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Fall migration of radio-tagged Broad-winged Hawks (*Buteo platypterus*) in California

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ABSTRACT—Little is known about migration patterns of Broad-winged Hawks (*Buteo platypterus*) in the western United States apart from small numbers that have been recorded at migration monitoring sites. To better understand their movements in coastal California, we radio-tracked 5 juveniles (1 in 1994, and 4 from 2012 to 2015) during fall migration from the Marin Headlands (near San Francisco) to the US–Mexico border. One hawk died near the Headlands within 2–3 d of release and the other 4 crossed into Baja California in 4–6 flight days with no stopovers beyond the Headlands. Daily straight-line flight distances ranged from about 110 to 265 km (mean = 189 ± 47 km SD). Migration began 2.5–3 h after sunrise and ended a similar amount of time before sunset. Flight paths along mountain ranges, and radio signal patterns, indicated slope-soaring was a primary strategy. The detailed flight paths we identified will be helpful to better evaluate proposed renewable energy facilities, given their current rapid development and potential for killing birds. More study is needed to determine complete migration routes and breeding and wintering grounds of Broad-winged Hawks on the Pacific coast. *Received 26 June 2019. Accepted 18 February 2020.*

Key words: citizen science, flight paths, radio telemetry, slope-soaring

Migración de otoño de aguilillas de alas anchas con radio transmisor (*Buteo platypterus*) en California

RESUMEN (Spanish)—Se conoce poco sobre los patrones de migración de la aguililla ala-ancha (*Buteo platypterus*) en el oeste de Estados Unidos, aparte de un número reducido que han sido registrados durante su migración en sitios monitoreados. Para entender mejor los movimientos en la costa de California, colocamos radio-transmisores en 5 juveniles (uno en 1994 y 4 de 2012–2015) durante la migración de otoño, de Marin Headlands (cerca de San Francisco) a la frontera de Estados Unidos-México. Un aguililla murió cerca de Headlands los primeros 2–3 días de liberación y las otras 4 cruzaron a Baja California en 4–6 días sin hacer escalas después de Headlands. La distancia del vuelo diaria en línea recta fue de 110–265 km (media = 189 ± 47 km DS). La migración empezó 2.5–3 horas después del amanecer y termino en un tiempo similar antes de atardecer. Los rutas de vuelo a lo largo de cordilleras y los patrones de las señales de radio, indicaron que su estrategia principal fue vuelo en ladera. Los detalles en los patrones de vuelo identificados serán de ayuda para evaluar mejor las instalaciones de energía renovables que han sido propuestas, dado su rápido desarrollo actual y el potencial en la mortandad de aves. Se necesitan más estudios para determinar las rutas de migración completas, así como las zonas de crianza y de invernación del aguililla de alas anchas en la costa del Pacífico.

Palabras clave: ciencia ciudadana, patrones de vuelo, radio telemetría, vuelo en ladera

The nominate subspecies of Broad-winged Hawk (*Buteo platypterus*; hereafter BWHA) is a complete, long-distance migrant that breeds mostly in eastern North America and winters mainly from southern Mexico to southern Brazil and northern Argentina. Five other subspecies are resident in the West Indies (AOU 1998, Goodrich et al. 2014, Kilpp et al. 2018, McCabe et al. 2020). The BWHA is well known for its large concentrations of fall migrants at many sites across the eastern United States, concentrations that swell dramatically to tens of thousands as the hawks converge on the Gulf Coast in Texas and Mexico. The general nature of the fall migration in the eastern United States has been known since the late 1800s (Bildstein 1999).

In western North America, BWHA have recently expanded their breeding range in Canada, but no breeding in or west of the Rocky Mountains is known in the United States. In British Columbia, the species was first recorded in 1965 and the first evidence of breeding (an observation of 2 fledglings with 2 adults) was in 1986 (Campbell et al. 1990, Siddle 2010). Since then, breeding has been confirmed at several locations in east-central British Columbia (Phinney 2015). Breeding also has been confirmed in Northwest Territories, representing the northernmost breeding for the species (Machtans 2000). At fall migration monitoring sites in the West, sightings appear to be increasing but still number only in the tens to low hundreds (Smith et al. 2001, 2008; Stirling 2001, Carlisle et al. 2007; HawkWatch International, unpubl. data).

Along the Pacific coast, the first record of BWHA was a juvenile male collected in December 1966 in the Tijuana River Valley in southern

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California (McCaskie 1968). In Washington and Oregon, first records were from spring 1975 and 1983, respectively (Clark and Anderson 1984; Oregon Bird Records Committee, unpubl. data). In California, BWHA were noted annually in small numbers during 1972–1977 fall migration counts at the Marin Headlands, near San Francisco (Binford 1979), where the Golden Gate Raptor Observatory (GGRO) was established in 1985 (Hall et al. 1992). From 1986 to 2018, the range of GGRO sightings of BWHA was 25–344 per fall (mean 115 sightings ± 64 SD), excluding an outlier of 756 sightings in 2012. The migration window was almost entirely from 8 September to 27 October, with a peak on 27 September. The GGRO also trapped and banded 46 BWHA from 1985 to 2018, so far with just 1 recovery (reported here). Individual BWHA are rarely reported wintering along the California coast from the San Francisco Bay area southward (CBRC 2007, eBird Basic Dataset 2017).

In 1990 the GGRO also began a volunteer-led radio telemetry program to better understand how migrant and dispersing raptors navigated the highly urbanized San Francisco Bay area. Although satellite tracking can follow the movements of birds over longer periods of time, including in recent studies of BWHA from breeding territories east of the Rocky Mountains (Haines et al. 2003, McCabe et al. 2020), ground tracking can provide finer-scale details of movements and habitat use (Kenward 1985, Vilella and Hengstenberg 2006). We tracked our first BWHA in 1994 and, after many years of tracking other raptor species more locally, resumed our study in 2012 and tracked 4 more from 2012 to 2015. We did not track additional BWHA after 2015 because the GGRO traps and bands BWHA infrequently and unpredictably (none in some years) and because of the tremendous volunteer effort needed to track one. That effort includes being on-call for extended periods without a guarantee of time in the field.

Our primary objectives in tracking BWHA during fall migration were to determine (1) detailed flight paths from the Marin Headlands to as far south as the US–Mexico border, (2) diurnal timing of movements, and (3) roost locations. These data help fill a conspicuous void in our understanding of BWHA migration in the West, although much remains to be learned.

Methods

We radio-tracked 5 BWHA that were trapped in the Marin Headlands during normal fall banding operations of the GGRO (see Hull et al. 2008) and were released near Hawk Hill (37°49′42.37″N, 122°29′55.11″W; Fig. 1). We attached a 6 g radio transmitter (<2% of mass; Holohil Systems, Ontario, Canada, model RI-2C, from 2012 to 2015; AVM Instrument Company, Livermore, CA, USA, in 1994) to a central tail feather. Tracking was performed by 2–4 teams of GGRO volunteers traveling by automobile among strategically determined high points in the mountain ranges of coastal California (Fig. 1). Access to high points often required coordination with land management agencies. Teams were often out of communication in 1994, prior to cellular phone technology. We detected signals with handheld Yagi and car-mounted omnidirectional whip antennae. We took bearings every 15 min on the quarter hour, or more frequently when bearings were changing quickly, and recorded signal pattern (steady, erratic, circling) and a subjective measure of signal strength (0–5) as well. Circling was indicated by a pattern of alternating strong and weak signals. For example, increasing signal strength as the alternating pattern continued indicated altitude gain by thermal soaring. An extended steady signal that decreased in strength with time indicated a glide (Cochran 1972). All teams had periods during tracking days when no signal was heard. Tracking teams did not cross the US–Mexico border.

We easily determined precise locations of roosts in the Marin Headlands. Elsewhere, when teams were more distant from the hawks, we were able to estimate locations of roosts when we either did not lose the radio signal at the end of flight days (as birds descended to roost) or when we regained it before the next morning's flight. When we lost the signal and did not regain it until the next morning's flight began, we estimated locations of "roost areas" with less confidence (Fig. 1). We used Google Earth (Mountain View, CA, USA) to plot all bearings and estimate flight paths and roosts by considering cross-bearings (intersections of bearings from 2 or more teams that were within ~5 min of each other), single bearings, signal strengths, and topography. Google Earth files were later mapped by using ArcMap 10.6.1 (ESRI, Redlands,

Figure 1. Flight paths and roost locations of radio-tagged Broad-winged Hawks during fall migration in 1994 and 2012–2015 in California, along with primary high points used for tracking. Numbered high points: 1 San Pablo Ridge, 2 Hawk Hill, 3 San Bruno Mountain, 4 Skylawn Memorial Park, 5 Mount Hamilton, 6 Fremont Peak, 7 North Chalone Peak, 8 Idria Peak, 9 Parkfield Grade, 10 Williams Hill, 11 Cuesta Ridge, 12 Mount Pinos, 13 Figueroa Mountain, 14 La Cumbre Peak, 15 Mount Wilson, 16 Saddle Peak, 17 San Jacinto Ridge, 18 Elsinore Peak, 19 Palomar Lookout, 20 Double Peak, 21 Mount Laguna, 22 Mount Soledad, 23 Tecate Peak.

Table 1. Approximate daily flight distances (km) of Broad-winged Hawks from the Marin Headlands to the US–Mexico border in California.

Day after release	BW1	BW2	BW3	BW4	BW5
0	0	0	0	0	100[a]
1	130	170	5	0	205
2	250	185	0	145	110
3	265	255	–	175	145
4	215	245	–	195	170
5	–[b]	ND[c]	–	160	85[d]
6	–	–	–	115[e]	–
Total	860	855		790	815

[a]Distance after release; unknown where the hawk began the day.
[b]Began the day south of the US–Mexico border and was tracked until its signal faded away to the south.
[c]Began the day south of the US–Mexico border but was not tracked.
[d]Distance shown is to the border; the signal was lost just before the hawk reached the border.
[e]Crossed the US–Mexico border, continued south, and its signal was lost; distance shown is to the border.

CA, USA, 2018) and Photoshop, Illustrator, and InDesign CC (Adobe, San Jose, CA, USA, 2018). We based flight distances on straight lines between roosts or "roost areas" and rounded to the nearest 5 km.

Results

We began tracking the hawks on 27 September 1994 (BW1), 17 September 2012 (BW2), 29 September 2012 (BW3), 29 September 2013 (BW4), and 23 September 2015 (BW5). All 5 hawks were juveniles of unknown sex. Mass ranged from 390 to 477 g and each hawk had an empty crop. Release times ranged from 1200 to 1746 h PDT. The hawk with the earliest release time (BW5) resumed migration immediately and the other 4 remained in the Marin Headlands overnight.

Four of the hawks reached the US–Mexico border in 4–6 flight days, while BW3 did not depart the release area (Fig. 1, Table 1). Among flight days, migration distances ranged from about 110 to 265 km (mean 189 ± 47 km SD; $n = 16$) and sums of daily flight distances to the border ranged from about 790 to 860 km. Only BW1 was tracked as it continued southward into Baja California; the final intersection of cross-bearings before we lost the signal was about 130 km south of the border. In addition to flight days, 2 stationary days without migratory movement occurred, when BW3 and BW4 remained in or near the Marin Headlands the day after they were released due to stagnant air associated with, respectively, a high-pressure system that resulted in air temperatures >32 °C and a low-pressure system that brought a persistent, low, misty fog throughout much of the San Francisco Bay area. BW4, in fact, remained in a red willow (*Salix laevigata*) thicket all day, never taking flight.

BW3 was also still near the Marin Headlands on the second day after release but died, likely that afternoon. The bird was seen flying over Hawk Hill the day after release and it roosted that night on nearby Angel Island in San Francisco Bay. It was again active the next morning of 1 October 2012, but 3 local teams all lost the signal abruptly at 1215 h; for a fourth team 90 km to the southeast atop Mount Hamilton, Yagi antenna orientation for strongest signal detection changed from horizontal to vertical. The signal did not vary thereafter, and we recovered the carcass on 4 October on Angel Island. A necropsy revealed a 4–6 mm diameter dorsal puncture wound that appeared to end in the left lung, consistent with a talon strike from another raptor.

The 4 birds that continued migrating flew similar paths along slopes of the Coastal Ranges of central California and the Transverse and Peninsular ranges of southern California, with some obvious local differences (Fig. 1). Consistent with these flight paths, radio signals were most often a combination of erratic and steady and relatively weak, indicative of slope-soaring and orographic lift. Less often, soaring patterns followed by glides indicated the hawks appeared to also use thermals. In the San Francisco Bay area, 2 birds flew down the west side of the bay, BW4 even crossing over the Santa Cruz Mountains to fly along the coast near Monterey, and 2 birds flew along the east side of the bay. Farther south, all 4 birds crossed the Salinas Valley and flew along the east slope of the Santa Lucia Mountains before joining the east–west oriented Transverse Ranges north of Los Angeles, BW2 clearly more inland. At the Los Angeles Basin, BW1 and BW2 continued along mountain slopes to the north and east during light westerly winds, later entering Baja California east of Tecate. BW4 and BW5 continued down the coast, including over urban areas, crossing the border farther west. Their flight paths may have been affected by

episodic offshore Santa Ana winds characteristic of the region during fall and winter (Guzman-Morales et al. 2016). For example, easterly wind speeds at Elsinore Peak were more than 15 m/s on 4 October 2013 as BW4 passed by to the west that afternoon in a distinct soar-glide pattern.

Sustained flight and first circling signals were detected typically about 2.5–3 h after sunrise. Departure from the roost area, however, did not necessarily occur immediately. For example, as BW1 departed the Marin Headlands, it took flight at 0940 h (2 h 37 min after sunrise) but was only just beginning southward movements over San Francisco Bay at 1030 h. Compared with takeoff time after sunrise, end of southward movement was likely a similar amount of time before sunset. For example, the signal of BW2 was lost suddenly by 2 teams at 1600 h (about 3 h before sunset) on the second flight day, indicating the hawk had reduced altitude below ridge lines. The hawks may also have been locally active after ending southward flight. Based on a variable signal, BW2 was still moving as late as 1 h before sunset after it had crossed into Baja California. However, signal strengths were no longer decreasing, indicating southward flight had stopped at least 2 h before sunset. Similarly, trackers on Figueroa Mountain interpreted signals at least 2.5 h before sunset as indicating BW5 may have been scouting for a roost site.

Among 4 Marin Headlands roosts, BW3 was visually confirmed in a blue gum eucalyptus (*Eucalyptus globulus*), BW4 roosted in a red willow thicket, and BW1 and BW2 may have roosted in Monterey pine (*Pinus radiata*) trees. After leaving the Marin Headlands, we estimated 7 roosts among 4 birds that were mostly in remote areas on the slopes of mountain ranges. Of these roosts, we achieved visual contact of a hawk at just one. During the morning of 1 October 1994, we observed BW1 perched in a western sycamore (*Platanus racemosa*) at a golf course in a suburban neighborhood in the northern Los Angeles Basin, where it was being harassed by 3 Common Ravens (*Corvus corax*). We also estimated locations of 11 other "roost areas" (Fig. 1).

Discussion

Through ground-based tracking of radio-tagged birds, we were able to determine previously unknown fall migration routes of BWHA in coastal central and southern California. We followed 4 birds from the San Francisco Bay area to the US–Mexico border as they flew primarily along the slopes of mountain ranges and crossed into Baja California. The mountain ranges and valleys south of the Marin Headlands release site, oriented NNW–SSE and associated with the San Andreas Fault, likely served as leading lines for BWHA, analogous to the Central Appalachian Mountains for migrants at Hawk Mountain Sanctuary in Pennsylvania (Bildstein 1999).

The average daily flight distance we estimated (189 km) was similar to fall migration speeds of satellite-tagged adult Swainson's Hawks (*Buteo swainsoni*) from breeding sites in California's Central Valley (Airola et al. 2019), but comparisons with travel rates from 2 satellite telemetry studies of BWHA are less clear due to the inclusion of stopover days in those calculations. McCabe et al. (2020), however, did calculate faster rates for certain 10° latitudinal blocks for BWHA from Pennsylvania and Alberta breeding sites. Haines et al. (2003) calculated a rate of only about 100 km/day and did not analyze speed by latitudinal zones. Diurnal timing of migration in our study was consistent with takeoff and landing times observed at a spring roost area (Kerlinger and Gauthreaux 1985).

Flight paths along the Peninsular Ranges into Baja California (BC), including 2 near the Pacific coast, combined with growing numbers of observations of BWHA in Baja California Sur (BCS), indicate that at least some birds may continue south and winter on the peninsula, rather than flying east over the top of the Gulf of California en route to known wintering areas from southern Mexico to South America. BWHA were noted at the southern end of BCS in Cabo San Lucas as early as 1968, when several birds were observed beginning 31 October (Wilbur 1987). Erickson et al. (2001) considered the species a casual winter visitor on the peninsula through 1999. From 2000 through January 2019, approximately 15 and 66 birds were observed in BC (27 Sep–6 Apr) and BCS (5 Oct–17 Apr), respectively (eBird Basic Dataset 2017; RA Erickson, San Diego Natural History Museum, 2019, pers. comm.). Most observations in BC have been of single birds (high count = 3), while numerous observations of

multiple birds exist for BCS, with high counts of 8 (15 Nov 2015) and 12 individuals (5 Jan 2018).

We suspect that BWHA that enter the BC Peninsula will be unlikely to cross the Gulf of California, given the reluctance to cross open water seen elsewhere (e.g., Kerlinger 1985) and in California. Among California's offshore islands, only 3 BWHA records exist, all since 2001 at San Clemente Island, about 100 km northwest of San Diego. All 3 birds stayed for extended periods, arriving perhaps over low stratus cloud cover or during strong offshore winds (Sullivan and Kershner 2005, CBRC 2007, eBird Basic Dataset 2017). At the South Farallon Islands, about 45 km west of the Marin Headlands, migrant birds have been tallied daily since 1968 and no BWHA have been recorded (Richardson et al. 2003; P Pyle, Institute for Bird Populations, 2019, pers. comm.). Among islands off the BC Peninsula, only one BWHA has been observed, on 9 October 2011 at Isla Natividad, BCS, <10 km offshore (RA Erickson, pers. comm.).

We consider that now is a critical time to identify raptor migratory corridors and their component pathways, given the rapid development of renewable energy facilities and their potential for causing avian injury and death (McCrary et al. 1986, Seeland et al. 2012, Kagan et al. 2014, Smith and Dwyer 2016). Closely documenting these pathways will enable more complete evaluations of the potential impacts of proposed or existing wind- and solar-power facilities on raptors. For example, substantial annual mortality of raptors has been documented at the Altamont Pass Wind Resource Area in the hills about 50 km east of San Francisco Bay (Smallwood and Thelander 2008), but the coastal-transiting BWHA we tracked remained close to the bay shoreline. Farther south, the hawks flew along some of the same mountain ranges used by California Condors (*Gymnogyps californianus*), where wind speeds considered suitable for wind energy development occur (Poessel et al. 2018). Further study of BWHA along the Pacific coast is needed to identify complete migration routes, wintering grounds, and breeding areas in the West.

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