



Rings and Pings: Band Encounters and Motus Elucidate the Overwintering Locations and Movements of Sharp-shinned Hawks in Western North America

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ABSTRACT.—Understanding avian ecology across the annual cycle is essential for effective conservation, yet overwintering periods remain understudied for many species. Sharp-shinned Hawks (*Accipiter striatus*), small migratory forest raptors, are well documented during migration, but their overwintering locations and movements in western North America remain poorly understood. We analyzed 35 yr of band encounter data (1988–2023) from the central coast of California, and used the Motus Wildlife Tracking System to investigate overwintering locations and movement patterns of Sharp-shinned Hawks. Band encounters ($n = 147$) revealed that overwintering individuals were widely distributed across coastal and central California, with some ranging north to Oregon and south to Baja California, Mexico. Males overwintered at higher latitudes on average than females, and individuals migrating later in the season tended to winter farther south. Motus-tagged individuals ($n = 8$) provided additional insights into movement dynamics, revealing larger intra-winter movements than previously documented. These results highlight the complexity of overwintering strategies among Sharp-shinned Hawks and emphasize the need for multifaceted tracking approaches to accurately assess movement patterns during the nonbreeding season. Understanding these dynamics is critical for developing conservation strategies that address habitat availability and potential threats to migratory raptor populations.

KEY WORDS: *band encounter; HybridTag; migration; Motus; overwintering.*

ANILLOS Y SEÑALES: EL ENCUENTRO DE ANILLOS Y LOS DATOS DE MOTUS ESCLARECEN LOS SITIOS DE INVERNADA Y LOS MOVIMIENTOS DE *ACCIPITER STRIATUS* EN EL OESTE DE AMÉRICA DEL NORTE

RESUMEN.—Comprender la ecología de las aves a lo largo del ciclo anual es esencial para su efectiva conservación. Sin embargo, el periodo de invernada sigue siendo poco estudiado en muchas especies.

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Accipiter striatus, una pequeña ave rapaz migratoria de bosques, ha sido bien estudiada durante la migración, pero sus sitios de invernada y movimientos en el oeste de América del Norte siguen siendo poco conocidos. Analizamos 35 años de datos de encuentros de aves anilladas (1988–2023) en la costa central de California y utilizamos el sistema de seguimiento de fauna Motus para investigar las áreas de invernada y los patrones de movimiento en esta especie. Los encuentros ($n = 147$) revelaron que los individuos invernantes estaban ampliamente distribuidos por la costa y el centro de California, con algunos extendiéndose hacia Oregón y Baja California, México. Los machos invernaron, en promedio, en latitudes más altas que las hembras, y los individuos que migraron más tarde en la temporada tendieron a invernar más al sur. Los individuos marcados con Motus ($n = 8$) aportaron información adicional sobre la dinámica de movimientos, revelando desplazamientos intra-invernales mayores a los documentados anteriormente. Estos resultados resaltan la complejidad de las estrategias invernales de *A. striatus* y enfatizan la necesidad de enfoques de seguimiento polimodales para evaluar con precisión los patrones de movimiento durante la temporada no reproductiva. Comprender estas dinámicas es fundamental para desarrollar estrategias de conservación que aborden la disponibilidad de hábitat y las amenazas potenciales para las poblaciones de rapaces migratorias.

[Traducción del equipo editorial]

INTRODUCTION

Knowledge of species ecology across the annual cycle is critical for avian conservation because breeding, nonbreeding, and migratory life-history stages are intricately linked. For many species, research is biased toward the breeding season when habitat use is more confined and known nest sites enable easier observations (Marra et al. 2015). Research into understudied life-history stages, such as the nonbreeding (overwintering) period, can provide insights into carry-over effects that can have population-level impacts in subsequent stages (Norris and Marra 2007). For example, overwintering movements provide insights into the key landscapes and ecological requirements that sustain populations outside the breeding season (Faaborg et al. 2010).

Overwintering periods often represent a time of high ecological importance, as they influence survival rates, reproductive readiness, and overall population dynamics (Newton 2004). Examining where and how birds overwinter allows researchers to monitor population trends (Holmes 2007), to identify threats such as habitat loss (Sherry and Holmes 1996) and climate change (Culp et al. 2017), and to develop conservation strategies that target these critical life stages (Latta and Faaborg 2009). Despite the importance of overwintering ecology, there are substantial gaps in our understanding of this life stage, particularly for species with elusive behaviors or those occupying remote or inaccessible habitats. These investigations are especially important for migratory species that traverse large geographic distances between breeding and wintering areas. This life history strategy may expose these species to higher rates of anthropogenic threats or predation and has higher energetic costs than residency (Ydenberg et al. 2007, Nemes et al. 2023).

The Sharp-shinned Hawk (*Accipiter striatus*) is a small forest raptor and songbird-specialist predator of the western hemisphere (Bildstein et al. 2020) that exemplifies these challenges. The Sharp-shinned Hawk is a highly migratory species that primarily breeds in the forests of the northern latitudes of North America and overwinters in the United States to as far south as Central America (Bildstein et al. 2020). As such, they are conspicuous migrants commonly observed at raptor migration monitoring stations across the continent (Goodrich and Smith 2008, Bildstein et al. 2020). Although some aspects of Sharp-shinned Hawks' migratory behaviors, including their use of major flyways and diet during migration, have been studied (e.g., Culliney and Gardali 2011, Rosenfield et al. 2011, Bourbour et al. 2024), details about their overwintering locations and movements remain poorly understood, particularly in western North America. These knowledge gaps are especially pronounced for juvenile hawks, which often face the greatest survival challenges due to environmental pressures and limited experience (Newton 1979). For example, migratory populations of Sharp-shinned Hawks can face elevated exposure risks to environmental toxins, such as legacy pollutants and insecticides (Wood et al. 1996), heavy metals (Chandler et al. 2004, Rimmer et al. 2010, Bourbour et al. 2019, Keyel et al. 2020), and anticoagulant rodenticides (Elliott et al. 2022); this challenge is directly linked to foraging habitats and has unknown consequences on first-winter survival or carryover effects.

Traditional methods of studying raptor ecology, such as migration counts, stable isotope analysis, and banding, have provided useful data but are often insufficient for addressing the complexities of overwintering

dynamics. Previous movement research suggests that juvenile Sharp-shinned Hawks from interior North America exhibit a chain migration pattern (Smith et al. 2003) and therefore wintering locations may be dictated by where individuals originate. Western migratory and wintering populations may have a broad range of origin as revealed by hydrogen stable isotope analysis (Wommack et al. 2020), but other studies have suggested problems with this method, such as high intra-individual variation and low association with breeding areas (Smith et al. 2008, Briggs et al. 2017). Band encounter data are limited by anthropogenic biases in recovery rates (e.g., McIntyre 2012), and so may underrepresent rural and wildland regions (Lutmerding et al. 2012). For species like the Sharp-shinned Hawk, these methodological limitations hinder efforts to accurately map and assess overwintering ranges and to understand their ecological needs during this critical period.

Although high resolution tracking technology (e.g., satellite telemetry) is not readily available for species as small as the Sharp-shinned Hawk, other modern tracking technologies, such as the Motus Wildlife Tracking System (Motus), can be used to obtain coarse movement data (Taylor et al. 2017). Motus is a worldwide network of stationary radio telemetry receivers used to study movements of various taxa (<https://motus.org/>) and includes a growing number of receiver stations in western North America in recent years. Transmitters that communicate with Motus receiver stations are relatively small, providing unique opportunities to study the movements of highly mobile small animals, such as Sharp-shinned Hawks.

In this study, we focused on the overwintering movements of Sharp-shinned Hawks in California. We aimed to address knowledge gaps in our understanding of the species' ecology during the overwintering season. Our objectives were: (1) to investigate overwintering locations of Sharp-shinned Hawks by compiling and analyzing 35 yr of band encounter data from a banding station located on the central coast of California, and (2) to investigate winter movement patterns through Motus station detections. California's extensive land-mass (42.4 million ha) and diversity of landscapes (Barbour et al. 1993) make it an ideal region to explore post-migration and overwintering movements and locations that may be important for Sharp-shinned Hawks.

METHODS

Study Area, Banding, and Transmitter Deployment. From 1988 to 2019, and 2021 to 2023, we captured migrating Sharp-shinned Hawks along the central coast of California at banding stations operated by the

Golden Gate Raptor Observatory (GGRO) in the Marin Headlands, California, USA (37°49'49"N, 122°29'59"W) between mid-August and the end of December. We used bow nets, mist nets, and dho-gazas (see Hull and Bloom [2001] and Hull et al. [2009] for details on trapping methodology). After capture, we banded each bird with a US Geological Survey aluminum metal band and took morphometric measurements, including weight (g), wing chord (mm), tail length (mm), and culmen length (mm) (Hull and Bloom 2001). We used wing chord to determine the sex of each bird and used plumage characteristics to separate birds into juvenile and adult age classes (Pyle et al. 2008, Wheeler 2018).

In 2023, we radio-marked Sharp-shinned Hawks with Motus transmitters. We weighed candidate birds to ensure the transmitter was less than 3% of its body weight and inspected the bird's overall health. After processing, we fitted individual hawks with a Cellular Tracking Technologies (CTT) 2.5-g HybridTag with 3D printed leg-loop housing and nylon coated braided steel antennas. We affixed the leg-loop harnesses using the method described by Rappole and Tipton (1991), which we modified for small raptors. The CTT 3D-printed leg-loop housing contained four holes in the plastic tab. Using a heated awl, we widened the holes to accommodate 2.5-mm Spectra ribbon (Bally Ribbon Mills, PA, USA), which we cut to a length of 400 mm. After tying a knot at the midpoint of the ribbon, we fed it through the top two holes in the housing. The knot prevented the ribbon from sliding and kept the unit centered. We then threaded the free ends of the Spectra ribbon through the other two holes in the housing to create two large loops (Fig. 1A). Once the loops were fitted above the bird's thighs and centered, we tied two knots, and all knots were secured with superglue (Fig. 1B). This leg-loop harness positioned the Motus tag closer to the bird's pelvis. We cut the excess ribbon before release (Fig. 1C). Finally, we weighed the excess ribbon that was removed and deducted that from the initial unit weight.

Band Encounters. The GGRO maintains a band encounter database for raptors banded at the Marin Headlands based on the band encounters reported to the US Geological Survey Bird Banding Laboratory from 1983 to 2024. A team of community scientists followed up with all individuals who reported bands to ensure the accuracy of the encounter reports. The date of encounter and bird status for each band was confirmed with the reporting party to reduce errors in the data (Houston and Francis 1993). To limit encounters to the winter period, we

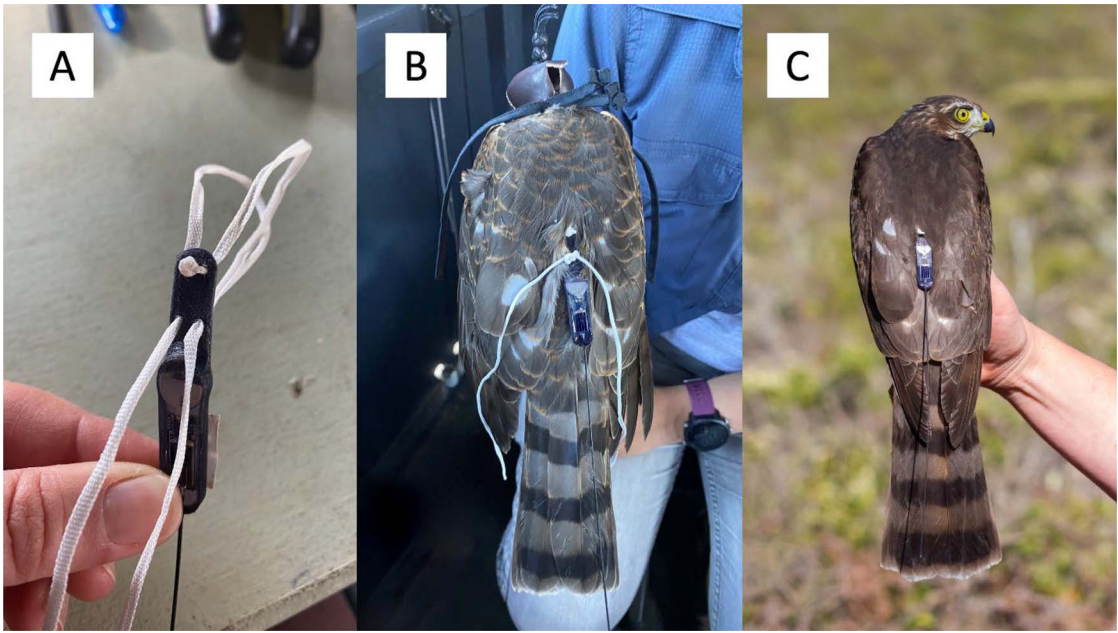


Figure 1. Radio-marking of a Sharp-shinned Hawk with a Cellular Tracking Technologies 2.5-g HybridTag: (A) HybridTag with 3D printed leg-loop housing threaded with Spectra ribbon through widened loops, (B) HybridTag applied to hawk with Spectra ribbon knotted, and (C) Spectra ribbon tails removed and hawk ready for release with newly fitted HybridTag. Photographs by TEE (A, B) and RPB (C).

filtered encounter records to 1 November–31 March, using fall migration counts from the Marin Headlands as a guide (Elliott and Fish 2016). We removed recoveries for which it was unclear how long the individual had been dead (i.e., the individual may have died before the overwintering period). We used ArcGIS Pro 3.3.1 to calculate distance and direction from the banding site.

We used a MANOVA to examine differences in overwintering locations between sexes and age classes. Our dependent variables were latitude and longitude coordinates of the location where an individual was encountered. We first looked for and removed two outliers encountered in southern Baja California, Mexico, as they were encountered over 900 km from the next closest encounter, and preliminary analyses suggested those points could have high leverage on the analysis. However, analyses run with those outliers yielded similar results.

We used day of year the bird was initially captured, sex, age (i.e., juvenile versus adult), the interaction of sex and age, and year of capture in our models. We analyzed all data in R 4.3.1 (R Core Team 2024). We used $\alpha = 0.05$ for all analyses, and values are presented as mean $\pm$ SE. We used a chi-

square analysis to compare the number of male versus female initial captures versus band encounters to determine if we were equally likely to encounter each sex as a banded individual as they overwintered.

Motus Detections. We used the R package *motus* to retrieve Motus detection data (Birds Canada 2024). We followed the data filtering process outlined in the package's documentation by running a preliminary filter to remove invalid detections and to filter out detections with a run time less than three to account for potentially false positive detections (Birds Canada 2024). We manually checked the data for accuracy and filtered detection dates to the overwintering period (1 November–31 March). We summarized the Motus detections and estimated distance traveled away from tagging location by summing the path distances (excluding back-and-forth movements between adjacent stations) between Motus receiver stations for each hawk.

RESULTS

Band Encounters. From 1988–2024 we trapped and banded 13,995 Sharp-shinned Hawks (4974 males, 9015 females, 6 unknown sex) and we

Table 1. Sharp-shinned hawks banded at the Golden Gate Raptor Observatory in the Marin Headlands, California, USA between 1988–2019 and 2021–2023. The number of Sharp-shinned Hawks subsequently encountered and reported to the USGS Bird Banding Laboratory are included in parentheses.

Sex	Adult	Adult Encounter (%)	Juvenile	Juvenile Encounter (%)	Unknown	Total	Total Encounter (%)
Female	298 (7)	2.3	8716 (189)	2.2	1 (0)	9015 (196)	2.2
Male	129 (0)	0	4843 (51)	1.1	2 (0)	4974 (51)	1.0
Unknown	0 (0)	0	6 (0)	0	0 (0)	6 (0)	0
Total	427 (7)	1.6	13565 (240)	1.8	3 (0)	13995 (247)	1.8

received data for 247 band encounters (i.e., bird found alive or dead; 1.8%; Table 1). Of those, 147 (34 males and 113 females) were encountered in the overwintering period between 1 November and 31 March. Most encountered individuals were juveniles at the time of capture ($n = 144$) and encounter ($n = 107$). Two juvenile females were encountered in Baja California, Mexico, during the overwintering period but were considered outliers and removed from subsequent analyses. This is because these points were so much farther than any other point, they had the potential to drive statistical significance (i.e., they could have high leverage). Overwintering encounters occurred throughout much of California, particularly in the Coast Range mountains both north and south of the San Francisco Bay (Fig. 2). There were no differences in movements across years in the study ($P = 0.67$). On average, individuals migrating earlier in the fall tended to migrate farther to their wintering ground ($P < 0.01$; Fig. 3A). Males overwintered farther north ($37.45^\circ \pm 0.30^\circ$ latitude) than females ($36.42^\circ \pm 0.27^\circ$ latitude; Fig. 3B), with a mean difference of 112 km. Juveniles tended to overwinter farther east ($-120.84 \pm 0.32^\circ$ longitude) than adults ($-121.04^\circ \pm 0.23^\circ$ longitude; Fig. 3C), with a mean difference of 18 km. However, there was considerable overlap between ages in latitude and longitude of overwintering sites. Explanatory power was moderate to low for all variables (partial $\eta^2 = 0.08$; Table 2). Banded males (0.7%) were encountered less frequently in the overwinter period than banded females (1.3%; $\chi^2 = 9.82$, $P = 0.002$).

Motus Detections. In 2023, we placed Motus transmitters on eight birds (female juvenile = 4, male juvenile = 3, female adult = 1) from 23 October to 14 November. Six individuals (male juvenile = 2; female juvenile = 3; female adult = 1) were detected during the overwintering period (Table 3). Individual birds were detected for an average of 24.7 ± 13.8 d, and individuals moved on average, a maximum distance

of 244.0 ± 123.5 km (range: 65–819.5 km) from the tagging location ($n = 6$; Fig. 2; Table 3).

DISCUSSION

Given their small size, secretive habits, and preference for dense forest habitat, Sharp-shinned Hawks have received little attention, particularly for overwintering movements and ecology in western North America. The present study compares a 35 yr data set of Pacific region band recoveries for Sharp-shinned Hawks with a 2023 tracking study using Motus technology. This comparison demonstrated the benefits and disadvantages of the two tracking methodologies while elucidating patterns of age- and sex-based differentiation in Sharp-shinned Hawk overwintering movements.

In this study, we found that Sharp-shinned Hawks passing through a migration bottleneck along the central coast of California primarily overwintered throughout the coastal and Central Valley regions of California, but notably ranged from northern California to southern Baja California, Mexico. Interestingly, some individuals traveled north of the banding location for at least part of their overwintering period, a pattern also described for western Red-tailed Hawks (*Buteo jamaicensis*) from southern California nesting areas (Bloom et al. 2015). This highlights the complexity of avian migration and how individuals, especially juveniles, may be taking advantage of locally available prey or avoiding predators during overwintering periods (Davis 1992, Roth et al. 2006, Hendricks 2024). Both band encounters and Motus detections provided evidence that migratory movements of populations through the Marin Headlands may be more complicated than a classic north-south migration. Additionally, Motus tracking revealed that Sharp-shinned Hawks commonly made large within-winter movements in central California, potentially moving hundreds of km, which is greater than previous telemetry data had shown for the species (Roth

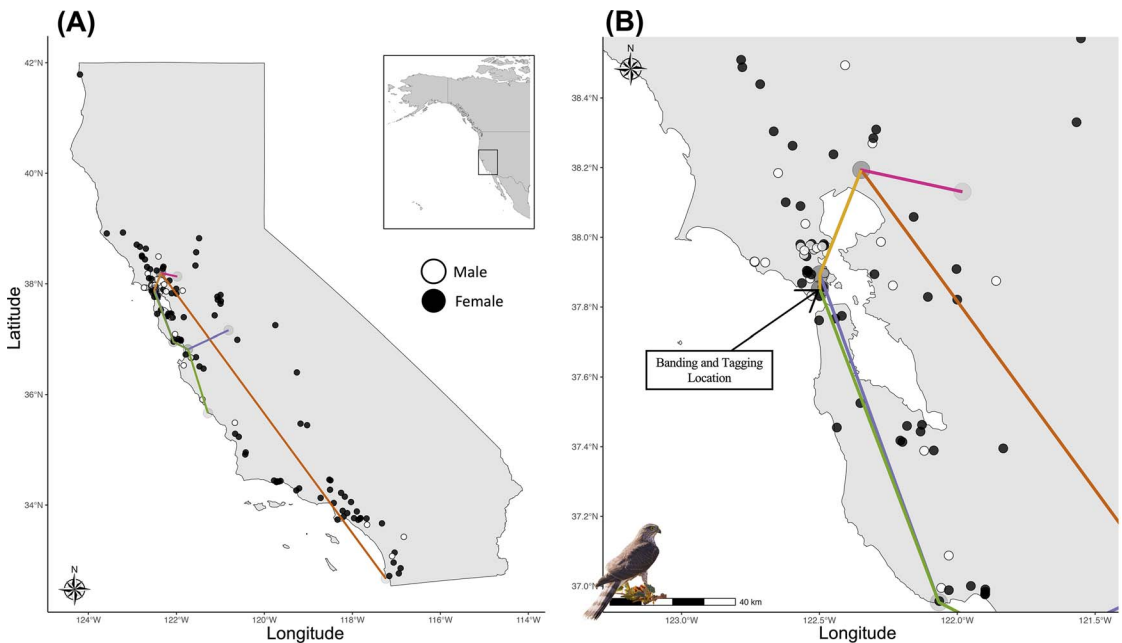


Figure 2. Band encounter locations (black and white dots) and Motus telemetry tracks (large gray dots and colored tracks) across (A) California and (B) around trapping sites of Sharp-shinned Hawks banded and tagged in the Marin Headlands, CA. Band encounter data were from birds banded between 1 November and 31 March each year (1988–2023). Motus telemetry track data were collected from six individuals (five juveniles and one adult [dark orange]) from 11 October 2023 through 21 April 2024. Large gray Motus points are centered on receiver location.

et al. 2006). This suggests that individuals may not be sedentary in their overwintering territories, and that encounter data for overwintering Sharp-shinned Hawks might be part of larger, within-season, movement patterns.

The band encounter data indicated that adult Sharp-shinned Hawks overwintered in different locations than juveniles, and that adults that migrated later may have overwintered farther north. This may be true more generally across several raptor species (e.g., Hoffman et al. 2002). However, in previous studies, both juvenile and adult Sharp-shinned Hawks appeared to show overwinter site fidelity (Powers 1996, McKinley and Mattox 2010), suggesting that individuals may not be site-faithful based on age, or that there may be a shift in migration strategy in individuals across years (Kerlinger 1989, Bildstein 2006). Motus detections in this study suggested that juvenile Sharp-shinned Hawks moved freely over the winter, with large intra-winter movements. Our results also demonstrated that older birds could overwinter farther north and south from the Marin Headlands where they were captured. This suggests that some individuals might not have high interannual overwintering site fidelity, or that

Sharp-shinned Hawks in general make larger movements to take advantage of locally abundant sources of prey.

We found that trapping numbers and band encounters were strongly skewed toward females. This bias may be driven by dietary differences between the sexes (e.g., Bourbour et al. 2024), coupled with trapping methodology that uses lure birds to attract individuals to nets. Alternatively, differential encounter rates between sexes may be related in part to carcass detection rates, which are notably smaller for smaller birds (e.g., Ponce et al. 2010); male Sharp-shinned Hawks average 43% lighter in weight than their female counterparts (Clark and Wheeler 2001).

Contrary to the chain migration pattern found in Sharp-shinned Hawks from the Intermountain West (Smith et al. 2003), we found that coastal birds that migrated earlier in the fall also overwintered farther north and south from the banding location. This may indicate that birds banded later in the season (e.g., late-October and November) overwintered locally or regionally, whereas birds banded earlier in the season may have had a mixed

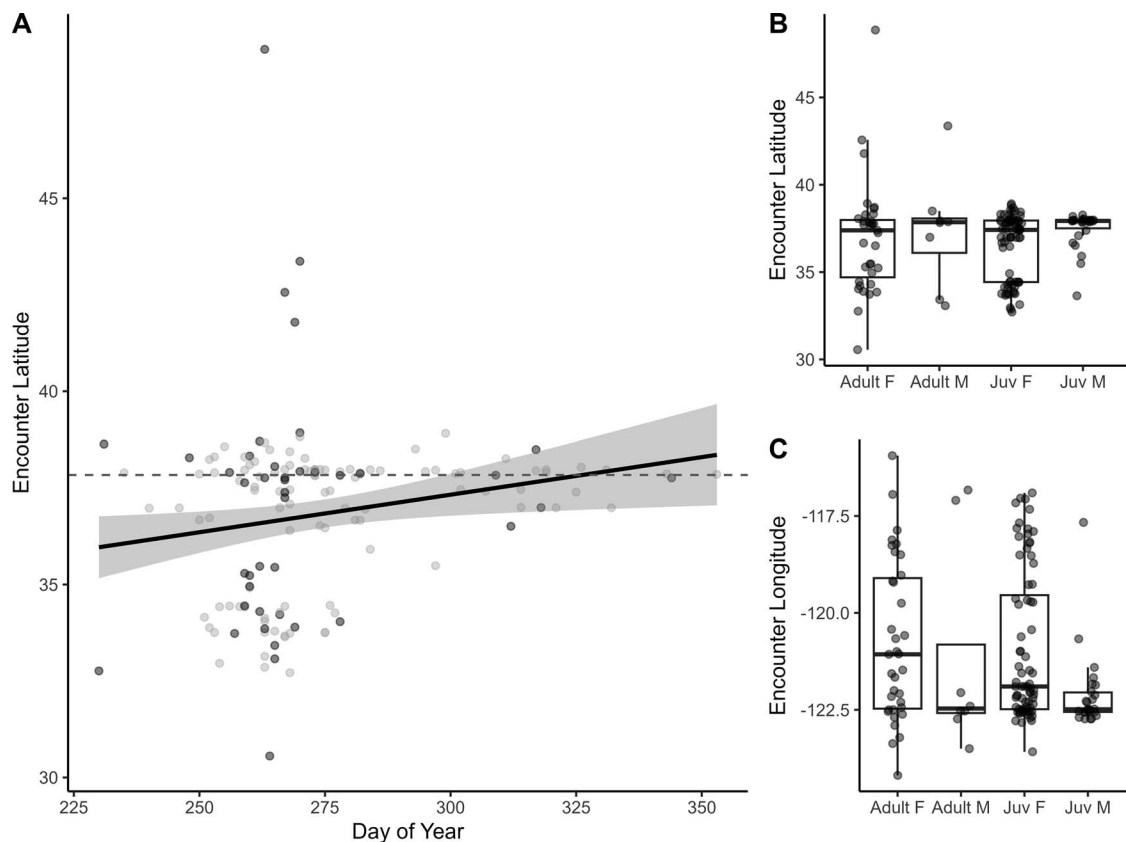


Figure 3. Linear model showing relationship between latitude, sex (light gray = male; dark gray = female), and day of year of banding (A), as well as just age and sex relationships with latitude (B), and longitude (C) of Sharp-shinned Hawks migrating through the Marin Headlands and subsequently encountered between 1 November and 31 March, 1988–2023. Shading differences in (B) and (C): light grey = individual points; dark grey = overlapping points.

strategy, with some remaining relatively local, while others migrated >250 km from the Marin Headlands. Another possible explanation for this pattern could be related to population origin. There may be strong migratory connectivity between breeding and overwintering sites in different Sharp-shinned Hawk breeding populations (Webster et al. 2002), in which some breeding populations are more likely to overwinter farther south. Similarly, Red-tailed Hawks

migrating through the Marin Headlands show differences in migration timing correlated with population origin (Hull et al. 2009, Briggs et al. 2020). Therefore, birds captured in November and December in the Marin Headlands are likely using the Headlands for wintering foraging opportunities and simply dispersing throughout the overwinter period rather than migrating. However, we cannot assess differential population movements and overwintering

Table 2. Parameter estimates from MANOVA of latitude and longitude of encounter locations from overwintering Sharp-shinned Hawks banded during fall migration in the Marin Headlands, CA.

Parameter	Pillai	Approximate F	Num DF	Den DF	P	Partial η^2
Age	0.083	4.2	3	139	0.01	0.08
Sex	0.082	4.1	3	139	0.01	0.08
Capture Day	0.082	4.2	3	139	0.01	0.08

Table 3. Motus station location information and tracking duration for six Sharp-shinned Hawks trapped and given Motus tags in the Marin Headlands during fall migration 2023. Fem = female, Juv = juvenile, Mal = male.

Motus Tag ID	Age/Sex	Deploy Date	Receiver Name	Detection Date(s)	Days Detected	Total Detections	Path Distance from Deployment (km)
50976	Juv/Fem	11 Oct 2023	Wolback Ridge	11 Oct 2023–12 Dec 2023	35	465	1.7
51358	Adu/Fem	31 Oct 2023	Richardson Bay Audubon	12 Oct 2023–13 Dec 2023	57	92,134	6.5
			Wolback Ridge	31 Oct 2023–4 Nov 2023	3	185	2.5
			Richardson Bay Audubon	1 Nov 2023–4 Nov 2023	2	273	7.3
			Napa Sonoma Marsh	1 Nov 2023–4 Nov 2023	2	144	43.1
			Point Loma	16 Nov 2024	1	5	819.5
51393	Juv/Fem	1 Nov 2023	Wolback Ridge	1 Nov 2023–2 Nov 2023	2	262	2.5
			Richardson Bay Audubon	2 Nov 2023	1	6	7.3
			CDFW Santa Cruz	3 Nov 2023	1	337	121.1
			Elkhorn Slough	3 Nov 2023–4 Nov 2023	2	61	154.1
51556	Juv/Fem	9 Nov 2023	Salt Slough	4 Nov 2023–5 Nov 2023	2	11	243.7
			Wolback Ridge	9 Nov 2023–1 Nov 2023	2	9	2.5
			Richardson Bay Audubon	10 Nov 2023	1	113	7.3
			Napa Sonoma Marsh	10 Nov 2023	1	93	43.1
			Grizzly Island	10 Nov 2023	1	40	75.9
51562	Juv/Mal	10 Nov 2023	Wolback Ridge	10 Nov 2023	1	5	1.7
			CDFW Santa Cruz	16 Nov 2023–24 Nov 2023	4	1266	108.4
			Elkhorn Slough	23 Nov 2023–24 Nov 2023	2	157	141.4
			Piedras Blancas	28 Nov 2023–30 Nov 2023	3	62	275.9
51618	Juv/Male	14 Nov 2023	Wolback Ridge	14 Nov 2023–16 Nov 2023	3	37	1.7
			Richardson Bay Audubon	16 Nov 2023	1	60	6.5
			Napa Sonoma Marsh	28 Nov 2023–21 Apr 2024	21	915	42.3

patterns from just our dataset, and will need more data on the origins of migrating Sharp-shinned Hawks in coastal California to fully understand their complex movements.

By combining a 35-yr band encounter database and the first study to deploy Motus tags on Sharp-shinned Hawks migrating during the fall, this research provides a novel, multi-scale perspective on overwintering movement ecology of the species along the Pacific Coast. This integrative framework is readily transferable to other small raptors as the number of Motus stations increases in number and coverage, and as Motus transmitters become smaller and lighter. Applying such a framework across taxa and years will allow conservationists to pinpoint wintering hot-spots. These results highlight the complexity of overwintering strategies in Sharp-shinned Hawks and emphasize the need for multifaceted tracking approaches to accurately assess movement patterns during the nonbreeding season. Understanding these dynamics is critical for developing conservation strategies that address habitat availability and potential threats to migratory raptor populations.

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