

The Value of Extensive Raptor Migration Monitoring in Western North America.

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ABSTRACT

Monitoring raptor migration at migratory concentration points is an efficient and cost-effective method for tracking raptor populations over long periods and large geographic scales. HawkWatch International (HWI) and its organizational precursors have been monitoring fall and spring raptor migrations in western North America since the late 1970s. HWI has gathered more than a decade of annual count data for primarily 16 diurnal raptor species in Nevada (fall), Utah (fall), and New Mexico (fall and spring), and coordinates counts at another 13 sites (3 spring, 10 fall) from Texas to Montana and Washington state to Veracruz, Mexico. The HWI effort is unique in applying standard methods across a geographically extensive network of sites, which is critical for accurately tracking regional population trends. However, several other annual counts in the region also add important nodes to the monitoring network and contribute valuable information about regional population trends and flyway dynamics. HWI also conducts banding programs at five sites (2 spring, 3 fall). Together with data from other projects, band encounters from these sites document three distinct regional flyways west of the Great Plains, which we call the Pacific Coast, Intermountain, and Rocky Mountain flyways. Count data from four of HWI's long-term sites and elsewhere document widespread population increases for Ospreys *Pandion haliaetus*, Merlins *Falco columbarius*, Peregrine Falcons *F. peregrinus*, and Turkey Vultures *Cathartes aura*, but indicate concern for Northern Goshawks *Accipiter gentilis* in the northern Rocky Mountains and Golden Eagles *Aquila chrysaetos* in the Great Basin since the late 1970s. The effort to monitor raptor migrations in western North America, although young, is yielding substantial understanding about the dynamics of raptor migrations through the region, valuable information to guide conservation actions, and much additional information concerning the biology and migratory ecology of diurnal raptors. Three primary needs remain: (1) expand the monitoring network to include more of western Canada, the central Rocky Mountains in Colorado and Wyoming, the Sierra Nevada and southern mountains of California, and northern and central Mexico; (2) establish intensive nest productivity studies on selected species to help validate migration monitoring as an effective indicator of population trends; and (3) further improve analytical methods for overcoming biases and summarizing trend data.

INTRODUCTION

Raptors typically occupy top positions in biological food pyramids, occur in most habitats, use resources over broad areas, and are sensitive to chemical contamination and other forms of habitat disturbance. For this reason, raptors represent important biological indicators of environmental change and ecosystem health (Bednarz *et al.* 1990a, b; Bildstein & Zalles 1995). However, many raptors occur at relatively low densities, are secretive in nature, occupy habitats that are difficult to access, and use large home ranges. Accordingly, developing monitoring programs to track the status of populations over long periods and appropriate geographic scales is difficult (Fuller & Mosher 1981, 1987; Titus *et al.* 1989; Bildstein 1998; Kirk & Hyslop 1998). Although not free from inherent biases and methodological problems, monitoring raptors at migratory concentration points is an efficient and cost-effective alternative for gathering substantial information on the population dynamics of multiple species (Kerlinger 1989, Bednarz & Kerlinger 1989, Bildstein *et al.* 1995, Bildstein & Zalles 1995, Dunn & Hussell 1995). Moreover, using standardized methods at multiple sites is essential for yielding accurate information about regional changes in status and population trends (Titus *et al.* 1989, Dixon *et al.* 1998), which today is often the scale of interest for assessing the impact of human activities.

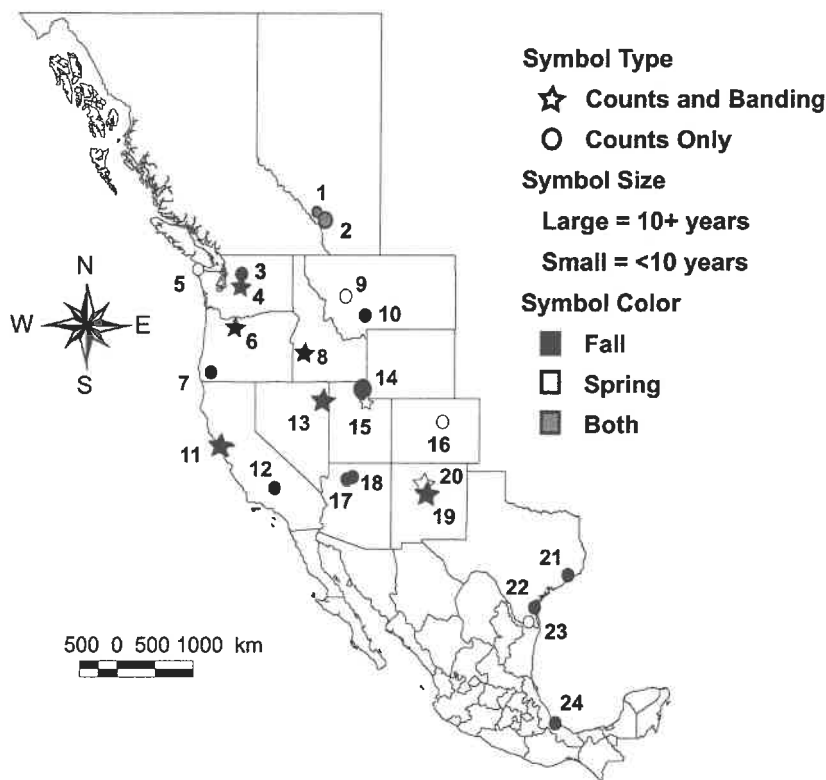
Specific benefits of long-term, geographically extensive monitoring of raptor migrations include: (1) standardized counts are an efficient, cost-effective method for tracking long-term population trends of multiple raptor species, and help develop understanding of migratory ecology by documenting variation in the timing of migratory activity for different species, sexes, and age classes in relation to various environmental parameters (e.g., weather); (2) banding enables large-sample studies of raptor morphology, moult, physiology, genetics, and health (e.g., parasites, fat levels), and foreign encounters with banded birds help identify migratory routes, connections between breeding and wintering grounds, causes of injury and mortality, and longevity in the wild; (3) migration studies provide opportunities to engage the public in monitoring activities and to promote grass roots conservation on behalf of raptors and the ecosystems that support them; and (4) a standardized network of monitoring sites enables detailed delineation of flyways and subpopulations, increases statistical power for detecting regional population trends, enables fine-scale tracking of threats to raptor populations, increases the diversity of samples for biological studies, and greatly expands opportunities for public outreach.

In this paper, we review the status of raptor-migration monitoring in western North America, emphasizing the value and results of pioneering efforts by HawkWatch International (HWI) to establish a broad network of counting and banding sites in the region. Although raptor migration has been intensively studied in the eastern United States for more than 50 years (e.g., Allen & Peterson 1936, Broun 1949, Mueller & Berger 1967, Heintzelman 1975), intensive efforts to document migration patterns in western North America did not commence until the late 1970s (Binford 1979, Hoffman 1985). Now, with information spanning more than a decade at several western sites, migration counts and banding are beginning to reveal the intricacies of western flyways and provide valuable information about regional population trends.

WESTERN NORTH AMERICA RAPTOR MONITORING NETWORK

HWI and its organizational precursors have been monitoring fall and spring raptor migrations in western North America since 1977. HWI has gathered more than a decade of full-season, daily count data at four sites in Utah (fall), Nevada (fall), and New Mexico (spring and fall), and coordinates counts that have proceeded for more recently initiated counts at another 13 sites (3 spring, 10 fall) ranging from Montana to Texas and Washington to Veracruz, Mexico (Table 1, Fig. 1). Supervision by a single organization ensures a high degree of methodological standardization across this extensive network of sites, which greatly facilitates integrating multi-site data and tracking regional population trends (Titus *et al.* 1989, Bildstein & Zalles 1995, Dunn & Hussell 1997, Link & Sauer 1998). HWI monitoring sites encompass three of the largest known concentrations of migratory raptors in North America: Veracruz, Mexico; Corpus Christi, Texas; and the Goshute Mountains, Nevada (Table 1).

Figure 1. Locations of established full or near full-season diurnal raptor migration counts and multi-species raptor banding projects in western North America (numbers refer to sites as listed in Tables 1 and 2).



Several other noteworthy raptor migration monitoring programs exist in the region besides the HWI efforts (Table 1, Fig. 1). Establishment of fall counts at Boise Ridge, Idaho in 1994 (run by the Idaho Bird Observatory [IBO]) and Dinosaur Ridge, Colorado in 1990 (run by the Denver Museum of Natural History) benefited from HWI technical support. Since 1986, the Golden Gate Raptor Observatory (GGRO) has monitored movements at Pt. Diablo, California that rival the concentration in the Goshute Mountains (Binford 1979, GGRO 1997). A sharp rise in raptor migration monitoring activity has recently occurred in western Canada. Windy Point and Mt. Lorette are two prominent sites in Alberta where both spring and fall counts have been conducted since 1986-88 and 1992, respectively, and several other sites in British Columbia, Alberta, and the Yukon Territory offer additional promise for the future in western Canada (Sherrington 1997, 1998). Since 1994, the Kern River Research Center has been monitoring the fall migration through the Kern River Valley of California, which may attract as many as 40,000 Turkey Vultures *Cathartes aura* each year (Rowe & Gallion 1996, McDermot 1997). Variation in methods ultimately may preclude direct comparison of data from these and HWI's network of sites. Nevertheless, all nodes in the raptor monitoring network of western North America can provide valuable comparative information on population trends and flyway dynamics (Kirk & Hyslop 1998). This will be particularly true if all operations follow standardized data recording procedures of the Hawk Migration Association of North America (HMANA) and other guidelines outlined in the Raptor Migration Watch-site Manual prepared by Hawks Aloft Worldwide (Bildstein & Zalles 1995).

Table 1. Ongoing, annual, full or near full-season, multi-species diurnal raptor migration counts in western North America.

Map # ¹ Site	Organization	Season	Year Initiated	Species	Annual Counts	References
1 Mt. Lorette, Alberta	Peter Sherrington <i>et al.</i>	spring/fall	1992	18	4000–5000 ²	Sherrington 1997, 1998
2 Windy Point, Alberta	Wayne Smith	spring/fall	1986/88 ³	15	3000–5000	Sherrington 1997, 1998
3 Chelan Ridge, Washington	HWI	fall	1997	15	1500–2000	Rosman 1998
4 Diamond Head, Washington	HWI	fall	1993	16	1300–1700	Prosser and DeSorbo 1998
5 Cape Flattery, Washington	HWI	spring	1990	16	3000–9000	Clark <i>et al.</i> 1998
6 Bonney Butte, Oregon	HWI	fall	1993	18	2300–2700	Grindrod and Smith 1998a
7 Dutchmans Peak, Oregon	HWI	fall	1997	16	≈5400 ⁴	HWI unpubl. data
8 Boise Ridge, Idaho	Idaho Bird Observatory	fall	1994	18	3500–5900	Tilly 1997
9 Rogers Pass, Montana	HWI	spring	1988	13	1200–2200	Tilly and Tilly 1998
10 Bridger Mts., Montana	HWI	fall	1991	17	2500–3500	Beason and Scifres 1998
11 Pt. Diablo, California	Golden Gate Raptor Observatory	fall	1986	19	14000–30000 ⁵	GGRO 1997
12 Kern River Valley, California	Kern River Research Center	fall	1994	14	20000–40000 ⁴	McDermot 1997
13 Goshute Mts., Nevada	HWI	fall	1983	18	17000–23000	Hoffman <i>et al.</i> in review
14 Wellsville Mts., Utah	HWI	fall	1977 ⁵	18	3000–6000	Hoffman <i>et al.</i> in review
15 Jordanelle, Utah	HWI	spring	1997	17	1300–1500	Miller and Smith 1998
16 Dinosaur Ridge, Colorado	Denver Museum of Natural History	fall	1990	19	2200–5400	Grindrod 1998
17 Yaki Pt., Arizona	HWI	fall	1997	18	4000–5000	Thomas and Smith 1998
18 Lipan Pt., Arizona	HWI	fall	1991	18	6000–10000	Thomas and Smith 1998
19 Manzano Mts., New Mexico	HWI	fall	1985	18	4000–7000	Hoffman <i>et al.</i> in review
20 Sandia Mts., New Mexico	HWI	spring	1985	20	3000–6000	Hoffman <i>et al.</i> in review
21 Smith Point, Texas	HWI; Gulf Coast Bird Observatory	fall	1997	19	≈43000 ^{6,7}	Grindrod and Smith 1998b
22 Corpus Christi, Texas	HWI	fall	1997	24	≈840000 ⁷	Simon and Grindrod 1998
23 Santa Ana NWR, Texas	Santa Ana NWR	spring	1992	15	6000–60000	Economidy 1998
24 Veracruz, Mexico	Pronatura Veracruz; HWI; Hawk Mountain Sanctuary Association	fall	1992	22	2–5 million	Pronatura/HWI/HMSA unpubl. data

¹ Number-coded locations shown in Figure 1.² 80–90% Golden Eagles.³ Partial, intermittent counts since 1967.⁴ 85–99% Turkey Vultures.⁵ Values are indicative of passage activity but not necessarily numbers of individuals because of multi-directional flight paths.⁶ Sampled 1977–1979 and 1987–present.⁷ 70% (Smith Pt.) and 99% (Corpus Christi) Broad-winged Hawks.

Table 2. Annual, multi-species migratory raptor banding operations in western North America.

Map # ¹ Site	Organization	Season	Year Initiated	Species	Total Captures Through Spring 1998	Reference
4 Diamond Head, Washington	Falcon Research Group	fall	1993	10	≈1000	J. Bettesworth pers. comm.
6 Bonney Butte, Oregon	HWI	fall	1995	9	371	Grindrod and Hallett 1998
8 Boise Ridge, Idaho	Idaho Bird Observatory	fall	1993	12	3322	G. Kaltenecker pers. comm.
11 Pt. Diablo, California	Golden Gate Raptor Observatory	fall	1983	15	12274	GGRO 1997
13 Goshute Mts., Nevada	HWI	fall	1980	13	36961	Meehan and Carver 1998
15 Jordanelle, Utah	HWI	spring	1998	6	50	Covert 1998
19 Manzano Mts., New Mexico	HWI	fall	1990	11	7179	Stravers and Smith 1998
20 Sandia Mts., New Mexico	HWI	spring	1990	12	2193	Smith and Smith 1999

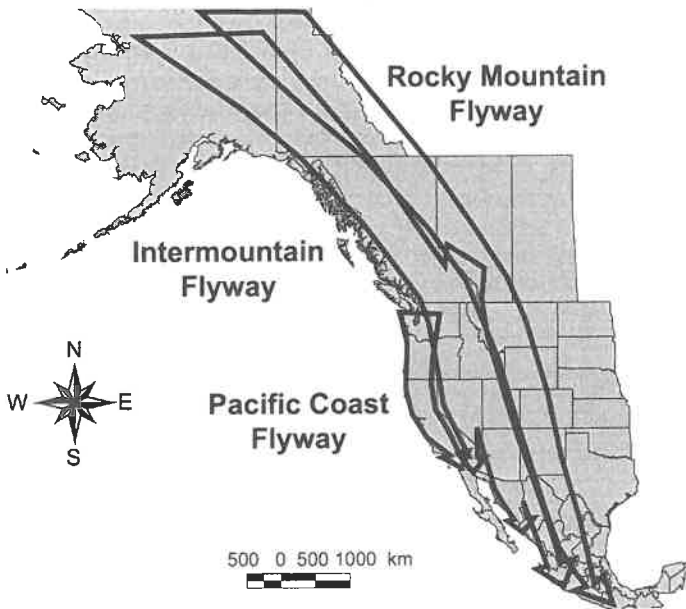
¹ Number-coded locations shown in Figure 1.

HWI also conducts raptor banding programmes at five sites (Table 2, Fig. 1). Banding programmes provide essential information on breeding and wintering ranges, migratory routes, and the health and morphology of migrants. Knowledge of migratory routes and associated breeding and wintering ranges is critical for establishing the spatial context for specific migration counts and for tracking the causes of observed population trends (Senner & Fuller 1989). Other large-scale, multi-species, migratory raptor banding projects in the region that we are aware of include GGRO Pt. Diablo, IBO Boise Ridge, and the Falcon Research Group (FRG) project at Diamond Head, Washington (also the location of a HWI count station since 1993; Table 2, Fig. 1). Long-term banding by Peter Bloom and colleagues in California at nests and elsewhere also has yielded valuable information about migratory pathways along the Pacific Coast (e.g., Bloom 1985).

Regional Flyways

A primary value of long-term banding programmes is that foreign encounters with previously banded birds help delineate migratory routes and flyway boundaries (Kerlinger 1989). Band-encounter information from HWI Goshute and New Mexico sites (HWI unpubl. data), FRG Diamond Head (J. Bettesworth pers. comm.), GGRO Pt. Diablo (Scheuermann 1996), IBO Boise Ridge (G. Kaltenecker pers. comm.), and Bloom (1985) indicate at least three distinct regional flyways, which we call Pacific Coast, Intermountain, and Rocky Mountain (Fig. 2). These flyways ultimately converge in southern Mexico for species known to winter in Latin America (e.g., Turkey Vulture and Swainson's Hawk *Buteo swainsoni*). However, for the four species that constitute the bulk of birds banded at migration monitoring sites in the West—Sharp-shinned Hawk *Accipiter striatus*, Cooper's Hawk *A. cooperii*, Red-tailed Hawk *Buteo jamaicensis*, and American Kestrel *Falco columbarius*—all three flyways terminate within North America.

Figure 2. Major raptor migration flyways in western North America.

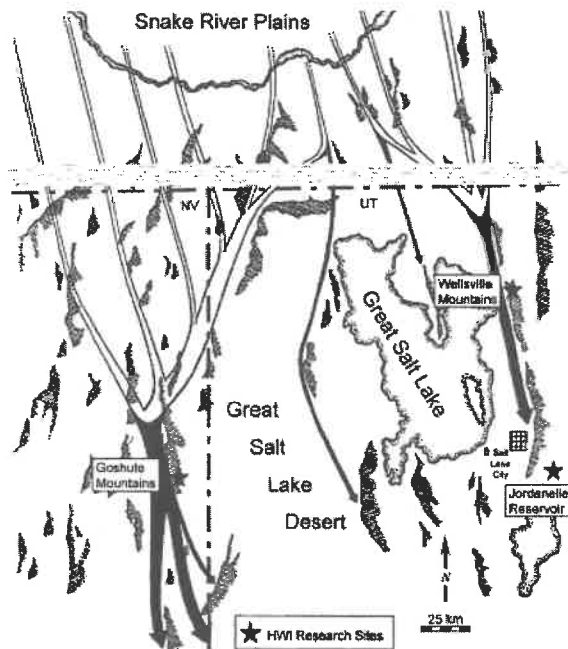


Based on data for these species from GGRO Pt. Diablo, Bloom (1985), and FRG Diamond Head, the Pacific Coast flyway extends from the Cascade Mountains in northwestern Washington to primarily southern California, but also occasionally into Baja California and along the west coast of Mexico, running primarily west of the Cascade Mountains and Sierra Nevada. Based on data from

HWI Goshute Mountains and IBO Boise Ridge, the Intermountain flyway extends from interior Alaska, along the western flanks of the Rocky Mountains through Canada, between the Rocky Mountains and Cascade/Sierra Nevada ranges in the United States, to Baja California and the coastal states of Mexico primarily along or west of the Sierra Madre Occidental. Based on data from HWI's two New Mexico sites, the Rocky Mountain flyway extends from northern Alaska to southern Mexico, running primarily along the eastern and central Rocky Mountains and within the belt extending from the eastern flanks of the Sierra Madre Occidental to the western flanks of the Sierra Madre Oriental. In addition to these truly western flyways, the HWI sites along the gulf coast of Texas and in Veracruz monitor a continuation of eastern and midwestern flyways that funnel large numbers of raptors, especially Broad-winged Hawks *Buteo platypterus*, into Latin America for the winter (e.g., see Goodrich *et al.* 1996).

As additional information accumulates, other aspects of major flyways will be revealed. Encounter information from the HWI Bonney Butte and FRG Diamond Head sites will be of particular interest for delineating boundaries between the Pacific Coast and Intermountain flyways, whereas information from the HWI Jordanelle site will help delineate boundaries between the Intermountain and Rocky Mountain flyways (Fig. 1). For example, several exchanges between the HWI Goshute and IBO Boise Ridge sites indicate a strong connection within the Intermountain flyway; however, winter encounters of Boise Ridge birds thus far have been concentrated slightly northwest (northwestern Mexico, Baja California, and southern California) of most Goshute encounters (mostly central and southern coastal states of Mexico).

Figure 3. Probable raptor migration flyways near the Great Salt Lake and Great Salt Lake Desert of Utah.



Comparing band-encounter information from the HWI Utah and Nevada sites also will be important for determining how migrants respond to the Great Salt Lake and Great Salt Lake Desert. Large bodies of water and otherwise inhospitable habitat often act as major barriers for migrating raptors (Kerlinger 1989). We believe that the Goshute Mountains are a major concentration point for

migrating raptors largely because the range lies at the western edge of the Great Salt Lake Desert at the point where many birds accumulate after skirting around the desert from the northeast (Fig. 3). Encounter data from the newly established HWI Jordanella banding site in Utah near the eastern edge of the Great Salt Lake will help determine if the Wasatch and Goshute flyways attract distinct subpopulations. Inconsistencies in count data from the HWI Goshute and Wellsville, Utah sites suggest that this may be the case for some species (Hoffman *et al.* in review); however, additional verification of flyway affinities is needed to enable definitive interpretation of the count trends.

Population Trends

The primary value of long-term migration counts is that they facilitate tracking of population trends, especially when combined with knowledge of flyway dimensions and information about regional variation provided by a multi-site monitoring network. Hoffman *et al.* (in review) recently analyzed long-term trends in annual passage rates (total raptors counted / total hours observed) through spring 1998 for 16 species counted in the Wellsville, Goshute, Manzano (fall), and Sandia (spring) mountains (Fig. 1). They adjusted daily counts for variation in observer numbers based on Smith and Hoffman (in review), and conducted site-specific trend analyses using primarily linear regression on the log scale (Bednarz & Kerlinger 1989, Titus & Fuller 1990, Hatfield *et al.* 1996). Although a variety of methods are available for combining multi-site data in integrated analyses (e.g., Hussell 1981, Titus *et al.* 1990, Link & Sauer 1998), Hoffman *et al.* elected to follow the recommendation of Dunn and Hussell (1995) for independent, site-specific analyses because of uncertainties about the monitored populations each count represents. Table 3 summarizes the results of these analyses.

These analyses (hereafter called "HWI analyses") consistently reveal significant increases in annual passage rates for Turkey Vulture, Osprey *Pandion haliaetus*, Broad-winged Hawk, Merlin *Falco columbarius*, and Peregrine Falcon *F. peregrinus* at the four sites (Table 3, Fig. 4). Data on the regional status of western Turkey Vultures and Merlins are limited (Pattee & Wilbur 1989, Sodhi *et al.* 1993); thus, the insight provided by migration count data is particularly valuable. North American Breeding Bird Survey (BBS) data for the western region (Sauer *et al.* 1997) and Canada (Kirk & Hyslop 1998), and migration count data from GGRO Pt. Diablo (A. M. Fish, GGRO, pers. comm.) and Hawk Ridge, Minnesota (Hussell & Brown 1992) also indicate increasing trends for Turkey Vultures. This population growth may reflect expansion of open habitat from logging and rural development, and increases in carrion availability associated with an expanding human population (Wilbur 1983, Hoffman *et al.* in review).

Evidence from several migration count sites and BBS routes suggests a possible widespread decline among Broad-winged Hawks in eastern North America (Titus & Fuller 1990, Hussell & Brown 1992, Goodrich *et al.* 1996, Kirk & Hyslop 1998). However, recent increases in general sightings in the western United States and signs of breeding activity in western Canada suggest that the species is expanding its breeding range in the West (Goodrich *et al.* 1996, Hoffman *et al.* in review).

Ospreys, Merlins, and Peregrine Falcons continue to rebound after suffering during the DDT era (Speitzer *et al.* 1978, Henny & Anthony 1989, Cade *et al.* 1988, Sodhi *et al.* 1993). Widespread availability of artificial nesting platforms and reservoirs also has helped Ospreys (Swenson 1981, Henny & Kaiser 1995). Similarly, aggressive conservation action and widespread artificial propagation and release bolstered recovery of Peregrine Falcons, and artificially reared stocks contributed to expansion of Merlins in southern Alberta and Saskatchewan (Platt & Enderson 1989). BBS data confirm the increasing trend for Ospreys in the western region and the increasing trend for Merlins in Canada (Sauer *et al.* 1997, Kirk & Hyslop 1998). Migration counts from GGRO Pt. Diablo confirm increasing detection rates for Merlins and Peregrine Falcons (A. M. Fish, GGRO, pers. comm.), migration counts from Hawk Ridge Minnesota confirm increasing trends for all three species (Hussell & Brown 1992), and nesting surveys in Canada also indicate stable or increasing Peregrine populations (Holroyd & Banasch 1996).

Table 3. Summary of trend results for four raptor migration count sites in western North America (adapted from Hoffman *et al.* in review).¹

Raptor species	Scientific name	Wellsville Mts., UT		Goshute Mts., NV		Manzano Mts., NM		Sandia Mts, NM	
		1977-79 vs 87-97	1987-1997	1983-1997	1985-1997	1985-1997	1985-1997	1985-1997	1985-1997
		t-test	Regression	Regression	Regression	Regression	Regression	Regression	Regression
Turkey Vulture	<i>Cathartes aura</i>	(1)	(1) ²	I*	I*	I*	I*	I*	I*
Osprey	<i>Pandion haliaetus</i>	I*	(1) ²	I*	I*	I*	I*	I*	I*
Northern Harrier	<i>Circus cyaneus</i>	-	-	I ³	-	-	-	-	-
Broad-winged Hawk	<i>Buteo platypterus</i>	I*	-	I	-	I*	I*	I*	I*
Swainson's Hawk	<i>Buteo swainsoni</i>	I*	(1) ²	-	-	I ³	-	-	-
Red-tailed Hawk	<i>Buteo jamaicensis</i>	I*	-	-	-	-	-	-	-
Ferruginous Hawk	<i>Buteo regalis</i>	I*	-	I ³	-	-	-	-	-
Golden Eagle	<i>Aquila chrysaetos</i>	D	-	-	-	D	-	-	-
Bald Eagle	<i>Haliaeetus leucocephalus</i>	-	-	-	-	-	-	-	-
Sharp-shinned Hawk	<i>Accipiter striatus</i>	-	D	-	-	-	-	-	-
Cooper's Hawk	<i>Accipiter cooperii</i>	-	-	I	-	-	-	-	-
Northern Goshawk	<i>Accipiter gentilis</i>	D*	-	-	-	-	-	-	-
American Kestrel	<i>Falco sparverius</i>	-	D ³	I*	-	-	I ³	I*	I*
Merlin	<i>Falco columbarius</i>	I	-	I*	-	I*	-	-	-
Prairie Falcon	<i>Falco mexicanus</i>	-	-	I	-	-	-	-	-
Peregrine Falcon	<i>Falco peregrinus</i>	I* ⁴	-	I*	-	I*	-	-	I*

¹ I* = highly significant increase, $p \leq 0.01$; I = significant increase, $0.01 < p \leq 0.05$; (I) = marginally significant increase, $0.05 < p \leq 0.10$; D* = highly significant decrease; D = significant decrease; - = not significant, $p > 0.10$. Note that all linear regressions were also tested using nonparametric rank trend analysis (Titus *et al.* 1990), and cases where the two approaches yielded substantially different conclusions are indicated by footnotes 2 and 3.

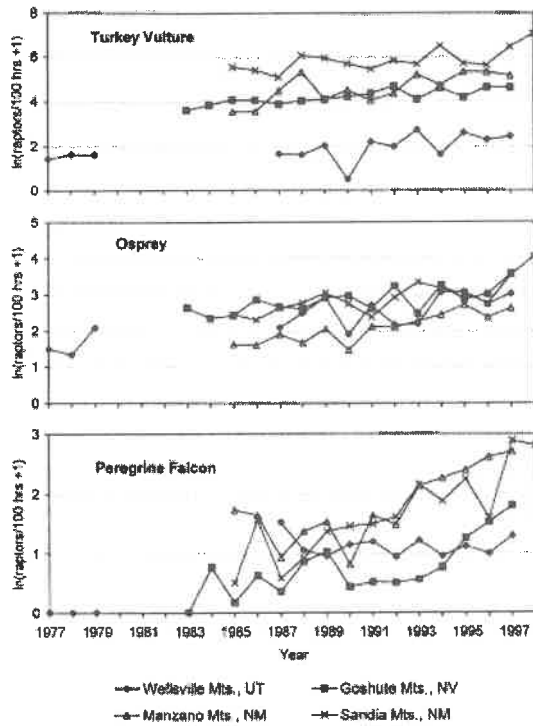
² Nonparametric rank trend analysis indicates significant increasing trend ($0.01 < p \leq 0.05$).

³ Nonparametric rank trend analysis indicates no trend ($p > 0.10$).

⁴ Based on nonparametric Mann-Whitney U-test because of zero counts during 1970s.

The HWI analyses indicate significant declines for five species, but in each case only at one site (Table 3). Moreover, only Sharp-shinned Hawk, Northern Goshawk *Accipiter gentilis*, and Golden Eagle *Aquila chrysaetos* showed a decline at one site and no increasing trends. The apparent, recent decline in Sharp-shinned Hawk passage rates at the Wellsville site may be an artifact of inclement weather leading to a poor count in 1997 (Hoffman *et al.* in review). Although no significant long-term trends were evident, data from the other three HWI sites showed recent increases (Hoffman *et al.* in review). Moreover, BBS data for the western region indicate no trend for 1980–1996 (Sauer *et al.* 1997), most evidence summarized by Kirk and Hyslop (1998) for Canada indicated stable or increasing trends, and migration counts from Hawk Ridge, Minnesota indicate stable trends for Sharp-shinned Hawks (Hussell & Brown 1992).

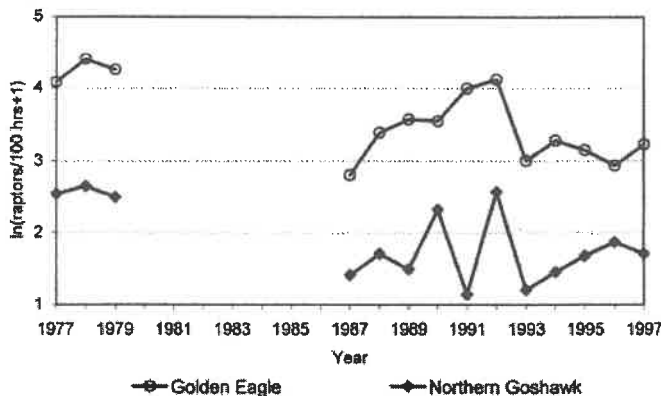
Figure 4. Examples of increasing population trends as discerned from raptor migration counts in Utah, Nevada, and New Mexico (adapted from Hoffman *et al.* in review).



For Northern Goshawks and Golden Eagles, the HWI analyses indicated no significant long-term trends except in the Wellsvilles (Table 3). Passage rates of immature Northern Goshawks and Golden Eagles declined significantly in the Wellsvilles between the late 1970s and late 1980s (Fig. 5), suggesting that productivity declined in the north-central Rocky Mountains during this period and has not recovered. In comparison, Goshute Northern Goshawks showed two previously unequalled spikes in immature detection rates during the past six years, suggesting that productivity in the Great Basin may be improving for this species (Hoffman *et al.* in review). Passage rates of adult Golden Eagles also have generally increased in recent years at the three HWI fall sites. However, because adults of both species are largely non-migratory in many areas (Palmer 1988), indications of increased migratory movements among adults may reflect poor winter conditions on breeding grounds rather

than increasing populations (Hoffman *et al.* in review). Recent decreases in immature : adult ratios at the three HWI fall count sites also probably reflect poor breeding conditions for Golden Eagles in the Intermountain region (Hoffman *et al.* in review).

Figure 5. Declines in migration passage rates of immature Northern Goshawks and immature/subadult Golden Eagles in the Wellsville Mountains of Utah between the late 1970s and late 1980s (adapted from Hoffman *et al.* in review).



The United States Fish and Wildlife Service (USFWS) recently concluded that Northern Goshawks are a forest generalist and that listing under the U.S. Endangered Species Act was not warranted for populations west of the 100th meridian (USFWS 1998). Nonetheless, many indications suggest that Northern Goshawks do best in relatively undisturbed tracts of mature or old-growth forest, are sensitive to excessive forest fragmentation, and have declined in several local areas as a result of habitat disturbance (e.g., Crocker-Bedford 1990, Reynolds *et al.* 1992, Woodbridge & Detrich 1994, Iverson *et al.* 1996, Squires & Reynolds 1997). Thus, we suggest that Northern Goshawks at least warrant additional careful monitoring, particularly in the northern and central Rocky Mountains and Pacific Northwest.

Indications of trouble for Golden Eagles are consistent with evidence of declining territory occupancy and productivity in the Snake River area of Idaho (Steenhof *et al.* 1997) and among breeding populations in Utah (K. Keller, Salt Lake City, Utah, pers. comm.). Throughout much of the interior West, the reproductive success of Golden Eagles is tightly coupled with the abundance of Black-tailed Jackrabbits *Lepus californicus*; (Beecham & Kochert 1975, Steenhof & Kochert 1988, Steenhof *et al.* 1997, K. Keller, Salt Lake City, Utah, pers. comm.). Jackrabbits naturally undergo cyclic population fluctuations; however, the current low-abundance period has been more severe and prolonged than normal, and peak abundances in the early 1990s were substantially lower than during previous high years (Steenhof *et al.* 1997). In the Great Basin, jackrabbits occupy shrub habitats and avoid thick grassland habitats (Knick & Dyer 1997). Consequently, widespread degradation and conversion of native sagebrush habitats caused by poor management of livestock grazing and fire, expanding agriculture, and especially invasions of exotic grasses (primarily cheatgrass, *Bromus tectorum*) has negatively affected jackrabbit populations in many areas (Harlow & Bloom 1989, United States Department of Interior 1996, Steenhof *et al.* 1997, Marzluff *et al.* 1997). Thus, aggressive efforts to restore shrub-steppe ecosystems in the Great Basin and monitor the future status of Golden Eagle populations in the region is warranted (Hoffman *et al.* in review).

Causes of Mortality

Another important benefit of raptor banding is information about longevity and causes of injury and mortality derived from foreign encounters with previously banded birds. Encounter information may be biased towards human factors because the probability of recovery is highest near centres of

human activity. Therefore, analysts must pursue assessing the relative importance of natural and human-related causes of mortality with caution. Regardless, the knowledge gained about human-related causes of mortality or removal from wild populations is important for establishing conservation and education agendas. For example, as of 1997, 35% of the 190 foreign encounters with birds banded in the Goshute Mountains (44% of mortalities) resulted from shooting incidents, primarily in Mexico (HWI unpubl. data). At the same time, encounter rates in Mexico have declined during the past decade, which suggests that educational efforts may be reducing shooting pressure. In the United States and Canada, the disposition of most foreign encounters with injured or dead HWI-banded birds is "found dead-unknown cause" (67%; HWI unpubl. data). Otherwise, collision with human structures (e.g., fences, cars, windows, and power lines) accounts for at least 44% of HWI encounters with a known cause of injury or death (Hoffman *et al.* in prep).

Long-term band encounter data from HWI sites also indicate noteworthy differences in the probability of recovering males and females (HWI unpubl. data). Male : female banding ratios for Sharp-shinned Hawks, Cooper's Hawks, Northern Goshawks, American Kestrels at the Goshute, Manzano, and Sandia sites average between 0.7–1.5 : 1, whereas foreign encounter ratios average from 0–0.5 : 1 and HWI recapture ratios average 0–0.3 : 1. These results suggest three possibilities: (1) accident and mortality rates are higher for females; (2) females are more likely to be discovered after death because they occupy more open habitats where they are more easily discovered by humans, and (3) females are less wary or selective in pursuing prey—in this case lure birds at trapping stations—than males and therefore are more likely to be retrapped. Clark (1985) also documented higher recovery rates for female Sharp-shinned Hawks, and suggested that greater exposure to humans through use of relatively open habitats explained this result. He suggested that greater exposure to humans probably results in both a higher probability of discovery and higher injury and mortality rates from shooting, trapping, and collisions with structures, automobiles, and power lines. A potential, alternative explanation is that males are less prone to accidents and repeating unproductive pursuit of lure birds because their hunting skills are more refined. Lower absolute metabolic energy requirements may allow males to be more selective in pursuing prey because they generally experience less energetic stress than larger females (Mosher & Matray 1974). In addition, for most raptor species, the principal role of males during nesting is to provide prey to females and nestlings (Brown & Amadon 1968). Therefore, males probably develop better hunting skills and more finely tuned pursuit strategies, which may make them more wary and less apt to engage in careless and unproductive hunting pursuits.

Migration Ecology

For raptor species with readily distinguishable age classes or sexes, long-term monitoring of migratory flights offers an opportunity to study differences in timing across sex–age groups. For some species, addition of a migrant banding program is essential for providing useful sex–age-specific information. In addition, location information gleaned from winter and summer encounters with previously banded birds enable determinations of how distances travelled vary across sex–age classes. Evidence from raptor migration and nesting studies generally indicate the following concerning differential migration (see Kerlinger 1989 for review): (1) immature birds generally depart from breeding grounds before adults in the fall, with adult males the last to depart; (2) adults winter farther north than immatures; (3) adults depart from wintering grounds and arrive on breeding grounds before immatures; and (4) among short-distance or partial migrants, adult males often winter farther north and return to breeding grounds before adult females; however, among long-distance or complete migrants, adults of both sexes usually winter at similar latitudes and return to breeding grounds at similar times, often already paired. Kerlinger (1989) reviews six hypotheses evoked to explain various aspects of differential migration, but concurs with Ketterson and Nolan (1983) that only three merit strong consideration. These three hypotheses concern social dominance structures, age and sex-specific variation in body size, and the importance of spring arrival times.

Migration count data from HWI sites generally confirm these sex and age-specific trends (Jewell 1998, Jewell & Smith 1998). Goshute band encounter data, although still limited by small sex and

age-specific sample sizes, also appear to confirm that adults tend to winter farther north than immatures and males tend to winter farther north than females among American Kestrels and Sharp-shinned, Cooper's, and Red-tailed hawks (HWI unpubl. data). DeLong and Hoffman (in press) recently used data on migratory timing from HWI Goshute and New Mexico sites to test hypotheses about relationships between foraging efficiency and differential migration.

Weather may be the most important source of extraneous variation in migration counts, potentially affecting the timing and pace of migratory movements, flight paths, and the visibility of migrants at monitoring sites (Mueller & Berger 1961, Kerlinger 1989, Hall *et al.* 1992, Allen *et al.* 1996, Maransky *et al.* 1997). Documenting how weather affects counts over time at different sites and developing analytical methods to account for weather-related variation is therefore of great importance for increasing statistical power to detect underlying population trends (Hussell 1981, 1985). Fall migration research in eastern North America has revealed that migratory activity often is greatest 1–3 days after passage of a cold front when northwest winds are strong (Allen *et al.* 1996). In contrast, although no comprehensive statistical analyses have been conducted yet, HWI's inland migration data suggest that raptor migration activity in the West is heaviest just ahead of advancing cold fronts when west winds create strong ridge updrafts but montane temperatures remain moderate, or during periods of warm, fair weather when either light southwest or calm winds prevail and thermal activity is high (Millsap & Zook 1983, Hoffman 1985).

Thus, as long-term data accumulate and in-depth analyses become possible, western migration studies likely will add important new dimensions to our understanding of how weather and climate affect raptor migration. In addition, as the network of western banding operations expands and matures, we will be able to generate greater understanding of the migratory ecology of different subpopulations. In turn, this information will facilitate tailoring local and regional conservation activities and management plans to accommodate subtle differences in the ecology of associated raptor populations.

Morphology, Physiology, and Health Assessments

Banding operations also offer a rich opportunity to study a variety of morphological and physiological parameters. Banding at migration sites, in particular, often yields very large sample sizes for such studies, which greatly increases statistical power for analyzing patterns and trends. Knowledge of size characteristics derived from migratory banding enabled accurate classification of accipiters (Mueller *et al.* 1976, 1981a, b; Hoffman *et al.* 1990; Smith *et al.* 1990) and contributed to understanding of ecological relationships between morphological variation and adaptation to different environments (e.g., Smith 1988, Smith *et al.* 1990). Migratory banding enables advances in understanding of the moult process and associated energetics (e.g., Gorney & Yom-Tov 1994), raptor hematology and hemoparasites (Gessaman *et al.* 1986, Powers *et al.* 1994), and metabolic physiology (e.g., Gessaman & Hoffman 1990, Kennedy & Gessaman 1991). Blood samples also can yield information about chemical contamination (e.g., Wood *et al.* 1996) and enable genetic studies that may help track migrant source populations (Haig & Avise 1995). In addition, HWI migration banding has led to accumulation of considerable data on external parasites and body fat levels of migrants, which will facilitate health assessments in relation to environmental conditions (HWI unpubl. data). Another potential project that we envision in conjunction with HWI banding efforts is collecting feather samples to enable stable isotope analyses. Stable isotope analysis is a cutting-edge tool that offers promise for supplementing band encounter information to identify the geographic origins of migrants (Chamberlain *et al.* 1997, Hobson & Wassenaar 1997).

Public Outreach

Raptors constitute an invaluable tool for promoting public interest in the natural world and conservation activities, because they are incredibly dynamic and impressive creatures. At HawkWatch International, as at other institutions such as Hawk Mountain Sanctuary and Golden Gate Raptor Observatory, our mission is to promote raptor conservation through scientific research and an extensive education programme. Having live, captive raptors on hand during educational programmes at schools

and in the community often is the key to captivating audiences and ultimately motivating greater interest in HWI activities. However, we have observed that witnessing the migration spectacle first hand and experiencing live, wild birds up close through trapping and banding at migration monitoring sites is by far the most powerful tool for producing life-long raptor enthusiasts and conservationists. Accordingly, the more extensive the monitoring network, the more opportunities we will have to effectively engage the public and expand awareness of raptor ecology and conservation needs (Bildstein *et al.* 1995, Bildstein 1998).

Needs For the Future

Substantial progress has been made in developing an extensive, standardized network of raptor migration monitoring sites in western North America. Nevertheless, aside from needing more time to accumulate long-term data, there remain several needs for improvement. The first need is further expansion of the monitoring network. Canadian researchers recently have made considerable progress in identifying new potential sites and setting up annual, standardized counts at known concentration points, especially in Alberta (Sherrington 1997, 1998). Areas of primary interest for additional count coverage include the Coast Mountain and Rocky Mountain regions of British Columbia, the Yukon Territory, and far west Northwest Territories (Fig. 1). Establishment of one or more migratory banding operations in western Canada also would be a valuable addition to the network. In the United States, primary needs for expansion include better coverage of the central and southern Rocky Mountains in Wyoming and Colorado, along the Sierra Nevada in California and western Nevada, and in montane areas of southern California, southern Nevada, and southern Arizona (Fig. 1). Further south in Mexico and Baja California, little is known about migratory flyways and activity other than what has been learned from the Veracruz count in southern Mexico; this region is therefore wide open for exploratory work.

The second primary need for improvement of the raptor monitoring network in western North America is to establish intensive breeding productivity studies of selected species in carefully selected areas to provide more specific and stronger validation of migration monitoring as an effective indicator of regional and perhaps local population trends. This will require prior knowledge gained from band encounters or telemetry studies to ensure that breeding and migration studies represent the same monitored populations (*sensu* Dunn & Hussell 1995). Many authors have sought and found reasonable agreement between trends indicated by raptor migration counts and breeding-season surveys like the BBS (e.g., Hussell & Brown 1992, Kirk & Hyslop 1998, and see Dunn & Hussell 1995 for a general review). Moreover, qualitative agreement between the history of DDT use in the United States and trends in long-term migration counts from Hawk Mountain, Pennsylvania (Bednarz *et al.* 1990b) and Cedar Grove, Wisconsin (Mueller *et al.* 1988) clearly demonstrated that migration counts are a useful indicator of regional population trends. Nevertheless, we are not aware of any past or present efforts to conduct well-matched breeding and migration studies that would provide strong, quantitative corroboration of the premise that migration counts accurately track actual trends in population size and productivity.

Finally, during the past two decades a variety of approaches have been developed to account for various confounding factors and enable robust statistical analysis and interpretation of trends in migration counts (e.g., Hussell 1981, 1985; Titus & Fuller 1990; Titus *et al.* 1989, 1990; Bednarz & Kerlinger 1989; Bednarz *et al.* 1990b; Dunn & Hussell 1995; Allen *et al.* 1996; Hatfield *et al.* 1996; Smith & Hoffman in review). Standardization of data collection methods likely will solve many problems with methodological biases (Bednarz & Kerlinger 1989, Dunn & Hussell 1995). Much more effort is needed, however, to document the effects of weather on flight dynamics and visibility, and to develop efficient statistical methods for removing weather-related variation in counts to improve statistical power for detecting underlying population trends (Dunn and Hussell 1995). We also believe that age-specific trend analyses offer promise for tracking the reproductive success of monitored populations, particularly for species such as the Northern Goshawk where most adults are non-migratory or irruptive migrants but most immatures undergo regular migration (Hoffman *et al.* in

review; also see Bednarz *et al.* 1990b). However, one important potential bias that has been little studied concerns the effects of variation in proportions of unaged individuals on the accuracy of age-specific analyses.

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