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Research Paper

Fall bird migration in western North America during a period of heightened wildfire activity

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ABSTRACT. Billions of birds annually migrate between breeding and nonbreeding grounds in North America. During fall 2020, there was a series of alarming mass-mortality events of migratory birds across the western United States, with estimates of 100,000 to 1 million birds having perished. One potential culprit behind these die-offs is wildfires, though there has been little research documenting the indirect effects of wildfires on actively migrating birds. We undertook a multi-year assessment of potential impacts that wildfires may have had on fall bird migration over the past decade, with a particular focus on fall 2020, using systematic bird banding data from southeastern Utah. We used a correlative approach to evaluate the relationship between estimates of acres burned by wildfires in western North America on several variables representing bird abundance and body condition. Notably, in our best fit models of birds banded at our research site during fall 2020, we found both a positive relationship for the number of bird captures and a negative relationship for body mass index with more daily burned acres. We provide an examination of incorporating lag effects of wildfires on different metrics of bird migration to account for potential impacts of fires on birds before migration and banding. Additionally, we assess the usefulness of different proxies of body condition in highly stressed land birds and introduce a scale for scoring emaciation of birds in the hand while banding. Our insights into avian migration ecology are one of the few studies that explore the role wildfires may have had in affecting migratory bird movements and health.

Migration automnale d'oiseaux dans l'ouest de l'Amérique du Nord en période intense d'incendies de forêt

RÉSUMÉ. Des milliards d'oiseaux migrent chaque année entre les aires de nidification et celles en dehors de la saison de nidification en Amérique du Nord. Au cours de l'automne 2020, une série d'évènements alarmants de mortalité massive d'oiseaux migrateurs a eu lieu dans l'ouest des États-Unis, l'estimation d'oiseaux ayant péri oscillant entre 100 000 et 1 million. Les incendies de forêt sont l'un des potentiels responsables de ces mortalités, bien que peu de recherches aient été menées sur les effets indirects de ceux-ci sur les oiseaux en migration active. Nous avons entrepris une évaluation pluriannuelle des impacts potentiels des incendies sur la migration automnale des oiseaux au cours de la dernière décennie, en portant une attention particulière à l'automne 2020, au moyen des données de baguage d'oiseaux dans le sud-est de l'Utah. Nous avons utilisé une approche corrélative pour évaluer la relation entre le nombre d'acres brûlés par les incendies de forêt dans l'ouest de l'Amérique du Nord et plusieurs variables décrivant l'abondance et la condition physique des oiseaux. Fait notable, nos meilleurs modèles, à partir des oiseaux bagués à notre site de recherche au cours de l'automne 2020, ont révélé une relation positive du nombre de captures d'oiseaux et une relation négative de l'indice de masse corporelle avec une superficie plus grande d'acres brûlés quotidiennement. Nous avons examiné la possibilité d'incorporer les effets différés des incendies de forêt sur différentes mesures de la migration des oiseaux afin de tenir compte des impacts potentiels des incendies sur les oiseaux avant leur migration et leur baguage. De plus, nous avons évalué l'utilité de différents indicateurs de l'état corporel chez des oiseaux terrestres fortement stressés et nous proposons une échelle destinée à classer l'émaciation des oiseaux en main pendant le baguage. Notre étude de l'écologie de la migration aviaire est l'une des rares à explorer le rôle que les incendies de forêt ont pu avoir sur les déplacements et la santé des oiseaux migrateurs.

Key Words: *avian abundance; bird banding; body condition; climate change; emaciation; lag effect; movement ecology; mortality; ornithology*

INTRODUCTION

Bird migration is one of the most studied types of animal movements in the world, with billions of birds annually traveling between breeding and non-breeding grounds in North America alone (Dokter et al. 2018). Migratory birds, which can spend up to one-third of each year migrating (Mehlman et al. 2005), typically break up journeys of up to thousands of kilometers between wintering and breeding grounds by utilizing multiple stopover sites along their migratory routes (Mehlman et al. 2005, Blount et al. 2021, Roques et al. 2022). However, in recent decades there have been significant declines in neotropical migratory birds in North America (Robbins et al. 1989, Nebel et al. 2010, Rosenberg et al. 2019), with an estimated 13.6% decline in nocturnal migratory biomass contributing to a predicted net loss

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of 2.5 billion birds since 1970 (Rosenberg et al. 2019). In addition to habitat loss, climate change is a major and growing threat to migratory birds (Wormworth and Şekercioğlu 2011, Abolafya et al. 2013), and 98% of western birds in North America are vulnerable to climate change (Bateman et al. 2020). It is therefore important to better understand how different aspects of climate change affect migratory bird movements in western North America.

During the fall of 2020, there was a series of widespread mass die-off events of migratory birds in the western United States. The first notable mortality event occurred on August 20 at the White Sands Missile Range in New Mexico (Higgins 2020, Johnson 2020, Weston 2020). Although this event was initially believed to be an isolated incident (Hobson and Hagan 2020), dead birds continued to be reported from across the state throughout September and into October (Higgins 2020), with a major and well-publicized spike in mortalities occurring between September 9 and 14 (e.g., D'Ammassa 2020, Higgins 2020, Johnson 2020, McCullough 2020, Weston 2020). Over 10,000 documented dead birds were reported during fall 2020 (Weston 2020), mostly from New Mexico but also from other western states (Mittermeier 2020, Tabachnik 2020), and it is estimated that 100,000 to upward of a million birds were likely to have perished across the western United States and four Mexican states (D'Ammassa 2020, Johnson 2020, Weston 2020).

Examination of specimens collected in New Mexico revealed that the dead birds had undergone long-term starvation (NMDGF 2020). The majority of these individuals had depleted fat stores, severely reduced breast muscles, empty stomachs and intestines, kidney failure, and severely emaciated bodies (NMDGF 2020, Weston 2020). In fact, these birds had become so emaciated that their major flight muscles were wasted, a sign indicating the birds were already stressed well before their deaths (NMDGF 2020, Weston 2020). These birds were largely insectivorous and long-distance neotropical migrants, and mostly consisted of swallows, warblers, and tyranid flycatchers (D'Ammassa 2020, Higgins 2020, McCullough 2020, Mittermeier 2020), but granivores including sparrows also perished (D'Ammassa 2020). In addition to mortalities, there were also a multitude of lethargic birds recorded across the western United States, including in New Mexico (D'Ammassa 2020, Hobson and Hagan 2020) and both Utah and Colorado (observations by and reports conveyed to the authors).

The second most severe wildfire season on record for the western United States happened to be 2020, with over 58,950 wildfires burning over 10.1 million acres (CRS 2021). With the height of the fire season occurring during fall bird migration, it is possible that migratory birds were indirectly affected by wildfires across the West (Overton et al. 2021). Intense wildfires have been known to instigate early or evasive migration and affect other dynamics of songbird movement (Berthold 1996, Frost 2018, Johnson 2020). However, there is little research documenting the effects of wildfires on migratory bird movements because of the difficulty in spatially and temporally comparing bird migration with fires (Overton et al. 2021). Rather, fire studies primarily focus on local changes to bird communities following a burn (e.g., Apfelbaum and Haney 1981, Pons and Prodon 1996, Saab et al. 2007, Keele et al. 2019, Hutto et al. 2020).

Although the examination of specimens from New Mexico failed to find any evidence of smoke poisoning or damage in the lungs of the dead birds (Fox 2020, NMDGF 2020), it is possible migrants were able to avoid the smoke but still be displaced and affected by the fires (Cunningham 2020, Overton et al. 2021). For example, one recent study showed that satellite-tagged Tule Geese (*Anser albifrons elgasi*) significantly altered their migratory movements to avoid flying through extensive wildfire smoke (Overton et al. 2021), which happened to occur in the same week in September 2020 as the notable spike in songbird mortalities. Birds are also known to use environmental cues to depart before an impending natural disaster or hazard (Yosef 1997, Chilson et al. 2012, Streby et al. 2015, Heckscher 2018), so examining birds for signs of smoke distress may not be the appropriate measure of determining avian responses to fires. It is possible that wildfires forced songbirds to prematurely migrate before they were sufficiently prepared for the long journey with the proper fat reserves. Wildfires can force birds into other habitats (Overton et al. 2021) where they must compete with resident species for resources, and burnt stopover sites can result in birds either continuing their flight in search of habitat or skipping stopovers altogether in an effort to fly as far south as possible (Frost 2018).

We undertook an assessment of potential indirect effects that wildfires may have had on fall migration in western North America. We first used 10 years of systematic fall bird banding data, from the Bonderman field station at Rio Mesa in southeastern Utah, to evaluate potential correlative annual impacts of wildfires on three avian variables: total number of captures, fat score, and body mass. With fall 2020 consisting of a series of mortality events across the Southwest, we then focused on this particular season and evaluated on a finer timescale the impacts of wildfires on our avian migration variables on a daily basis. Finally, we assessed how we could use abundance and body condition information, including emaciation collected through bird banding research to better understand responses of stressed birds to external factors during migration.

METHODS

Study site

Fieldwork was conducted at the Bonderman field station at Rio Mesa in Grand County, Utah (38°47′56.7″N, 109°12′17.2″W), a restricted-access research station that is owned and managed by the University of Utah (Kittelberger 2021). Rio Mesa is located on the floor of a canyon in the Colorado Plateau at an elevation of 1280 m asl, surrounded by the Dolores River (Kittelberger 2021). A strip of riparian vegetation ranging from roughly 30 to 70 meters in width extends along the riverside, bordered by more sparsely vegetated and open field-type habitat. The predominant vegetation is tamarisk (*Tamarix chinensis*), skunkbush (*Rhus trilobata*), Russian knapweed (*Rhaponticum repens*), and New Mexico privet (*Forestiera pubescens*). It is at the boundary of these two habitat types where mist-nets are located for seasonal bird banding. Rio Mesa is located within the western or pacific flyway (La Sorte et al. 2014, Rosenberg et al. 2019).

Bird surveys

Bird banding occurred annually each fall from 2011 through 2020. Most banding seasons lasted from late August to early November,

encapsulating the entire duration of fall landbird migration in eastern Utah. We used 16 38 mm mesh mist-nets, measuring 12 m by 3 m, along a roughly 300-meter stretch of riparian habitat. Nets were erected at consistent sites across years through the use of rebar marking net pole locations. At each site, nets were either distanced from one another or connected together lengthwise to create net walls. We opened nets 30 minutes before sunrise and typically checked every half-hour for the next 6 hours, every day for 10 days during a 12-day period. Sometimes this schedule had to be adjusted because of adverse weather conditions.

We extracted all birds from the nets and identified individuals to species. If possible, we also determined the age and sex of individuals (Pyle 2001) and recorded morphometric information such as fat score and body mass, the latter of which was measured by weighing the bird on a small scale. Fat score was measured on a scale of zero to seven and was an indication of the amount of fat a bird had deposited on its body around the abdomen, flanks, and furculum. Aluminum butt-end leg bands (Bird Banding Laboratory, USGS) were fitted on the legs of newly captured birds while the band numbers of recaptured individuals were recorded.

Datasets

Bird banding data

Our 10 year Rio Mesa fall banding dataset consisted of 107 species, 8 distinctive subspecies, and 3 groupings of birds that either could not be identified past genus level or consisted of hybrids. Taxonomic classifications were based on BirdLife International (2022), which maintains its own taxonomic list of the birds of the world that is reviewed and adopted by the BirdLife Taxonomic Working Group (BirdLife International 2022). Because our focus was to compare the fall 2020 banding season with previous years, we standardized our dataset by restricting each fall season to banding days between August 31 and November 3, the period of time that we banded during fall 2020.

Wildfire data

We accessed archived shapefile data of all recorded wildfires in the western United States between 2011 and 2020 from the open source platform National Interagency Fire Center (NIFC 2019), and from Canada for the same years from the open source platform Canadian Forest Service (CFS 2021). First, we extracted the shapefiles of wildfire perimeters (NIFC 2019, CFS 2021) using ArcGIS Pro (ESRI 2020, version 2.7.3.) and selected all fire events across the 10-year period located within an area encompassing a majority of the western United States (including the Alaskan panhandle), most of British Columbia, and part of Alberta (Appendix 1, Fig. A1.1). We then summed up all of the recorded GIS acres for each wildfire to calculate the overall number of acres burned each year (Appendix 1, Table A1.2 and Fig. A1.1). We chose this general area to incorporate wildfires across much of the migratory range for species migrating through Utah that have breeding grounds in northwestern boreal North America (see Appendix 1, Table A1.1 for a list of the most numerous bird species in our dataset for fall 2020); we hereafter refer to this selected region when discussing wildfires in western North America in our analyses.

The period prior to the start of migration is critical to birds for fat loading in preparation for their long-distance journeys (Morton and Pereyra 1994, Bairlein 2002, Bonier et al. 2007, Guglielmo 2018, La Sorte et al. 2018), with birds undergoing a dramatic increase in food consumption known as hyperphagia that allows them to rapidly gain fat (Odum 1960, Bairlein 2002). The duration of this fattening varies across species but frequently spans one to two weeks (Driedzic et al. 1993, Morton and Pereyra 1994, Bairlein 2002). A reduction in this fat-deposition due to external stressors can force birds to either migrate under suboptimal traveling conditions or delay migration (La Sorte et al. 2018). Hence, across the 10 years, we incorporated the 2 weeks prior to the start of our banding season to include data from fires that may have impacted birds while they were fattening, subsetting wildfires across the 10-year period, to those that were active from within 2 weeks before the start of the banding season (i.e., fire perimeter date established as early as August 17) and as late as November 3, depending on the year (Appendix 1, Fig. A1.1).

Estimates of daily acres burned by wildfires in western North America were then calculated for the fall 2020 banding season. First, we selected all fires in 2020 that were size classes E, F, or G, respectively, burning 300 to 1000, 1000 to 5000, or 5000 or more acres (NWCG 2021). We chose wildfires of these size classes for our analyses because these fires were likely large enough to have an important impact on migratory birds (Appendix 1, Fig. A1.2). Next, we researched publicly available information about the duration of fires of those that were active between August 17 and November 3 of 2020; we examined fires that were listed as beginning up to four weeks prior to August 31 to ensure we were incorporating those that had started before but were active on or after August 17. This approach allowed us to include fires burning during the critical premigration fat loading phase for birds. The complete daily fire dataset consisted of 150 large fires. We divided the total number of acres burned for each fire by the total number of days the fire lasted to calculate an estimate of daily acres burned and used these daily estimates to fill in the average acres burned across each day of a fire's known lifespan. We then summed up average daily acres burned by all fires across each day to produce an estimate of daily acres burned by wildfires in the West (hereafter, "wildfire acres").

Statistical analyses

During the 10-year period, comparisons among years for the total number of birds captured and the proportion of birds with low fat scores (0 and 0 or 1, based on the fact that emaciated birds in 2020 had fat scores of 0 and 1; Table 1) in relation to the total number of burned acres were conducted using one-way ANOVAs. We log-transformed the total number of acres annually burned by wildfires and then scaled this variable to have a mean of 0 and a standard deviation of 1. To address differences in daily sampling effort, we included the number of net hours for each banding day as scaled covariates in our model for total number of bird captures. In both fat score models, we filtered out any birds that lacked recorded fat scores and then used the *cbind* function in R (R Core Team 2020) for birds either with and without a fat score of 0 or with and without a fat score of 0 or 1.

For 2020, we created a series of generalized linear models (GLMs), with either a quasi-poisson (for abundance) or quasi-binomial (for the fat scores) error structure to account for overdispersion in the data, to test our three avian variables against the estimate of daily wildfire acres. We also created a linear mixed-effects model (LMEM) to evaluate the ratio of individual bird

Table 1. Emaciated birds captured in mist-nets during fall migration 2020 at Rio Mesa, Utah. Body mass index was calculated by taking a bird's measured body mass and dividing it by the species' mean mass.

Species Name	Alpha Code	Primary Diet	Fat	Body Mass (g)	Mean Species Mass (g)	Body Mass Index	Date	Notes
Sage Thrasher *Oreoscoptes montanus*	SATH	Invertebrate	1	33.0	43.2	-0.76	9/2	Emaciated
Wilson's Warbler *Cardellina pusilla*	WIWA	Invertebrate	0	6.0	7.0	-0.86	9/14	Protruding keel
Brewer's Sparrow *Spizella breweri*	BRSP	Seed	0	9.1	10.9	-0.83	9/14	Protruding keel
Western Tanager *Piranga ludoviciana*	WETA	Invertebrate	0	23.0	29.3	-0.78	9/15	Emaciated
Hammond's Flycatcher *Empidonax hammondii*	HAFL	Invertebrate	0	7.7	10.0	-0.77	9/15	Protruding keel
Warbling Vireo *Vireo gilvus*	WAVI	Invertebrate	1	9.6	13.4	-0.72	9/16	Thin
Brewer's Sparrow *Spizella breweri*	BRSP	Seed	0	8.8	10.9	-0.81	9/16	Thin
Western Tanager *Piranga ludoviciana*	WETA	Invertebrate	0	24.5	29.3	-0.84	9/16	Protruding keel
Hammond's Flycatcher *Empidonax hammondii*	HAFL	Invertebrate	1	8.2	10.0	-0.82	9/18	Protruding keel
Warbling Vireo *Vireo gilvus*	WAVI	Invertebrate	1	10.7	13.4	-0.80	9/19	Protruding keel
Blue-gray Gnatcatcher *Polioptila caerulea*	BGGN	Invertebrate	0	4.9	6.0	-0.82	9/29	Protruding keel
Gambel's White-crowned Sparrow *Zonotrichia leucophrys gambelii*	GWCS	Seed	0	21.0	38.5	-0.55	10/8	Thin
Gambel's White-crowned Sparrow *Zonotrichia leucophrys gambelii*	GWCS	Seed	0	24.5	38.5	-0.64	10/17	Thin

body mass at capture to the species' average mass (hereafter, body mass index) against daily wildfire acres, with species included as a random effect to control for taxonomic variation across birds; data on a species' average body mass were extracted from a global dataset of avian ecological traits (Appendix 1, Table A1.1; see Şekercioğlu et al. 2004, 2019 for more details of these methods and a description of this dataset). For this index, we filtered out any individuals that did not have a recorded mass or were not identified to species and therefore could not be compared against an average species' mass. Forty-three total individuals were removed, resulting in 1105 birds with a body mass index. We used the same approach as in our 10-year models to transform or scale the variables and to account for differences in sampling effort.

Depending on where a bird is migrating from, the wildfire acres on the day a bird is captured and banded may not necessarily be an accurate reflection of the possible effect of burned acres on this individual. Therefore, for each avian response variable, we examined potential lag effects of fire, before capture, by standardizing daily wildfire acres based on the following time periods prior to the start of the banding season: no lag effect, half a week (4 days), 1 week, and 2 weeks (i.e., we shifted the total daily acres burned on a given day by the number of days in the lag effect such that, for example, the daily acres on September 10 with a lag effect of 1 week were actually originally from September 3). We then used the R package, *AICcmodavg* (Mazerolle 2020), to evaluate among these lag effects, the effect(s) that best fit the models involving our different avian response variables, ranking these models by AIC_c and providing model weights (w_i) for each model (Burnham and Anderson 2002). We considered the model with the lowest AIC_c for each response variable to be the model best supported by the data (Harrison et al. 2018). If there were competing models that were within a ΔAIC_c value of 2, we noted these along with their coefficients and Akaike weights (Burnham and Anderson 2002, Cade 2015). This exploration of wildfire lag effects provided the opportunity to assess whether lag effects might have occurred and, if so, over what time frame.

For plots of our 10-year ANOVAs, we used loess smooth lines with a span of 0.6 to best visualize trends. All statistical analyses and graphing were conducted in R (R Core Team 2020, version 4.0.2).

RESULTS

Captures, fat, and emaciation

There were 10,031 individual bird captures in our dataset for total bird captures across all 10 years, and 9491 individual captures in our dataset assessing fat score across the same time period. During fall 2020, there were 1148 bird captures. There were 25 species captured 10 or more times during this season (Appendix 1, Table A1.1), of which 18 were full migrants in Utah, 3 were partial migrants, and 4 were resident species. The species containing the highest number of individuals with 0 fat this year (Appendix 1, Table A1.3) were White-crowned Sparrow (*Zonotrichia leucophrys*; n = 51), Song Sparrow (*Melospiza melodia*; n = 48), and Blue-gray Gnatcatcher (*Polioptila caerulea*; n = 46). The species with the highest proportion of individuals with 0 fat (Appendix 1, Table A1.3) were Blue-gray Gnatcatcher (60.5%), Wilson's Warbler (*Cardellina pusilla*; 54.8%), and Western Tanager (*Piranga ludoviciana*; 50.0%).

During fall 2020, we encountered a number of emaciated birds throughout the season, particularly during mid-September after a significant early season snow and windstorm event. Many birds were found starving and were very lethargic, with at least two birds, including an *Empidonax* flycatcher, found dead on the ground during this week. Beginning in mid-September, we began to note whether birds displayed symptoms of emaciation, recording this for 13 birds for the remaining duration of the season (Table 1). All of these birds were migrants; 9 were insectivores and the other 4 were granivores. Nine of the birds also had a fat score of 0 while the other four had a score of 1. The mass of these birds ranged from 55% to 86% below the average mass for the species (Table 1).

Wildfire impacts

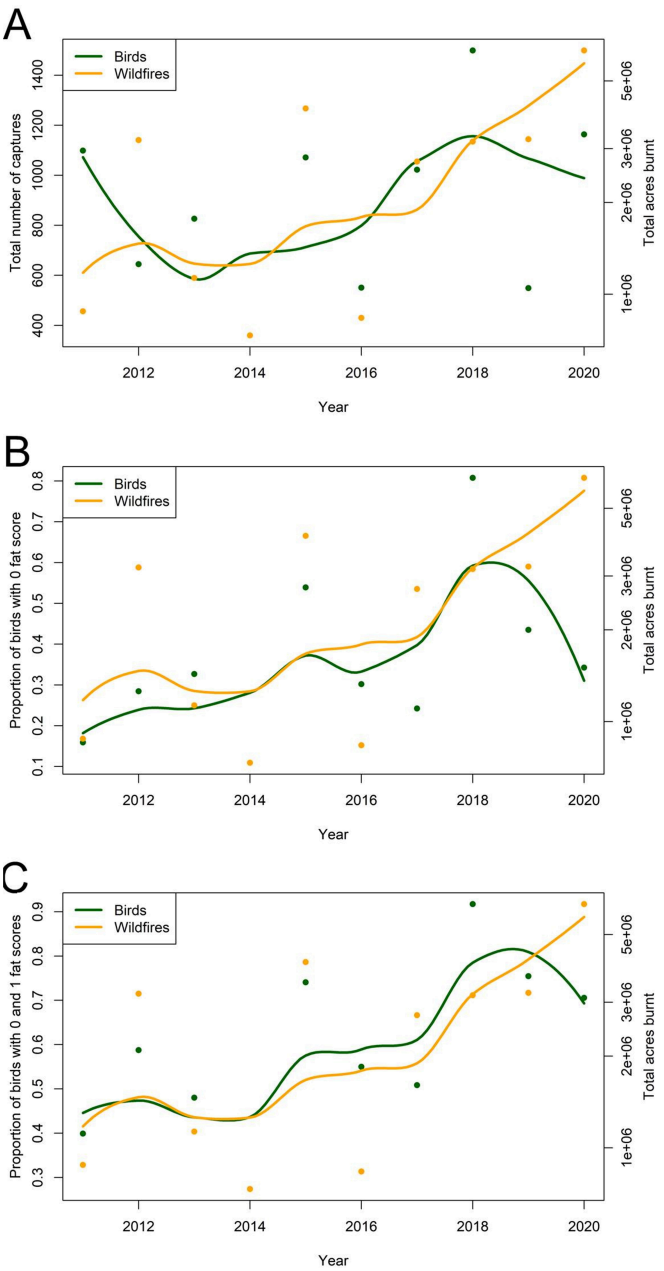
For our ANOVA's of wildfires across years (n = 10 years), we found no significant relationship between the annual number of acres burned and either the total number of bird captures (Fig. 1A; f(1) = 2.556, p = 0.154) or the proportion of birds with a fat score of 0 (Fig. 1B; f(1) = 2.778, p = 0.134). We found a significant relationship between acres burned and the proportion of birds with a fat score of 0 or 1 (Fig. 1C; f(1) = 6.477, p = 0.034).

In our GLMs for fall 2020 (Table 2; n = 55 days each), no lag effect for wildfire acres resulted in our best fit model for the total number of bird captures ($AIC_c w_i$ = 0.57, 0.102 ± 0.048), such that more bird captures were correlated with more acres burned. This top-ranked model was 2.1 times better than the next best model ($\Delta AIC_c < 2$) with a lag effect of half a week: ($AIC_c w_i$ = 0.27, 0.091 ± 0.046). For both fat scores 0 ($AIC_c w_i$ = 0.82, -0.200 ± 0.099) and 0 and 1 ($AIC_c w_i$ = 0.60, -0.150 ± 0.101), our best fit model was with a lag effect of two weeks. In both cases, an increase in the number of burned acres was correlated with a decrease in the number of birds with low fat scores. For fat scores of 0 and 1, our top-ranked model was 2.5 times better than the next best model ($\Delta AIC_c < 2$), which lacked any lag effect ($AIC_c w_i$ = 0.24, -0.120 ± 0.101).

For body mass index, there were 772 birds (70%) in fall 2020 that had body masses below the average mass for their species, and 333 birds (30%) with above average masses. In our LMEMs evaluating body mass index (Table 2; n = 55 days), our best fit model had a lag effect of one week for wildfire acres ($AIC_c w_i$ = 0.36, -0.005 ± 0.003), such that a decline in body mass index and therefore a reduction in body mass of captured birds was correlated with more acres burned one week prior. Our top-ranked model was 1.2 times better than our next best model. Our two competing models ($\Delta AIC_c < 2$) had a lag effect of half a week ($AIC_c w_i$ = 0.31, -0.005 ± 0.003) and no lag effect ($AIC_c w_i$ = 0.23, -0.004 ± 0.003).

Although we believe for total captures, fat scores of 0 and 1, and body mass index that our top-ranked models are best (Burnham and Anderson 2002), we cannot rule out that a competing model ($\Delta AIC_c < 2$) may be more appropriate. However, while the temporal scale of the predictor variable may vary among the competing models, the sign of the effects of these predictors on the three response variables does not vary from those in the respective top-ranked models (Table 2).

Fig. 1. Comparing (A) the total number of bird captures, (B) the proportion of birds with 0 fat, and (C) the proportion of birds with fat scores of 0 or 1 with the annual number of acres burned in our selected region of western North America between 2011 and 2020 for birds during fall migration at Rio Mesa, Utah. Loess smooth lines with a span of 0.6 are used to visualize the trends for both birds and wildfires during this period.



DISCUSSION

When comparing fall migration of birds with wildfires during a 10-year period in Utah, we found no correlation in the annual number of acres burned in the West and either the total number of bird

Table 2. The relationship between 4 avian response variables (total number of birds captured, proportion of birds with 0 fat, proportion of birds with a fat score of 0 or 1, and body mass index) and daily wildfire acres for birds migrating through the Rio Mesa field station in southern Utah during fall 2020 (n = 55 days), according to 4 different types of lag effects: none, half a week (4 days), 1 week, and 2 weeks. Models are ranked for each response variable according to AICc. K indicates the number of parameters in each model.

Avian Response Variable	Lag Effect	K	AIC_c	ΔAIC_c	AIC_c Weight	Estimate	Standard Error
Total Captures	None	3	398.30	0.00	0.57	0.102	0.048
	½ week	3	399.81	1.52	0.27	0.091	0.046
	1 week	3	400.86	2.56	0.16	0.084	0.045
	2 weeks	3	408.99	10.70	0.00	-0.011	0.047
Proportion with Fat 0	2 weeks	2	313.20	0.00	0.82	-0.200	0.099
	None	2	316.67	3.47	0.15	0.155	0.097
	½ week	2	320.22	7.02	0.02	0.105	0.099
	1 week	2	322.85	9.66	0.01	-0.024	0.097
Proportion with Fat 0 or 1	2 weeks	2	306.82	0.00	0.60	-0.150	0.101
	None	2	308.67	1.85	0.24	0.120	0.101
	½ week	2	310.19	3.37	0.11	0.093	0.104
	1 week	2	311.92	5.11	0.05	0.033	0.102
Body Mass Index	1 week	4	-2169.88	0.00	0.36	-0.005	0.003
	½ week	4	-2169.57	0.31	0.31	-0.005	0.003
	None	4	-2168.93	0.95	0.23	-0.004	0.003
	2 weeks	4	-2167.33	2.55	0.10	-0.001	0.003

captures or the proportion of birds with zero fat. We found a significant relationship with the proportion of birds that had fat scores of 0 or 1. However, an annual scale may be too broad for evaluating the impact on birds from wildfires. For fall 2020, a daily estimate of the number of acres burned by wildfires in western North America, compared with our avian response variables, allowed us to parse out the finer relationships between wildfires and migrating birds. Because emaciated birds in fall 2020 had undergone long-term starvation (NMDGF 2020), we included data from wildfires that were active during the premigration fat loading period and incorporated potential lag effects of wildfire acres into our models.

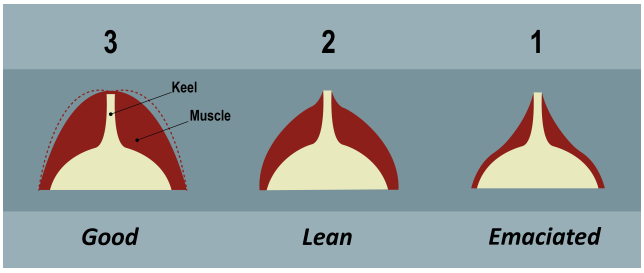
For the daily number of bird captures in fall 2020, we found a positive correlation with wildfire acres lacking any lag effect in our best fit model (Table 2), such that more bird captures at our banding station in southeastern Utah corresponded with more acres burned in the larger western region. This result is notable because it suggests an overall higher number of migratory songbirds were migrating through southeastern Utah on days with more extensive and impactful wildfires in western North America. This increase in volume could consequently be an indication that birds may have been shifting their migratory routes away from directions that were adversely affected by wildfires, something that has at least been demonstrated in migratory geese during the same time frame (Overton et al. 2021). It is not uncommon for bird movements on a given day to be affected by recent and proximate factors prior to flight (Chilson et al. 2012, Streby et al. 2015, Hong et al. 2018, La Sorte et al. 2018, Overton et al. 2021, Van Den Broeke and Gunkel 2021). This context is important particularly for migratory neotropical landbirds that can fly hundreds to thousands of kilometers on average in a night during migration (Wikelski et al. 2003, Stutchbury et al. 2009, Bayly et al. 2013, Renfrew et al. 2013, Gómez et al. 2017).

We found negative correlations between daily wildfire acres with a lag effect of two weeks and the proportion of birds with 0 or 0 and 1 fat scores. Fat score has been frequently used as a proxy for body condition in birds (i.e., McKinnon et al. 2015, Collins et al. 2017, Lupi et al. 2017), and fat scores typically correlate well with fat mass (Seewagen 2008, Salewski et al. 2009, Labocha and Hayes 2012). However, our results show that daily wildfire acres with this longer lag effect are correlated to a decrease in the proportion of birds with low fat scores. This correlation would seemingly contradict the reality that many birds suffered from poor body condition during fall 2020. On the other hand, when examining the correlation of daily wildfire acres with our body mass index in individual birds, we found a negative correlation in our best fit model with a lag effect of one week (Table 2), indicating that more acres burned by wildfires one week before capture are correlated to a reduction in body mass. This notable difference between results for low fat scores versus body mass index (Table 2), and the fact that most of the birds banded at our station during fall 2020 that lacked body fat were not emaciated whereas those that were emaciated did not exclusively have fat scores of 0 (Table 1), is consistent with the literature that fat score is not a comprehensive indicator of starvation and heightened stress in birds (Rogers 1991, Seewagen 2008, Labocha and Hayes 2012, McKinnon et al. 2015). Moreover, fat score has poor resolution for quantifying lipid mass at the lower end of the scale (Seewagen 2008), and birds with low fat scores can store fat elsewhere on their body that is not detected by traditional scoring (Rogers 1991, Seewagen 2008, Labocha and Hayes 2012). Thus, there are limitations to using fat score as a metric for body condition when there are many birds with scores of 0 (Rogers 1991, Seewagen 2008, Labocha and Hayes 2012), and low levels of fat may not actually be indicative of poor body condition (McKinnon et al. 2015, Wenker et al. 2022).

For studies involving many birds with low fat scores, avian body condition may be better represented by body mass index as well as a scale for emaciation. Some studies have used scales that assess pectoral muscle size (i.e., Tonra et al. 2013, Cooper et al. 2015, McKinnon et al. 2015, Ferretti et al. 2019), but emaciation is not a measurement typically recorded while banding in the field in North America, and there subsequently is no standardized scoring system for emaciation comparable to fat when banding. As a result of our observations of emaciated birds in 2020 (Table

1), we developed a standardized protocol for scaling emaciation in wild birds, which ranges from 1, for a bird that is emaciated, to 3, for a bird with good body condition (Fig. 2). Emaciation can be noted while a bander evaluates other body metrics (i.e., breeding features, fat, and body molt) by assessing the size of the keel in relation to the breast or pectoral muscles on either side. In typical muscular birds (score 3), the muscles around the keel are rounded and fully convex, resulting in a "barrel-chested" shape that sometimes forms a divot where the muscles meet the keel (Fig. 2). In lean birds (score 2), there is a slight concavity to the muscles closest to the keel, and these individuals can have normal or no fat reserves (Fig. 2). In emaciated birds (score 1), which have little to no body fat, the median ridge of the keel is well-defined; there may be severe atrophy of the breast and keel with the pectoral muscles very thin and concave resulting in the keel "peaking" (Fig. 2). This emaciation scale is informed by several publications on scaling avian body condition from pectoral muscles (Gosler 1991, Schoener 2010, SHARP 2011, Danner 2012, McKinnon et al. 2015), and because the birds we catch are alive, we have eliminated emaciation scores that would require dissection. It would be beneficial for banding stations to begin recording emaciation in captured birds to help researchers better detect avian responses to external stressors such as wildfires.

Fig. 2. A scale for assessing emaciation in migratory birds while banding. Muscular birds (score 3, good) will show rounded and fully convex breast or pectoral muscles around the keel; sometimes the muscles can be expanded, as indicated by the dotted lines, resulting in a "barrel-chested" shape that can create a divot where the muscles meet the keel. Although the ridge of the keel may be discernible, it remains flush with the surface of the convex breast muscles. Lean birds (score 2) have a slight but noticeable concavity to the muscles closest to the keel, with the keel now produced and defined; note that some species may normally appear lean. Birds scored as a 2 or 3 can be considered healthy. In emaciated birds (score 1), the pectoral muscles are concave, resulting in the median ridge of the keel being highly defined and distinctive from the breast muscles. In severely emaciated birds, there can be extreme atrophy of the breast and keel, with the pectoral muscles very thin and concave, resulting in the keel "peaking." Emaciation can be scaled while a bander is blowing on the breast and belly of the bird to score, for example, fat or brood patch. Muscle and keel can also be felt with two fingers on either side of the keel while holding the bird in the bander's grip. Be aware that any pressure might cause slight protrusion of the keel and could result in an incorrect scoring. It is best to judge score by both visual and tactile techniques.



Future studies should continue to examine responses of migratory birds to wildfires across temporal and spatial scales in western North America as well as to evaluate the influence of other potential confounding variables on fall bird migration such as inclement weather. For example, on September 9 of 2020, a historic windstorm struck the mountainous regions of the interior West. This storm was then followed by an extreme drop in temperature of up to 38°C overnight, with record temperature lows and snowfall across the region (McCullough 2020). Adverse weather is known to hinder bird migration by disrupting bird flightpaths or by forcing birds to land and remain grounded (Komenda-Zehnder et al. 2002, Elkins 2005, Gordo 2007, Pastorino et al. 2017, Bozó et al. 2018). There is also a history of inclement weather, such as harsh cold and unseasonal snow, resulting in major avian mortality events (Alexander 1933, Jehl et al. 1999, Newton 2007). Although the drop in temperature and snow could have had an effect on avian food sources and thereby birds migrating through the region in early September (Newton 2007), this storm does not account for the mortalities that began in mid-August or those that continued well after (Higgins 2020, Johnson 2020, Mittermeier 2020). Weather therefore could be another piece of the larger puzzle of ongoing changes in birds during fall migration in western North America.

CONCLUSION

Avian body condition information, particularly body mass and emaciation collected at long-term bird banding sites, can help us to better understand how various climatic stressors are affecting the dynamics of fall bird migration in western North America. The pattern for wildfires is clear. Their size and intensity in the West are progressively increasing over time (Fig. 1), fueled by worsening anthropogenic climate change (Abatzoglou and Williams 2016), and as a result there may be a growing risk from these fires to bird migration and movements in the West (Overton et al. 2021, Sanderfoot and Gardner 2021). In this study, we used a correlative approach to examine bird banding data from southeastern Utah to assess how wildfires may be indirectly affecting migratory birds. Notably, we found that during fall 2020, more bird captures were correlated with more acres burned for the day birds were captured and that a decline in body mass index, and therefore a reduction in body mass of captured birds, was correlated with more acres burned one week prior (Table 2). We also evaluated different lag effects of wildfires in models of various metrics of bird migration. Additionally, we examined the usefulness of different proxies of body condition in highly stressed birds and introduced an emaciation scale (Fig. 2) to help researchers track landbird body condition and health better than with fat.

Although we did not evaluate the impact of other factors on fall migrants, we provide an important exploration of the impact wildfires may be having on migratory birds. With the conservation status of migratory birds declining globally (Horns and Şekercioğlu 2018) and those in North America undergoing significant population declines over the last several decades (Robbins et al. 1989, Nebel et al. 2010, Rosenberg et al. 2019), our exploratory study offers some insight into avian migration ecology and is an important first step into examining how wildfires may be playing an understudied role in affecting migratory birds. These findings may be important to help

understand future avifaunal trends, movements, and health in the interior West in autumns with heightened wildfire activity that is on par with or worse than that of 2020.

Author Contributions:

KDK wrote the manuscript with assistance from MKM; KDK conceived the original idea for the paper; ÇH & KDK acquired funding and resources; MKM and KDK helped lead fieldwork during fall 2020; KDK compiled the datasets for this paper with help from MKM; KDK statistically analyzed the data and created the figures and tables; MKM designed the emaciation scale and figure with help from KDK; all co-authors contributed to and gave final approval of the manuscript.

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LITERATURE CITED

Abatzoglou, J. T., and A. P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western U.S. forests. Proceedings of the National Academy of Sciences 113 (42):11770-11775. https://doi.org/10.1073/pnas.1607171113

Abolafya, M., O. Onmuş, Ç. H. Şekercioğlu, and R. Bilgin. 2013. Using citizen science data to model the distributions of common songbirds of Turkey under different global climatic change scenarios. PLoS ONE 8(7):e68037. https://doi.org/10.1371/journal.pone.0068037

Alexander, W. B. 1933. The swallow mortality in central Europe in September 1931. Journal of Animal Ecology 2(1):116-118. https://doi.org/10.2307/945

Apfelbaum, S., and A. Haney. 1981. Bird populations before and after wildfire in a Great Lakes pine forest. Condor 83(4):347-354. https://doi.org/10.2307/1367504

Bairlein, F. 2002. How to get fat: nutritional mechanisms of seasonal fat accumulation in migratory songbirds. Naturwissenschaften 89(1):1-10. https://doi.org/10.1007/s00114-001-0279-6

Bateman, B. L., C. Wilsey, L. Taylor, J. Wu, G. S. LeBaron, and G. Langham. 2020. North American birds require mitigation and adaptation to reduce vulnerability to climate change. Conservation Science and Practice 2(8):e242. https://doi.org/10.1111/csp2.242

Bayly, N. J., C. Gómez, and K. A. Hobson. 2013. Energy reserves stored by migrating Gray-cheeked Thrushes, *Catharus minimus*, at a spring stopover site in northern Colombia are sufficient for a long-distance flight to North America. Ibis 155(2):271-283. https://doi.org/10.1111/ibi.12029

Berthold, P. 1996. Control of bird migration. First edition. Chapman and Hall, London, UK.

BirdLife International. 2022. BirdLife data zone. BirdLife International, Cambridge, UK.http://datazone.birdlife.org

Blount, J. D., J. J. Horns, K. D. Kittelberger, M. H. C. Neate-Clegg, and Ç. H. Şekercioğlu. 2021. Avian use of agricultural areas as migration stopover sites: a review of crop management practices and ecological correlates. Frontiers in Ecology and Evolution 9:650641. https://doi.org/10.3389/fevo.2021.650641

Bonier, F., P. R. Martin, J. P. Jensen, L. K. Butler, M. Ramenofsky, and J. C. Wingfield. 2007. Pre-migratory life history stages of juvenile arctic birds: costs, constraints, and trade-offs. Ecology 88 (11):2729-2735. https://doi.org/10.1890/07-0696.1

Bozó, L., T. Csörgõ, and W. Heim. 2018. Weather conditions affect spring and autumn migration of Siberian leaf warblers. Avian Research 9(1):33. https://doi.org/10.1186/s40657-018-0126-5

Burnham, K., and D. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer, Berlin, Germany.

Cade, B. S. 2015. Model averaging and muddled multimodel inferences. Ecology 96(9):2370-2382. https://doi.org/10.1890/14-1639.1

Canadian Forest Service (CFS). 2021. Canadian National Fire Database - Agency FireData. Natural Resources Canada, Canadian Forest Service, Ottawa, Ontario, Canada.https://cwfis.cfs.nrcan.gc.ca/ha/nfdb

Chilson, P. B., A. Daniel, S. B. Cocks, D. S. Berkowitz, V. Melnikov, W. F. Frick, A. C. Wood, and J. F. Kelly. 2012. The response of birds to abrupt natural hazards as observed using weather radar. ERAD 2012 - the seventh European conference on radar in meteorology and hydrology, Toulouse, France. http://www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/NMUR_064_ext_abs.pdf

Collins, M. D., G. E. Relyea, E. C. Blustein, and S. M. Badami. 2017. Heterogeneous changes in avian body size across and within species. Journal of Ornithology 158:39-52. https://doi.org/10.1007/s10336-016-1391-x

Congressional Research Service (CRS). 2021. Wildfire statistics. Congressional Research Service, Washington, D.C., USA. https://fas.org/sgp/crs/misc/IF10244.pdf

Cooper, N. W., T. W. Sherry, and P. P. Marra. 2015. Experimental reduction of winter food decreases body condition and delays migration in a long-distance migratory bird. Ecology 96 (7):1933-1942. https://doi.org/10.1890/14-1365.1

Cunningham, V. 2020. Birds can fly away from wildfires, but not out of reach of the aftermath. StarTribune, October 6. https://www.startribune.com/birds-can-fly-away-from-wildfires-but-not-out-of-reach-of-the-aftermath/572649932/

D'Ammassa, A. 2020. Hundreds of thousands, if not millions: New Mexico sees massive migratory bird deaths. Las Cruces Sun-News, September 12. https://www.lcsun-news.com/story/news/2020/09/12/mass-deaths-migratory-birds-new-mexico-environment/5780282002/

Danner, R. M. 2012. The effects of limited winter food availability on the population dynamics, energy reserves, and feather molt of the Swamp Sparrow. Dissertation. Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA. https://vtechworks.lib.vt.edu/bitstream/handle/10919/38688/Danner_RM_D_2012.pdf

Dokter, A. M., A. Farnsworth, D. Fink, V. Ruiz-Gutierrez, W. M. Hochachka, F. A. La Sorte, O. J. Robinson, K. V. Rosenberg, and S. Kelling. 2018. Seasonal abundance and survival of North America's migratory avifauna determined by weather radar. Nature Ecology and Evolution 2:1603-1609. https://doi.org/10.1038/s41559-018-0666-4

Driedzic, W. R., H. L. Crowe, P. W. Hicklin, and D. H. Sephton. 1993. Adaptations in pectoralis muscle, heart mass, and energy metabolism during premigratory fattening in Semipalmated Sandpipers (*Calidris pusilla*). Canadian Journal of Zoology 71 (8):1602-1608. https://doi.org/10.1139/z93-226

Elkins, N. 2005. Weather and bird migration. British Birds 98 (5):238-256. https://britishbirds.co.uk/wp-content/uploads/article_files/V98/V98_N05/V98_N05_P238_256_A003.pdf

Environmental Systems Research Institute (ESRI). 2020. ArcGIS Pro. Version 2.7.3. ESRI, Redlands, California, USA. https://www.esri.com/en-us/home

Ferretti, A., I. Maggini, S. Lupi, M. Cardinale, and L. Fusani. 2019. The amount of available food affects diurnal locomotor activity in migratory songbirds during stopover. Scientific Reports 9(1):19027. https://doi.org/10.1038/s41598-019-55404-3

Fox, A. 2020. Southwest bird die-off caused by long-term starvation. Smithsonian Magazine, December 29. https://www.smithsonianmag.com/smart-news/southwest-bird-die-caused-long-term-starvation-180976643/

Frost, G. 2018. Fire and birds. Audubon, August 15.https://ca.audubon.org/news/fire-and-birds-0

Gómez, C., N. J. Bayly, D. R. Norris, S. A. Mackenzie, K. V. Rosenberg, P. D. Taylor, K. A. Hobson, and C. Daniel Cadena. 2017. Fuel loads acquired at a stopover site influence the pace of intercontinental migration in a boreal songbird. Scientific Reports 7(1):3405. https://doi.org/10.1038/s41598-017-03503-4

Gordo, O. 2007. Why are bird migration dates shifting? A review of weather and climate effects on avian migratory phenology. Climate Research 35:37-58. https://doi.org/10.3354/cr00713

Gosler, A. G. 1991. On the use of greater covert moult and pectoral muscle as measures of condition in passerines with data for the Great Tit *Parus major*. Bird Study 38(1):1-9. https://doi.org/10.1080/00063659109477061

Guglielmo, C. G. 2018. Obese super athletes: fat-fueled migration in birds and bats. Journal of Experimental Biology 121(Suppl_1): jeb165753. https://doi.org/10.1242/jeb.165753

Harrison, X. A., L. Donaldson, M. E. Correa-Cano, J. Evans, D. N. Fisher, C. E. D. Goodwin, B. S. Robinson, D. J. Hodgson, and R. Inger. 2018. A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 6:e4794. https://doi.org/10.7717/peerj.4794

Heckscher, C. M. 2018. A nearctic-neotropical migratory songbird's nesting phenology and clutch size are predictors of accumulated cyclone energy. Scientific Reports 8(1):9899. https://doi.org/10.1038/s41598-018-28302-3

Higgins, D. 2020. Researchers still don't know why so many birds died this fall. Sierra Club, November 10.https://www.sierraclub.org/sierra/researchers-still-don-t-know-why-so-many-birds-died-fall

Hobson, J., and A. Hagan. 2020. We really don't know if bird die-off in New Mexico is related to climate change, expert says. Wbur Here and Now, September 15. https://www.wbur.org/hereandnow/2020/09/15/birds-dying-new-mexico

Hong, S.-Y., S. P. Sharp, M.-C. Chiu, M.-H. Kuo, and Y.-H. Sun. 2018. Flood avoidance behaviour in Brown Dippers *Cinclus pallasii*. Ibis 160(1):179-184. https://doi.org/10.1111/ibi.12508

Horns, J. J., and Ç. H. Şekercioğlu. 2018. Conservation of migratory species. Current Biology 28(17):PR980-R983. https://doi.org/10.1016/j.cub.2018.06.032

Hutto, R. L., R. R. Hutto, and P. L. Hutto. 2020. Patterns of bird species occurrence in relation to anthropogenic and wildfire disturbance: management implications. Forest Ecology and Management 461:117942. https://doi.org/10.1016/j.foreco.2020.117942

Jehl, J. R., A. E. Henry, and S. I. Bond. 1999. Flying the gantlet: population characteristics, sampling bias, and migration routes or Eared Grebes downed in the Utah desert. Auk 116(1):178-183. https://doi.org/10.2307/4089464

Johnson, K. 2020. The Southwest is facing an 'unprecedented' migratory bird die-off. Audubon, September 16.https://www.audubon.org/news/the-southwest-facing-unprecedented-migratory-bird-die

Keele, E. C., V. M. Donovan, C. P. Roberts, S. M. Nodskov, C. L. Wonkka, C. R. Allen, L. A. Powell, D. A. Wedin, D. G. Angeler, and D. Twidwell. 2019. Relationships between wildfire burn severity, cavity-nesting bird assemblages, and habitat in an eastern Ponderosa pine forest. American Midland Naturalist 181(1):1-17. https://doi.org/10.1674/0003-0031-181.1.1

Kittelberger, K. D. 2021. New regional record of *Brechmorhoga mendax* (Pale-faced Clubskimmer) in eastern Utah, with notes on the species' status in Utah and known northern distribution boundaries. ARGIA 33:27-28.

Komenda-Zehnder, S., F. Liechti, and B. Bruderer. 2002. Is reverse migration a common feature of nocturnal bird migration? An analysis of radar data from Israel. Ardea-Wageningen 90 (2):325-334.

Labocha, M. K., and J. P. Hayes. 2012. Morphometric indices of body condition in birds: a review. Journal of Ornithology 153:1-22. https://doi.org/10.1007/s10336-011-0706-1

La Sorte, F. A., D. Fink, W. M. Hochachka, A. Farnsworth, A. D. Rodewald, K. V. Rosenberg, B. L. Sullivan, D. W. Winkler, C. Wood, and S. Kelling. 2014. The role of atmospheric conditions in the seasonal dynamics of North American migration flyways. Journal of Biogeography 41:1685-1696. https://doi.org/10.1111/jbi.12328

La Sorte, F. A., D. Fink, and A. Johnston. 2018. Seasonal associations with novel climates for North American migratory bird populations. Ecology Letters 21(6):845-856. https://doi.org/10.1111/ele.12951

Lupi, S., I. Maggini, W. Goymann, M. Cardinale, A. Rojas Mora, and L. Fusani. 2017. Effects of body condition and food intake on stop-over decisions in Garden Warblers and European Robins during spring migration. Journal of Ornithology 158:989-999. https://doi.org/10.1007/s10336-017-1478-z

Mazerolle, M. 2020. AICcmodavg: model selection and multimodel inference based on (Q)AIC(c). R package version 2.3-1. https://CRAN.R-project.org/package=AICcmodavg

McCullough, J. 2020. The data behind mysterious bird deaths in New Mexico. North American birds field ornithology, September 14.https://www.aba.org/the-data-behind-mysterious-bird-deaths-in-new-mexico/

McKinnon, E. A., J. A. Rotenberg, and B. J. M. Stutchbury. 2015. Seasonal change in tropical habitat quality and body condition for a declining migratory songbird. Oecologia 179(2):363-375. https://doi.org/10.1007/s00442-015-3343-1

Mehlman, D. W., S. E. Mabey, D. N. Ewert, C. Duncan, B. Abel, D. Cimprich, R. D. Sutter, and M. Woodrey. 2005. Conserving stopover sites for forest-dwelling migratory landbirds. Auk 122 (4):1281-1290. https://doi.org/10.1093/auk/122.4.1281

Mittermeier, J. C. 2020. Thousands of migratory birds suddenly died in New Mexico. What does this mean for conservation? American Bird Conservancy, Bird Calls, October 1.https://abcbirds.org/blog20/thousands-of-migratory-birds-suddenly-died-in-new-mexico-what-does-this-mean-for-conservation/

Morton, M. L., and M. E. Pereyra. 1994. Autumnal migration departure schedules in mountain White-crowned Sparrows. Condor 96(4):1020-1029. https://doi.org/10.2307/1369111

National Interagency Fire Center. 2019. Wildland fire open data. National Interagency Fire Center, Boise, Idaho, USA.https://data-nifc.opendata.arcgis.com/

Nebel, S., A. Mills, J. D. McCracken, and P. D. Taylor. 2010. Declines of aerial insectivores in North America follow a geographic gradient. Avian Conservation and Ecology 5(2):1. https://doi.org/10.5751/ACE-00391-050201

Newton, I. 2007. Weather-related mass-mortality events in migrants. Ibis 149(3):453-467. https://doi.org/10.1111/j.1474-919X.2007.00704.x

New Mexico Department of Game and Fish (NMDGF). 2020. Starvation, unexpected weather to blame in mass migratory songbird mortality. New Mexico Department of Game and Fish, Sante Fe, New Mexico, USA.https://content.govdelivery.com/accounts/NMDGF/bulletins/2afbc3e?reqfrom=share

National Wildfire Coordinating Group (NWCG). 2021. Size class of fire. National Wildfire Coordinating Group, Potomac, Maryland, USA.https://www.nwcg.gov/term/glossary/size-class-of-fire

Odum, E. P. 1960. Premigratory hyperphagia in birds. American Journal of Clinical Nutrition 8(5):621-629. https://doi.org/10.1093/ajcn/8.5.621

Overton, C. T., A. A. Lorenz, E. P. James, R. Ahmadov, J. M. Eadie, F. Mcduie, M. J. Petrie, C. A. Nicolai, M. L. Weaver, D. A. Skalos, S. M. Skalos, A. L. Mott, D. A. Mackell, A. Kennedy, E. L. Matchett, and M. L. Casazza. 2021. Megafires and thick smoke portend big problems for migratory birds. Ecology 103(1):e03552. https://doi.org/10.1002/ecy.3552

Pastorino, A., J. R. Roman, G. Dell'Omo, and M. Panuccio. 2017. Fog and rain lead migrating White storks, *Ciconia ciconia*, to perform reverse migration and to land. Avocetta 41(1):5-12. https://doi.org/10.30456/AVO.2017102

Pons, P., and R. Prodon. 1996. Short term temporal patterns in a Mediterranean shrubland bird community after wildfire. Acta Oecologica 17(1):29-41. https://www.academia.edu/18024706/Short_term_temporal_patterns_in_a_Mediterranean_shrubland-_bird_community_after_fire

Pyle, P. 2001. Identification guide to North American birds. Slate Creek Press, Point Reyes Station, California, USA.

R Core Team. 2020. R: a language and environment for statistical computing. Version 2.6.2. R Foundation for Statistical Computing, Vienna, Austria.

Renfrew, R. B., D. Kim, N. Perlut, J. Smith, J. Fox, and P. P. Marra. 2013. Phenological matching across hemispheres in a long-distance migratory bird. Diversity and Distributions 19 (8):1008-1019. https://doi.org/10.1111/ddi.12080

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. Proceedings of the National Academy of Sciences 86 (19):7658-7662. https://doi.org/10.1073/pnas.86.19.7658

Rogers, C. M. 1991. An evaluation of the method of estimating body fat in birds by quantifying visible subcutaneous fat. Journal Field Ornithology 62(3):349-356. https://sora.unm.edu/sites/default/files/journals/jfo/v062n03/p0349-p0356.pdf

Roques, S., P.-Y. Henry, G. Guyot, B. Bargain, E. Cam, and R. Pradel. 2022. When to depart from a stopover site? Time since arrival matters more than current weather conditions. Ornithology 139(1):ukab057. https://doi.org/10.1093/ornithology/ukab057

Rosenberg, K. V., A. M. Dokter, P. J. Blancher, J. R. Sauer, A. C. Smith, P. A. Smith, J. C. Stanton, A. Panjabi, L. Helft, M. Parr, and P. P. Marra. 2019. Decline of the North American avifauna. Science 366(6461):120-124. https://doi.org/10.1126/science.aaw1313

Saab, V. A., R. E. Russell, and J. G. Dudley. 2007. Nest densities of cavity-nesting birds in relation to postfire salvage logging and

time since wildfire. Condor 109(1):97-108. https://doi.org/10.1093/condor/109.1.97

Salewski, V., M. Kéry, M. Herremans, F. Liechti, and L. Jenni. 2009. Estimating fat and protein fuel from fat and muscle scores in passerines. Ibis 151(4):640-653. https://doi.org/10.1111/j.1474-919X.2009.00950.x

Saltmarsh Habitat and Avian Research Program (SHARP). 2011. SHARP body condition scoring SOP. https://www.tidalmarshbirds.org/?page_id=1596

Sanderfoot, O. V., and B. Gardner. 2021. Wildfire smoke affects detection of birds in Washington State. Ornithological Applications 123(3):1-14. https://doi.org/10.1093/ornithapp/duab028

Schoener, E. R. 2010. Gastrointestinal parasites in endemic, native, and introduced New Zealand passerines with a special focus on Coccidia. Thesis. Massey University, Palmerston North, New Zealand. https://mro.massey.ac.nz/handle/10179/2284

Seewagen, C. L. 2008. An evaluation of condition indices and predictive models for noninvasive estimates of lipid mass of migrating Common Yellowthroats, Ovenbirds, and Swainson's Thrushes. Journal of Field Ornithology 79(1):80-86. https://doi.org/10.1111/j.1557-9263.2007.00132.x

Şekercioğlu, Ç. H., G. C. Daily, and P. R. Ehrlich. 2004. Ecosystem consequences of bird declines. Proceedings of the National Academy of Sciences 101(52):18042-18047. https://doi.org/10.1073/pnas.0408049101

Şekercioğlu, Ç. H., C. D. Mendenhall, F. Oviedo-Brenes, J. J. Horns, P. R. Ehrlich, and G. C. Daily. 2019. Long-term declines in bird populations in tropical agricultural countryside. Proceedings of the National Academy of Sciences 116 (20):9903-9912. https://doi.org/10.1073/pnas.1802732116

Streby, H. M., G. R. Kramer, S. M. Peterson, J. A. Lehman, D. A. Buehler, and D. E. Andersen. 2015. Tornadic storm avoidance behavior in breeding songbirds. Current Biology 25(1):98-102. https://doi.org/10.1016/j.cub.2014.10.079

Stutchbury, B. J. M., S. A. Tarof, T. Done, E. Gow, P. M. Kramer, J. Tautin, J. W. Fox, and V. Afanasyev. 2009. Tracking long-distance songbird migration by using geolocators. Science 323 (5916):896. https://doi.org/10.1126/science.1166664

Tabachnik, S. 2020. What's going on with all the dead birds across Colorado and the Southwest? Denver Post, September 24. https://www.denverpost.com/2020/09/24/dead-birds-colorado-new-mexico-migration/

Tonra, C. M., P. P. Marra, and R. L. Holberton. 2013. Experimental and observational studies of seasonal interactions between overlapping life history stages in a migratory bird. Hormones and Behavior 64(5):825-832. https://doi.org/10.1016/j.yhbeh.2013.10.004

Van Den Broeke, M. S., and T. J. Gunkel. 2020. The influence of isolated thunderstorms and the low-level wind field on nocturnally migrating birds in central North America. Remote Sensing in Ecology and Conservation 7(2):187-197. https://doi.org/10.1002/rse2.179

Wenker, E. S., E. L. Kendrick, M. Maslanka, and M. L. Power. 2022. Fat scoring in four sparrow species as an estimation of body condition: a validation study. Journal of Field Ornithology 93 (2):5. https://doi.org/10.5751/JFO-00119-930205

Weston, P. 2020. Mass die-off of birds in south-western U.S. caused by starvation. Guardian, December 26. https://www.theguardian.com/environment/2020/dec/26/mass-die-off-of-birds-in-south-western-us-caused-by-starvation-aoe?eType=EmailBlastContent&eId=24a2f245-5f5b-4165-b426-89c0d7766be6

Wikelski, M., E. M. Tarlow, A. Raim, R. H. Diehl, R. P. Larkin, and G. H. Visser. 2003. Costs of migration in free-flying songbirds. Nature 423(6941):704. https://doi.org/10.1038/423704a

Wormworth, J., and Ç. H. Şekercioğlu. 2011. Winged Sentinels: birds and climate change. Cambridge University Press. Cambridge, UK.https://doi.org/10.1017/CBO9781139150026

Yosef, R. 1997. Reactions of birds to an earthquake. Bird Study 44(1):123-124. https://doi.org/10.1080/00063659709461047

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Wildfires and Fall Bird Migration Appendix.

TABLE A1.1. Ecological traits for the bird species captured 10 or more times during fall migration 2020 at Rio Mesa, Utah. The data for these traits were extracted from a global dataset of avian ecological traits (Şekercioglu et al., 2004, 2019). Since migrant status in this global dataset is determined by a species' movements across its entire range, we modified the migrant status designation for some birds to be more representative of the species' status in Utah. Species common and scientific names follow BirdLife International (2022) taxonomy.

Species Name	Scientific Name	Migrant Status	Primary Diet	Average Mass (g)
American Dusky Flycatcher	*Empidonax oberholseri*	full migrant	Invertebrate	10.37
Warbling Vireo	*Vireo gilvus*	full migrant	Invertebrate	13.40
House Wren	*Troglodytes aedon*	full migrant	Invertebrate	11.70
Bewick's Wren	*Thryomanes bewickii*	partial	Invertebrate	9.83
Blue-gray Gnatcatcher	*Polioptila caerulea*	full migrant	Invertebrate	6.00
Black-capped Chickadee	*Poecile atricapillus*	not a migrant	Invertebrate	12.27
Mountain Chickadee	*Poecile gambeli*	not a migrant	Invertebrate	11.55
American Bushtit	*Psaltriparus minimus*	not a migrant	Invertebrate	5.15
Ruby-crowned Kinglet	*Regulus calendula*	full migrant	Invertebrate	6.63
Sage Thrasher	*Oreoscoptes montanus*	full migrant	Invertebrate	43.20
Hermit Thrush	*Catharus guttatus*	full migrant	Invertebrate	27.00
Orange-crowned Warbler	*Leiothlypis celata*	full migrant	Invertebrate	8.15
Audubon's Warbler	*Setophaga auduboni*	full migrant	Invertebrate	13.00
MacGillivray's Warbler	*Geothlypis tolmiei*	full migrant	Invertebrate	10.50
Wilson's Warbler	*Cardellina pusilla*	full migrant	Invertebrate	7.03
Yellow-breasted Chat	*Icteria virens*	full migrant	Invertebrate	26.50
Brewer's Sparrow	*Spizella breweri*	full migrant	Seed	10.90
Song Sparrow	*Melospiza melodia*	partial	Seed	16.45
Lincoln's Sparrow	*Melospiza lincolnii*	full migrant	Seed	17.40
White-crowned Sparrow	*Zonotrichia leucophrys*	full migrant	Seed	38.50
Dark-eyed Junco	*Junco hyemalis*	full migrant	Seed	20.50
Spotted Towhee	*Pipilo maculatus*	partial	Seed	42.20
Western Tanager	*Piranga ludoviciana*	full migrant	Invertebrate	29.25
House Finch	*Haemorhous mexicanus*	not a migrant	Seed	21.20
Pine Siskin	*Spinus pinus*	full migrant	Seed	14.60

TABLE A1.2. Fall bird banding information from the Rio Mesa Banding Station in southeastern Utah and total wildfire acres burned for each year in the study. Fat 0 = the number of birds with zero fat, Fat 1 = the number of birds with a fat score of 1, Total Fat = the number of birds for which fat scores were record, and Total Birds = the total number of birds banded.

Year	Fat 0	Fat 1	Total Fat	Total Birds	Fire Acres	Banding Days
2011	149	225	937	1099	879102.2	49
2012	180	192	633	644	3202489	54
2013	264	124	808	825	1131013	60
2014	39	59	358	362	732823.8	28
2015	570	213	1057	1071	4064662	51
2016	157	129	520	551	836742.6	48
2017	246	270	1015	1023	2720821	43
2018	1091	148	1351	1498	3163607	57
2019	218	160	501	549	3222037	50
2020	393	417	1148	1163	6291627	55

TABLE A1.3. Body condition of bird species captured 10 or more times in mist nets during fall migration 2020 at Rio Mesa, Utah. The proportion of birds within each species with no fat is calculated by taking the number of individuals with a fat score of 0 and dividing by the total number of birds with recorded fat scores. The first and last dates of capture for each species are also included. Species' names follow taxonomic classifications in BirdLife International (2022).

Species	Fat 0	Total Number	Proportion	First Capture	Last Capture
American Dusky Flycatcher	3	10	0.300	9/1	9/20
Warbling Vireo	10	26	0.385	9/1	10/2
Black-capped Chickadee	6	40	0.150	9/24	11/3
Mountain Chickadee	5	28	0.179	9/7	10/31
American Bushtit	6	55	0.109	9/19	10/19
Ruby-crowned Kinglet	9	39	0.231	9/16	11/2
Bewick's Wren	5	26	0.192	9/4	10/29
House Wren	2	18	0.111	8/31	10/13
Blue-gray Gnatcatcher	46	76	0.605	9/1	10/10
Sage Thrasher	8	29	0.276	9/1	10/9
Hermit Thrush	4	19	0.211	9/28	11/2
House Finch	5	27	0.185	9/13	11/3
Pine Siskin	3	19	0.158	10/28	11/1
Song Sparrow	48	144	0.333	9/5	11/3
Lincoln's Sparrow	23	68	0.338	9/3	10/23
White-crowned Sparrow	51	164	0.311	9/4	11/3
Dark-eyed Junco	14	36	0.389	9/28	11/3
Brewer's Sparrow	29	62	0.468	8/31	9/20
Spotted Towhee	8	18	0.444	8/31	11/3
Yellow-breasted Chat	5	28	0.179	8/31	9/27
Orange-crowned Warbler	5	27	0.185	9/1	10/18
MacGillivray's Warbler	7	21	0.333	9/1	10/1
Audubon's Warbler	2	10	0.200	9/13	10/13
Wilson's Warbler	23	42	0.548	8/31	10/7
Western Tanager	5	10	0.500	9/3	9/17

FIGURE A1.1. Wildfires within our selected region of western North America between 2011 and 2020. The specific banding seasonal time periods each year within which fire perimeters were entered into the National Interagency Fire Center (2019) and Canadian Forest Service (2021) are noted in the legend. The location of the Rio Mesa Field Station is also noted on the map. This map was created using ArcGIS Pro (ESRI, 2020; version 2.7.3.).

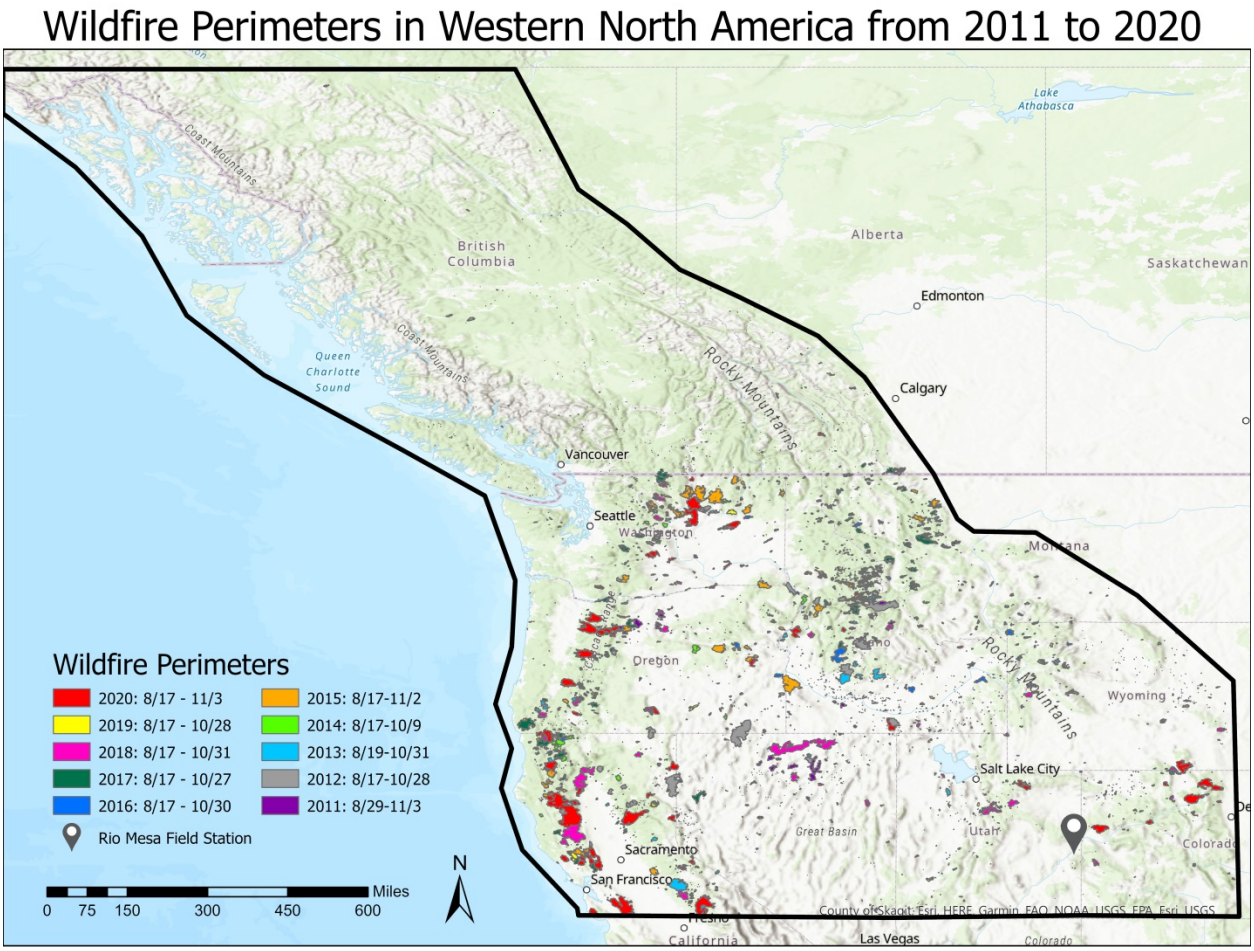


FIGURE A1.2. Wildfires within part of our selected region of the western United States during 2020 according to fire size class. The fire size classes and their accompanying size and color are noted in the legend. A majority of the visible class colors are of fires belonging to the largest size class. The location of the Rio Mesa Field Station is also included on the map. This map was created using ArcGIS Pro (ESRI, 2020; version 2.7.3.).

