Large Tree Swallow Roost Verified in California's Central Valley

Bruce Cousens, Georgia Basin Ecological Assessment and Restoration Society, #4 - 1150 N. Terminal Ave., Unit 117 Nanaimo, BC, Canada V9S 5L6

Jim Rowoth, 612 Brent Ave., Stockton, CA 95207

Daniel A. Airola, Airola Environmental Consulting, 2700 6th Ave., Sacramento, CA 95818

INTRODUCTION

Recent studies have emphasized the importance of migratory periods as a limiting time of year for many bird populations, thereby increasing the importance of acquiring information on migration routes, migratory stopover ecology, and key stopover habitats (Carlisle et al. 2009) The migratory Tree Swallow (*Tachycineta bicolor*) is known to form large roosting flocks during migration (Childs 1900, Robertson et al. 1992, del Hoyo et al. 2004), but information on migration routes, flock formation, timing, size and habitats used is largely lacking, especially in western North America (Armstrong et al. 2005).

Recent use of radar imaging has allowed detection of large nocturnal roosts used by Purple Martins (*Progne subis*) during fall migration in the eastern United States (Russell et al. 1998, Russell and Gauthreaux 1998, Tautin et al. 2005) and in wintering areas in Brazil (Hill et al. 2004). Burney (2002) conducted an extensive radar survey and analysis of composition, distribution and temporal and spatial dynamics of mixed-species fall swallow and martin roosts in the eastern U. S. in 2000-01. Winkler (2006) reviewed the roosting, dawn dispersal and migration behaviour of swallows and martins (Hirundinidae).

Use of radar to locate swallow roosts in western North America has not been documented prior to this study and little other published information on such roosts exists. Cousens began exploring use of weather radar systems in the west to locate swallow roosts in 2006, using U. S. National Weather Service (USNWS) radar imagery posted to the Internet in near-real time. To date, three large roosts have been detected in the Willamette Valley in Oregon, the Central Valley of California, and the lower Colorado River Valley on the southeast California border. The large predominantly Barn Swallow (*Hirundo rustica*) roost southwest of Portland, Oregon, was verified from ground observations and described (Cousens and Schrock 2007). Limited attempts to field-verify assumed swallow roost sites observed in radar images along the lower Colorado River near Yuma, Arizona,

detected evening pre-roosting flights of Tree and Barn Swallows, but no roost site was located (Cousens and Schrock 2007). This paper reports the first radar detection and field verification in the west of a large swallow roost dominated by Tree Swallows, which occurred in San Joaquin County, California, during October 2008, with additional roost observations in 2009 and 2010.

The USNWS Doppler Radar system (NEXRAD WSR-88D) consists of a network of ground-based radar facilities used for weather (i.e. precipitation, wind speed and direction) monitoring and prediction (Russell and Gauthreaux 1998, Burney 2002). Doppler radar detects intensity of reflection of the radar signal pulse from radar-opaque objects in the beam path, including rain, hail, and snow, but also flocks of birds and bats and insect swarms, as well as their direction and speed of motion, within a series of narrow angular elevation beam segments from 0.5 degrees above horizontal. Radar imagery from the nearly 200 USNWS Doppler weather radar sites is posted to the Internet in near real time every ~6-10 minutes and is available from both the NWS (<http://radar.weather.gov>) and other secondary providers (e.g. Weather Services International <www.intellicast.com> and Weather Underground Incorporated <www.wunderground.com>) in various formats. Use of Doppler weather radar imagery to locate bird roosts takes advantage of the radar's ability to detect daily morning dispersal movements of large numbers of birds from nocturnal roost sites when they reach sufficient altitude to intersect the lower radar beam segment, which is angled at +0.5 degree above horizontal, so detection altitude varies with distance from the radar beam source (Burney 2002, Winkler 2006, above links).

Members of the swallow family that form large nocturnal roosts show a characteristic roost dispersal pattern or "echo signature" in unfiltered Doppler weather radar images. (These signatures are removed with other "noise" during filtering and processing for weather imagery displays.) The pre-dawn dispersal of large roosts appears on radar images first as a growing dense circular echo above the roost, then as a characteristic expanding ring or arc shape (see Figure 1, center spread on pages 12-13). The departing flocks are identifiable as swallows because of their habit of ascending above the roost site to heights of 1,000-1,500 m (thus within at least the lower radar beam segment) before moving outward at altitude in a wide expanding arc or ring, then disappearing from radar as they disperse to densities below the echo detection threshold and descend below the radar beam to surrounding areas to spend the day foraging (Burney 2002, Winkler 2006).

Other communal-roosting species such as crows and magpies (Corvidae), blackbirds (Icteridae), European Starlings (*Sturnus vulgaris*) and American Robins (*Turdus migratorius*) may also appear on Doppler weather radar during dawn dispersal and may on occasion also produce expanding circular, arc or annular dispersal patterns (Eastwood et al. 1962,

Mizrahi et al. 1998, Burney 2002). However, some of these species differ in timing, with roost size peaking in winter after swallows have left temperate latitudes on migration, and all typically disperse at lower altitudes and produce smaller, shorter-lived diffuse echoes in radar images. Large swallow roost dispersal echoes often reach or exceed 1,000 km^2 in maximum ring area (>35 km in diameter) at peak roost size and may be visible at altitude in multiple successive radar images for an hour or longer (Burney 2002). During the 4-year Doppler radar survey of swallow roosts in the western U.S., of which this study is a part, all three detected and ground-verified roosts with typical swallow dispersal echo signatures and timing have contained only swallow species. Several other roost echoes have not yet been verified and their species composition is unknown, although the timing and dispersal patterns were consistent with known swallow roosts nearby. No roosts of species other than swallows have been detected on radar and verified (Cousens, unpub. data).

These nocturnal roosts form in low elevation (<500 ft) valley-bottom areas during the late summer and fall as migration proceeds, with timing depending on species and latitude, and serve as a staging area while birds forage prior to continuing migration. Roosts at any one site may persist for several weeks to a month or more, build to a peak as arrivals exceed departures, then decline as rates of turnover and departure increase until eventually the roost is abandoned, often as the weather deteriorates. Thus the total number of birds using a roost over its duration may considerably exceed its peak population.

METHODS

Cousens monitored radar images for the lowest (+0.5°) beam segment from 25 USNWS Doppler weather radar facilities west of the Rocky Mountains (see http://www.wunderground.com/radar/map.asp for facility locations) daily at dawn (0530-0600 to 0730-0830 PDST) from August 25 to October 31, 2008, to look for characteristic images of swallows dispersing from nocturnal roost sites at dawn (Russell et al. 1998). Five of these sites covered portions of California's Central Valley: Sacramento (radar site DAX), Oroville - Beale Air Force Base (BBX), New Almaden (near San Jose; MUX), Hanford (HNX) and Edwards Air Force Base (EYX). When potential roost signatures were observed, digital radar base reflectivity images and time series loops were stored as .gif files, as well as image files for several other processed weather radar analytical products (including higher beam angle segments and composite, radial velocity, echo tops and velocity azimuth displays) used to confirm and document swallow roost dispersal patterns. General roost locations were determined from Google Maps (http://maps.google.com/) and Google Earth (http://earth.google.com/) and observations and general locations were posted to the Central Valley Birds list server (http://groups.yahoo.com/group/central_valley_birds). Rowoth

searched the identified sites during evening hours when birds were returning to roost to locate the roosting area. He then posted messages on the list server, which attracted more observers, who also posted information from their observations. We compiled and summarized our own and others' observations for this paper.

RESULTS

On 27 September, Cousens detected what appeared to be a small roost dispersal image on the Sacramento radar site in the general area of the northern portion of the Yolo Bypass, Yolo County, (~30 km northwest of Sacramento) in California's Central Valley, and reported it on the Central Valley Birds list server. On 2 October, Todd Easterla reported seeing mixed groups of approximately 4,500 Barn Swallows, Tree Swallows, and Violet-green Swallows (*Tachycineta thalassina*) foraging over agricultural fields south and within several miles of Davis, Yolo County, about 10-20 km from the radar-indicated location of the roost (http://groups.yahoo.com/group/central_valley_birds/message/11033). (Hereafter, citations of information from this list server are cited as "CV Birds message #", which identifies individual messages at the web address listed above.) Dispersal from this roost continued to be visible on radar at dawn intermittently through the first week of October, although sometimes masked by precipitation or "ground clutter" (bending of the radar beam and return echo downwards by refraction due to atmospheric conditions to produce anomalous detection of ground targets). Dispersal was observed during this period from another small roost in the Delta area near Isleton (also observed briefly in 2007). Neither roost was located and verified on the ground. Both signals disappeared from radar by mid-October, indicating the birds had moved to another location.

On 13-16 October Cousens detected on radar a larger roost of "perhaps 100,000 birds or more" ~10 km south of the town of Lathrop and ~10 km east of Tracy, east of Interstate 5, and a second smaller roost 2-3 mi west of Stockton, both in San Joaquin County. The abrupt appearance and large size of the former just as the roost ~110 km to the north disappeared from radar suggested the birds from Yolo Basin may have joined others at the new location. Airola contacted Rowoth on 17 October and suggested that he or someone local check these areas for swallow concentrations and Rowoth agreed to investigate.

On the afternoon of 17 October, Rowoth drove to the described area to search for the roosting birds. He later reported on the Central Valley Birds list server that he could "scarcely believe the numbers of small black dots in the air above and around me." Many swallows foraged over cut alfalfa, asparagus and fallow agricultural fields. He then observed "a veritable maelstrom of swallows" conservatively estimated at 500,000, above a large field of uncut corn (CV Birds message 11081). Unlike other dried corn fields

in the area, this one was still green. These observations triggered near nightly visits to the site by many birders and a number of messages posted to the Central Valley Birds list server.

The roost site was located on Wright Road, 4.5 km south of the intersection of Interstates 5 and 205, and approximately 10 km east of the town of Tracy. The San Joaquin River forms the eastern border of the field. The landscape features closely match those for the Barn Swallow roost in Oregon.

Rowoth returned on 18 October to the Wright Road roost site and observed the large flock entering the previously used cornfield at 18:00. Large numbers of swallows came in from the south and west to form a "massive cloud" above the field. He described the descent into the corn field as follows:

> "As I watched, the mass grew larger and larger with many birds swooping down just to the tops of the corn plants. After several minutes, I became aware that they were no longer swooping low, but it looked like the mass was rising higher and higher. Then the front portion all started moving as one in a vortex, and at 6:34 [pm], the chattering stopped and I heard a "swoosh" as what appeared to be the entire flock disappeared into the middle of the corn... This took less than 30 seconds. When I looked up again, I could see there was still a huge number of birds in the air, and at 6:36, there was another halt in the chattering, and another swooping dive into the corn further away from me. Looking up again in the fading light, there were still lots of birds in the air, but clearly the vast majority were down in the corn." (CV Birds message 11085).

Rowoth attempted to identify the swallow species in the flock both by sight and sound and observed only Tree Swallows on 18 October. Veronica Bowers, who also visited the site that day in response to the previous day's Central Valley Birds list server posting, observed some Barn Swallows and one Cliff Swallow (*Petrochelidon pyrrhonota*), but confirmed that the overwhelming majority of birds were Tree Swallows. She estimated numbers at "well over 500,000" (CV Birds message 11086).

Meanwhile, Cousens continued to monitor and document characteristics of the Wright Road roost on radar during dawn dispersal, as well as search for other roosts. Near its peak (~Oct. 21) swallows from the roost dispersed outward on radar for at least 40-50 km, with the drift direction depending on winds aloft. The dispersal echo was clearly detected by both the Sacramento radar 90 km away and the New Almaden-San Jose radar 70 km away from ~07:00-08:20, and was detected at altitude from the Beale AFB radar 175 km away from ~07:20-08:00. It was not detected near the range limit (230 km) of the Hanford radar, 220 km away. Tree Swallows were detected at heights in excess of ~1,500 m (5,000 ft) from Sacramento and New Almaden

Figure 2. Tree Swallows (*Tachycineta bicolor*) returning to the Wright Road corn field roost near Tracy, San Joaquin Co., on 24 October 2008.
Photo © Daniel Lee Brown

radars with the "Echo Tops" signal-processing function, and were detected at times in the 1.45° and 2.4° beam angle segments, suggesting maximum altitudes in excess of 2,000 m (~6,500 ft) from beam angle and distance calculations, assuming no beam distortion. Doppler radial velocity analysis indicated outward dispersal flight speeds of 10-20 knots (kn). The height and range of swallow dispersal observed from radar analysis were similar to those described for martins (*Progne* spp.) dispersing from a roost on the wintering grounds in Brazil (Hill et al. 2004). Flight speeds were slightly slower than reported for the larger martins (21-26 kn; Russell and Gauthreaux 1998).

The flock returned in large numbers nightly (Figure 2) and was observed by many individuals through 26 October, with several observers reporting numbers substantially exceeding 500,000 birds (H. George, CV Birds message 11114). Nearly all visitors noted pre-roosting and roost entry behavior similar to that described by Rowoth, closely matching descriptions in the literature by Burney (2002), Winkler (2006), and others. A morning survey on 26 October indicated that dispersal began at 06:58 and all swallows had departed the roost area by 07:15 (D. Coursey, pers. comm., contrary to the 06:15 departure time originally reported in error in CV Birds message 11107). This dispersal event was also monitored on radar and was visible at altitude for well over an hour, from 07:04 until 08:22, reflecting radar's ability to detect birds at far greater heights and distances than they could be seen from the ground.

On 27 October the strength of the radar signal was weaker, indicating

that the size of the flock had decreased. On 28 October, only a weak dawn dispersal signal was observed briefly on radar and by 29 October it had almost disappeared. By the evening of 29 October, only a few swallows were seen at dusk in the area (D. Coursey, CV Birds message 11127), indicating that most birds had abandoned the roost site, presumably continuing southern migration.

During the period 27-29 October, as the roost at Wright Road was disbanding, a second roost signature appeared briefly on radar near Merced, Merced County, ~40 km to the southeast. Both radar signals had disappeared by 30 October, when the weather pattern shifted from several days of 10-20 kn southerly winds, providing a favourable tailwind in the direction of migration, to unfavorable 20-30 kn northerly headwinds, as a storm system with light rain passed through the area.

The reports of the roost interested local media, which reported extensively on the site, raising further public interest. The story was featured on several television news programs (see video clip at <http://www.news10.net/video/default.aspx?aid=64547>) and in several newspaper articles. As a result of bird list-server reports and media attention, large numbers of birders and the general public descended on the roost site nightly over a 10-day period until it was abandoned.

The Brazil family members, the on-site residents, were extremely cooperative with the needs of both the birds and the public that wanted to see them. They graciously allowed birders to access the site and park on their lands to observe the roost spectacle. They were relieved to learn that the swallows are insectivorous and do not eat corn. They had planned to harvest the occupied field, but graciously offered to delay harvest until a weather change would cause the birds to move elsewhere.

Mrs. Brazil reported that the occupied field had been planted in a typical crop rotation of corn and tomatoes in prior years, and had been grown to tomatoes in 2007. In 2009, the field was returned to tomatoes, but several adjacent fields were planted in normal rotation back to corn.

Another smaller possible swallow roost was detected intermittently on radar west of Fresno, Fresno County, in the southern portion of the Central Valley through most of October, also in an agricultural area, where possible roosts were detected but not verified in 2007. Heavy ground clutter was common within ~100 km of the Hanford radar and often partially or completely masked roost dispersal signatures, making radar detection, monitoring and accurate location difficult or impossible on some days. This site appeared to be occupied by far fewer birds and was not located and verified in the field. Thus the species present are unknown, although timing was consistent with abandonment of the Tree Swallow roost near Tracy.

In 2009, roosts again formed in the Central Valley in the vicinity of Yolo Basin, Tracy and Fresno between late September and late October, but none were as large or remained in place as long as the 2008 Wright Road roost, and none were located and verified through field observations. This pattern

of annual recurrence is consistent with observations of the large Barn Swallow roost complex near Dayton, Oregon, immediately adjacent to the Willamette River, where Barn Swallows have been observed by local birders to roost in corn fields in the same general area (within ~5 km, though not always in the same fields) for over a decade and have been monitored on radar annually since 2006 (Cousens and Schrock 2007). Similarly, Purple Martin roosts in the eastern U.S. are known to recur consistently in the same location and habitat for many successive years (Tautin et al. 2005).

In April 2010, while this paper was being edited for publication, a similar large Tree Swallow roost was located on radar and verified on the ground by local birders at the Great Valley Grasslands State Park and San Luis National Wildlife Refuge wetland and grassland conservation complex in Merced County, ~60 km southeast of Tracy. This observation documents Tree Swallow use of the central portion of the Central Valley for roosting during both spring and fall migration, which has not been reported previously. This recently discovered roost was in emergent wetland vegetation, which is a typical substrate of swallow roosts in the eastern U. S.

DISCUSSION

Significance of the Roost

The Wright Road roost near Tracy is the first large Tree Swallow fall roost site documented in western North America and the second swallow pre-migratory roost to be documented west of the Rocky Mountains, after the similarly large Barn Swallow roost in Oregon (Cousens and Schrock 2007). The lack of previous evidence of western roosts presumably reflects the effectiveness of the swallows' furtive strategy of returning at dusk to an isolated roosting area and departing en masse in near darkness just before dawn, as well as the apparent scarcity of such roosts, rather than suggesting that formation of large roosts here is a recent phenomenon. Notwithstanding the difficulty of detecting such a roost, by either intensive local ground searches or time-consuming broad scale Doppler radar surveys, its recent discovery in an area with a high human population and many birders is notable. While swallow and martin roosts are far more numerous in the eastern U. S. and several hundred have been documented in radar surveys (Tautin et al. 2005, Burney 2002, Russell et al. 1998), many of these roosts are equally unknown to local birders and have yet to be located and field-verified for species composition and habitat type.

The presence of this massive fall roost (and nearby spring roost) also clearly defines the Central Valley as a major migratory pathway for Tree Swallows and potentially other swallow species in the west, as it is known to be for many other migratory bird species. The large size of the roost indicates that it must have contained birds breeding in a wide geographic area and supported a large proportion of the western regional population.

For example, if the roost was occupied by at least 500,000 Tree Swallows, a figure repeatedly cited by field observers and easily supported by radar signal strength, it included 53% of the estimated breeding population of 950,000 within the coastal portion of the species breeding range, from coastal Alaska south to southern California west of the British Columbia Coast Range mountains, the Cascades, and the Sierra Nevada (Bird Conservation Regions 5, 15, and 32 of the North American Landbird Conservation Plan [Rich et al. 2004; http://www.rmbo.org/pif_db/laped/PED2.aspx]). Extending the potential source area to include inland portions of the breeding range west of the Rocky Mountains throughout most of Alaska, Yukon, British Columbia, and eastern Washington and Oregon (i.e. adding BCR 2, 4 and appropriate portions of BCR 9 and 10) increases the potential contributing breeding population to ~4 million birds, of which the roost population represents 12.5%, though a large proportion of this total may migrate east of the Cascades and use different roost sites.

Several factors suggest a potentially higher proportion of the breeding population using this site and the mid-Central Valley as a pre-migratory roosting area, including: 1) a range of abundance estimates by different observers that extended up to 1 million birds, 2) a likelihood of substantial turnover of swallows using the roost over its duration as new birds arrive and others leave to resume migration, as indicated for roosting Purple Martins (Tautin et al. 2005), and 3) the presence of other smaller roosts which may have included birds that did not use the Wright Road site. Even with adjustment for the fact that the roosting Tree Swallow population likely contained a significant proportion of hatch-year (HY) birds (as noted at the Barn Swallow roost in Oregon; Cousens and Schrock 2007), thus elevating the roost population relative to the adult breeding population, the Wright Road roost and the Central Valley nonetheless supported a substantial proportion of the western regional Tree Swallow population.

The occurrence of the roost in a corn field demonstrates the Tree Swallow's adaptability in selecting roost sites. While our knowledge of this one site precludes certain determination of roost site requirements or preferences, use of standing corn by Barn Swallows in Oregon and probable use in the lower Colorado River Valley, based on Google aerial photo mapping imagery (Cousens, unpub. data), suggests that corn may be particularly suitable as a roosting substrate. The relatively tall and dense, but pliable nature of corn foliage and stems may encourage roosting use. This structure is generally similar to tall emergent wetland vegetation often used for roosting by swallows and Purple Martins at eastern roost sites (Kirby 1978, Burney 2002, Tautin et al. 2005) and presumably reduces nocturnal predation risks from both aerial and terrestrial predators (Winkler 2006). Corn may have replaced tall emergent wetland vegetation for this purpose in valley-bottom areas on migration routes where food is seasonally abundant, extensive wetlands have been drained for agricultural development and/or corn is widely available.

Conservation Implications

Annual concentration of a large proportion of the regional Tree Swallow population in one location raises conservation concerns regarding potential vulnerability to adverse impacts, but none were evident in this instance. Use of agricultural crops for nocturnal pre-migratory roosts at the end of the growing season suggests potential for disturbance of roost sites (and perhaps migration) from harvesting and between-year roosting habitat loss due to crop rotation. The effect of such actions on swallows, while unknown, seems unlikely to be severe, given their use of lands that have long been subject to these practices, the abundance each year of other apparently suitable corn fields locally, and the mobility of these roosts.

Notably, harvesting of the corn field roost area was thoughtfully delayed briefly until the swallows had left, by which time all other such fields nearby had been cut to stubble. Presumably, cutting the roost field sooner would have forced the swallows to leave earlier or relocate to suitable wild habitat. The impact of such disturbance is unknown and would depend on the timing, availability of other suitable roost sites, and the condition of the birds preparing for migration at the time. In four years of monitoring such roosts on radar, none have persisted past the end of October, by which time the weather is often deteriorating, the insect food supply is likely declining, and the birds are presumably ready to leave.

Comparison of Abundance of Radar-Detected Roost Sites in Western and Eastern North America

Over 200 roosts likely containing martins and swallows, many still unconfirmed to species and habitat, have been identified from radar surveys and local reports east of the Rocky Mountains, most in the U. S. and a few in southeastern Canada near the U. S. border, within the range of USNWS radars (Tautin et al. 2005). In Canada, unfiltered WSR-88D radar signals are not posted to the internet for public access in near-real time, precluding this type of radar survey without institutional research access. Large swallow roosts, however, are not known to occur further north, perhaps because of the shorter period with food availability after the breeding season at higher latitudes in the northern part of the breeding range.

The far greater abundance of radar-detectable late summer-fall swallow roosts in eastern North America raises the question of why so few have been found in the west during four years of radar surveys (i.e., only three large roosts or roost complexes and a few small temporary staging roosts identified between Canada and Mexico west of the Rocky Mountains)? Are we somehow overlooking them? Although USNWS Doppler radar sites are more sparsely distributed in the west than in the east, this arrangement largely reflects topographic and landscape conditions that also constrain distribution of suitable swallow roost habitat. Most of the areas with only

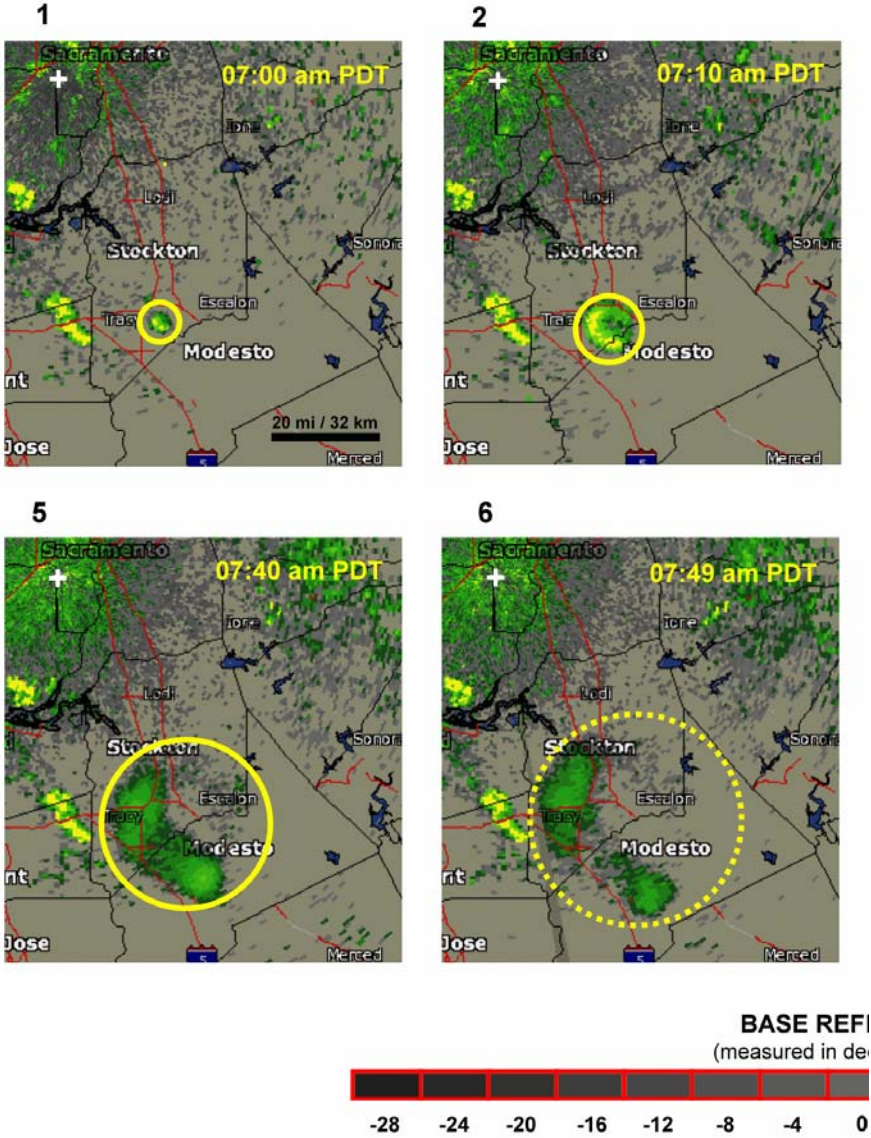
partial or no radar coverage (eastern Oregon, the Great Basin, Sierra Nevada, the deserts of the southwestern U. S., and parts of the Rocky Mountains) are at elevations of 2,500' to over 4,000' and lack suitable low elevation valley bottom habitat with abundant food for roosting swallows long after the breeding season. Higher elevation has a similar effect to higher latitude in shortening summer season food availability, perhaps explaining the detection of presumed, but as yet unverified, large swallow roosts east of the Cascades and Sierra Nevada so far only at elevations <~500', within the lower Colorado River Valley.

Swallow roost size thresholds for detection on radar are still unknown and local conditions for radar detection vary. Therefore, radar surveys may not reliably detect some small or transitory roosts of a few thousand birds, but available evidence suggests the scarcity of large swallow roosts in the west is real, and topography is likely the primary reason. North America east of the Rocky Mountains consists mostly of a flat, low- to mid-elevation rolling landscape with widespread roost habitat and few physical barriers to bird migration (e.g., the Appalachian Mountains). In contrast, topography in much of the west consists of a series of north-south oriented mountain ranges separated by long valleys (but at higher elevation east of the Cascades and Sierra Nevada), as well as the Pacific coastline, which provide narrow north-south migration corridors. Topography and variation in late summer-fall climate with latitude and elevation (and specifically seasonal variation in temperature as it regulates flying insect abundance and activity) combine to produce a very limited distribution of suitable low-elevation habitat within these migration corridors that is consistently able to provide abundant flying insect food supplies late in the season.

This set of conditions has significant implications for defining migration behavior and temporal and spatial distribution of roost sites. Rather than moving between a network of many roost sites spaced about a day's flying time apart, as is suggested in the eastern U. S. (Winkler 2006), migrating western swallows may be forced to concentrate in a few large roosts or roost complexes strategically located in lower elevation valleys that consistently provide optimal late-season foraging conditions.

As well, the moist maritime climate at more northerly latitudes in the Pacific Northwest, with a relatively cool wet fall with declining temperatures shortly after the breeding season (versus the eastern continental climate), likely limits food availability and forces earlier migration to warmer more southerly latitudes for pre-migratory roost staging than east of the Rocky Mountains. Seasonal climate variation with latitude likely also explains why earlier-migrating Barn Swallows congregate to roost in northern Oregon in late August and September, while later-migrating Tree Swallows are driven further south to roost in the Central Valley of California in late September and October. In both cases the roosts were abandoned as warm dry weather favorable for foraging deteriorated and cooler wetter weather prevailed.

Several other factors may also limit the abundance and temporal and



NOTE: Map colors represent different radar echo intensities (base reflectivity) measured on a decibel scale (dBZ).

SOURCE: Weather Underground Inc., 2008

Figure 1. Time series of Doppler weather radar images showing expa dispersal near Tracy, CA, at dawn on October 20, 2008.

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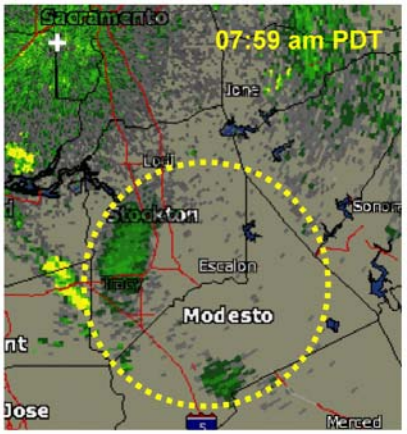

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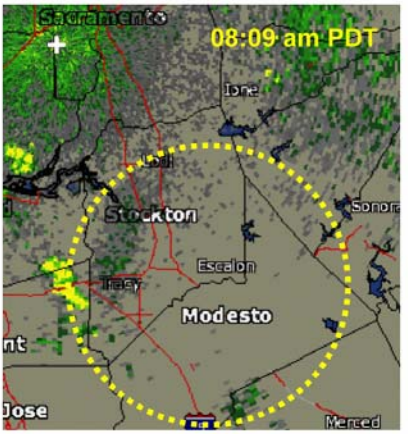

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ibel units, dBZ)

Stationary echos outside yellow circles are ground clutter. Sacramento weather radar station is "+" at upper left.

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nding partial ring echo of Tree Swallow nocturnal premigratory roost

spatial distribution of radar-detected swallow and martin roosts in the west, compared to eastern North America (recognizing the uncertainty of identifying dominant species using radar-detected roosts without ground verification). We list them here as potential areas for future investigation, since direct evidence to support the role of these possible contributing factors is lacking or unrecognized so far.

First, according to Breeding Bird Survey data, swallow species that form large roosts are notably less abundant in the west than in the east, likely reflecting the greater diversity of landscape and habitat types in the west, with large arid and high elevation areas being unsuitable or of low quality for breeding. The Tree Swallow population in North America is estimated at 20 million, of which only ~6.3 million (32%) occur west of the Rocky Mountains in ~40% of the continental range area (Rich et al. 2004). Similarly, only ~7.3 million (14%) of the estimated 51 million Barn Swallows in North America occur in the west, in ~34% of the continental range area (Rich et al. 2004)]. While these abundance estimates have variable levels of confidence and are subject to inter-annual variation, they indicate a smaller proportion of the occupied continental range in the west and a smaller proportion of suitable breeding habitat within the western range for both species. (See <http://www.mbr-pwrc.usgs.gov/bbs/htm03/ra2003_red_v2.html> for breeding distributions of both species [except north of ~50.5° latitude] from the available BBS data.)

Secondly, eastern North America supports an estimated 10 million breeding Purple Martins (Rich et al. 2004) and many documented annual pre-migratory roost locations (Tautin et al. 2005, Russell et al. 1998). Therefore, in the east it is often uncertain without ground verification whether characteristic "swallow" pre-migratory roosts identified on radar are occupied primarily by Barn or Tree Swallows or by martins where roost timing overlaps. With an at-risk Purple Martin population of fewer than 10,000 breeding birds in the west and no known roost locations (Western Purple Martin Working Group, unpub. data) this ambiguity does not occur – Tree and Barn Swallow roosts alone appear on radar.

Finally, the Violet-green Swallow is relatively abundant in the west, outnumbering both Tree and Barn Swallows, with an estimated breeding population of 8.7 million (Rich et al. 2004), but absent from the east. This species is common at low- and mid-elevations, breeding at higher elevations and farther from water than Tree Swallows (del Hoyo et al. 2004, Armstrong et al. 2005), but does not form or predominate at large pre-migratory roosts. Instead, it typically migrates in smaller flocks earlier in the season than roost-forming species (del Hoyo et al. 2004). Violet-green Swallows may compete with Tree Swallows for limited available nest cavities where they occur together in low-elevation habitat near water (Armstrong et al. 2005). The North American Breeding Bird Survey data show that both Tree Swallow and Barn Swallow populations are in long term decline in substantial areas of the west, although Tree Swallow populations in California may

be increasing. In contrast, Violet-green Swallows appear to be increasing in much of the Pacific Northwest but declining in California (Collins and Downs 2009, Sauer et al. 2008). The reasons for these ongoing population trends are unclear, though declines are often ascribed to habitat loss and limited availability of suitable nest cavities (Armstrong et al. 2005), and it is unknown whether they have had any influence on Tree Swallow roost abundance, distribution, and size.

Continued radar-based roost monitoring studies may further clarify the differences between eastern and western swallow migration behavior and roost abundance and distribution, and may also provide a basis for detecting large scale changes in populations of roost-forming swallows, independent of the Breeding Bird Survey and other monitoring programs. Such studies would provide a unique opportunity to easily and inexpensively monitor the relative abundance of an entire regional population over time, as well as recognize their potential vulnerabilities during the migratory portion of their annual cycle.

ACKNOWLEDGEMENTS

We thank the Brazil and Cash families for their cooperation in allowing viewing access and protecting the roost site. We also thank Todd Easterla, David Coursey, Elionora Bjur, Veronica Bowers, Helen George, Linda Adams, and other birders who posted information about the roost on the CV Birds list server, which provided valuable information for this collaborative paper. David Winkler and Tim Manolis provided useful review comments. We also thank the U. S. National Weather Service of NOAA for providing public access to raw and processed Doppler weather radar data via their website (http://radar.weather.gov) and Weather Services International (WSI) Corporation (www.intellicast.com) and Weather Underground Inc. (www.wunderground.com) for providing access to these data in different formats and access to additional analytical radar products, which made this study possible.

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