% |
| Other Federal Agencies | 165 | 0.3% | 15 | 0.2% |
| **Federal** | **4668** | **7.9%** | **2791** | **35.2%** |
| Department of Fish and Game | 1721 | 2.9% | 1377 | 17.4% |
| Department of Parks and Recreation | 408 | 0.7% | 295 | 3.7% |
| Department of Water Resources | 843 | 1.4% | 591 | 7.5% |
| Other State and Local | 298 | 0.5% | 179 | 2.3% |
| **State and Local** | **3270** | **5.6%** | **2442** | **30.8%** |
| River Partners | 55 | 0.1% | 15 | 0.2% |
| The Nature Conservancy | 1902 | 3.2% | 348 | 4.4% |
| Northern California Regional Land Trust | 1018 | 1.7% | 93 | 1.2% |
| **NGOs** | **2975** | **5.1%** | **456** | **5.8%** |
| **Private** | **47981** | **81.5%** | **2236** | **28.2%** |
| ***Total*** | ***58894*** | | ***7925*** | |

## Vegetation Analysis

Vegetation surveys were conducted along the survey routes and at cuckoo detection locations to characterize the habitat (although in many cases we only heard the cuckoo and had to estimate its location for the vegetation survey). We used ArcGIS to determine all vegetation survey points within 300 m of a positive cuckoo detection (n=39 vegetation survey locations) and all vegetation survey points greater that 600 m from a positive cuckoo detection (n=403 points). In our vegetation analyses we refer to these two groups as cuckoos present (Y) and absent (N). We used logistic regression to determine if vegetation variables were significant predictors of cuckoo presence and absence. In all cases the slope of the vegetation variable was not significant (likely due to the low number of cuckoos we detected, see Discussion) indicating that it was not a significant predictor of cuckoo presences; therefore we show boxplots for relevant variables to show how the distributions of vegetation variables varied. In the box and whisker plots, the bottom and top of the box are always the 25th and 75th percentile (the lower and upper quartiles, respectively), and the band near the middle of the box is always the 50th percentile (the median). The whiskers extend to maximum and minimum values excluding outliers. Outliers are shown as dots and are values more than 3/2 times the upper quartile or more than 3/2 times the lower quartile.

*Overstory measurements*

We estimated overall canopy cover using a densiometer (Figure 5). Canopy cover was similar between the two groups, although there was greater range and variance at the lower tail for sites without cuckoos.

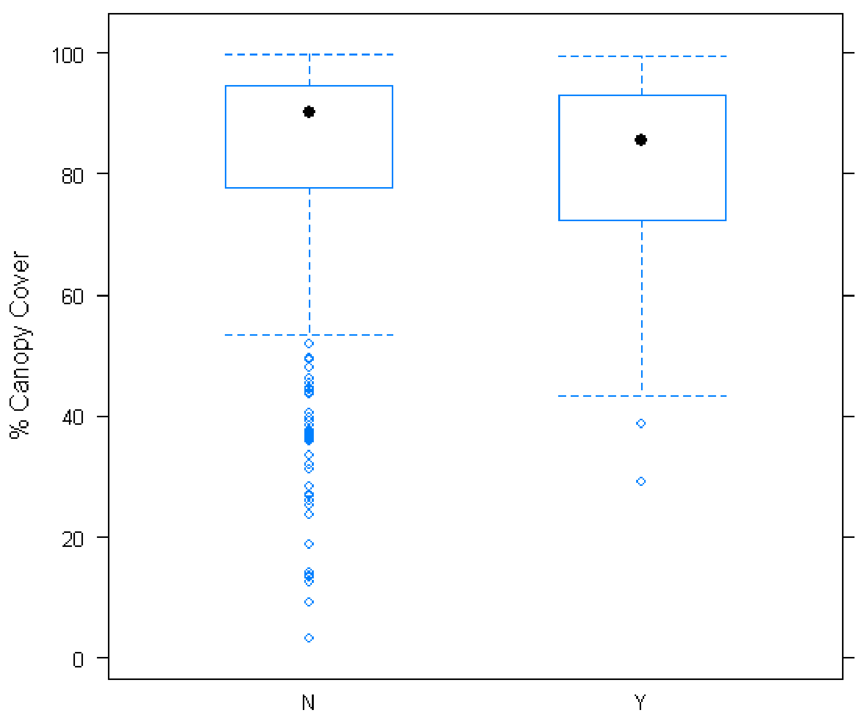


Figure 5. Canopy cover (derived from the average of four densiometer readings) for areas with (Y; n=39) and without (N; n=403) Yellow-billed Cuckoo detections.

Canopy structure was measured by estimating the bottom height, median height (50% of the canopy above and below this height), top height, and range in canopy height (Figure 6). When comparing sites with and without cuckoos there is a broad overlap in values. None of these variables were significant predictors for the presence of cuckoos.

We further broke down canopy structure by individual tree species to examine differences in associations. We included the nine most common species in our analyses: boxelder, Oregon ash, California black walnut, California sycamore, Fremont cottonwood, valley oak, sandbar willow, Goodding's black willow, and arroyo willow (see Figure 7 for scientific names). Sites with cuckoos present had similar maximum tree heights for the nine most frequently encountered tree species (Figure 7). The variables were not significant predictors of cuckoo presence.

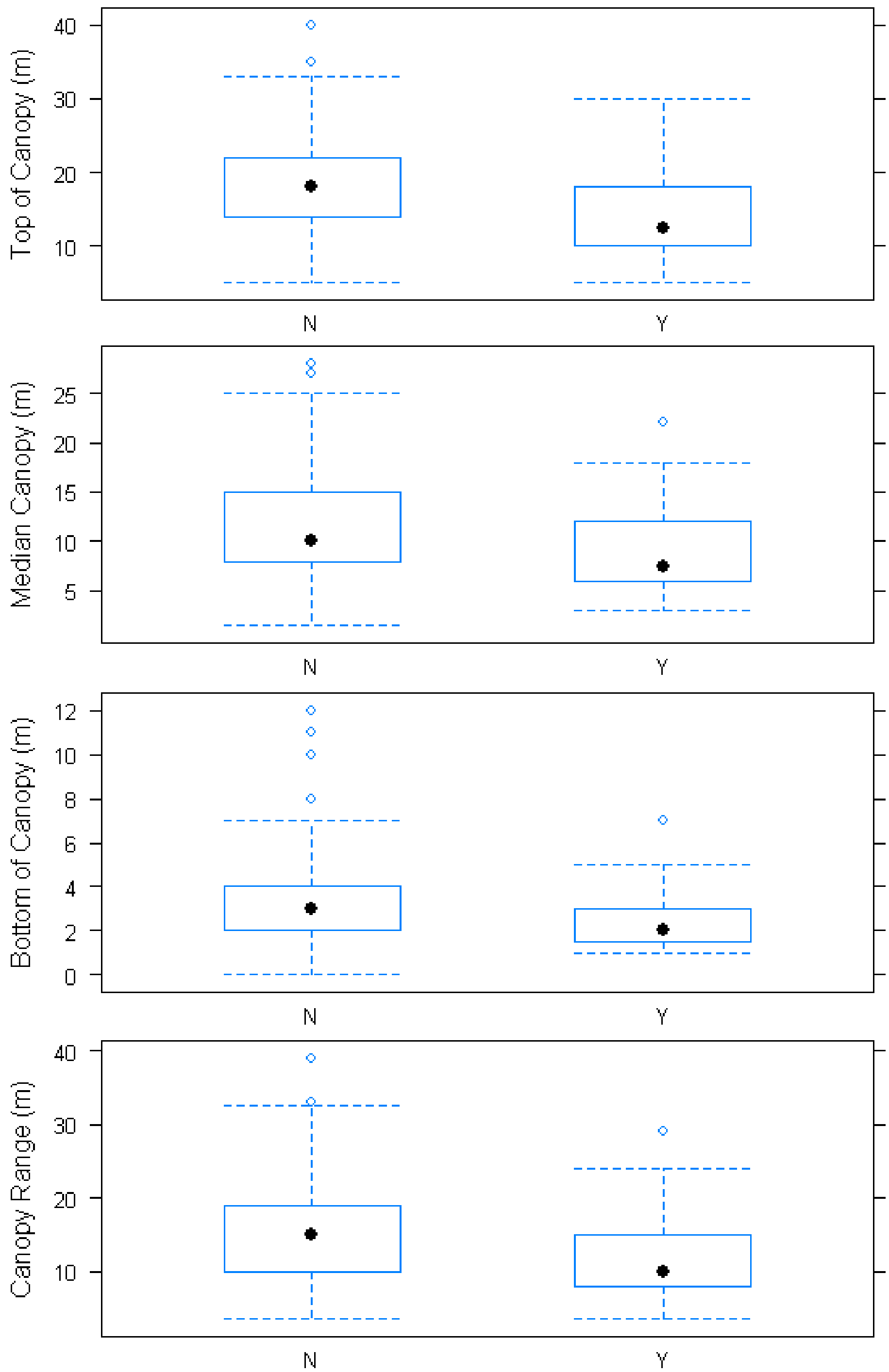


Figure 6. Canopy heights, in meters, for the top (tallest tree), median (50% of canopy is above this height), and bottom (lowest live branch) for areas with (Y; n=39) and without (N; n=403) Yellow-billed Cuckoo detections. Canopy Range is the distance between the top and bottom of the canopy.

.

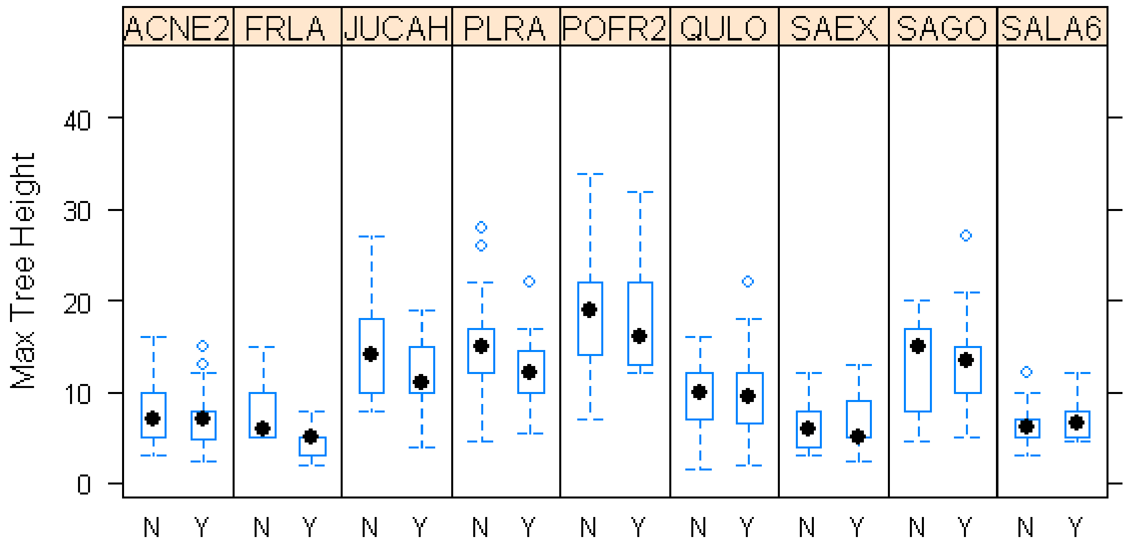


Figure 7. Maximum tree height for the nine most frequent tree species at sites with (Y; n=39) and without (N; n=403) cuckoos. Tree species included boxelder (*Acer negundo*, ACNE2); Oregon ash (*Fraxinus latifolia*, FRLA); California black walnut (*Juglans californica*, JUCAH); California sycamore (*Platanus racemosa*, PLRA); Fremont cottonwood (*Populus fremontii*, POFR2); valley oak (*Quercus lobata*, QULO); sandbar willow (*Salix exigua*, SAEX); Goodding's black willow (*Salix gooddingii*, SAGO); arroyo willow (*Salix lasiolepis*, SALA6).

We also calculated the vegetation profiles for all trees as well as the nine most frequently occurring species (Figure 8). The amount of cover provided by each species within four height ranges was recorded in order to characterize the structure of the forest. The cover provided by all species shows that the highest percent cover is from 1.4 to 15 m, with a modest amount from 15 to 30 m, and a very small amount above 30 m (Figure 8). In the lowest height range, boxelder, arroyo willow, and Fremont cottonwood are common. Above 5 m, Fremont cottonwood provides much of the cover.

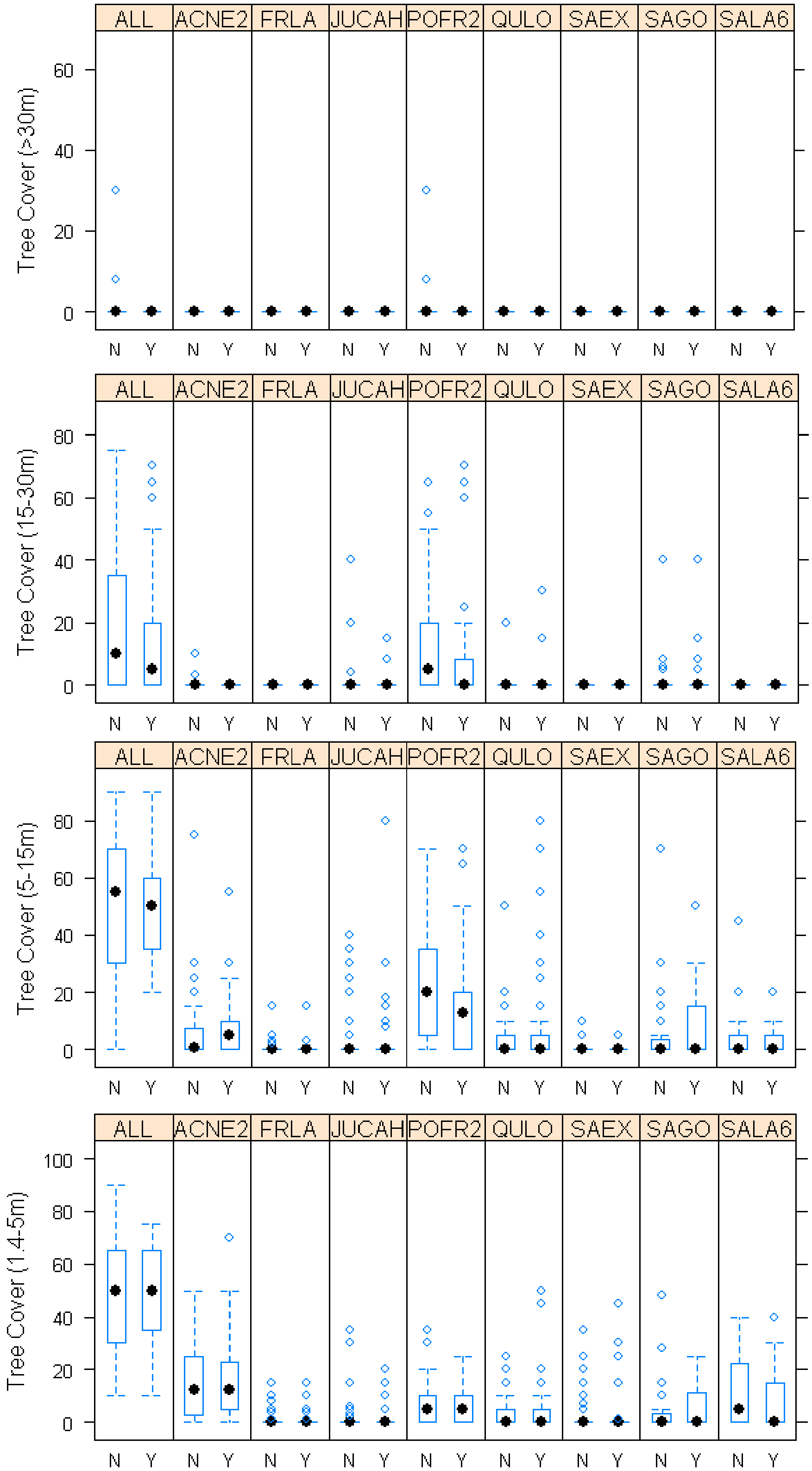


Figure 8. Vegetation profiles at sites with (Y; n=39) and without (N; n=403) for all trees and for 9 frequently occurring tree species. Tree cover is broken into four intervals. See Figure 7 for species codes.

*Understory measurements*

We also examined the shrub layer between 0.5 and 1.4 m to examine differences in sites with and without cuckoos. The amounts of cover provided by shrubs (live woody plants) and brush (dead woody plants) were similar in areas with or without cuckoo detections. Shrubs tended to provide between 0 and 20% of the cover in this low height range. Brush made up a smaller amount of cover. The high shrub height was also similar between areas (Figure 9).

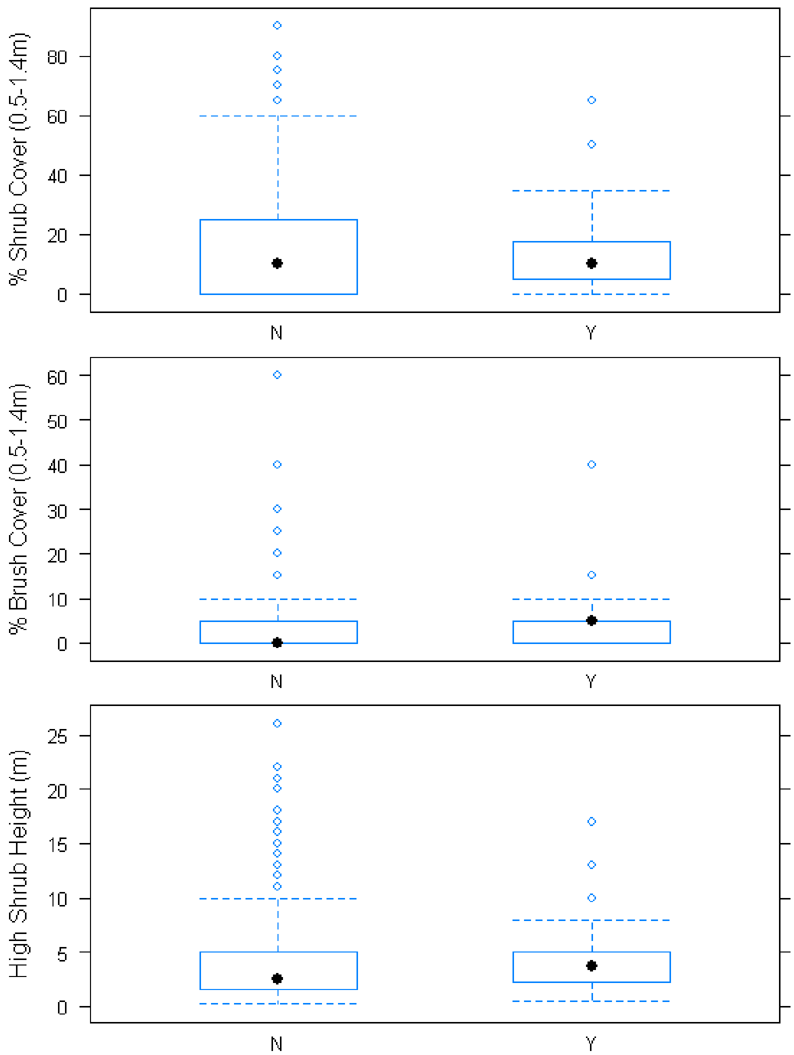


Figure 9. Measures of understory. Shrub and brush (dead woody debris) cover for areas with (Y; n=39) and without (N; n=403)  Yellow-billed Cuckoo detections. Height of tallest shrub includes

wild grape (*Vitis californica*) and poison oak (*Toxicodendron diversilobum*) that can climb high up into trees.

## DISSCUSSION

During the 2010 survey of the Sacramento River, we surveyed approximately 1500 call points over 1191 hours within riparian habitat on federal, state, NGO, and private lands. Collectively we estimate that we surveyed 5560 ha. We encountered 18 individual cuckoos on state (n=6), federal (n=11), and private lands (n=1). These cuckoos were observed at the following sites: LaBarranca (1), Ohm (1), Rio Vista (3), Pine Creek (1), Phelan Island (1), Llano Seco (2), Packer Island (2), Site 21 (4), Princeton East (1), Princeton South (1), and Moulton Island (1). Cuckoos were mostly detected during the second, third, and fourth survey rounds during the time period of 30 June to 17 August, which is the time period that is thought to correspond with the peak of their breeding activity in the Sacramento Valley (Halterman 1991).

### Comparison to Previous Years

We interpret that our 2010 results represent a decline from the previous 40 years (Table 4). Direct comparison of the 2010 and previous surveys is complicated by the different way in which the cuckoo responses were interpreted. Several past surveys have focused on evaluating the number of breeding pairs (Laymon and Halterman 1989, Halterman et al 2001). Pair status was determined by observation of two birds in close proximity or the type of call response given (Halterman et al 2001). With the recent finding that using the call type to determine the breeding status is unreliable (Halterman 2009), the previous survey results become more difficult to interpret.

Adding to the difficulty in comparing results from different surveys are the varying amounts of effort and area covered from survey to survey. In the earliest surveys (1972-73, 1977), the sites were surveyed only once during the breeding season, while in later surveys (1999-2000, 2010) sites were visited three or four times. There are also differences in effort between the 2010 and 1999-2000 surveys, with 312 points surveyed over 255 hrs in 1999 (Halterman et al. 2001) and about 1500 points surveyed over 1191 hrs in 2010.

Table 4. Yellow-billed Cuckoo surveys of the Sacramento River and the reported results (cuckoos detected; these results did not correct for probability of undetected cuckoos).

| Year | Reported Results | # Survey Rounds | Citation |
|---|---|---|---|
| 1972 | 28 individuals | 1 | Gaines 1974 |
| 1973 | 29 individuals | 1 | Gaines and Laymon 1984 |
| 1972-73 | 44 individuals | 1 | Gaines and Laymon 1984 |
| 1977 | 44 individuals | 1 | Gaines and Laymon 1984 |
| 1977 | 29-60 pairs | 1 | Halterman et al. 2001 |
| 1987 | 18 pairs, 19 unmated | 3 | Laymon and Halterman 1989 |
| 1987 | 18 pairs, 23 unmated | 3 | Halterman 1991 |
| 1988 | 35 pairs, 31 unmated | 3 | Halterman 1991 |
| 1989 | 26 pairs, 19 unmated | 3 | Halterman 1991 |
| 1990 | 23 pairs, 25 unmated | 3 | Halterman 1991 |
| 1999 | 28-32 pairs, 26 unmated | 3 | Halterman et al. 2001 |
| 2000 | 35-40 pairs, 38-42 unmated | 3 | Halterman et al. 2001 |
| 2010 | 18 individuals | 4 | Dettling and Howell 2011 |

The extensive effort and coverage in 2010 produced the fewest number of individuals over surveys from the past 40 years, not accounting for the differences in effort and interpretation noted above. We assume that if the amount of effort and area covered of past surveys were increased to the 2010 level, the number of cuckoos detected would have been even higher during those previous years. Even if we take the most conservative interpretation of previous data (i.e. birds counted as a pair are actually just one individual), the 2010 results indicate a decline in Yellow-billed Cuckoo numbers along the Sacramento River.

In 2010 cuckoos were detected at multiple sites along the stretch of river we surveyed, from river mile 240 to river mile 157. Halterman et al. (2001) primarily made surveys from the river and report the number of detections by river mile allowing us to compare whether river miles we found individuals in 2010 were also occupied in 1999-2000 (Table 5). One limitation is that we do not know where exactly along that river mile the 1999-2000 detections were. We detected cuckoos at three separate river mile locations where cuckoos were not detected in 1999-2000. These included the La Barranca Unit and two locations at the Rio Vista Unit (one restored in 1994-95 and one restored in 1998-99) which are both at the north end of the study area. Girvetz and Greco (2009) found that cuckoos occupied more patches south of Highway 32 than north, a pattern which held in our data in 2010 (Figure 2).

Table 5. Yellow-billed Cuckoo detection river miles (RM) for 2010 (including management unit from Appendix 1) in comparison to the 1999-2000 survey (Halterman et al 2001). For the 1999-2000 data we do not know what side of the river birds were detected on, so we cannot assume that they were in the same management unit as the 2010 surveys.

| 2010 Detection approx. RM | Unit or Area Name | Side of River for 2010 Detection | 1999 or 2000 Detection at a nearby RM? (approx. RM) |
|---|---|---|---|
| 240 | La Barranca | West | N |
| 235 | Ohm | East | Y (234) |
| 217 | Rio Vista | East | N |
| 216 | Rio Vista | East | N |
| 198.5 | Pine Creek | East | Y (197) |
| 191.5 | Phelan Island | West | Y (191.5) |
| 182 | Llano Seco | East | Y (182.5, 181.5) |
| 179 | Llano Seco | East | Y (179) |
| 167 | Packer | West | Y (167) |
| 165 | Site 21 | West | Y (165.5, 166) |
| 164 | Princeton East | East | Y (163) |

| | | | |
|---|---|---|---|
| 163 | Princeton South | West | Y (163) |
| 157 | Moulton Island | East | Y (157, 156.5) |

We did not encounter any breeding activity, such as birds carrying nesting material or food. Yellow-billed Cuckoos are very secretive in general and especially around their nests, so breeding behavior can be difficult to observe. We did not have time to follow up detections with intensive nest searching, because the large amount of area we were covering and the short two weeks we had to cover it during a survey round. The timing of our detections, between early July and early August, was during the cuckoo breeding season. There are no known major breeding populations further north, so it is unlikely that the birds we detected were migrating through.

## Implications of Occupancy Analyses

We applied recently developed statistical methods to the 2010 survey data to calculate occupancy (MacKenzie et al 2005).  We did this at multiple scales because the scale chosen can greatly affect the rate of occupancy (in our case the rate ranges from 10% to 42%). When using occupancy analysis to aid in estimating a population size, the scale that is most appropriate would correspond to the territory size for the study species. If the scale chosen is smaller than the actual territory size then the estimate of occupied territories may be an overestimate (i.e. two occupied territories might be occupied by one pair instead of two).  If the scale chosen is larger than the actual territory size then the estimate of occupied territories may be an underestimate (i.e. one occupied territory might be occupied by more than one pair).

With the reported territory sizes for Yellow-billed Cuckoos varying (Johanson et al. 2007, Halterman 2009, Henneman 2009), we felt it appropriate to report a range of occupancy estimates. Based on our experiences on the ground, we estimate that cuckoo territory size is less than 60 ha along the Sacramento River. If territory size was 60 ha (or greater) we would not have had as many detections as we did within the existing spatial configuration of the habitat. Additional research efforts, including telemetry studies, are needed to determine territory size for Sacramento Valley cuckoos.

At all territory sizes we considered, detection probabilities are lower than those calculated for the Kern River (0.35-0.83, Henneman 2009) and the Lower Colorado River (0.19-0.84, McNeil et al. 2010). The probability of detection of each survey period varied in our study, with the second (early to mid-July) and third (mid to late July) periods having the greatest probability. This pattern is also evident in the Kern and Lower Colorado River studies (Henneman 2009, McNeil et al. 2010). Though scales of other studies may not exactly match ours in terms of what size was used to delineate a territory, our range of territory sizes span those used in other studies. If cuckoos in northern California are not more secretive than those at the Kern or Lower Colorado rivers, the low detection probability indicates that population density is lower in the north.

Our occupancy analyses predict that between 32 and 38 cuckoo territories were occupied in the study region along the Sacramento River (Table 2). Given our knowledge about the spatial configuration of the cuckoos we observed, we believe the estimate of 38 better corresponds to our data. These estimates do not indicate how many of the territories are occupied by pairs or only an individual, so the estimate of total population size potentially ranges from 38 to 76 individuals. We do not have occupancy estimates from the 1999-2000 surveys of the Sacramento River, therefore we cannot make direct comparisons. Even with the difficulties in comparing our results with past results and unknowns about territory size in this region, our results indicate low population sizes which are a cause for conservation concern.

## Vegetation Structure

We found no differences in vegetation structure between sites with and without Yellow-billed Cuckoo detections. This is likely because areas we considered as not having cuckoos were actually suitable cuckoo habitat, but lacking in cuckoos during this year of surveys. Some of these sites may have been occupied in recent years by cuckoos. Previous studies along the Sacramento River have found cuckoos positively associated with low woody vegetation (Halterman 1991, Hammond personal communication), the presence of willows and cottonwood (Gaines 1974, Halterman et al. 2001), and a taller canopy that provides more cover (Halterman et al. 2001). We suspect that the small number of cuckoo detections we had also made such associations difficult to detect.

## Habitat Availability

Only 13.5% of the land within 2 km of the Sacramento River exists as riparian habitat, but the majority of that (71.8%) is in public ownership. Prior to the 1849 gold rush, most of this land was riparian forest, though portions were also grassland, wetland, and gravel bar habitats (Gibson 1975). Since 1989, federal and state agencies and NGOs have restored nearly 2,500 ha of riparian forest along the Sacramento River (Golet et al. 2008). Much of this work was done after 1996, so it either did not exist or was likely too young to provide cuckoo habitat during previous surveys in 1999-2000. Those same organizations continue to acquire and restore habitat along the river, steadily increasing the amount of habitat for cuckoos and other species such as migratory songbirds and the valley elderberry longhorn beetle. A large impact could be made by partnering with private landowners, who own the majority of the land, to encourage and assist in restoration projects. This could be especially effective in locations that would increase the size of existing riparian forest or connect remnant patches.

Our calculations of the extent of riparian habitat rely on the accuracy of the vegetation data layer we used (Geographical Information Center, California State University, Chico). The vegetation data has been shown to contain some inaccuracies in the spatial position of polygons as well as the vegetation classes assigned to the polygons (Viers et al. 2009). The data layer classified polygons by the dominant tree species, and in some cases were shown to have been misclassified (e.g. Fremont cottonwood as valley oak) a significant number of times (Viers et al. 2009). While misclassifications of forest type occurred, it was rare for a non-forest class to be misclassified as one type of forest and vice versa, so we believe our calculations of riparian habitat are fairly accurate.

While it is relatively straightforward to determine the amount of riparian habitat based on GIS data, additional information and research is needed to calculate the amount of riparian habitat suitable for cuckoos along the Sacramento River. While the GIS data indicate the types of vegetation present, especially the dominant tree species, cuckoos may key in on other attributes such as plant or tree height which is not currently readily available through GIS. The amount of suitable cuckoo breeding habitat is also affected by the misclassifications of dominant tree species in the GIS database. Cottonwood forests were sometimes classified as valley oak, and Goodding's black willow forests as black walnut, mixed willow, or valley oak (PRBO unpublished data, Viers et al. 2009). If we were to restrict the forest type to cottonwood and willow, the preferred habitat for cuckoos, in order to calculate the amount of cuckoo habitat, those misclassifications would introduce error. Suitable cuckoo breeding habitat also includes a well developed understory, which the vegetation classifications do not address somewhat limiting their usefulness to identifying cuckoo habitat.

Aside from the presence of "suitable" cuckoo habitat, the configuration of that habitat within the landscape is likely important. Girvetz and Greco (2009) used data collected by Halterman et al. (2001) and earlier cuckoo surveys to evaluate spatial occupancy of riparian forest patches. While the cuckoo data inputs for their modeling exercise were based on the old interpretation of cuckoo playback surveys (in which pair status was considered determinable from the response data), they nonetheless showed that cuckoos responded to the amount of riparian habitat in the landscape. This analysis should be re-run in the future with updated data inputs to match current interpretations of cuckoo playback data.

## Conservation Implications and Future Research Needs

Potential factors leading to low cuckoo numbers in the Sacramento Valley include problems on the wintering grounds, problems during migration, food limitation in the Sacramento Valley, habitat quality, or cuckoos choosing other breeding locations. Cuckoos numbers are known to fluctuate among years at the same site, even in suitable habitat (Halterman 2009). If there were problems on the wintering grounds we might expect equally poor results in other regions, however numbers on the Lower Colorado River were above average in 2010 (Halterman personal communication).

With such a small population, continued monitoring is recommended in addition to more focused studies on cuckoo biology in the region. Compiling historic data and "cross-walking" among different survey protocols would be very helpful in understanding cuckoo population trends in the Sacramento Valley over the past 40 years. Recently developed statistical techniques (occupancy analysis) may allow us to use these data to make population estimates that account for the difficulty in detecting the species.

Since occupancy estimates rely on defining the correct scale for the analyses, obtaining telemetry data on territory size would be very useful for calculating more accurate population assessments. In this 2010 study there were few areas in which we detected multiple individuals or territories within the same relative area, so differences in potential territory size did not have a large effect on our results. However, in previous surveys of the area in 2007-2008 there were multiple detections within an area (Hammond, personal communication), as well as in the 1999-2000 surveys, so it would be prudent to determine territory size for cuckoos on the Sacramento River. Knowing territory size would also allow us to determine the potential maximum population size for this area.

The protocol we used was developed by groups in California and Arizona (Halterman et al. 2001, Johnson et al. 2006, Halterman 2009, McNeil et al. 2010) to standardize data collection. Standardized protocols ensure that adequate data is taken by each surveyor and that results can be compared across the entire range of the species. While the collection of the data has been standardized, there has not been standardization regarding the interpretation and analysis of cuckoo play back survey data. Moreover, additional refinement and updating of the survey protocol may be warranted for the Sacramento River population since it is further north than other populations. We only detected one individual during the first survey round and future Sacramento surveys might consider dropping the first round or starting it later. Another potential refinement to the protocol could be to increase the number of survey rounds within the time period of highest activity as well as add confirmation follow-up visits.

It is imperative that the Sacramento Valley population remain viable if the Yellow-billed Cuckoo population in California is to recover and avoid extirpation. The factors under the most direct control of land managers in the Sacramento Valley are the amount and quality of riparian habitat available to breeding cuckoos. The impressive amount of restoration that has taken place over the last 20 years in the Sacramento Valley is a great conservation success story (Golet et al. 2008). However, even with recent increases in riparian habitat and potential cuckoo habitat, these efforts represent only a fraction of the historic riparian extent. Continued efforts to restore riparian habitat, and the river processes which maintain them, are needed to aid cuckoo recovery. Additional research is needed on cuckoo habitat selection cues, territory size, and overall habitat requirements in the Sacramento Valley.

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# APPENDICES

Appendix 1. 2010 Yellow-billed Cuckoo survey routes, the range of survey points over all rounds, and the dates of each survey round. *Surveys only partially completed due to mechanical issues. +Surveys not completed due to mechanical issues.

| Name | Number of Points | River Mile | Owner | Round 1 | Round 2 | Round 3 | Round 4 |
|---|---|---|---|---|---|---|---|
| LaBarranca 1 | 28-35 | 240 | USFWS | 15-Jun | 30-Jun | 16-Jul | 31-Jul |
| Blackberry Island | 10 | 239.5 | USFWS | 15-Jun | 30-Jun | 16-Jul | 5-Aug |
| LaBarranca 2 | 22-24 | 239 | USFWS | 15-Jun | 30-Jun | 15-Jul | 2-Aug |
| LaBarranca Stringer | 18-22 | 238 | USFWS | 15-Jun | 30-Jun | 16-Jul | 2-Aug |
| Todd Island | 17-19 | 237 | USFWS | 15-Jun | 30-Jun | 16-Jul | 2-Aug |
| Mooney 1 | 20-25 | 236.5 | USFWS | 15-Jun | 1-Jul | 16-Jul | 3-Aug |
| Mooney 2 | 20-21 | 236 | USFWS | 15-Jun | 1-Jul | 16-Jul | 3-Aug |
| East Ohm 1 | 9-15 | 235 | USFWS | 28-Jun | 12-Jul | 26-Jul | 12-Aug |
| Ohm 1 | 24-25 | 234.5 | USFWS | 14-Jun | 30-Jun | 15-Jul | 2-Aug |
| East Ohm 2 | 10 | 234 | USFWS | 28-Jun | 12-Jul | 26-Jul | 12-Aug |
| Ohm 2 | 30-31 | 233.5 | USFWS | 14-Jun | 30-Jun | 15-Jul | 2-Aug |
| Flynn 1 | 23-28 | 233 | USFWS | 17-Jun | 1-Jul | 17-Jul | 3-Aug |
| Flynn 2 | 16-23 | 232 | USFWS | 17-Jun | 1-Jul | 16-Jul | 3-Aug |
| Flynn 3 | 19-24 | 232 | USFWS | 17-Jun | 1-Jul | 17-Jul | 3-Aug |
| Flynn 4 | 26-32 | 231 | USFWS | 17-Jun | 1-Jul | 17-Jul | 3-Aug |
| Heron Island | 16-17 | 228 | USFWS | 28-Jun | 12-Jul | 26-Jul | 12-Aug |
| Kopta Slough 1 | 25-27 | 221 | TNC | 19-Jun | 6-Jul | 19-Jul | 6-Aug |
| Kopta Slough 2 | 29-30 | 220 | TNC | 19-Jun | 6-Jul | 19-Jul | 6-Aug |
| Woodson Bridge | 28-31 | 219 | CADPR | 19-Jun | 5-Jul | 19-Jul | 6-Aug |
| Woodson Bridge East | 10-11 | 219 | CADPR | 19-Jun | 30-Jun | 16-Jul | 5-Aug |
| Rio Vista 1 | 20 | 218 | USFWS | 18-Jun | 2-Jul | 20-Jul | 4-Aug |
| Rio Vista 2 | 22-31 | 217 | USFWS | 18-Jun | 2-Jul | 17-Jul | 4-Aug |
| Rio Vista 3 | 14-28 | 216 | USFWS | 18-Jun | 2-Jul | 19-Jul | 4-Aug |
| Rio Vista 4 | 12-20 | 216 | USFWS | 18-Jun | 2-Jul | 20-Jul | 4-Aug |
| Merrill's Landing 1 | 25-29 | 214 | DFG | 19-Jun | 6-Jul | 20-Jul | 5-Aug |
| Merrill's Landing 2 | 24 | 214 | DFG | 19-Jun | 6-Jul | 20-Jul | 5-Aug |
| Foster Island 1 | 6-13 | 211 | USFWS | 29-Jun* | 13-Jul | 27-Jul | 13-Aug |
| Foster Island 2 | 8-16 | 211 | USFWS | 29-Jun* | 13-Jul | 27-Jul | 13-Aug |
| Wilson's Landing | 21-22 | 203 | DFG | 29-Jun | 13-Jul | 27-Jul | 13-Aug |
| Pine Creek 1 | 25-27 | 198.5 | USFWS | 18-Jun | 2-Jul | 19-Jul | 4-Aug |
| Pine Creek 2 | 23-34 | 198.5 | USFWS | 18-Jun | 2-Jul | 17-Jul | 4-Aug |
| Pine Creek North 1 | 14-20 | 198 | DFG | 23-Jun | 7-Jul | 21-Jul | 9-Aug |
| Pine Creek North 2 | 22-24 | 197 | DFG | 21-Jun | 7-Jul | 21-Jul | 9-Aug |
| Bidwell-Sacramento River SP | 21-22 | 195 | CADPR | 21-Jun | 6-Jul | 19-Jul | 5-Aug |
| Pine Creek East | 18-21 | 195 | DFG | 25-Jun | 8-Jul | 21-Jul | 5-Aug |
| Pine Creek West | 24-26 | 195 | DFG | 19-Jun | 2-Jul | 18-Jul | 4-Aug |
| Capay | 11 | 194 | USFWS | 22-Jun | 7-Jul | 21-Jul | 6-Aug |
| Phelan Island | 30-33 | 191.5 | USFWS | 22-Jun | 6-Jul | 21-Jul | 7-Aug |
| Shannon Slough | 7 | 187 | DFG | + | 14-Jul | 28-Jul | 16-Aug |
| Jacinto/Shannon Slough | 10-13 | 186.5 | USFWS | 21-Jun | 7-Jul | 21-Jul | 6-Aug |

| Name | Number of Points | River Mile | Owner | Round 1 | Round 2 | Round 3 | Round 4 |
|---|---|---|---|---|---|---|---|
| South Ord 1 | 16 | 183 | USFWS | 22-Jun | 8-Jul | 24-Jul | 7-Aug |
| South Ord 2 | 11-14 | 183 | USFWS | 22-Jun | 8-Jul | 24-Jul | 7-Aug |
| Llano Seco 1 | 27-33 | 182 | USFWS | 25-Jun | 10-Jul | 29-Jul | 13-Aug |
| Jacinto | 30-31 | 181 | DFG | 23-Jun | 8-Jul | 23-Jul | 9-Aug |
| Llano Seco 2 | 28-29 | 181 | USFWS | 22-Jun | 7-Jul | 22-Jul | 7-Aug |
| Llano Seco 3 | 27-31 | 179 | USFWS | 29-Jun | 15-Jul | 28-Jul | 16-Aug |
| Riparian Sanctuary – Llano Seco | 43 | 176 | USFWS | 24-Jun | 9-Jul | 23-Jul | 11-Aug |
| Oxbow | 24-27 | 175 | DFG | 24-Jun | 10-Jul | 23-Jul | 11-Aug |
| Hartley Island | 20-21 | 173 | TNC | 25-Jun | 8-Jul | 23-Jul | 9-Aug |
| Site 78 | 21-25 | 172 | DWR | 22-Jun | 9-Jul | 22-Jul | 10-Aug |
| Beehive 1 | 20-21 | 170 | DFG | 22-Jun | 7-Jul | 20-Jul | 7-Aug |
| Beehive 2 | 22 | 170 | DFG | 22-Jun | 7-Jul | 20-Jul | 7-Aug |
| Sul Norte | 28 | 169 | USFWS | 23-Jun | 9-Jul | 23-Jul | 10-Aug |
| Codora | 18-19 | 168 | USFWS | 23-Jun | 9-Jul | 21-Jul | 6-Aug |
| Packer Island | 25-34 | 167 | USFWS | 24-Jun | 9-Jul | 22-Jul | 6-Aug |
| Afton | 17-18 | 166.5 | USFWS | 23-Jun | 9-Jul | 22-Jul | 10-Aug |
| Princeton North | 12-13 | 166.5 | DFG | 24-Jun | 9-Jul | 21-Jul | 6-Aug |
| Drumheller North | 10-11 | 165 | USFWS | 23-Jun | 7-Jul | 20-Jul | 5-Aug |
| Princeton East | 17-21 | 164 | DFG | 23-Jun | 7-Jul | 20-Jul | 5-Aug |
| Princeton Southeast | 14-15 | 161.5 | DFG | 24-Jun | 9-Jul | 22-Jul | 9-Aug |
| Moulton North | 8 | 157 | DFG | + | 16-Jul | 28-Jul | 14-Aug |
| Boeger | 15-22 | 148 | TNC | 24-Jun | 9-Jul | 24-Jul | 12-Aug |
| Colusa North | 25-26 | 147 | DFG | 24-Jun | 8-Jul | 23-Jul | 9-Aug |
| Colusa-Sacramento River SP | 24 | 145 | CADPR | 24-Jun | 8-Jul | 23-Jul | 9-Aug |
| Boat - Tehama | 30 | 230,232 236-238, 239 | private | 28-Jun | 12-Jul | 26-Jul | 12-Aug |
| Boat - Merrill's Landing | 6-24 | 205.5-207, 211-212.5 | private | 29-Jun* | 13-Jul | 27-Jul | 13-Aug |
| Dicus Slough | | 208-209 | DFG | | | | |
| Boat - Butte City | 51-54 | 187-192.5 | private | + | 14-Jul | 28-Jul | 16-Aug |
| | | 189-190 | DWR | | | | |
| Boat - Colusa | 68-72 | 169.5-171 | private | + | 15-Jul | 29-Jul | 17-Aug |
| Packer Island | | 167 | USFWS | | | | |
| Site 21 | | 165 | DFG | | | | |
| Princeton South | | 161.5-163 | DFG | | | | |
| Stegeman | | 159-160 | DFG | | | | |
| Moulton Island | | 157 | private | | | | |
| Moulton South | | 155-156 | DFG | | | | |

Appendix 2. Occupancy model selection using AIC values for each of the different territory sizes analyized. *This model allowed the probability of detection (p) to vary by survey round. +This model assumed the probability of detection was constant throughout the entire survey period.

| Territory Size (ha) | Model | AIC | ΔAIC | AIC weight |
|---|---|---|---|---|
| 15 | survey specific p* | 218.22 | 0 | 0.81 |
| | constant p+ | 221.11 | 2.89 | 0.19 |
| 30 | survey specific p* | 192.25 | 0 | 0.81 |
| | constant p+ | 195.14 | 2.89 | 0.19 |
| 45 | survey specific p* | 176.90 | 0 | 0.81 |
| | constant p+ | 179.80 | 2.90 | 0.19 |
| 60 | survey specific p* | 154.91 | 0 | 0.63 |
| | constant p+ | 155.96 | 1.05 | 0.37 |
| 75 | survey specific p* | 146.78 | 0 | 0.63 |
| | constant p+ | 147.83 | 1.05 | 0.37 |