Received: 10 September 2021 | Revised: 13 May 2022 | Accepted: 27 May 2022

DOI: 10.1002/jwmg.22284

RESEARCH ARTICLE

THE JOURNAL OF WILDLIFE MANAGEMENT | THE WILDLIFE SOCIETY

Developing an adaptive management approach to cowbird control on the Santa Clara River, California

Sophie S. Parker[1] | Linnea S. Hall[2] | Mary J. Whitfield[3] | Laura Riege[4] | Kathryn R. Selm[4] | René Corado[2]

[1]The Nature Conservancy, 445 S. Figueroa Street, Suite 1950, Los Angeles, CA 90071, USA

[2]Western Foundation of Vertebrate Zoology, 439 Calle San Pablo, Camarillo, CA 93012, USA

[3]Southern Sierra Research Station, 7872 Fay Ranch Road, P.O. Box 1316, Weldon, CA 93283, USA

[4]The Nature Conservancy, 1094 E. Main Street, Ventura, CA 93001, USA

Correspondence

Sophie S. Parker, The Nature Conservancy, 445 S. Figueroa Street, Suite 1950, Los Angeles, CA 90071, USA.
Email: sophie_parker@tnc.org

Funding information

Nature Conservancy, Grant/Award Number: California Conservation Science; Santa Clara River Trustee Council, Grant/Award Number: F12AP00598

Abstract

Brood parasitism by the brown-headed cowbird (*Molothrus ater*) has caused population declines for conservation-reliant songbird species such as the federally and state endangered subspecies least Bell's vireo (*Vireo bellii pusillus*). Although cowbird trapping has increased vireo populations, it is costly, and may prevent the development of parasitism-avoidance behaviors and result in high rates of non-target species captures. Therefore, wildlife managers have a compelling interest in evaluating multiple means of cowbird control. We conducted a study between 2016 and 2018 on the Santa Clara River (SCR) in Ventura County, California, USA, to test how the removal of cowbird traps would affect cowbird parasitism of the vireo. At our control site, cowbird trapping occurred in spring using modified Australian crow (*Corvus* spp.) traps. At our treatment site, we stopped this method of trapping and instead used target-netting of individual cowbirds and a very short duration trap to capture specific individual cowbirds (i.e., contingency trapping). We also tested the impact of shortening the cowbird trapping period on nest parasitism rates, and used point counts to compare cowbird densities between sites. Additionally, we compared the costs of these techniques. A shorter trapping period still resulted in a large number of cowbird captures on the control site ($n = 452$ captures) with no observed brood parasitism (*n* = 67 nests). On the treatment site, cowbird parasitism rates varied from 0% to 14% (*n* = 75 broods). The target-netting method was not effective for capturing female cowbirds, probably because of their low densities. The short-term contingency trapping method effectively removed female cowbirds in the vicinity of vulnerable vireo nests. Cowbird traps captured >300 individuals of 9 different non-target species each year on the control site, whereas target-netting and contingency trapping resulted in only 8 captures of 4 different non-target species. Costs of continuous trapping for 2 months versus point counts, nest monitoring, and contingency trapping were $21,100.00 versus $16,996.00, respectively. Based on these findings, we recommend that an adaptive cowbird management program to benefit songbird populations should consider using regular point counts and nest monitoring to provide data on cowbird impacts, in lieu of continued intensive trapping without monitoring. Thresholds for the density of cowbird females and the allowable level of parasitism for host species should also be established to guide an adaptive cowbird management program. Short-term contingency trapping based on the thresholds should be considered, but restoration of native vegetation, especially in southwestern riparian areas, is also crucial and effective at limiting parasitism, and so should strongly be considered. Lastly, large numbers of non-target species captures in cowbird traps are probably having consequential impacts to these species, and need to be monitored and minimized.

KEYWORDS

adaptive management, brown-headed cowbird, conservation reliance, least Bell's vireo, nest monitoring, non-target capture, parasitism, point counts, trapping

Population declines of Neotropical-Nearctic migratory songbirds have attracted attention for decades (Robbins et al. 1989; Terborgh 1989, 1992). Many of these migrants, including some listed under federal and state endangered species acts such as the least Bell's vireo (*Vireo bellii pusillus*; vireo; U.S. Fish and Wildlife Service [USFWS] 1986), breed in riparian vegetation zones in California, USA. Declines in songbird populations are attributable to a variety of threats; chief among them are habitat loss and degradation (Conard et al. 1977, Faber 1989), predation (Rogers et al. 1997, Morrison and Averill-Murray 2002, Whisson et al. 2004), and brood parasitism by brown-headed cowbirds (*Molothrus ater*; cowbird; Unitt 1987, Robinson et al. 1995, Rogers et al. 1997). In the early twentieth century, cowbird populations increased rapidly in California because of anthropogenic activities such as deforestation and agricultural practices that provided habitat for cowbirds (Rothstein 1994). As the most widespread native obligate brood parasite in North America (Peer et al. 2013), the cowbird has been documented laying eggs in the nests of ≥249 species (Lowther 2018); small host species with open, cup-shaped nests are particularly vulnerable (Friedmann 1929). Cowbird parasitism has been cited as a cause of population declines for the vireo (Franzreb 1989, USFWS 2002).

Throughout large parts of its range, the vireo may be considered a conservation-reliant species (Scott et al. 2005, Rohlf et al. 2014) because it is presumed to be dependent on human-directed cowbird control (Kus and Whitfield 2005, Cooper et al. 2019). This means that the threat posed by cowbird parasitism must be managed but cannot easily be eliminated (Goble et al. 2012). Cowbirds generally have been managed in California's riparian zones using the modified Australian crow (*Corvus* spp.) trap (Whitfield et al. 1999, Griffith and Griffith 2000, Whitfield 2000). Cowbird trapping is included as a recommended action in the decades-old recovery plan for the vireo (USFWS 1998), and has been effective at increasing vireo populations (Kus 1999). Cowbird trapping also has a variety of potentially negative consequences, which have been suggested and documented by many researchers, including the possible prevention of the development of parasitism-avoidance behaviors in host species (Rothstein and Peer 2005). Trapping can also result in non-target species captures and fatalities (Terpening 1997); for example, Eckrich et al. (1999) reported a single-trap caught 38 non-target individuals between 1 March and 30 June at Fort Hood, Texas, USA, in 1997, and McLeod and Koronkiewicz (2014) reported 247 non-target captures for a single trap operated from 17 May through 31 July at the Virgin River, Nevada, USA, in 2005. Although non-target species are released from traps, time spent away from their nests, especially overnight, may contribute to nest failures. This is particularly a concern for individuals that become habituated to the traps and to the food supplied, and are repeatedly captured. Trapping is also costly and labor intensive (USFWS 1998, Summers et al. 2006). Further, entities with profit motives may lobby for continued cowbird trapping and may not be subject to independent oversight or evaluation (Rothstein and Peer 2005) and control measures that involve euthanizing large numbers of cowbirds can present ethical questions that may be difficult for managers to address (Hall and Rothstein 1999, Rothstein and Peer 2005, Summers et al. 2007).

Adapting cowbird trapping techniques to address some of the downsides of trapping, developing alternate means of cowbird control, and comparing the efficacy of these techniques to that of cowbird trapping have been priorities for researchers, land managers, and regulatory agencies (USFWS 1998). Methods such as nest monitoring, coupled with cowbird egg removal (Kus 1999, Winter and McKelvey 1999), and shooting specific cowbirds (Summers et al. 2006) are intensive yet effective management techniques that have been used in lieu of cowbird trapping and euthanasia. For example, researchers at the Kern River Preserve in California (M. J. Whitfield, Southern Sierra Research Station, unpublished data) report that target-netting of territorial cowbirds is effective at significantly reducing cowbird numbers without impacts to non-target species. The removal of features such as roads or livestock that attract cowbirds (Summers et al. 2007) and increasing microhabitat cover and understory density through habitat restoration (Sharp and Kus 2006) are alternative methods that may reduce cowbird parasitism without having to conduct direct cowbird control. Site-specific information about the efficacy and cost of these various alternatives of cowbird control is required to best guide management decisions.

Cowbird trapping to benefit populations of vireos and other riparian bird species has been conducted on the Santa Clara River (SCR) in Ventura County, California, since 1993. Trapping has helped reduce cowbird numbers, significantly reduced parasitism of vireos, and contributed to an increase in vireo numbers on the SCR (Stanton et al. 2019). Recent cowbird point count and trapping data indicate a decline in cowbird detections and captures (Figure 1); thus, use of heavy or expanded trapping may no longer be needed to benefit songbird populations on the river. Over-deployment of cowbird traps could constitute a waste of conservation funds, negatively affect non-target species caught in cowbird traps, and have ethical ramifications.

In 2015, representatives from various organizations and institutions gathered to form a cowbird working group for the Lower SCR in Ventura County, California. Members of the group came from TNC, Western Foundation of Vertebrate Zoology, Southern Sierra Research Station, SCR Trustee Council, USFWS, United States Geological Survey, CDFW, Sweetwater Authority, Smithsonian Conservation Biology Institute, California State University-Channel Islands, and University of California-Santa Barbara. The goal of this group was to ensure the use of adaptive management of cowbird control to minimize costs, reduce non-target species captures, and lessen the conservation reliance of the vireo on trapping, while still positively affecting its population and those of other riparian bird species. The working group met annually through 2020, and conducted a 3-year study to test how altering the cowbird management program on TNC property would influence cowbird parasitism, nest success, and fecundity of the vireo and other songbirds on the river.

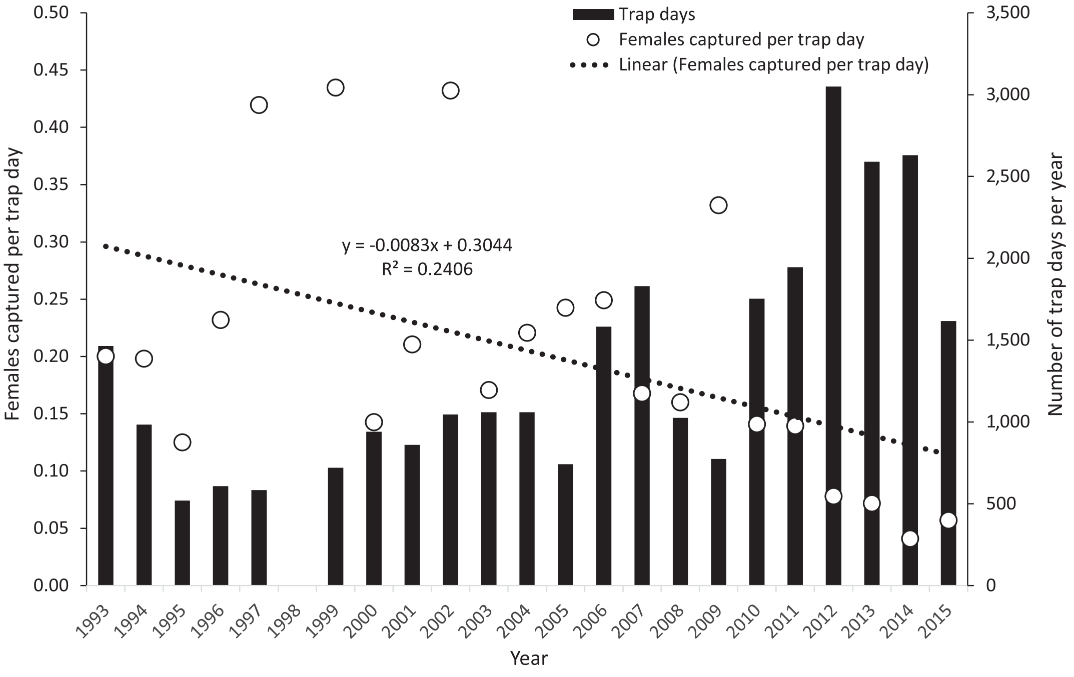

FIGURE 1 Number of trap days (bars) and female cowbirds caught per trap day (open circles) at the Santa Clara River, Ventura County, California, USA, 1993–2015. Each open circle represents the number of female cowbirds captured in all traps on the lower Santa Clara River during the spring trapping season of that year, divided by the number of trap days for that year. No trapping occurred in 1998. The data shown were collected from numerous locations along the lower Santa Clara River, including the control and treatment sites included in this study.

Our study involved testing how alterations to cowbird management on properties owned by The Nature Conservancy (TNC) influenced cowbird parasitism rates of the vireo, cowbird densities, and captures of non-target species on the SCR. We predicted that vireo parasitism rates would increase when intensive trapping was reduced, but that short-duration target-netting would be a useful alternative strategy for controlling parasitizing cowbirds.

STUDY AREA

Our study area was located on the Lower SCR in Ventura County, California (Figure 2). The Mediterranean climate features hot dry summers (Jul–Sep), and cooler, wetter fall (Oct–Dec) and winter (Jan–Mar) seasons, with an average annual rainfall of 44 cm. Spring (Apr–Jun) is the primary growing and flowering season for many annual plants. The second largest river in southern California, the mainstem of the Santa Clara is roughly 180 km in length and drains a watershed of approximately 4,200 km^2. We conducted our study in the spring and summer, between April and July of 2016 to 2018 at 2 sites along the mainstem of the SCR (Figure 2) that consist of braided river wash and adjacent, gently sloping riparian uplands that range from 55 m to 150 m in elevation. The treatment site was approximately 161 ha of riparian woodland vegetation located within 2 adjacent parcels owned and managed by TNC (Hanson and Bunn-Birrell). The control site was located 11 km upstream of the treatment site, and contained approximately 300 ha of riparian woodland vegetation on 3 adjacent parcels (Heritage Valley Parks, the Fillmore Cienega, and Shiells) owned by TNC and the California Department of Fish and Wildlife (CDFW).

Land uses in the SCR Valley included nature preserves, agriculture, housing developments, roads, and commercial areas. Common riparian plants included mulefat (*Baccharis salicifolia*), red willow (*Salix laevigata*),

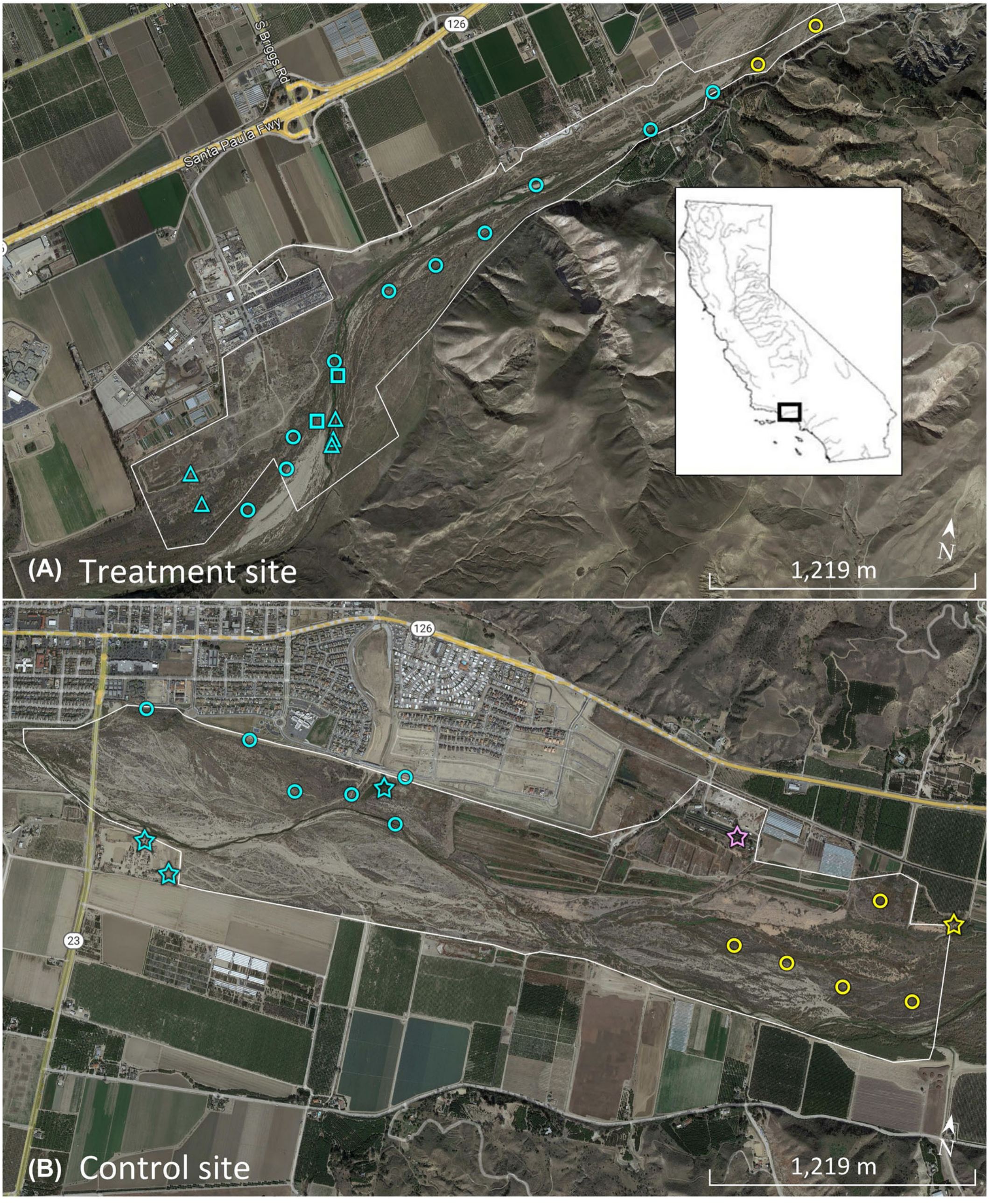

FIGURE 2 Study area on the Lower Santa Clara River in Ventura County, California, USA, 2016–2018, showing the treatment site (A) where we removed cowbird traps and tested target netting, and the control site (B) where contractors conducted cowbird trapping. The point count locations are depicted with circles and modified Australian crow trap locations with stars. Traps 1 and 2 on the control site are located together at stables at the southwest end of the site. Target-netting locations are shown on the treatment site, with squares indicating the 2016 locations, and triangles indicating the 2017 locations. For the treatment site, locations shown in blue are on the Hanson property, and those in yellow are on the Bunn-Birrell property. At the control site, locations shown in blue are on the Heritage Valley Parks property, the one in pink is on the Fillmore Cienega property, and those in yellow are on the Shiells property.

sandbar willow (*S. exigua*), arroyo willow (*S. lasiolepis*), understory species such as California blackberry (*Rubus ursinus*), and the non-native invasive plant species giant reed arundo (*Arundo donax*). Vireos typically build nests within 1.5 m of the ground (Sharp and Kus 2006) in willow, mulefat, and blackberry on the SCR (L. S. Hall, Western Foundation of Vertebrate Zoology, unpublished data). Common nest predators included Cooper's hawk (*Accipiter cooperii*) and California scrub-jay (*Aphelocoma californica*). Other common fauna included California towhee (*Melozone crissalis*), red-tailed hawk (*Buteo jamaicensis*), mule deer (*Odocoileus hemionus*), and bobcat (*Lynx rufus*).

METHODS

Historical cowbird trapping on the SCR

We used information about past cowbird trapping on the SCR for the study design. Before our study, between 1993 and 2015, managers conducted cowbird trapping using modified Australian crow traps (USFWS 1998) on the river. The number of trap days and location of traps varied over time, from zero traps used in 1998 to 20 traps deployed on TNC property during 3,000 trap days in 2012 (Figure 1). Independent contractors conducted trapping at a maximum cost of $76/trap/day plus setup and take down costs of $800 for each trap at the beginning and end of the trapping season. Trapping costs averaged $1,700/month/trap (Table 1). For comparison purposes, 2018 costs have been applied throughout this paper.

Traps were located in variable numbers on TNC properties, other private properties, and publicly owned lands on the river from 1993–2015. Most recently and relevantly, trapping on or adjacent to TNC properties between 1 April and 30 June was initiated in 2010 using 10 traps, and continued through 2015, with a maximum of 20 traps deployed (resulting in a maximum of 1,820 trap days per year and a maximum cost of $154,320 per year). From 2010 to 2015, 5 traps were specifically deployed each year at the control site, whereas on the treatment site there were 2 traps deployed each year from 2010 to 2012, and 1 trap deployed each year from 2013 to 2015. In the 2 breeding seasons (Apr–Jul) before our project started, 339 cowbirds (283 males, 142 females) were trapped at the control site in 2015, and 143 cowbirds (93 males, 43 females) were trapped in 2014; in contrast, on the treatment

TABLE 1 Comparison of a single season of cowbird management expenditures at the control site and treatment site on the Santa Clara River, Ventura County, California, USA, 2018. Costs are for the performance of activities alone, and do not include travel expenses, coordination, mapping, reporting, or bookkeeping.

Site	Management technique	Line item	Cost per unit	Units	Units required	Total cost
Control	Cowbird trapping	Trap operation	$76	Trap day	225	$17,100.00
	Cowbird trapping	Set-up and take-down	$800	Trap	5	$4,000.00
		Total				$21,100.00
Treatment	Point counts		$320	Survey	3	$960.00
	Nest monitoring		$4,952	Month	3	$14,856.00
	Cowbird trapping (contingency traps)	Trap operation	$76	Trap day	5	$380.00
	Cowbird trapping (contingency traps)	Set-up and take-down	$800	Trap	1	$800.00
		Total				$16,996.00

site, only 1 female cowbird was trapped in 2015, and 2 female cowbirds were trapped in 2014 (J. T. Griffith, Griffith Wildlife Biology, unpublished data).

Experimental trapping in 2016 and 2017

In 2016 and 2017, we collaborated with a permitted independent contractor to continue the use of 5 modified Australian crow traps on the control site. Each trap was 1.8 m wide × 2.4 m long × 1.8 m tall, with a 3.4-cm-wide capture slot on the top of the trap. A foraging tray was located on the front center of the floor panel under the capture slot. Four perches made of 1.3-cm-diameter wooden dowels were installed in each trap. Shade cloth covered the west-facing side panel. The traps included a 3.78-L water guzzler, approximately 0.6 kg of no-sunflower wild birdseed in the foraging tray, and live male and female decoy cowbirds in the ratio of 2:3, each with their right primary wing feathers clipped. Contractors serviced the traps daily on weekdays and locked them closed on weekends. Contractors removed and euthanized humanely (Fair et al. 2010) all captured cowbirds following permit restrictions from the USFWS and CDFW. Contractors recorded the numbers of male and female cowbirds, adult and juvenile cowbirds, and the daily number and species of all non-target individuals captured before releasing non-target individuals from the traps.

Five traps operated from 1 April through 31 May each year at the control site. Because historical cowbird trapping data from 2010–2015 on the SCR showed that the rate of cowbird captures fell markedly by the end of May each year (J. T. Griffith, unpublished data), and because Lynn and Kus (2014) demonstrated that shortening the cowbird trapping period by 2 months did not diminish the effectiveness of trapping, we tested the efficacy of a shorter trapping period by eliminating trapping in June, thereby shortening the trapping period by 1 month. We investigated whether the shorter trapping period would continue to be effective at reducing cowbird parasitism while also benefitting non-target species with fewer trap days. At the treatment site, we did not deploy any modified crow traps continuously throughout the April–May trapping period. Instead, we tested 2 different cowbird capture methods: a very short-term target-netting technique and a contingency trap technique.

We conducted target-netting at the treatment site on 5, 6, 14, 20, and 29 April and 7 May 2016, and on 25 May and 3, 21, and 30 June 2017 to test seasonal effectiveness of this method. We conducted target-netting in locations where female cowbirds had been detected on point counts or during other observations, and locations near parasitized nests. We conducted all netting in riparian vegetation suitable for, and occupied by, nesting vireos. We used nylon mist-nets (2.6 m tall × 6 m long, with 36-mm-wide openings) in combination with playback of cowbird vocalizations and a taxidermied, mounted female cowbird. We used 2 nets, either at angles or in a line depending on vegetation structure, in conjunction with the taxidermy mount placed about 1 m high on a shrub at the center of the nets. We placed a digital speaker on the ground below the mount to broadcast female cowbird chatter calls intermittently at 70 decibels. To minimize stress on any birds captured in the nets, we monitored the nets continuously from approximately 20–40 m away, and removed all birds immediately upon capture. We removed and euthanized any captured cowbirds. We released all other birds in the same location where we caught them with minimal processing following guidelines established by Fair et al. (2010).

To further evaluate cowbird management techniques on the treatment property, we also prepared to use a very short-term procedure in 2017 and 2018 should we not be able to remove territorial female cowbirds (those that we observed frequenting the same vireo territories over multiple days) using the target-netting procedure. The methods for these short trap sessions (contingency trapping) were identical to the longer sessions for the modified Australian crow trap on the control site (above), except for the length of time we used the traps (≤5 days). A permitted independent contractor operated the traps. Costs for the contingency trap were $800 for setup and take down plus $76 per day on the days the trap was deployed (Table 1).

Point counts

We conducted point counts on the control and treatment sites in 2016–2017, and as a follow-up on the treatment site in 2018, to determine densities of cowbirds. We conducted 3 counts on the control (12, 14, 28 Apr) and treatment sites (5, 6, 20 Apr) in 2016, and 2 counts on control (8, 26 May) and treatment sites (5, 23 May) in 2017, at 11 control points and 12 treatment points (Figure 2). In 2018, we conducted 2 counts on treatment sites: 1 on 7 May and 1 on 6 June, at 10 points. We conducted the counts at different times each year to evaluate the optimal timing for determining the numbers of cowbirds that might be parasitizing vireos at the sites.

The point count methodology followed standard passerine counting protocol (Ralph et al. 1995); all points were located at least 250 m apart throughout the riparian vegetation on the control and treatment properties, and we conducted counts on foot in the 4 hours following dawn each season, on weather days with no heavy fog, medium to heavy rains, or wind speeds >15 km/hour. During each count day, the stations on each property were divided between 2 observers. Observer variability was low, with the primary observer conducting counts on 11 of the 12 total sampling dates across the 3 years, 1 observer counting on 4 dates on the control site, and 2 other observers counting on 2 sampling dates on the treatment site. All observers had extensive passerine point counting experience. All counts were single-observer 10-minute counts. During each count observers recorded the age, sex, number, and distance (in m) to each cowbird from the center of each station.

To estimate cowbird densities, we analyzed all point count data using program DISTANCE (version 7.3; Thomas et al. 2010, Buckland et al. 2015) in R Studio (version 1.2.5019; RStudio Team 2020). We did not truncate distances because the sample size of cowbird detections was low, and so truncation is not recommended (Buckland et al. 2015). We used the following models based on Akaike's Information Criterion and goodness-of-fit statistics (goodness-of-fit P-values from 0.11–0.51): for the control site in 2016, the hazard rate model with Hermite polynomial; for the treatment site in 2017, the half normal model with Hermite polynomial; and for the treatment site in 2018, the hazard rate model with simple polynomial. For all other years and locations, we did not count any cowbirds so we could not calculate density estimates. We compared density estimates between the control and treatment sites using 2-sample t-tests. Point count surveys cost $320 per survey (Table 1).

Nest monitoring

We conducted vireo nest monitoring on the control and treatment sites in 2016 and 2017 from the time vireos were on territory (~1–15 Apr) until they had finished all nest attempts (~31 Jul). In 2018 we conducted nest monitoring only on the treatment site, between 1 April and 31 July. All nest visits in all 3 years followed standard vireo protocols developed by Kus (1999) and Sharp and Kus (2006). When we located a nest, if the behavior of an adult or pair indicated that they were building, then we avoided a nest visit. We made nest visits only after carefully observing the immediate area for potential predators such as Cooper's hawks and California scrub-jays, and when the parents were off gathering food for the young. We checked contents from a distance of approximately 1.5 m with telescoping poles with mirrors. We revisited nests no more frequently than once every 5–8 days to minimize impacts. At each check we recorded the number of vireo eggs or nestlings, the number of cowbird eggs or nestlings, or evidence of depredation. Because vireos do not eject or otherwise remove cowbird eggs, cowbird eggs laid between nest checks remain in the nest. Vireos may very infrequently abandon parasitized nests as a response to parasitism, but the cowbird egg also remains in the nest after abandonment, allowing for determination of parasitism rates. We addled any cowbird eggs found in vireo nests once the vireo clutch was complete (i.e., contained ≥3 vireo eggs) and left cowbird eggs in place so that vireos would not abandon the nest. Nest monitoring costs were $4,952 per month (Table 1).

RESULTS

In 2016, the contractor reported that they captured 271 cowbirds (102 females, 169 males) in the 5 traps between 1 April and 31 May at the control site (Table 2), with 190 (70.1%) captured in April. Trap numbers 1 and 2 (Figure 2) captured 224 of the 271 cowbirds (82.7%; 136 males, 88 females). All 5 of the traps also captured 340 non-target birds of 5 species: California towhee, yellow-headed blackbird (*Xanthocephalus xanthocephalus*), red-winged blackbird (*Agelaius phoeniceus*), house finch (*Haemorhous mexicanus*), and house sparrow (*Passer domesticus*). The contractor reported 3 mortalities of non-target species in the traps. On point counts, we observed 2 cowbirds at the Heritage Valley Parks portion of the control site, 1 male and 1 female, for an estimated density of 0.083 ± 0.083 (SE) cowbirds/ha (Table 3). On the Shiells property portion of the control site, we did not observe cowbirds (Table 3). The contractor monitored 27 vireo nests in 2016, and none of the nests were parasitized (Table 2).

In 2017, the contractor reported catching 181 cowbirds (97 females, 84 males) in the traps at the control site in April and May, with 103 cowbirds (56.9%) captured in April. Trap numbers 1 and 2 (Figure 2) captured 126 of the 181 cowbirds (69.6%; 53 males, 73 females). Among all 5 traps, 303 non-target individuals of 8 species were captured. The same species captured in 2016 were captured in 2017 plus white-crowned sparrow (*Zonotrichia leucophrys*), northern mockingbird (*Mimus polyglottos*), and Brewer's blackbird (*Euphagus cyanocephalus*). One California towhee perished in the trap. We did not count any cowbirds on the control site in 2017 (Table 3). The contractor monitored 40 vireo nests and family groups in 2017, and none were parasitized (Table 2).

In 2016, during target-netting on the treatment site, we did not catch any female cowbirds, but we captured 5 non-target individuals of 2 species: 1 common yellowthroat (*Geothlypis trichas*) and 4 song sparrows (*Melospiza melodia*). None of the non-target individuals were harmed, and they were released in <10 minutes. On point counts we did not detect any cowbirds on the treatment site (Table 3). We monitored 5 vireo nests and family groups on the treatment site in 2016 and found no parasitism (Table 2).

In 2017, during target-netting at the treatment site, we captured no female cowbirds, but we captured 1 male cowbird and 1 individual of 3 non-target species: black phoebe (*Sayornis nigricans*), song sparrow, and yellow warbler (*Setophaga petechia*). None of the birds were harmed, and we released them in <10 minutes. A comparison of numbers of female cowbirds captured between the control and treatment sites across 2016 and 2017 indicated that we trapped more cowbirds on the control than the treatment site ($t_2 = 39.8$, $P = 0.001$). On point counts in 2017, we observed 6 cowbirds on the Hanson portion of the treatment site, for an estimated density of 0.075 ± 0.05 cowbirds/ha (Table 3). On the Bunn-Birrell portion of the treatment site, we did not observe any cowbirds (Table 3). A comparison of cowbird densities between the control and treatment sites across 2016 and 2017 did not provide any evidence that densities differed between sites ($t_2 = 0.072$, $P = 0.95$). We monitored 50 vireo nests and family groups in 2017, 7 of which (14.0%) were parasitized (Table 2). A comparison of the number of

TABLE 2 Comparison of numbers of cowbirds captured and cowbird parasitism at control and treatment sites on the Santa Clara River, Ventura County, California, USA, 2016–2018.

Site	Year	Number of cowbirds captured	Number of female cowbirds captured	Ratio (and %) of parasitized least Bell's vireo broods
Control	2016	271	102	0/27 (0%)
	2017	181	97	0/40 (0%)
Treatment	2016	0	0	0/5 (0%)
	2017	0	0	7/50 (14.0%)
	2018	4	2	0/20 (0%)

TABLE 3 Density statistics from point counts of brown-headed cowbirds on the treatment and control sites on the Santa Clara River, Ventura County, California, USA, 2016–2018.

Year, location	Density estimate (cowbirds/ha)	SE	% CV	Lower CI	Upper CI	Df	Goodness-of-fit test statistic	Goodness-of-fit *P*-value	Number of cowbirds counted
2016									
Heritage Valley Parks (control)	0.083	0.083	1.00	0.0098	0.7047	5	0.333	0.11	2
Shiells (control)	0.000								0
Hanson (treatment)	0.000								0
Bunn-Birrell (treatment)	0.000								0
2017									
Heritage Valley Parks (control)	0.000								0
Shiells (control)	0.000								0
Hanson (treatment)	0.075	0.050	0.6669	0.0191	0.2970	9	0.143	0.41	6
Bunn-Birrell (treatment)	0.000								
2018									
Hanson (treatment)	0.016	0.011	0.6667	0.0040	0.0627	9	0.116	0.51	8

parasitized broods between the control and treatment sites across 2016 and 2017 did not provide any evidence that parasitism differed between sites (t_2 = −1.00, P = 0.42).

In 2018, point counts on the treatment site detected 8 cowbirds for an estimated density of 0.016 ± 0.011 cowbirds/ha (Table 3). We monitored 20 vireo nests on the treatment site in 2018, and did not record parasitism (Table 2).

In 2018, 2 female cowbirds were repeatedly observed within the vicinity of 4 vireo territories at the treatment site and might have parasitized these nests had they not been removed. For this reason, we opened a contingency trap from 7–11 May 2018, and it captured 4 male and 2 female cowbirds (Table 2). We removed the trap after 5 days.

At the control site, a single season of trapping for 225 trap days with trap set-up at the beginning of the season and break down at the end resulted in a cost of $21,000 (Table 1). At the treatment site, a single season of point counts and nest monitoring cost $15,815. The contingency trap was operated for 5 days for a cost of $1,180. Thus, total costs for a single season of point counts, nest monitoring, and contingency trapping at the treatment site were $16,995 (Table 1). We based costs on the performance of activities alone. Travel expenses and administrative costs are not included.

DISCUSSION

Cowbird control methods comparison

This study was designed to evaluate a variety of techniques for cowbird control and monitoring, with the aim of providing adaptive management alternatives for managers. First, for modified Australian crow traps, we tested the impacts of shortening the cowbird trapping period, and found that a reduction from 3 months to 2 months during the bird breeding season still resulted in a large number of cowbird captures, with no observed nest parasitism on the control site, among 67 nests monitored. These results were similar to a 4-year study on the San Diego River where shortened trapping (2 months) was effective at reducing cowbird parasitism, and increasing vireo nest success and productivity (Lynn and Kus 2014). Next, we evaluated what happened with parasitism rates when modified crow traps were removed, and only 1 very short-term contingency trap session was conducted; over a 3-year period, we observed parasitism only in the second year. In follow-up monitoring in 2020, vireo nest monitoring similarly showed only 10% parasitism (i.e., 3 nests of 30 monitored; L. S. Hall, Western Foundation of Vertebrate Zoology, unpublished data). Thus, intensive, routine, and long-term trapping was not needed on the treatment properties from 2016 through 2018, and even into 2020, to keep parasitism at low levels for the vireo.

Our study also tested the efficacy of target-netting as an alternate form of direct cowbird control. The target-netting method tested during this study was not as effective as cowbird traps. We did not capture any female cowbirds using the netting technique over 2 seasons. Although the technique has worked well elsewhere, our poor results may have been due to a combination of factors. First, we had very low densities of cowbirds as determined by playback on the treatment site in both 2016 and 2017, similar to the low number of captures in modified crow traps on the site in 2014 and 2015 (only 3 cowbirds). In contrast, on the South Fork Kern River, cowbird numbers are much higher, averaging 0.43 female cowbirds/station in 2017 and 0.36 female cowbirds/station in 2018 (M. J. Whitfield, unpublished data). On the Kern River in 2018, researchers captured 74 female cowbirds using target-netting (in 45 attempts), whereas only 11 females were caught in their 4 modified crow traps over 250 trap days. In 2017, 29 females were caught in 40 target-netting attempts on the Kern, whereas 12 females were caught in 3 traps over 187 trap days in their study. The traps at Kern River Preserve are not opened until May, so few (if any) migrating cowbirds were captured. Thus, their higher densities of cowbirds may have made the target-netting technique more effective at the Kern River Preserve than at our treatment site on the Santa Clara River.

Other possible reasons for our poor netting results may have included the large size of our treatment properties, and the wide extent of riparian vegetation across the property. For example, we tested target-netting in a separate location in 2016 and 2017 in Ventura County (TNC's Ormond Beach property), and in 1 session we captured 2 female cowbirds within just a few hours. The Ormond Beach site is much easier for researchers to access, is much smaller in size (~60 ha), and the songbird habitat at the site is more concentrated within a portion of the property, allowing for efficient netting. Thus, target-netting may have site-specific effectiveness that should be considered prior to its use by managers.

In contrast to target-netting, the contingency trap method was very effective at removing female cowbirds in the vicinity of vulnerable vireo nests on the treatment site. In 2018, the contingency trap was used for 5 days to capture 2 females that were repeatedly observed in the vicinity of several vireo territories, and had the potential to parasitize nests that we were monitoring. Thus, the contingency trap method, combined with nest monitoring, may be a more desirable control method for managers when a low number (and density) of cowbird females are influencing vireos or other sensitive bird species' nesting efforts.

Non-target species captures

In 2016 and 2017, cowbird trapping using the standard modified crow trap resulted in >300 captures each year of non-target species, especially California towhees, as opposed to ≤5 non-target species captures using target-netting. It is likely that many of the non-target species captures in the modified crow traps were of the same individuals, but because they were not marked, the contractor could not determine their numbers. Non-target capture data from cowbird traps set at the Sweetwater Reservoir in San Diego County, California, indicated high recapture rates (94.6%) for California towhees in particular (P. Famolaro, Sweetwater Authority, unpublished data). In our study, individuals caught in traps were kept all day or overnight, because the traps were checked only once per day, which is standard for this type of trapping. The retention of non-target species in the traps for periods of this length likely led to some nest failures, as compared to the non-target species that were released from target-nets within minutes of their captures (Rothstein and Peer 2005, Rothstein and Cook 2000). In addition, in our target-netting, no vireos or other sensitive songbirds were attracted into the nets, nor was there any songbird mortality with this method, whereas there were 4 mortalities in the modified crow traps on the control site across both years. Thus, our study indicated that it is important for managers to monitor the numbers of individual non-target species in all cowbird traps to determine annual effects to these species, and to carefully evaluate any trapping that leads to high numbers of non-target species captures, to determine if these potentially high impacts are justified.

Estimating cowbird densities

On the control site, estimated cowbird densities based on point counts in April and May were low: 0–0.083 cowbirds/ha in 2016 and no cowbirds in 2017. This is despite the contractor reporting 199 female cowbirds trapped at this site over the 2 seasons. The main reason for this difference is that cowbirds typically commute between separate feeding and breeding areas (Rothstein et al. 1984, 1987; Chace et al. 2005). The point counts detect cowbirds in their breeding areas in the morning, whereas the traps attract cowbirds feeding in the afternoon. Traps contain decoy birds and a steady supply of seeds easily seen by cowbirds from outside, and can lure cowbirds commuting from up to 7 km away (Rothstein et al. 1984). Thus, traps in our study were likely drawing cowbirds from surrounding areas, increasing their numbers relative to the estimated point count densities. Another factor likely affecting estimated cowbird densities versus trapped cowbird numbers was that point count stations on the control site were located in the center of songbird habitat within the riparian channel, whereas 2 of the cowbird traps (numbers 1 and 2; Figure 2) were located about 400 m from the points and were purposely situated at a horse stables, where they captured 70–83% of all the cowbirds trapped on the control site in 2016 and 2017 (and in 2014 and 2015 during pre-treatment trapping). Although useful for trapping cowbirds, the stables likely attracted them from a much larger area than the proximal riparian floodplain. If cowbird captures are excluded from these 2 traps, only 102 cowbirds were captured in 2016–2017 among the other 4 traps on the river, versus 452 with the 2 traps included. Thus, only 23% of the cowbirds caught during the study on the control site were actually located in the riparian area that we were sampling, and so our low estimated densities were more reflective of this. Based on this and reports from other researchers (Purcell and Verner 1999, Farmer 1999), we believe that the point count method, which is a well-established method for estimating bird densities and has been used extensively to monitor cowbirds and their host species (Rothstein et al. 1987, Whitfield et al. 1999, Chace et al. 2005), still has real utility for managers for providing an index to cowbird activity within the area that is of most direct concern to songbirds.

We determined that April may not be the best month for estimating cowbird densities because many cowbirds are still migrating (Peer et al. 2020), and thus may not be representative of the numbers of parasitizing birds. In April 2016 and 2017, there was a temporary pulse in the numbers of female cowbirds trapped (i.e., 293 cowbirds in Apr vs. 159 in May) across both years, accounting for 68–70% of all of the female cowbirds trapped. May counts, and possibly early June counts when cowbirds are still vocalizing and females are targeting re-nesting species including vireos, are probably best for determining densities of actively parasitizing cowbirds.

Parasitism and adaptive management

Parasitism rates ranged from zero to 14% during our trap reduction experiment at the treatment site. In comparison, at the San Luis Rey River in San Diego, California, cowbird parasitism of vireo nests increased from a low of 19% in 1996 while trapping was in place (Kus 1999), to a high of 56% in 2003 after trapping stopped in 1999 (Sharp and Kus 2006). Our results also sit midway between those seen during similar experiments conducted for Kirtland's warbler (*Setophaga kirtlandii*) in the northern Lower Peninsula of Michigan, USA (Cooper et al. 2019), and black-capped vireo (*Vireo atricapilla*) in Fort Hood, Texas (Kostecke et al. 2010). In Michigan, only 20 cowbirds were detected during 3 years of surveys (2015–2017) after trapping reductions began, and few nests were parasitized. In Texas, parasitism rates increased rapidly from 7% in 2006 to a high of 33% in 2009 after trapping and shooting ceased but remained very low or at zero at nearby control sites where these practices continued. For comparison, parasitism rates on the Edwards Plateau in in Real, Bandera, Kerr, and Edwards counties, Texas in the absence of control measures were 30–31% in 2012–2013 (Locatelli et al. 2016). These varied results suggest that in addition to the effect of trap reduction, parasitism rates are influenced by differences in the landscape context of the songbirds' habitats, host densities, and the life history of cowbirds. Large populations of cowbirds have existed year-round in Texas (Lowther 1993, Peterjohn et al. 2000), and black-capped vireo habitat at Fort Hood is surrounded by agriculture. In contrast, cowbirds did not arrive on the Michigan peninsula until the late nineteenth century (Mayfield 1960, 1977), and occur at much lower numbers within a forested landscape (Peer et al. 2020).

In developing an adaptive management approach to cowbird control, one must consider the rate of parasitism that can be tolerated by the songbird of interest. Based on an analysis of 20 years of data from vireo populations in southern California, Kus and Whitfield (2005) determined that with a population already at carrying capacity (and thus, not declining), it could maintain equilibrium with parasitism frequencies of up to 30%. On the SCR, however, the vireo population continues to expand, so it has not yet reached carrying capacity. Additionally, the SCR is a potential source population for vireo recolonization of their historical range in the Central Valley of California. Vireos have been observed breeding farther north in restored riparian vegetation at the San Joaquin River National Wildlife Refuge (Wood et al. 2006) and other areas in the Central Valley (Howell et al. 2010), and high parasitism rates could hamper progress in their recolonization of these areas. Kus and Whitfield (2005) and our SCR cowbird working group have recommended that increasing and source populations for colonization of the historical range should be managed with parasitism thresholds <30%. In this study, the parasitism rates for the vireo that we observed over a 3-year period, even with trap removal, were well below that threshold, and were likely low enough to be well tolerated by the vireo population on the SCR, which is currently estimated to be ≥500 pairs (Stanton et al. 2019). Based on this, the cowbird working group recommended to managers in 2018 that vireo parasitism rates >15–20% should trigger reinstatement of trapping efforts using modified crow traps or contingency traps, or both if needed, to reduce parasitism rates.

Land managers encounter competing narratives related to cowbird control. One narrative is that control measures could and should be expanded to maximize cowbird captures and eliminate all brood parasitism. Another narrative suggests that any control is too much, and a third narrative is that there should be a balance, and an adaptively managed way of planning. Trap density at our control site was high compared with other sites across the region, with an average of 1 trap per 11 ha, with a correspondingly high cost. Trap density at our treatment site historically was much lower with a maximum of 1 trap per 45 ha. Based on our findings with experimental trap duration and removal (Table 1), and on the findings of other researchers, recommendations for expanding or intensifying the use of cowbird traps on the SCR appear to be currently unnecessary and would be a poor use of funds. We encourage managers to conduct similar reviews of their trap densities, to make sure that they are not needlessly saturating an area with traps. Rather than supporting or expanding cowbird trapping programs, limited conservation funds may in many cases be better spent protecting and restoring habitat (Rothstein et al. 2003, Rothstein and Peer 2005) and where this is not possible, funding non-breeding season research. It has been repeatedly demonstrated that over the long term, protection and management of riparian landscapes and conservation during the non-breeding season is key to the long-term survival of many Neotropical-Nearctic migratory birds (Rothstein et al. 2003, Rothstein and Peer 2005, Faaborg et al. 2010, Rosenberg et al. 2019). Riparian vegetation supports exceptional productivity, density, and diversity of bird species (Sanders and Edge 1998) and is among the most threatened of vegetation types in California (Katibah 1984), occupying <5% of its original extent (Luther et al. 2008). The SCR's riparian vegetation is no exception; natural resources in the watershed are increasingly threatened by land conversion and hydrological modifications (Parker et al. 2014).

Over the past 2 decades, TNC, other land trusts, and the State of California have acquired several thousand hectares along the SCR, and these and other entities manage more than 600 ha of riparian restoration projects. Researchers with a study area at the 105-ha Hedrick Ranch Nature Area reserve on the SCR reported that high-quality vegetation limits cowbird parasitism. For example, traps were completely removed or limited on this restored site to just 1 used during the 2015–2017 breeding seasons, and there was no parasitism at ≥30 vireo nests for the study period and subsequently (L. S. Hall, unpublished data). The researchers concluded that this was likely due to the existence of high-quality vireo habitat on the reserve, namely dense and multi-layered vegetation that can prevent vireo nest detection and provide a wide variety of host species for cowbirds, thereby reducing the probability that vireo nests are parasitized.

While recognizing the importance of riparian vegetation quantity and quality for the long-term recovery and maintenance of migratory bird populations, we also recognize that cowbird control remains an important management tool in California's riparian ecosystems, particularly when used in a framework that can respond to changing conditions in real time. Additionally, the time and expense required for land acquisition and restoration (Parker et al. 2016) require interim measures to prevent songbird population declines and assist region-wide recovery efforts. The high number of non-target species captures and the costs associated with daily trap maintenance can make broadly applied cowbird trapping costly, both monetarily and ecologically. By examining daily capture data for female cowbirds, we were able to reduce our trapping duration from 3 months to 2 months at a considerable cost savings and reduction in non-target species' captures with no impact on parasitism rates. We also were able to maximize trapping efficiency by determining how and where to deploy traps using an adaptive framework of point counts and nest monitoring concurrent with short-term, intensive trapping. Our deployment of a contingency trap at the treatment site after observing 2 female cowbirds allowed us to capture both individuals relatively quickly and with no impact to non-target species, thereby avoiding the financial and ecological costs associated with a full season's worth of trap deployment. Long-term point count and nest monitoring data may also allow for the development of a predictive model to forecast cowbird parasitism rates, thereby providing managers with a means of preparing their management plans ahead of time.

MANAGEMENT IMPLICATIONS

Adaptive management of cowbirds (and their hosts) has been called for many times over many years. In our study we conducted an adaptive experimental evaluation of techniques, timing, and strategies, and found that there were meaningful ways to adapt to be more effective and efficient in our cowbird management. The implications for managers are that intensive, routine, and long-term cowbird trapping may not be needed in all instances, and should be thoroughly evaluated on a site- and time-specific basis. The duration of trapping, and the types of traps or capture methods used, can be modified as needed to make management more flexible, and again is influenced by site and time needs. Additionally, there can be several costs associated with long-term use of modified Australian crow traps, namely that the expense of trapping efforts reduces available funds for vegetation restoration. Restoration might ultimately be more productive for imperiled bird hosts. There are also costs associated with potential captures of non-target bird species that can have their breeding season disrupted significantly. Finally, there are alternatives or at least complementary monitoring methods (specifically counts to determine cowbird densities and nest monitoring of host parasitism rates) that can provide useful information to evaluate the success, or failure, of cowbird management. The number of individual non-target species should be monitored in cowbird traps to determine impacts to these species. We recommend marking these birds upon their first capture so that all recaptured individuals can be counted when recaptured, and recommend that traps that capture moderate to high non-target species numbers (e.g., >3 individuals/day) be checked twice per day to release non-target species individuals more often so that they have a greater chance of successfully nesting. Checking some traps more often will increase costs but will benefit non-target species' populations.

ACKNOWLEDGMENTS

We thank all members of the Santa Clara River Cowbird Working Group, including A. H. Alvarado, M. J. Anderson, N. W. Cooper, P. C. Famolaro, S. C. Hampton, B. E. Kus, J. Marek, E. Morrisette, E. J. Remson, S. I. Rothstein, and L. N. Verdone. We thank A. J. Searcy, J. Sexton, J. C. Griffith, J. T. Griffith, and D. Kisner for nest-monitoring of vireos and cowbird trapping and netting, P. Larramendy for DISTANCE analyses, and J. Watson for her time on contract management. We thank The Nature Conservancy and the Santa Clara River Trustee Council for funding this research, and The Southern Sierra Research Station and Western Foundation of Vertebrate Zoology for staff time and logistical support on this project.

ETHICS STATEMENT

All data included in this study that involved the care and use of vertebrate animals were collected following animal welfare protocols and guidelines of the North American Ornithological Council (Fair et al. 2010), and were approved by The Nature Conservancy and the Western Foundation of Vertebrate Zoology. All nest monitoring was conducted by permitted contracted biologists, and authors L. S. Hall and R. Corado under USFWS permit TE36500A-1 and CDFW permit SC-006803 and a Memorandum of Understanding (MOU). All target-netting was conducted by permitted biologist D. Kisner (U.S. Geological Survey banding permit 22372-K and CDFW permit SC-008126). All cowbird captures in modified Australian crow traps, and subsequent euthanasia, were made through permit to Griffith Wildlife Biology (USFWS permit TE758175-7 and CDFW MOU).

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available on request because of privacy or ethical restrictions.

ORCID

Sophie S. Parker https://orcid.org/0000-0002-9134-0742
Linnea S. Hall https://orcid.org/0000-0001-5404-631X
Mary J. Whitfield https://orcid.org/0000-0001-9405-5501
Kathryn R. Selm https://orcid.org/0000-0003-4399-9494
René Corado https://orcid.org/0000-0002-2532-6395

REFERENCES

Buckland, S. T., E. A. Rexstad, T. A. Marques, and C. S. Oedekoven. 2015. Distance sampling: methods and applications. Methods in Statistical Ecology. Springer, New York, New York, USA.

Chace, J. F., C. Farmer, R. Winfree, D. R. Curson, W. E. Jensen, C. B. Goguen, and S. K. Robinson. 2005. Cowbird (*Molothrus* spp.) ecology: a review of factors influencing distribution and abundance of cowbirds across spatial scales. Ornithological Monographs 2005:45–70.

Conard, S. G., R. L. MacDonald, and R. F. Holland. 1977. A short review of the status of riparian forests in California. Pages 47–55 *in* A. Sands, editor. Riparian forests in California, their ecology and conservation. Institute of Ecology Publication 15. University of California, Davis, USA.

Cooper, N. W., C. S. Rushing, and P. P. Marra. 2019. Reducing the conservation reliance of the endangered Kirtland's warbler through adaptive management. Journal of Wildlife Management 83:1297–1305.

Eckrich, G. H., T. E. Koloszar, and M. D. Goering. 1999. Effective landscape management of brown-headed cowbirds at Fort Hood, Texas. Studies in Avian Biology 18:267–274.

Faaborg, J., R. T. Holmes, A. D. Anders, K. L. Bildstein, K. M. Dugger, S. A. Gauthreaux, P. Heglund, K. A. Hobson, A. E. Jahn, D. H. Johnson, et al. 2010. Conserving migratory land birds in the New World: Do we know enough? Ecological Applications 20:398–418.

Faber, P. M. 1989. The ecology of riparian habitats of the southern California coastal region: a community profile. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Fair, J. M., E. Paul, and J. Jones. 2010. Guidelines to the use of wild birds in research. Ornithological Council, Washington, D.C., USA.

Farmer, C. 1999. The density and distribution of brown-headed cowbirds: The central coastal California enigma. Studies in Avian Biology 18:62–67.

Franzreb, K. E. 1989. Ecology and conservation of the endangered least Bell's vireo. Fish and Wildlife Service Sacramento, California Endangered Species Office, Sacramento, USA.

Friedmann, H. 1929. The cowbirds: a study in the biology of social parasitism. Charles C. Thomas, Springfield, Illinois, USA.

Goble, D. D., J. A. Wiens, J. M. Scott, T. D. Male, and J. A. Hall. 2012. Conservation-reliant species. BioScience 62:869–873.

Griffith, J. T., and J. C. Griffith. 2000. Cowbird control and the endangered least Bell's vireo: a management success story. Pages 342–356 *in* J. N. M. Smith, T. L. Cook, S. I. Rothstein, S. K. Robinson, and S. G. Sealy, editors. Ecology and management of cowbirds and their hosts: studies in the conservation of North American passerine birds. University of Texas Press, Austin, USA.

Hall, L. S., and S. I. Rothstein. 1999. Cowbird control: the efficacy of long-term control and proposed alternatives to standard control practices. Studies in Avian Biology 18:254–259.

Howell, C. A., J. K. Wood, M. D. Dettling, K. Griggs, C. C. Otte, L. Lina, and T. Gardali. 2010. Least Bell's vireo breeding records in the Central Valley following decades of extirpation. Western North American Naturalist 70:105–113.

Katibah, E. F. 1984. A brief history of riparian forests in the Central Valley of California. Page 23–29 *in* R. E. Warner, and K. M. Hendrix, editors. California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley, USA.

Kostecke, R. M., D. A. Cimprich, and S. G. Summers. 2010. Partial cessation of cowbird management at Fort Hood, Texas: year five. Pages 101–123 *in* Endangered Species Monitoring and Management at Fort Hood, Texas: 2010 Annual Report. The Nature Conservancy, Fort Hood Project, Fort Hood, Texas, USA.

Kus, B. E. 1999. Impacts of brown-headed cowbird parasitism on productivity of the endangered least Bell's vireo. Studies in Avian Biology 18:160–166.

Kus, B. E., and M. J. Whitfield. 2005. Parasitism, productivity, and population growth: response of least Bell's vireos (*Vireo bellii pusillus*) and southwestern willow flycatchers (*Empidonax traillii extimus*) to cowbird (*Molothrus* spp.) control. Ornithological Monographs 57:16–27.

Lowther, P. E. 1993. Brown-headed cowbird (*Molothrus ater*), version 2.0. The birds of North America. Cornell Lab of Ornithology, Ithaca, New York, USA.

Lowther, P. E. 2018. Lists of victims and hosts of the parasitic cowbirds (*Molothrus*). Field Museum, Chicago, USA.

Luther, D., J. Hilty, J. Weiss, C. Cornwall, M. Wipf, and G. Ballard. 2008. Assessing the impact of local habitat variables and landscape context on riparian birds in agricultural, urbanized, and native landscapes. Biodiversity and Conservation 17:1923–1935.

Lynn, S., and B. E. Kus. 2014. Distribution, abundance, and breeding activities of the least Bell's vireo along the San Diego River, California. 2008–2012 summary report. Prepared for the San Diego River Conservancy, San Diego, California.

Mayfield, H. F. 1960. The Kirtland's warbler. Cranbrook Institute Science, Bloomfield Hills, Michigan, USA.

Mayfield, H. F. 1977. Brown-headed cowbird: agent of extermination. American Birds 31:107–113.

McLeod, M. A., and T. J. Koronkiewicz. 2014. Comparison of capture and escape rates between different types of portable cowbird traps. Wildlife Society Bulletin 38:611–618.

Morrison, M. L., and A. Averill-Murray. 2002. Evaluating the efficacy of manipulating cowbird parasitism on host nesting success. Southwestern Naturalist 47:236–243.

Parker, S. S., E. J. Remson, and L. N. Verdone. 2014. Restoring conservation nodes to enhance biodiversity and ecosystem function along the Santa Clara River. Ecological Restoration 32:6–8.

Parker, S. S., L. N. Verdone, E. J. Remson, and B. S. Cohen. 2016. Prioritizing riparian conservation: a methodology developed for the Santa Clara River, California. Ecological Restoration 34:61–67.

Peer, B. D., B. E. Kus, M. J. Whitfield, L. S. Hall, and S. I. Rothstein. 2020. Management of the brown-headed cowbird: implications for endangered species and agricultural damage mitigation. Human-Wildlife Interactions 14:461–475.

Peer, B. D., J. W. Rivers, and S. I. Rothstein. 2013. The brown-headed cowbird: North America's avian brood parasite. Chinese Birds 4:93–98.

Peterjohn, B. G., J. R. Sauer, and S. Schwarz. 2000. Temporal and geographic patterns in population trends of brown-headed cowbirds. Pages 21–34 *in* J. N. M. Smith, T. L. Cook, S. I. Rothstein, S. K. Robinson, and S. G. Sealy, editors. Ecology and management of cowbirds and their hosts: studies in the conservation of North American passerine birds. University of Texas Press, Austin, USA.

Purcell, K. L., and J. Verner. 1999. Abundance and rates of brood parasitism by brown-headed cowbirds over an elevational gradient in the southern Sierra Nevada. Studies in Avian Biology 18:97–103.

Ralph, C. J., S. Droege, and J. R. Sauer. 1995. Managing and monitoring birds using point counts: standards and applications. Pages 161–168 *in* C. J. Ralph, J. R. Sauer, and S. Droege, technical editors. Monitoring bird populations by point counts. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. Proceedings of the National Academy of Sciences 86:7658–7662.

Robinson, S. K., S. I. Rothstein, M. C. Brittingham, L. J. Petit, and J. A. Grzybowski. 1995. Ecology and behavior of cowbirds and their impact on host populations. Pages 428–460 *in* T. E. Martin and D. M. Finch, editors. Ecology and management of neotropical migratory birds. Oxford University Press, New York, New York, USA.

Rogers, C. M., M. J. Taitt, J. N. M. Smith, and G. Jongejan. 1997. Nest predation and cowbird parasitism create a demographic sink in wetland-breeding song sparrows. Condor 99:622–633.

Rohlf, D. J., C. Carroll, and B. Hartl. 2014. Conservation-reliant species: toward a biology-based definition. BioScience 64: 601–611.

Rosenberg, K. V., A. M. Dokter, P. J. Blancher, J. R. Sauer, A. C. Smith, P. A. Smith, J. C. Stanton, A. Panjabi, L. Helft, M. Parr, and P. R. Marra. 2019. Decline of the North America avifauna. Science 366:120–124.

Rothstein, S. I. 1994. The cowbird's invasion of the far West: history, causes and consequences experienced by host species. Studies in Avian Biology 15:301–315.

Rothstein, S. I., and T. L. Cook. 2000. Introduction to Cowbird management, host population regulation and efforts to save endangered species. Pages 323–332 *in* J. N. M. Smith, T. L. Cook, S. I. Rothstein, S. K. Robinson, and S. G. Sealy, editors. Ecology and management of cowbirds and their hosts: studies in the conservation of North American passerine birds. University of Texas Press, Austin, USA.

Rothstein, S. I., B. E. Kus, M. J. Whitfield, and S. J. Sferra. 2003. Recommendations for cowbird management in recovery efforts for the southwestern willow flycatcher. Studies in Avian Biology 26:157–167.

Rothstein, S. I., and B. D. Peer. 2005. Conservation solutions for threatened and endangered cowbird (*Molothrus* spp.) hosts: separating fact from fiction. Ornithological Monographs 57:98–114.

Rothstein, S. I., J. Verner, and E. Stevens. 1984. Radio-tracking confirms a unique diurnal pattern of spatial occurrence in the parasitic brown-headed cowbird. Ecology 65:77–88.

Rothstein, S. I., J. Verner, E. Stevens, and L. V. Ritter. 1987. Behavioral differences among sex and age classes of the brown-headed cowbird and their relation to the efficacy of a control program. Wilson Bulletin 99:322–337.

RStudio Team. 2020. RStudio: integrated development for R. RStudio, Boston, Massachusetts, USA.

Sanders, T. A., and W. D. Edge. 1998. Breeding bird community composition in relation to riparian vegetation structure in the western United States. Journal of Wildlife Management 62:461–473.

Scott, J. M., D. D. Goble, J. A. Wiens, D. S. Wilcove, M. Bean, and T. Male. 2005. Recovery of imperiled species under the Endangered Species Act: the need for a new approach. Frontiers in Ecology and the Environment 3:383–389.

Sharp, B. L., and B. E. Kus. 2006. Factors influencing the incidence of cowbird parasitism of least Bell's vireos. Journal of Wildlife Management 70:682–690.

Stanton, J., J. Marek, L. Hall, B. Kus, A. Alvarado, B. Orr, E. Morrissette, L. Riege, and W. Thogmartin. 2019. Recovery planning in a dynamic system: integrating uncertainty into a decision support tool for an endangered songbird. Ecology and Society 24:11.

Summers, S. G., R. M. Kostecke, and G. L. Norman. 2006. Efficacy of trapping and shooting in removing breeding brown-headed cowbirds. Wildlife Society Bulletin 34:1107–1112.

Summers, S. G., R. M. Kostecke, and G. L. Norman. 2007. Cowbird control: management issues, controversies and perceptions, and the future. Pages 74–86 *in* Proceedings of the 12th Wildlife Damage Management Conference. D. L. Nolte, W. M. Arjo, and D. H. Stalman, editors. Internet Center for Wildlife Damage Management. April 9–12 2007, Corpus Christi, Texas, USA.

Terborgh, J. 1989. Where have all the birds gone?: essays on the biology and conservation of birds that migrate to the American tropics. Princeton University Press, Princeton, New Jersey, USA.

Terborgh, J. 1992. Why American songbirds are vanishing. Scientific American 266:98–105.

Terpening, K. K. 1997. Golden-cheeked warbler fatality in a cowbird trap. Studies in Avian Biology 18:290–291.

Thomas, L., S. T. Buckland, E. A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.

Unitt, P. 1987. *Empidonax traillii extimus:* an endangered subspecies. Western Birds 18:137–162.

U.S. Fish and Wildlife Service [USFWS]. 1986. Endangered and threatened wildlife and plants; determination of endangered status for the least Bell's vireo. Final Rule. Federal Register 51:16474–16482.

U.S. Fish and Wildlife Service [USFWS]. 1998. Draft recovery plan for least Bell's vireo. USFWS, Portland, Oregon, USA.

U.S. Fish and Wildlife Service [USFWS]. 2002. Southwestern willow flycatcher recovery plan. USFWS, Albuquerque, New Mexico.

Whisson, D. A., J. H. Quinn, K. Collins, and A. Engilis. 2004. Developing a management strategy to reduce roof rat, *Rattus rattus*, impacts on open-cup nesting songbirds in California riparian forests. Proceedings of the Vertebrate Pest Conference 21:8–12.

Whitfield, M. J. 2000. Results of a brown-headed cowbird control program for the southwestern willow flycatcher. Pages 371–378 *in* J. N. M. Smith, T. L. Cook, S. I. Rothstein, S. K. Robinson, and S. G. Sealy, editors. Ecology and management of cowbirds and their hosts. University of Texas Press, Austin, USA.

Whitfield, M. J., K. M. Enos, and S. P. Rowe. 1999. Is brown-headed cowbird trapping effective for managing populations of the endangered southwestern willow flycatcher? Studies in Avian Biology 18:260–266.

Winter, K. J., and S. D. McKelvey. 1999. Cowbird trapping in remote areas: alternative control measures may be more effective. Studies in Avian Biology 18:282–289.

Wood, J. K., C. A. Howell, and G. R. Geupel. 2006. Least Bell's vireo breeds in restored riparian at San Joaquin River National Wildlife Refuge. Unpublished report submitted to U.S. Fish and Wildlife Service, San Luis National Wildlife Refuge Complex, Los Banos, California, USA.

Associate Editor: Courtney Duchardt.

How to cite this article: Parker, S. S., L. S. Hall, M. J. Whitfield, L. Riege, K. R. Selm, and R. Corado. 2022. Developing an adaptive management approach to cowbird control on the Santa Clara River, California. Journal of Wildlife Management 86:e22284. https://doi.org/10.1002/jwmg.22284