Avian Responses to Rapid Climate Change: Examples from the Putah Creek Christmas Bird Count

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ABSTRACT

As we enter an era of rapid climate change, shifting bird populations provide an early indication into their ability to rapidly adjust to new climate realities. Within the confines of the Putah Creek Christmas Bird Count (CBC) in Napa, Solano, and Yolo counties, California, increases in winter temperatures appear linked to significant increases in some bird species populations. Specifically, an examination of CBC data shows a marked increase in winter records of Turkey Vulture and 16 insectivores that may be due to warmer winters. These species account for the more than half of the regularly occurring aerial and arboreal insectivores in the region.

Birds have proven to be one of the most adaptable of taxonomic groups in responding to climate change and mass extinctions. Most modern bird lineages evolved in the aftermath of Cretaceous-Tertiary (K-T) extinction event 66 million years ago, caused by a large asteroid strike and a volcanic period of global warming that famously wiped out non-avian dinosaurs (Petersen et al. 2016). After that cataclysm, bird families quickly evolved to fill a wide range of ecological niches. Most modern bird lineages evolved in the few million years after the K-T extinction (Jarvis et al. 2014).

Ten million years later, 55.5 million years ago, many marine and plant species suffered another mass extinction event during the Paleocene-Eocene Thermal Maximum (PETM). The PETM was a period of rapid climate warming associated with rising atmospheric CO_2 levels. The earth's average temperature increased by about 5 degrees Celsius (^oC), resulting in the extension of tropical conditions nearly to the Arctic Circle. It "was a time of avian diversification as a result of favorable global climatic conditions" (Lindow and Dyke 2006). Perhaps due to their mobility, birds did well, evolving and surviving.

The PETM is considered our closest analog to the current era of climate change, but with one major difference. While warming during the PETM occurred over thousands of years, the current warming is occurring in just hundreds of years, and especially during the last several decades. During the PETM, average earth surface temperature rose about 1^oC per 1,200 years. The

present warming rate is about 1°C every 50 years, about ten times faster (Zeebe et al. 2016, Gingerich 2019). Although climate change during the PETM is considered rapid in geologic time, it would have scarcely been noticed by organisms on the ground. In contrast, the current warming is noticeable within a few generations of birds or even within the lifespan of an individual bird. Adaption through evolution is not an option; birds will need to adapt immediately.

A warming climate can affect birds in several ways. First, it directly changes the weather. In the Sacramento Valley, this has meant generally warmer daytime high temperatures and warmer overnight low temperatures in winter. Since 1985, average winter temperatures have risen nearly 1°C (Figure 1), consistent with worldwide trends. In winter, this change has resulted in a decline in hard freezes and foggy days, as well as greater swings between dry and wet winters. Recent research has also linked the decline in tule fog to a decrease in air pollution (Gray et al. 2019). These changes can reduce energetic demands on birds and increase their forage base. Foraging opportunities may increase for insectivores and fructivores due to greater insect abundance and activity and increased availability of fruits and flowers. Resident species' populations may expand, finding more food to sustain them year-round. Birds that normally winter further south may over-winter with greater frequency in the Sacramento Valley.

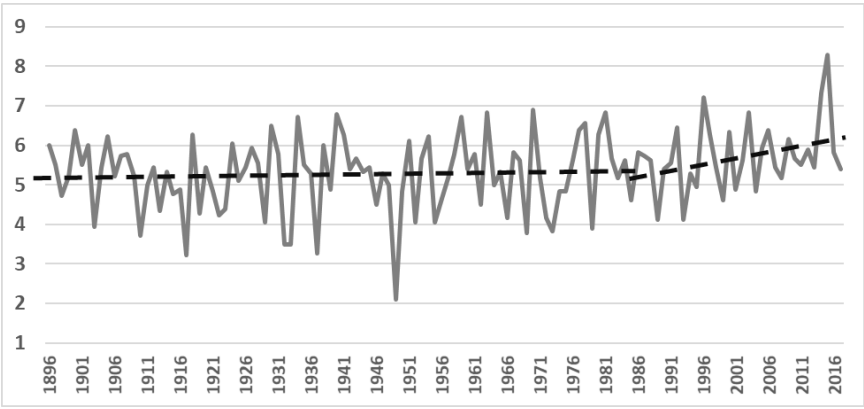

Figure 1. Sacramento Valley average winter temperature (°C) (November-February), 1901-2017, with trendlines for 1901-1984 and 1984-2017. Source: NOAA National Weather Service.

Several large-scale analyses of the effects of climate change on wintering birds have been conducted. In a report for the National Audubon Society, Niven et al. (2009) examined Christmas Bird Count data across North America, finding that the winter ranges of many woodland and feeder birds were

shifting north, while grassland birds were not, likely pinched between climate change and grassland conversion to agriculture. Audubon's follow-up report "389 Bird Species on the Brink" (Wilsey et al. 2019), focused on projections for the future. Seavy et al. (2018) provide a comprehensive survey of the research to date on the effects of climate change on landbirds in western North America. They concluded, "Despite the considerable body of literature given to the potential future effects of climate change on birds, we found little that pertained to how the terrestrial avifauna of western North America have already been affected by climate change." They found no studies focused on the winter distribution of landbirds in western North America.

This study was initiated to evaluate and characterize changes in bird species occurrence and abundance in the Putah Creek CBC area in association with recent increases in winter temperature.

STUDY AREA

The Putah Creek Christmas Bird Count (CBC) is conducted within a 24.1 km (15 mi)-diameter circle within Napa, Solano, and Yolo counties, California, centered at the Pleasants Valley Road bridge over Lake Solano. The count is bisected north and south by the transition from the Sacramento Valley to the Coast Ranges, and thus is composed of a mixture of chaparral, canyons, and hills on the west side, and agricultural fields of the valley floor to the east. Putah Creek bisects the count from west to east, providing the largest band of riparian habitat. The town of Winters is within the count circle, as is Lake Solano and the easternmost end of Lake Berryessa.

The count area experienced three major habitat changes since its initiation in 1971. Residential development in Winters and northern Vacaville replaced agricultural fields, oak woodland, and riparian areas. Lake Solano accumulated a substantial amount of silt, losing half of its storage volume (Rabidoux 2016) and forming a marsh near the Lake Solano Diversion Dam. Finally, extensive areas of fallow and pastureland have been converted to orchards in recent years.

METHODS

The Putah Creek CBC has been conducted annually since 1971 according to standard count methodologies. The first four years of the count (1971-1974) had limited effort. Since 1975, however, the effort level has been remarkably constant, usually ranging between 130 and 180 party-hours. The count is always conducted on the first Sunday of the count period, over December 14-20.

I examined the Putah Creek CBC data from 44 counts during 1975-2018 (the 76th thru the 119th CBCs) to evaluate changes in bird populations. The count has recorded 214 taxa. I excluded from the analysis 73 species that were not seen regularly on the count; only those 141 taxa seen on at least 25

of the 44 counts were included. I then examined the correlation coefficients (r) between abundance of each bird (using birds per party-hour) and time (years). {Species whose correlations were low (between 0.40 and -0.40) were excluded from the analysis, as this suggested weak increasing or decreasing trends over time. For the remaining species, I compared each species' average count per party-hour between the first decade (1975-1984) and the last decade (2009-2018).

For brevity, I omit scientific names for bird species. Common names follow those of the American Ornithological Society (Chesser et al. 2019).

RESULTS AND DISCUSSION

Eighty-eight taxa (Appendix A) that were present on at least 25 counts did not have strong correlations with time ($r > 0.4$ or <-0.4) and so are not further addressed.

Fifty-four species were recorded on at least 25 counts and had strong correlations with time ($r > 0.4$ or <-0.4). Of these, 38 increased and 16 decreased. These species are listed in Table 1, sorted by the ratio of average birds per party-hour in the last decade (2009-2018) compared to the first decade (1975-1984). For example, a ratio of 0.50 would mean that, in recent years, the average count for that species has been only half of what it was during the earlier time period. A ratio of 2.00 would mean that the average number of birds per party-hour in the last ten years was double that of the first decade. The ratio for Wild Turkey is undefined because it was not recorded at all on the early counts.

Several patterns emerge from the analysis. The decreasing species include nearly every breeding grassland bird in the region (Table 1). This decline is consistent with trends observed regionally (Pandolfino and Handel 2018) and nationally (Rosenberg et al. 2019). The decline within the count circle, this is not surprising, due to the conversion of pasture, alfalfa, and rangeland to orchards and residential housing.

Numbers have changed for 16 species that are associated with water and wetlands, including 12 that are increasing and four that are decreasing (Table 1).The increasing water and wetland species are primarily diving ducks and other piscivorous birds, while the decreasing species are two dabbling ducks and the coot and gallinule. This result is largely a function of changing ecological conditions at Lake Solano, where most of these species were recorded within the count circle, following the substantial amount of sedimentation between 1973 and 2013 (Rabidoux 2016). For reasons that are not clear, the Bufflehead has dramatically increased, replacing the American Wigeon as the most abundant duck on the lake in winter.

Table 1. Species that have increased and decreased on the Putah Creek CBC, with the ratio of the abundance (average birds per party-hour) during the last ten years (2009-2018) to the first ten years (1975-1984). Aerial and arboreal insectivores, water- and wetland-associated species, and breeding grassland species are denoted.

Decreasing Species			
White-throated Swift*	0.01	Rock Wren	0.45
Bell's Sparrow	0.04	White-tailed Kite[O]	0.46
Gadwall[#]	0.11	Western Meadowlark[O]	0.47
Burrowing Owl[O]	0.11	Lesser Goldfinch	0.47
Ring-necked Pheasant[O]	0.19	American Coot[#]	0.51
American Wigeon [#]	0.20	Brewer's Blackbird	0.52
Canyon Wren	0.25	Loggerhead Shrike[O]	0.57
Common Gallinule[#]	0.29	American Kestrel[O]	0.66

Increasing Species			
Wild Turkey	undefined	Great Egret[#]	3.66
Hooded Merganser[#]	91.74	Hairy Woodpecker*	3.18
Barrow's Goldeneye[#]	91.23	Orange-crowned Warbler*	3.06
Common Raven	87.86	Wood Duck[#]	2.96
Bufflehead [#]	71.73	Anna's Hummingbird*	2.90
Turkey Vulture	49.94	Mourning Dove	2.70
Pileated Woodpecker*	44.44	Northern Mockingbird*	2.65
Snowy Egret[#]	18.85	Mallard[#]	2.61
Common Goldeneye[#]	12.58	Black Phoebe*	2.42
Canada Goose[#]	10.65	White-breasted Nuthatch*	2.21
Red-shouldered Hawk	9.59	Rock Pigeon	2.03
Bald Eagle[#]	8.13	Nuttall's Woodpecker*	1.98
House Wren*	7.30	Hutton's Vireo*	1.88
Merlin	6.40	Golden-crowned Sparrow	1.64
Sora	6.23	Lincoln's Sparrow	1.75
American Crow	5.90	Say's Phoebe*[O]	1.73
Yellow-rumped Warbler (Audubon's)*	5.18	Western Bluebird*	1.70
Acorn Woodpecker*	3.70	Belted Kingfisher[#]	1.69
Phainopepla*	3.67	Wrentit*	1.58

*Aerial and arboreal insectivores

[#]Water and wetland associated species

[O]Breeding grassland species

Some species have unique stories. A colony of White-throated Swifts at Monticello Dam disappeared for unknown reasons, eliminating the only reliable location to find them within the count circle. In most years, fewer than ten Bell's Sparrows are recorded for the count. However, double-digit numbers were reported five times in the early years, which drives the trend. This result may have been an artifact of access to appropriate habitat, and thus not truly representative of the species' status. On the increasing side, Wild Turkeys were introduced into the Coast Ranges after 1960 and have been expanding into the count circle area (Fothergill 2007). The Common Raven has been expanding across the state in recent decades (Command Oil Spill Trustee Council 2004; Boarman et al 2006) mirroring the results in the count circle.

Turkey Vultures were rare on the Putah Creek CBC until 1987 (Figure 2). Given their need to soar on warm air currents, the increase in balmy winter days and decrease in tule fog may be the driving factor in their marked increase on the count.

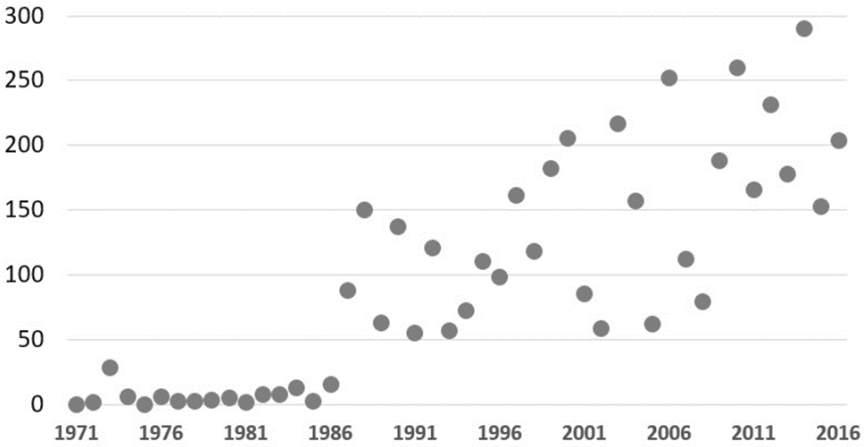

Figure 2. Numbers of Turkey Vultures recorded on the Putah Creek CBC.

The presence of 16 insectivores on the list of increasing species (Table 1) stands out. Although some terrestrial-foraging insectivores are decreasing (Canyon Wren, Rock Wren, Western Meadowlark, and Brewer's Blackbird), all of the aerial or arboreal insectivores, except White-throated Swift, are increasing. These 16 birds represent nearly half (16 of 35) of the aerial and arboreal insectivores that occur regularly on the count. Eighteen other aerial or arboreal insectivores showed weak positive correlations with time ($r \leq -0.40$) (Appendix A) suggesting increases; only the swift decreased.

Warming winters could be expected to be a boon to insectivores. Locally, a few degrees of warming makes the difference between freezing temperatures and the lack thereof, thus potentially having a dramatic effect on available fruit and insect prey. Among aerial and arboreal insectivores, many resident species are increasing. Most notable in this category has been a dramatic range extension of Pileated Woodpecker into local blue oak woodland since 1988, with a significant increase beginning in 2006 (Figure 3; Trochet et al. 2017)). Nuttall's and Hairy Woodpeckers, also year-round residents, have increased as well. Several other resident insectivores have likewise increased: Anna's Hummingbird, Black Phoebe, Hutton's Vireo, White -breasted Nuthatch, Wrentit, Western Bluebird, and Northern Mockingbird. The small Phainopepla population within the count circle appeared to double in 2003, and then set six high records in the next ten years.

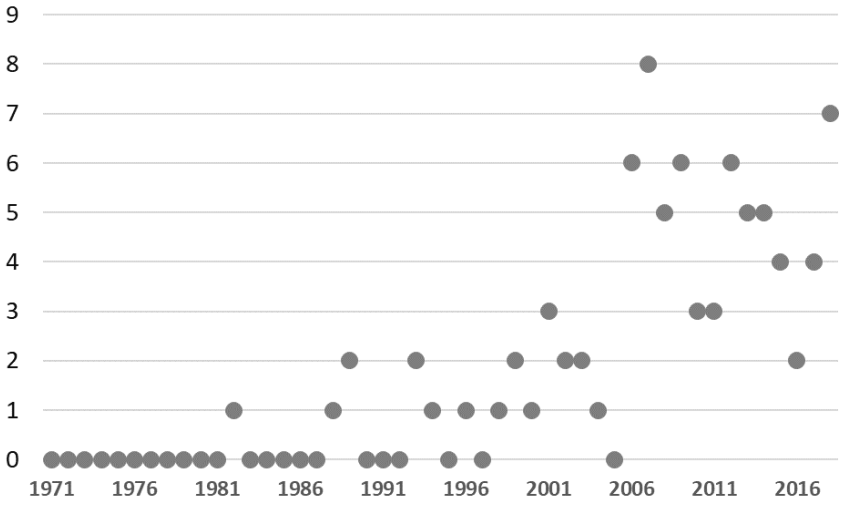

Figure 3. Numbers of Pileated Woodpeckers recorded on the Putah Creek CBC.

The insectivore increase also apply to migrants. Say's Phoebe is primarily a winter visitor. Its regional increase was also noted by Pandolfino and Handel (2018). Its increase may be due to improved local conditions for wintering or perhaps due to the expansion of their breeding range (Dunford et al. 2019). The House Wren and Orange-crowned Warbler, both local breeders and transient migrants, were historically rare in winter, primarily wintering south of the count circle. Their numbers on the count have both increased. The increase in over-wintering House Wrens, which began in 1986 and became sustained in 2006, has been especially dramatic (Figure 4). Orange-crowned Warbler numbers have been up substantially since 1994.

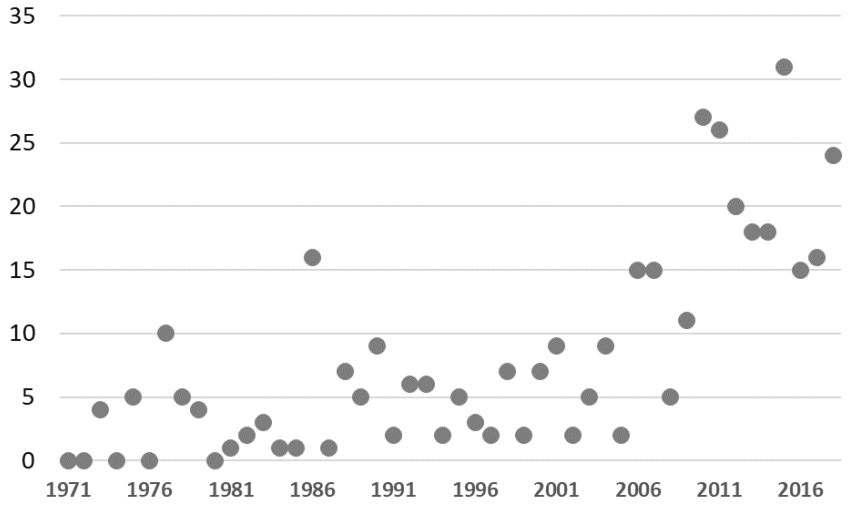

Figure 4. Numbers of House Wrens recorded on the Putah Creek CBC.

Not included in this analysis are the increasing records of unexpected neotropical migrants, also insectivores. The Putah Creek CBC is increasingly documenting the normally rare Cassin's Vireo, Warbling Vireo, Black-throated Gray Warbler, Townsend's Warbler, Wilson's Warbler, and Western Tanager (Figure 5). All of these species generally winter farther south and are only known as rare winter visitors, if they occurred at all, in the CBC area. In the first 27 years of the count (1971-1997), there were only six records of these species (average = 0.22/yr): four Black-throated Gray and two Townsend's Warblers. In the more recent 21 years (1998-2018), there have been 44 records (2.1/yr): three Cassin's Vireos, one Warbling Vireo, eight Black-throated Gray Warblers, 14 Townsend's Warblers, two Wilson's Warblers, and 16 Western Tanagers.

Pandolfino (2012) examined the abundance of swallows from 17 Central Valley CBCs and found increasing winter abundance of Tree Swallows and increasing records of Barn Swallows, both aerial insectivores. He attributed the changes to warming winters. Nevins et al. (2009) showed that 305 widespread bird species in North America had shifted their winter range north an average of 35 miles between 1970 and 2006. There may be tipping points in this movement and the Sacramento Valley, now without hard freezes, has crossed a tipping point for wintering insectivores.

The Putah Creek CBC's 44 years of bird abundance data offer a lens into this extraordinary period in natural history where the planet is warming at an unprecedented rate. The data show that many species, both migrants and resident, are encountered more frequently in winter now than in the past. A

shift of a few degrees in winter temperatures may not seem like much, but winter conditions above freezing reduces energy demands on birds and results in a more abundant supply of insects and extends the availability of autumn fruit and berries. In response, many insectivores and fructivores appear to be expanding their wintering range into the Putah Creek CBC area and increasing in numbers in response to these opportunities.

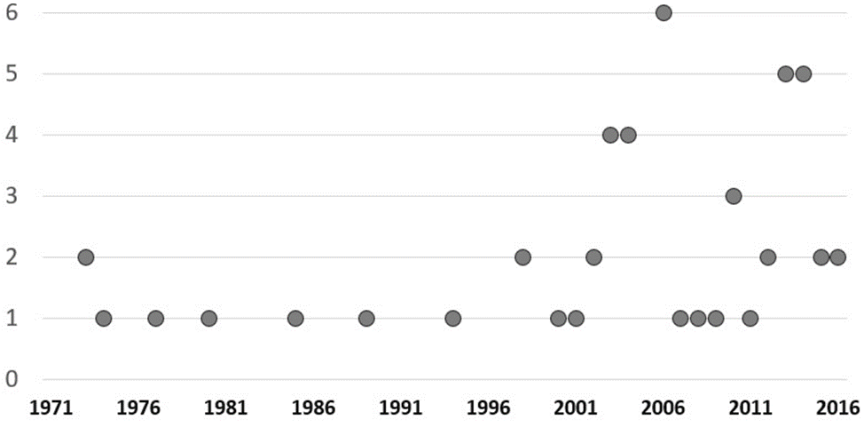

Figure 5. Numbers of neotropical migrant individuals recorded on the Putah Creek CBC.

The connection of increased winter bird abundance to warmer winters and climate change relies on circumstantial evidence and coincidental timing rather than elucidation of exact mechanisms. The patterns in the data (Figures 2 thru 5) closely mirror other climate-driven phenomenon, such as the number of acres burned by wildfires in California each year (Petras et al. 2018). Additional analyses of other CBC data, both in the Sacramento Valley region and elsewhere, could further support this hypothesis.

Research into the diets of these species would shed more light on the exact drivers of their increased numbers. For example, Pileated Woodpeckers and Western Tanagers are known to consume both insects and fruits. Is their increased occurrence in winter a result of either or both of those foods being more available in warmer winters? With regard to the decreasing insectivores, the decline in Brewer's Blackbird and the Western Meadowlark may be explained by loss of suitable habitat within the count circle. But what about the Rock Wren and Canyon Wren? Could they be finding themselves in new competition with other ground insectivores during warmer winters, such as lizards and salamanders?

With respect to local climate change, this analysis identified more species that were winners than losers, at least in terms of their numbers in winter within the Putah Creek CBC circle. These changes, however, may be

temporary. As climate change continues, changes in habitat may later work against these species. Also, there are potential contravening factors, such as impacts from increasing use of neonicotinoid pesticides (Eng et al. 2019, Airola in press) that may overwhelm these increases in the future.

Additionally, it is not difficult to imagine that climate change may cut both ways and that some species that winter in the Putah Creek CBC area could be negatively impacted on their breeding grounds. For example, grassland species everywhere will be increasingly threatened by habitat conversion to agriculture as humans seek to maintain food supply during shifting climate regimes. Other wintering species, if near the southern limits of their range, could decline in the count circle if their ranges contract northward. Additionally, some species that breed within the CBC area could be negatively affected by increasing summer temperatures and associated changes in habitat conditions.

Climate change has now reached the point where its impacts can be detected and should be expected. CBC data, with its long time series and many survey circles, provide an excellent opportunity to examine avian population shifts due to rising winter temperatures. Small scale analyses, such as this one focusing on a single count circle, allow for the control of local factors (such as conditions at Lake Solano) in the analysis.

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Appendix 1. Species with weak (r = <0.40 or >-0.40) population trends over time on the Putah Creek Christmas Bird Count 1971-2018.

Greater White-fronted Goose	Bonaparte's Gull	Hermit Thrush*
Northern Shoveler	Ring-billed Gull	American Robin *
Northern Pintail	California Gull	Varied Thrush*
Green-winged Teal	Herring Gull	California Thrasher
Ring-necked Duck	Band-tailed Pigeon	European Starling*
Lesser Scaup	Barn Owl	American Pipit
Common Merganser	Western Screech-Owl	Cedar Waxwing*
Ruddy Duck	Great Horned Owl	Yellow-rumped Warbler (Myrtle)*
Mountain Quail	Northern Pygmy-Owl	Chipping Sparrow
California Quail	Lewis's Woodpecker*	Lark Sparrow
Pied-billed Grebe	Red-breasted Sapsucker*	Fox Sparrow
Eared Grebe	Downy Woodpecker*	Dark-eyed Junco (Slate-colored)
Western Grebe	Northern Flicker (Yellow-shafted)*	Dark-eyed Junco (Oregon)
Double-crested Cormorant	Northern Flicker (Red-shafted)*	White-crowned Sparrow
Great Blue Heron	Prairie Falcon	White-throated Sparrow
Green Heron	Steller's Jay	Vesper Sparrow
Osprey	California Scrub-Jay	Savannah Sparrow
Golden Eagle	Yellow-billed Magpie	Song Sparrow
Northern Harrier	Horned Lark	California Towhee
Sharp-shinned Hawk	Oak Titmouse*	Rufous-crowned Sparrow
Cooper's Hawk	Bushtit *	Spotted Towhee
Red-tailed Hawk	Brown Creeper*	Red-winged Blackbird
Ferruginous Hawk	Pacific Wren	Brown-headed Cowbird
Virginia Rail	Marsh Wren	House Finch
Killdeer	Bewick's Wren *	Purple Finch
Spotted Sandpiper	Blue-gray Gnatcatcher*	Pine Siskin
Greater Yellowlegs	American Dipper	American Goldfinch
Long-billed Curlew	Golden-crowned Kinglet*	House Sparrow
Least Sandpiper	Ruby-crowned Kinglet*	
Wilson's Snipe	Hermit Thrush*	

*Aerial and arboreal insectivore