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Autumn Raptor Migration in Yellowstone National Park, 2011–2015

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Raptors are wide-ranging, vagile avian predators whose populations can be difficult and costly to monitor on their breeding or winter range. However, monitoring raptors during their annual northbound or southbound migration is a cost-effective and efficient alternative to time-intensive, single-species breeding surveys. In 2010, we observed numerous Swainson's Hawks (*Buteo swainsoni*) and Red-tailed Hawks (*Buteo jamaicensis*) migrating through the Hayden Valley in central Yellowstone National Park, prompting an investigation into raptor migration patterns in the park. Our objectives were to monitor annual autumn raptor migration in Hayden Valley from 2011 to 2015 and to determine the relative role of this undocumented migration site by comparing our observations to simultaneously collected migration data from three other sites in the Rocky Mountain Flyway. From 2011 to 2015, we observed 6441 raptors of 17 species across 170 d and 907 h of observation. Red-tailed Hawks, Swainson's Hawks, and Golden Eagles (*Aquila chrysaetos*) accounted for 51% of the total individuals observed over five years. Overall counts from Hayden Valley were comparable to counts from the three migration sites in the Rocky Mountains, although abundance of individual species varied by site. Data from this study suggest that Hayden Valley may serve as a stopover site for migrating raptors and presents an opportunity for future research. By improving our understanding of where raptors migrate and the characteristics of stopover areas in the Rocky Mountains, land managers may develop effective strategies for protecting raptor populations and habitat from threats including development and climate change.

Key Words: Migration; raptor; birds; Yellowstone National Park; Rocky Mountain Flyway; Wyoming

Introduction

Raptors are wide-ranging, vagile avian predators whose populations are difficult and costly to monitor using time-intensive, single-species surveys on their breeding or wintering grounds. However, as raptors concentrate along mountainous ridgelines during their annual northbound or southbound migration, counts of multiple raptor populations can be conducted simultaneously by relatively few personnel. Thus, migration offers a unique opportunity to assess raptor populations in a relatively efficient and cost-effective manner (Bildstein *et al.* 2007). Each year, millions of raptors migrate from their breeding areas to wintering grounds following traditional migratory pathways throughout North America (McCarty and Bilstein 2005). Along these corridors, observers have identified hundreds, or even thousands, of raptors across multiple species in individual seasons (Hoffman and Smith 2003; Lott 2006). Over time, these data have been used to detect trends in populations of individual species (Farmer *et al.* 2007; Bildstein *et al.* 2008), determine changes in the timing of migration (Jaffré *et al.* 2013), and identify important migratory pathways (Bedrosian *et al.* 2015).

Migration requires raptors to navigate long-distances through potentially risky terrain (e.g., wind farms; Johnston *et al.* 2013) and locate stopover areas with reliable sources of prey (Pocewicz *et al.* 2013; Vardanis *et al.* 2016). Many raptors migrate across international and even continental boundaries (Kochert *et al.* 2011). For example, Swainson's Hawks (*Buteo swainsoni*) have one of the longest migration routes of any raptor in the world (Fuller *et al.* 1998; Bechard *et al.* 2010; Kochert *et al.* 2011). Each year tens of thousands of Swainson's Hawks leave their breeding grounds in west-central North America for wintering areas in the open grasslands or pampas of Argentina in South America, a roundtrip of over 20 000 km (Bechard *et al.* 2010; Kochert *et al.* 2011). Even short-distance migrants such as Golden Eagle (*Aquila chrysaetos*) and Rough-legged Hawk (*Buteo lagopus*) cross international boundaries from breeding areas in Alaska and Canada to wintering grounds throughout the western United States and Mexico (Bechard and Swem 2002; McIntyre *et al.* 2008).

In 2010, we observed a large number of Swainson's Hawks and Red-tailed Hawks (*Buteo jamaicensis*) migrating through Hayden Valley in central Yellowstone National Park (YNP), prompting further interest in local migration patterns. While much is known about the migratory paths of raptors in the eastern USA (McCarty and Bildstein 2005), comparatively little is known about the migratory paths and stopover areas of raptors that use the Rocky Mountain Flyway (Hoffman and Smith 2003; Bedrosian *et al.* 2015; Craighead *et al.* 2016). The complex topography of the Rocky Mountains results in a broad migratory front as raptors are dispersed along competing ridgelines, making it diffi-

cult to assess migration patterns in this area (Fuller *et al.* 1998; Lott and Smith 2006; Craighead *et al.* 2016). Thus, we were broadly interested in both contributing to the general knowledge of autumn raptor migration within the Rocky Mountain Flyway and determining the particular importance, if any, of YNP to migrating raptors. In this study, our objectives were to 1) monitor the annual autumn raptor migration in Hayden Valley in central YNP from 2011 to 2015 and 2) learn how species diversity and the timing of autumn migration at this previously undocumented migration site compared with data collected during the same period at three additional migration sites in the Rocky Mountain Flyway.

Study Area

We monitored raptor migration in the Hayden Valley of central YNP, Wyoming, USA (Figure 1) from atop a small hill approximately 0.5 km west of the road at 44.66°N, 110.47°W and at 2411 m elevation. The Hayden Valley is an approximately 75 km^2 subalpine valley located along the Yellowstone River. Vegetation in the bottomlands is dominated by Mountain Big Sagebrush (*Artemisia tridentata* var. *vaseyana* (Rydberg) B. Boivin), Silver Sagebrush (*Artemisia cana* Pursh), and Idaho Fescue (*Festuca idahoensis* Elmer), while Lodgepole Pine (*Pinus contorta* Douglas ex Loudon) dominates the uplands (Despain 1990). Climate in the region is characterized by short summers with an average temperature of 11.8°C during July and long cold winters with an average temperature of −10.8°C in December (Crait and Ben-David 2006). The region receives an average of 513 mm of annual precipitation, most of which falls as snow during the winter (Crait and Ben-David 2006).

Hayden Valley is a low-lying sagebrush steppe grassland bounded to the north by the east-west trending Washburn Range and by large forested plateaus on either side of the valley (Despain 1990). As many migration observation sites are located along mountain peaks and ridgelines (Hoffman and Smith 2003), Hayden Valley is distinctly atypical. Raptors migrating south through Hayden Valley in autumn must pass over the Washburn Range at a mean elevation of 2808 m before entering the valley. Although Hayden Valley may not provide the typical orographic uplift (lift provided by a steep elevational gradient such as the edge of a mountain range) that concentrates raptors at many migration observation sites, the river valley and surrounding topography may provide thermal lift as well as foraging opportunities that may appeal to migrating raptors (Bildstein *et al.* 2007). Thus, this site provides a unique and potentially valuable vantage point to monitor raptor migration in the western United States.

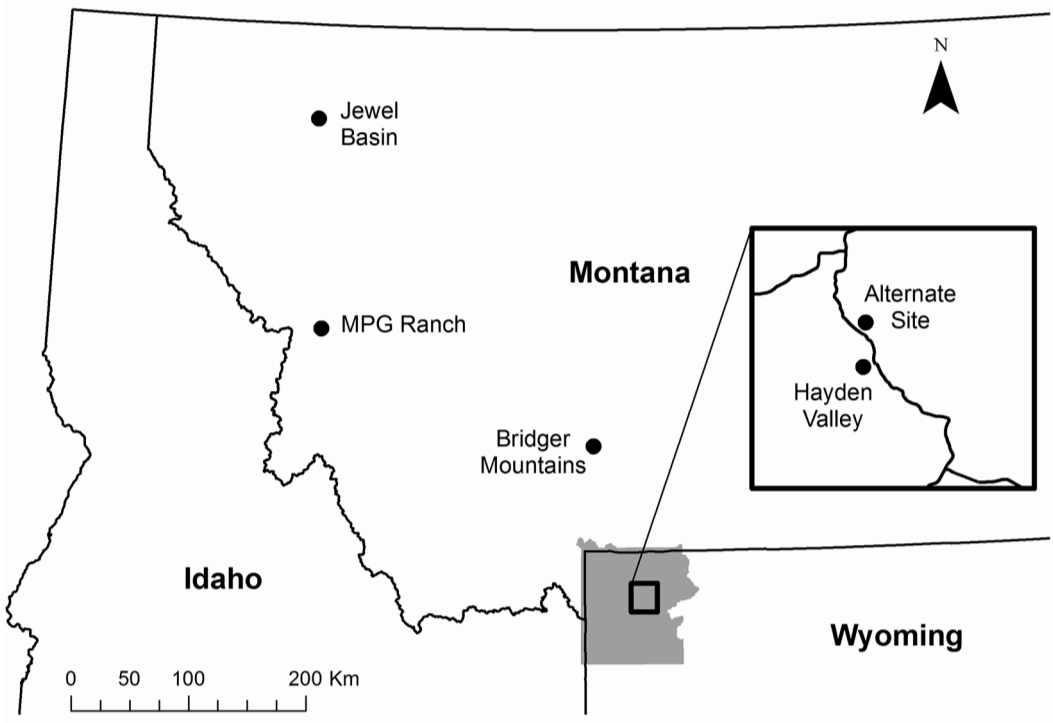

FIGURE 1. Location of raptor migration count sites in Yellowstone National Park (YNP; shaded grey), Wyoming, and three comparison sites in northern and western Montana. Exact locations of Hayden Valley count site and the alternate site are shown in the insert, along the Grand Loop Road through central YNP.

Methods

Data Collection

We monitored raptors during their southbound migration during September and October 2011–2015. Although the start and end dates varied by year, we generally began counts during the first week in September and continued through the third week in October. Beginning in late October, weather conditions in YNP generally prohibit travel throughout the southern portion of the park, including Hayden Valley. At the beginning of each autumn migration season, experienced counters trained observers in the field for a minimum of two weeks before observers were permitted to collect observation data on their own. Additionally, an experienced observer was present during counts at least three days per week and usually 4–5 days per week. We conducted counts a minimum of five days per week and observed for approximately 6 h per day, beginning at 1000 hours and ending at 1600 hours. Two to four primary observers conducted each daily count and dependent observers worked together to adequately cover the broad viewshed, avoid double-counting, and accurately identify raptors to species. On each count day, a single observer recorded all detections. We did not attempt to correct our observations for detectability. Occasionally additional observers joined the count efforts and the recorder noted this on the data sheet.

During each count, observers scanned the entire northern portion of the sky in a 180° arc and then scanned north in an up-and-down motion to cover the entire northern portion of the sky. Observers used 10×42 binoculars to detect raptors and a spotting scope with 20–60× magnification to identify individuals if necessary. We recorded all raptors observed moving past the site by species. Observers also scanned without optics, particularly when spotting raptors directly overhead or those close to the observation point. Observers recorded the start and end time of observation periods, which usually lasted the full day (6 h); however, occasional interruptions occurred as a result of weather (i.e., lightning, heavy rain, or snow) or wildlife (e.g., bears [*Ursus* spp.] or American Bison [*Bison bison*] near the count site). Observers also recorded weather data using a Kestrel 2500 Weather Meter (Nielsen-Kellermen, Chester, Pennsylvania, USA) at the start and end of each observation period, in addition to hourly intervals throughout the day. We collected weather data including sky condition (cloud type and percent cover), average wind speed (km/h), maximum wind speed (km/h), wind direction (degrees), temperature (°C), barometric pressure (mmHg), and an estimate of overall visibility distance (km) from the count site. For each hour of observation, observers also noted the number of observers, total number of minutes of observation for that hour, and primary horizontal movement of raptors (i.e., east, west, or overhead). At the end of each count day we summed the totals over all hours of observation and across all species. We also calculated the observer effort for each count day (the number of observers multiplied by the number of survey hours).

Data Analysis

We summarized annual raptor counts and total observer effort (the sum of daily calculations of observer effort) for each study year. We also determined the average passage rate (the average number of raptors observed migrating over the count site per hour) for each of the five years and the average passage rate over the full time period. For species with more than 20 observations per year, we determined median and bulk passage dates over the five years. Bulk passage dates were defined as the range of dates between which the central 80% of the entire season's total for each species passed through the migration site (i.e., the first date is the date by which 10% of the season's cumulative sightings have been made and the last is the date by which 90% of the season's cumulative sightings have been made; Lott 2006).

Finally, we compared our migration count totals to counts from three additional sites in the Rocky Mountain Flyway, monitored during the same time period. All sites, including Jewel Basin, MPG Ranch, and Bridger Mountains, were located in Montana, USA, northwest of the Hayden Valley site (Figure 1). The three sites met the following criteria: 1) autumn migration data were collected from 2011 to 2015, 2) standard count procedures were used to collect migration data, and 3) permission was granted to use the data for comparisons with our dataset from YNP. To control for differences in the number of hours of observation among sites, and to make our data comparable to previous assessments of western raptor migration patterns (Hoffman and Smith 2003), we converted raptor observations to counts per 100 h of observation (raptors/100 observation hours = [total raptors counted/total hours of observation] × 100). We compared total raptor counts per 100 observation hours across all sites from 2011 to 2015 as well as counts per 100 h for ten of the most common species recorded at Hayden Valley.

Results

Observation Effort and Count Totals

We observed migrating raptors on a total of 170 d during September and October 2011–2015 with an average of 34 d per season (Table 1). On average, we observed migrating raptors for 181 h per season with observer effort (hours × observers) averaging 490 h per season.

The Hayden Valley count site posed numerous challenges during the study period. In 2011, the area surrounding the count site was closed as a result of two fatal Grizzly Bear (*Ursus arctos*) attacks. Therefore, we conducted all observations in 2011 from an alternate count site located approximately 4 km north in Hayden Valley (Figure 1). This alternate site had a similar view to our standard count site; although a small portion of

TABLE 1. Effort expended at the migration count site during 2011–2015 in Hayden Valley, Yellowstone National Park.

	2011	2012	2013	2014	2015	Mean	Total
Days	35	38	22	40	35	34	170
Mean observers per day	2.53	2.79	2.81	2.86	2.49	2.70	2.70
# hours	177	202	116	222	190	181	907
Observer effort*	448	564	326	636	474	490	2448

*Mean number of observers × number of hours of observation.

the western viewshed was blocked by a small hill in the foreground, a one-day comparison-count between the two sites revealed remarkable similarity in species' composition and abundance. We acknowledge a one-day comparison may not fully represent the variability between these sites; however, we feel our observations from the alternate site are comparable to what we would have observed from the regular Hayden Valley site and thus have included these data in our analyses.

From 2012 to 2015, we generally conducted counts from the standard count site. In 2012, however, several fires burning in Idaho and in YNP severely reduced visibility at the standard count site and contributed to poor observing conditions. The United States government sequestration (a shutdown of all non-essential government activities, including national parks) in 2013 prevented observers from data collection in Hayden Valley beginning 1 October, effectively ending the migration monitoring season three weeks early. Finally, in 2015, we occasionally counted migrating raptors from the alternate site due to high Grizzly Bear use in the area of the standard count site.

Despite these difficulties, observers recorded 6441 raptors belonging to 17 species (Table 2). Three species (Red-tailed Hawk, Swainson's Hawk, and Golden Eagle) accounted for about half (51%) of the total birds observed across all years. Red-tailed Hawk was by far the most numerous species across all years. We recorded fewer than 30 individuals per year for seven species of raptor, including Osprey (*Pandion haliaetus*), Turkey Vulture (*Cathartes aura*), Broad-winged Hawk (*Buteo platypterus*), Merlin (*Falco columbarius*), Northern Goshawk (*Accipiter gentilis*), Peregrine Falcon (*Falco peregrinus*), and Prairie Falcon (*Falco mexicanus*). Observers recorded the highest number of raptors in 2011 (n = 1846), most of which were Red-tailed Hawk, and the fewest in 2013 (n = 717).

Passage Rate and Timing

The average passage rate over the five years was 7 birds/h (Figure 2). During any given observation day, however, passage rate was lowest during the first hour of observation, peaked between 1100–1300 hours as air temperature increased, and thermals likely developed, and then tapered the rest of the day (Figure 2). Average passage rate was highest in 2011 (9.9 birds/h) and lowest in 2012 (4.8 birds/h).

Only seven species occurred with enough frequency to calculate average median and bulk passage dates (Table 3). We excluded 2013 data from this analysis because there was a 20-day period during which no data were collected. The bulk of raptors (80%) migrated

TABLE 2. Annual total, mean, coefficient of variation (CV), and proportion of raptors observed migrating through Hayden Valley in Yellowstone National Park during 2011–2015. Raptor species are sorted from highest to lowest number of observations.

Species	2011	2012	2013	2014	2015	Total	Mean	CV	% of Total
Red-tailed Hawk (*Buteo jamaicensis*)	571	235	177	382	402	1767	353	74	27
Swainson's Hawk (*Buteo swainsonii*)	357	46	171	208	68	850	170	123	13
Golden Eagle (*Aquila chrysaetos*)	241	134	35	187	105	702	140	95	11
American Kestrel (*Falco sparverius*)	73	62	64	155	104	458	92	73	7
Unidentified raptors	198	44	19	80	102	443	89	133	7
Sharp-shinned Hawk (*Accipiter striatus*)	65	72	68	109	80	394	79	38	6
Rough-legged Hawk (*Buteo lagopus*)	70	130	23	108	61	392	78	90	6
Northern Harrier (*Circus cyaneus*)	55	30	27	119	131	362	72	117	6
Bald Eagle (*Haliaeetus leucocephalus*)	93	68	26	95	60	342	68	70	5
Cooper's Hawk (*Accipiter cooperii*)	31	32	28	75	85	251	50	94	4
Ferruginous Hawk (*Buteo regalis*)	34	20	32	29	10	125	25	66	2
Osprey (*Pandion haliaetus*)	12	14	18	22	11	77	15	49	1
Turkey Vulture (*Cathartes aura*)	9	22	0	29	2	62	12	171	1
Broad-winged Hawk (*Buteo platypterus*)	0	7	1	35	9	52	10	234	1
Merlin (*Falco columbarius*)	13	11	6	12	7	49	10	53	1
Northern Goshawk (*Accipiter gentilis*)	10	7	9	14	3	43	9	78	1
Peregrine Falcon (*Falco peregrinus*)	10	8	8	7	5	38	8	40	1
Prairie Falcon (*Falco mexicanus*)	4	11	5	11	3	34	7	96	1
Total	1846	953	717	1677	1248	6441	1288	62	100

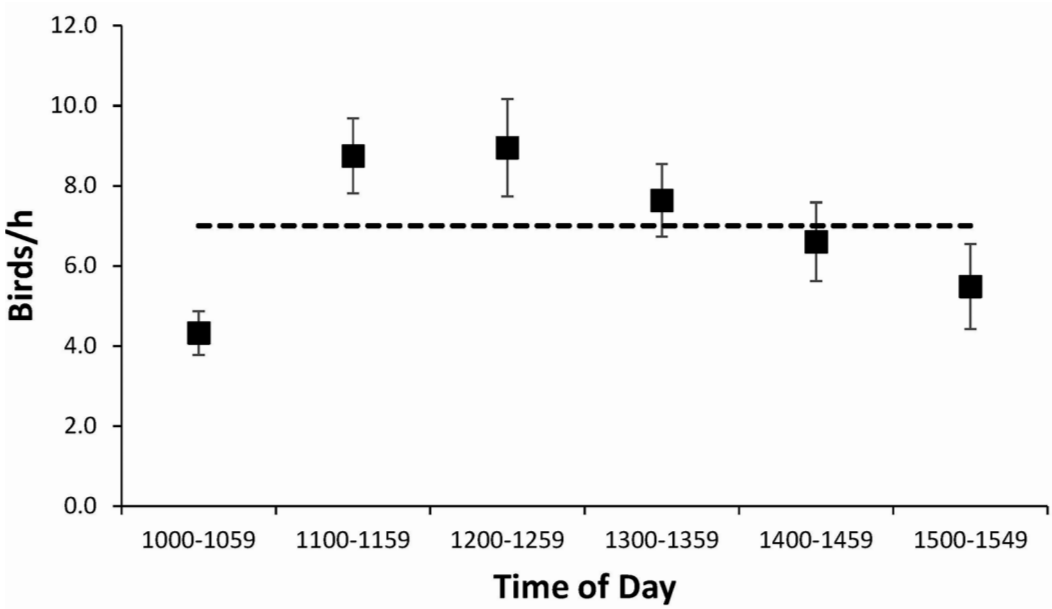

FIGURE 2. Mean hourly passage rate (birds/h) of raptors observed migrating through Hayden Valley in Yellowstone National Park during 2011–2015. Error bars are standard error and the horizontal dashed line is the overall average passage rate.

through Hayden Valley beginning in the first week in September through the third week in October. Although this roughly corresponds with our observation season, we saw a substantial decline in raptor observations by mid-October that suggests our season adequately captures the migration of most species through the study area. The bulk of Swainson's Hawks passed through the migration site during September. The bulk of Northern Harriers (*Circus cyaneus*), Red-tailed Hawks, Cooper's Hawks (*Accipiter cooperii*), and Sharp-shinned Hawks (*Accipiter striatus*) occurred from mid-September until mid-October. Golden Eagles and Rough-legged Hawks migrated primarily from early October through the end of our count period. Both Swainson's Hawks and Rough-legged Hawks exhibited the shortest duration of migration through Hayden Valley, while Sharp-shinned Hawks, Northern Harriers, and Red-tailed Hawks exhibited the longest migration through Hayden Valley.

Comparison to Other Migration Sites

Mean counts of raptors per 100 h of observation at Hayden Valley were comparable to counts per 100 h of observation at MPG Ranch and the Bridger Mountains, while Jewel Basin surpassed all three sites (Table 4). For individual species, Hayden Valley exhibited the highest Swainson's Hawk, Rough-legged Hawk, Northern Harrier, Bald Eagle (*Haliaeetus leucocephalus*), Ferruginous Hawk (*Buteo regalis*), and Red-tailed Hawk counts after controlling for hours of observation (Table 5). The average number of American Kestrel (*Falco sparverius*) and Cooper's Hawk was somewhat comparable to the other sites, but far fewer Golden Eagles and Sharp-shinned Hawks migrated

TABLE 3. Bulk passage dates summarized from 2011–2015, including 80% passage date range and median date, for migrating raptors with more than 20 observations per year at Hayden Valley, Yellowstone National Park. Standard deviations (SD) are given for the number of days over which 80% of birds were observed and for the median passage date.

Species	80% passage dates	Days	SD	Median date	SD
Swainson's Hawk (*Buteo swainsonii*)	7 Sep–19 Sep	12	4	13 Sep	5
American Kestrel (*Falco sparverius*)	8 Sep–30 Sep	24	5	19 Sep	3
Northern Harrier (*Circus cyaneus*)	10 Sep–13 Oct	33	8	27 Sep	5
Cooper's Hawk (*Accipiter cooperii*)	14 Sep–11 Oct	27	7	28 Sep	3
Sharp-shinned Hawk (*Accipiter striatus*)	11 Sep–18 Oct	37	5	29 Sep	4
Red-tailed Hawk (*Buteo jamaicensis*)	13 Sep–15 Oct	32	7	5 Oct	7
Golden Eagle (*Aquila chrysaetos*)	1 Oct–20 Oct	20	5	10 Oct	3
Rough-legged Hawk (*Buteo lagopus*)	10 Oct–22 Oct	12	2	16 Oct	4

TABLE 4. Total individual raptors counted per 100 hours of observation for four migration sites in the Rocky Mountain Flyway. Counts for Hayden Valley (this study) are shown in bold.

Year	Jewel*	MPG†	Bridger‡	**Hayden§**
2011	889	498	696.0	**1042**
2012	831	570	680.0	**472**
2013	721	1175	689.0	**618**
2014	983	778	720.0	**755**
2015	1090	862	822.0	**657**
Mean	903	777	721.4	**709**

*Jewel Basin, Montana; data provided and used with permission by Daniel Casey (Flathead Audubon, Montana and American Bird Conservancy).
†MPG Ranch, Montana; data provided and used with permission by Adam Shreading (Raptor View Research).
‡Bridger Mountains, Montana; data provided and used with permission by Steve Hoffman (Montana Audubon and Hawkwatch International).
§Hayden Valley, Wyoming.

through Hayden Valley than the other sites, with the exception of Golden Eagles at MPG Ranch. Counts from Hayden Valley were most similar to MPG Ranch.

Discussion

We conducted autumn counts of migrating raptors from 2011 to 2015 in Hayden Valley, Yellowstone National Park. Hayden Valley is a broad grassland river valley, atypical among migration observation sites. Furthermore, as the first effort to evaluate raptor migration in Yellowstone, this study helps fill both a geographic and topographic gap in our knowledge of raptor migration in the western United States. Our observations, including 6441 individuals belonging to 17 raptor species, were consistent to those from other migration count sites within the Rocky Mountain Flyway.

Our observations of bulk passage date indicate that, while our observation season likely captured the majority of autumn raptor migration, we may have truncated observations for some species by ending our season in late October. Several species, notably Rough-legged Hawks and Golden Eagles, were still migrating in the third week in October when our counts ended and may continue their migration through early December (McIntyre *et al.* 2008). Raptor observation in the southern portion of Yellowstone becomes logistically difficult after late October due to inclement weather and road closures. Additionally, both Rough-legged Hawks and Golden Eagles are residents in Yellowstone during the winter and it can be difficult to distinguish between migrants and residents in late autumn. However, extending the season into early November would be consistent with other autumn migration monitoring stations in the western United States (Hoffman and Smith 2003). Thus, we recommend that, if migration observation continues in Hayden Valley, future counts should consider a longer observation season, when possible, to better capture the migration patterns of all species. A longer observation season, combined with a long term dataset, may also help capture climate change effects on the timing of migration. For example, on Lake Superior, along the northern United States border, long spring and autumn migration monitoring periods revealed that the median raptor migration date advanced in spring and was delayed in autumn, and that these effects were particularly strong for short-distance migrants including Bald Eagle, Northern Harrier, and Sharp-shinned Hawk (Buskirk 2012).

During our study, a number of factors disrupted counts and resulted in inconsistent data collection methods. In 2011 and 2015, we were forced to count from an alternate site and, in 2012, fires reduced visibility and likely affected the overall count. In 2013, the United States government sequestration forced an early end to the season. Despite these factors, the number of raptors counted at Hayden Valley from the standard and alter-

TABLE 5. Raptor species counted per 100 hours of observation for four migration sites in the Rocky Mountain Flyway. Counts for Hayden Valley (this study) are shown in bold.

Species	Jewel*	MPG†	Bridger‡	**Hayden§**
Red-tailed Hawk (*Buteo jamaicensis*)	72	190	64	**195**
Swainson's Hawk (*Buteo swainsonii*)	0	5	1	**94**
Golden Eagle (*Aquila chrysaetos*)	162	17	316	**77**
American Kestrel (*Falco sparverius*)	24	64	34	**50**
Sharp-shinned Hawk (*Accipiter striatus*)	412	98	125	**43**
Rough-legged Hawk (*Buteo lagopus*)	7	31	14	**43**
Northern Harrier (*Circus cyaneus*)	14	31	21	**40**
Bald Eagle (*Haliaeetus leucocephalus*)	15	16	21	**38**
Cooper's Hawk (*Accipiter cooperii*)	126	50	55	**28**
Ferruginous Hawk (*Buteo regalis*)	0	1	1	**14**

*Jewel Basin, Montana; data provided and used with permission by Daniel Casey (Flathead Audubon, Montana and American Bird Conservancy).
†MPG Ranch, Montana; data provided and used with permission by Adam Shreading (Raptor View Research).
‡Bridger Mountains, Montana; data provided and used with permission by Steve Hoffman (Montana Audubon and Hawkwatch International).
§Hayden Valley, Wyoming.

nate count sites was similar to counts at the Bridger Mountains and the MPG Ranch monitoring sites. The relative abundance of individual species, however, varied by survey location, highlighting the importance of the information provided by this previously unmonitored migration site.

The number of Red-tailed Hawks was similar between Hayden Valley and the MPG Ranch, but was considerably higher than for Jewel Basin and the Bridger Mountains. While Swainson's Hawks were considerably more abundant at Hayden Valley than at the other three locations, fewer Golden Eagles were observed migrating through Hayden Valley than at Jewel Basin or the Bridger Mountains. The latter site was established primarily because of the large number of Golden Eagles observed migrating there (S. Hoffman, personal communication).

Golden Eagles rely more on orographic uplift during autumn migration than other raptors (Katzner *et al.* 2012). Because the Bridger Mountain site and the Jewel Basin migration site are located on a peak along a ridgeline, these sites are likely to offer more orographic lift than the low-lying Hayden Valley where thermals are more likely to develop (Katzner *et al.* 2012). Conversely, Red-tailed and Swainson's Hawks tend to rely more on thermal uplift (Preston and Beane 2009; Bechard *et al.* 2010), which probably explains the large number of those species observed in Hayden Valley. More buteos were observed migrating through Hayden Valley compared with the other comparison sites, suggesting that Hayden Valley may provide unique features required for some raptors and counts here may better represent migration patterns for these species.

In 2011, we observed the highest total number of raptors during the five years of surveys. This was surprising considering the viewshed at the alternate site was partially blocked to the west. We suspect, however, that at least some of the Swainson's and Red-tailed Hawks observed during 2011 were counted more than once. At the standard count site during subsequent years, observers noticed that as some raptors entered the valley from the north, they then descended into the valley and began making wide circular flights while foraging. From the standard count site, it was easier for observers to notice this pattern because the site was set farther back in the valley and the viewshed was larger. In the future, we may improve upon our count estimates and better detect differences among observation sites by conducting more rigorous counting protocols or analyses (e.g., independent observers or calculating detection probabilities).

Although foraging raptors may have led to an overestimation of the number of individuals passing through Hayden Valley in 2011, it also suggests that Hayden Valley may provide key foraging opportunities and serve as a valuable stopover location for migrating raptors. Stopover areas are important for raptors to rest, forage and replenish fat reserves, and to complete molt (Kirby *et al.* 2008; Kochert *et al.* 2011; Pocewicz *et al.* 2013; Craighead *et al.* 2016; Vardanis *et al.* 2016). Hayden Valley represents an undisturbed region within the Rocky Mountain Flyway in which raptors may recuperate after long flights. Although no formal studies have been conducted, observers witnessed numerous foraging events during most survey days, most commonly in the morning hours. Additionally, there appears to be an abundance of grasshoppers and other insects as well as a high small mammal population upon which Swainson's Hawks and other raptors may forage (Sherrod 1978; Schmutz *et al.* 1980; Johnson *et al.* 1987; Bednarz 1988; Woodbridge *et al.* 1995).

Migratory birds spend much of their annual life cycle travelling between their breeding grounds and wintering ranges, and migration can incur a high cost (Kirby *et al.* 2008). Mortality is six times greater during migration than during other times of the year, and time spent on migration accounts for half of all raptor mortality (Klaassen *et al.* 2014). Understanding where individual species migrate and identifying vital stopover areas is essential for developing effective management strategies for vulnerable or declining raptor populations. The data collected in this study may provide a baseline for comparison with future raptor migration studies. We found that a large number of raptors migrate through Hayden Valley in YNP during autumn and future investigations should further evaluate this region's importance as a stopover location for raptors using the Rocky Mountain Flyway, especially Swainson's Hawks and other buteos. Additionally, further collaboration among regional partners and landowners may help elucidate trends in raptor migration patterns throughout the Rocky Mountain region, identify key habitats that support migrating raptors, and develop more effective raptor management plans in the face of a developing landscape and warming climate.

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Literature Cited

Bechard, M. J., and **T. R. Swem.** 2002. Rough-legged Hawk (*Buteo lagopus*). *In* The Birds of North America Online. *Edited by* P. G. Rodewald. Cornell Lab of Ornithology, Ithaca, New York. Accessed 16 October 2016. https://birdsna.org/Species-Account/bna/species/rolhaw.

Bechard, M. J., C. S. Houston, J. H. Saransola, and **A. S. England.** 2010. Swainson's Hawk (*Buteo swainsoni*). *In* The Birds of North America Online. *Edited by* P. G. Rodewald. Cornell Lab of Ornithology, Ithaca, New York. Accessed 15 October 2016. https://birdsna.org/Species-Account/bna/species/swahaw.

Bednarz, J. C. 1988. A comparative study of the breeding ecology of Harris' and Swainson's hawks in southeastern New Mexico. The Condor 90: 311–323. https://doi.org/10.2307/1368559

Bedrosian, B. E., S. L. Cain, S. Wolff, and **D. J. Craighead.** 2015. Migratory pathways, timing, and home ranges of southern Greater Yellowstone Osprey. Journal of Raptor Research 49: 325–332. https://doi.org/10.3356/JRR-14-42.1

Bildstein, K. L., J. P. Smith, E. Ruelas Inzunza, and **R. R. Veit.** 2008. State of North America's Birds of Prey. Nuttall Ornithological Club and American Ornithologists' Union Series in Ornithology No. 3. Cambridge, Massachusetts and Washington, DC, USA.

Bildstein, K. L., J. P. Smith, and **R. Yosef.** 2007. Migration counts and monitoring. Pages 101–115 *in* Raptor Research and Management Techniques. *Edited by* D. M. Bird and K. L. Bildstein. Hancock House Publishers, Washington, DC, USA.

Buskirk, J. V. 2012. Changes in the annual cycle of North American raptors associated with recent shifts in migration timing. The Auk 129: 691–698. https://doi.org/10.1525/auk.2012.12061

Craighead, D., R. H. Crandall, R. N. Smith, and **S. L. Cain.** 2016. Migration of Red-tailed Hawks (*Buteo jamaicensis*) from northwest Wyoming. Wilson Journal of Ornithology 128: 150–158. https://doi.org/10.1676/wils-128-01-150-158.1

Crait, J. R., and **M. Ben-David.** 2006. River otters in Yellowstone Lake depend on a declining cutthroat trout population. Journal of Mammalogy 87: 485–494. https://doi.org/10.1644/05-MAMM-A-205R1.1

Despain, D. 1990. Yellowstone vegetation: consequences of environment and history in a natural setting. Roberts Rinehart Press, Boulder, Colorado, USA.

Farmer, C. J., D. J. T. Hussell, and **D. Mizrahi.** 2007. Detecting population trends in migratory birds of prey. The Auk 124: 1047–1062. https://doi.org/10.1642/0004-8038(2007)124[1047:DPTIMB]2.0.CO;2

Fuller, M. R., W. S. Seegar, and **L. S. Schueck.** 1998. Routes and travel rates of migrating Peregrine Falcons *Falco peregrinus* and Swainson's Hawks *Buteo swainsoni* in the western hemisphere. Journal of Avian Biology 29: 433–440. https://doi.org/10.2307/3677162

Hoffman, S. W., and **J. P. Smith.** 2003. Population trends of migratory raptors in western North America, 1977–2001. The Condor 105: 397–419. https://doi.org/10.1650/7146

Jaffré, M., G. Beaugrand, É. Goberville, F. Jiguet, N. Kjellén,, G. Troost, P. J. Dubois, A. Leprêtre, and **C. Luczak.** 2013. Long-term phenological shifts in raptor migration and climate. PLoS ONE 8: e79112. https://doi.org/10.1371/journal.pone.0079112

Johnston, N. N., J. E. Bradley, A. C. Pomeroy, and **K. A. Otter.** 2013. Flight paths of migrating Golden Eagles and the risk associated with wind energy development in the Rocky Mountains. Avian Conservation and Ecology 8(2): 12. https://doi.org/10.5751/ACE-00608-080212

Johnson, C. G., L. A. Nickerson, and **M. J. Bechard.** 1987. Grasshopper consumption and summer flocks of non-breeding Swainson's Hawks. The Condor 89: 676–678. https://doi.org/10.2307/1368663

Katzner, T. E., D. Brandes, T. Miller, M. Lanzone, C. Maisonneuve, J. A. Tremblay, R. Mulvihill, and **G. T. Merovich, Jr.** 2012. Topography drives migratory flight altitude of Golden Eagles: implications for on-shore wind energy development. Journal of Applied Ecology 49: 1178–1186. https://doi.org/10.1111/j.1365-2664.2012.02185.x

Kirby, J. S., A. J. Stattersfield, S. H. M. Butchart, M. I. Evans, R. F. A. Grimmett, V. R. Jones, J. O'Sullivan, G. M. Tucker, and **I. Newton.** 2008. Key conservation issues for migratory land- and waterbird species on the world's major flyways. Bird Conservation International 18: S49–S73. https://doi.org/10.1017/S0959270908000439

Klaassen, R. H. G., M. Hake, R. Strandberg, B. J. Koks, C. Trierweiler, K. Exo, F. Bairlein, and **T. Alerstam.** 2014. When and where does mortality occur in migratory birds? Direct evidence from long-term satellite tracking of raptors. Journal of Animal Ecology 83: 176–184. https://doi.org/10.1111/1365-2656.12135

Kochert, M. N., M. R. Fuller, L. S. Schueck, L. Bond, M. J. Bechard, B. Woodbridge, G. L. Holroyd, M. S. Martell, and **U. Banasch.** 2011. Migration patterns, use of stopover areas, and austral summer movements of Swainson's Hawks. The Condor 113: 89–106. https://doi.org/10.1525/cond.2011.090243

Lott, C. A. 2006. A new raptor migration monitoring site in the Florida Keys: counts from 1999–2004. Journal of Raptor Research 40: 200–209. https://doi.org/10.3356/0892-1016(2006)40[200:ANRMMS]2.0.CO;2

Lott, C. A., and **J. P. Smith.** 2006. A geographic-information-system approach to estimating the origin of migratory raptors in North America using stable hydrogen isotope ratios in feathers. The Auk 123: 822–835. https://doi.org/10.1642/0004-8038(2006)123[822:AGATET]2.0.CO;2

McCarty, K., and **K. L. Bildstein.** 2005. Using autumn hawk watch to track raptor migration and to monitor populations of North American birds of prey. Pages 718–725 *in* Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference, Volume 2. *Edited by* C. J. Ralph and T. D. Rich. General Technical Report PSW-GTR-191. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, USA.

McIntyre, C. L., D. C. Douglas, and **M. W. Collopy.** 2008. Movements of Golden Eagles (*Aquila chrysaetos*) from interior Alaska during their first year of independence. The Auk 125: 214–224. https://doi.org/10.1525/auk.2008.125.1.214

Pocewicz, A., W. A. Estes-Zumpf, M. D. Andersen, H. E. Copeland, D. A. Keinath, and **H. R. Griscom.** 2013. Modeling the distribution of migratory bird stopovers to inform landscape-scale siting of wind development. PLoS ONE 8: e75363. https://doi.org/10.1371/journal.pone.0075363

Preston, C. R., and **R. D. Beane.** 2009. Red-tailed Hawk (*Buteo jamaicensis*). *In* The Birds of North America Online. *Edited by* P. G. Rodewald. Cornell Lab of Ornithology, Ithaca, New York. Accessed 15 October 2016. https://birdsna.org/Species-Account/bna/species/rethaw.

Schmutz, J. K., S. M. Schmutz, and **D. A. Boag.** 1980. Coexistence of three species of hawks (*Buteo* spp.) in the prairie-parkland ecotone. Canadian Journal of Zoology 58: 1075–1089. https://doi.org/10.1139/z80-151

Sherrod, S. K. 1978. Diets of North American Falconiformes. Raptor Research 12: 49–121.

Vardanis, Y., J. Nillson, R. H. G. Klaassen, R. Strandberg, and **T. Alerstam.** 2016. Consistency in long-distance bird migration: contrasting patterns in time and space for two raptors. Animal Behavior 113: 177–187. https://doi.org/10.1016/j.anbehav.2015.12.014

Woodbridge, B., K. K. Finley, and **S. T. Seager.** 1995. An investigation of the Swainson's Hawk in Argentina. Journal of Raptor Research 29: 202–204.

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