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RH: Effects of falconry harvest on raptors

Effects of falconry harvest on wild raptor populations in the United States: theoretical considerations and management recommendations

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Abstract: We used recent population data and a deterministic matrix model that accounted for important aspects of raptor population biology to evaluate the likely impact of falconry harvest (including take of different age classes) on wild raptor populations in the United States. The harvest rate at maximum sustainable yield (MSY) ranged from 0.03 to 0.41 for the species examined. At least for peregrine falcons, harvest rate at MSY was greatest for a harvest exclusively of nestlings and lowest for a harvest of adults. The quality of demographic data for the species had a considerable influence on MSY. For most species, the state of current knowledge probably underestimates the capacity for allowed harvest because estimates of vital rates, particularly survival, are biased low, primarily because emigration is not distinguished from survival. This is offset somewhat by biases that might tend to overestimate sustainability inherent in MSY-based analyses and deterministic models. Taking these factors into consideration, and recognizing the impracticality of monitoring raptor populations to determine actual effects of harvest, we recommend that falconry harvest rates for juvenile raptors in the U.S. not exceed ½ of the estimated MSY up to a maximum of 5%, depending on species-specific estimates of capacity to sustain harvest. Under this guideline, harvest rates of up to 5% of annual production are supported for northern goshawks, Harris's hawks, peregrine falcons, and golden eagles; lower harvest rates are recommended for other species until better estimates of vital rates confirm greater harvest potential.

Key words: demographics, falconry, harvest, modeling, raptors, United States, maximum sustainable yield

Falconry has been practiced in the United States since at least the 1920s. Prior to inclusion of Falconiformes and Strigiformes under the Migratory Bird Treaty Act (MBTA) with amendment of the treaty with Mexico in 1972, falconry was not federally regulated, and no comprehensive records were available on the number of falconers or number of raptors removed from the wild annually. Regulations promulgated by the U.S. Fish and Wildlife Service (FWS) in 1976 (50 CFR Part 21) formally legalized falconry under MBTA, and necessitated that the FWS assess the likely impacts of falconry harvest on wild raptor populations. Those regulations required falconers to be permitted, and to report the harvest and subsequent disposition of raptors acquired for use in the sport. The requirements resulted in data useful in assessing the likely impacts of falconry on wild raptor populations, and the FWS used those data to conduct its first Environmental Assessment (EA) of falconry in 1988 (United States Department of the Interior 1988). The 1988 EA concluded that the impact of falconry on wild raptor populations in the United States was inconsequential.

Since 1988 two important things have changed. First, the American peregrine falcon (*Falco peregrinus anatum*) was removed from the federal list of Endangered and Threatened Wildlife in 1999. The subspecies had been protected from falconry harvest since federal regulation of the sport began because of its listed status. Subsequent to delisting, a conservative and carefully controlled harvest was allowed in the western United States (United States Fish and Wildlife Service 2004). This action prompted a legal challenge to the FWS's assertion that falconry harvest of American peregrine falcons will have minimal impacts on the wild population, and alleging that the FWS's failure to adequately monitor peregrine populations to determine the impact of harvest violates the MBTA (Audubon Society of Portland et al. vs. U.S. Fish and Wildlife Service 2004). Second, the federal government has adopted more stringent standards for information for making science-based decisions. The standard requires clearer articulation and more scientific peer review of the information used in such determinations (OMB 2004).

Several aspects of raptor population biology are particularly germane to an assessment of impacts of falconry harvest. In addition to the overall limiting effect of prey availability, nesting densities of healthy wild raptor populations are usually further constrained by the availability of suitable nesting sites, spatial restrictions imposed by territoriality, or both (Newton 1979, Hunt 1998). The net effect is that an upper limit exists on the number of adult individuals that can breed in a given landscape. This, in turn, may result in a large number of non-breeding adults awaiting opportunities to occupy vacancies at breeding territories (Newton 1988, Hunt 1998). These "floating" adults are not accounted for by conventional counts of territorial pairs or nestlings (Newton 1988), yet they can profoundly affect populations by buffering the effects of population declines, by contributing to decreases in reproductive success of breeders directly through interference competition and direct mortality (Tordoff and Redig 1997), and perhaps indirectly through competition for food resources (Newton 1988). Further, as a consequence of intense competition for nesting territories, age at first breeding is increased in healthy raptor populations, presumably because younger adults face competition with established or experienced older birds for vacancies at breeding sites.

This paper aims to describe the likely impact of falconry harvest on wild raptor populations in the United States, taking into account these features of raptor populations. We use the FWS's most recent data on numbers of raptors taken from the wild and employ deterministic models to assess estimated effects on populations. We also illustrate how the dynamics of most raptor populations make monitoring the short-term impact of falconry harvest on populations in the wild nearly impossible and certainly impractical, and we make recommendations on how this should be accounted for in harvest strategies.

Methods

Definitions

We use the term juvenile to refer to an individual <1 yr old, subadult refers to a raptor >1 yr of age but not old enough to typically breed, and floater refers to an adult that has not settled into a breeding slot at an established nesting site. Falconry harvest typically focuses on juvenile raptors, either nestlings (eyases) or fledged young <1 yr old (passagers). Harvest and take in this paper refer to the capture and removal from the wild of raptors for use in falconry. Harvest rate is the difference between the annual survival rate of the harvested age-class without harvest and with harvest; in the case of eyas and passage age classes, this equals the proportion of the annual cohort of young harvested by falconers. The maximum sustainable yield (MSY) is the greatest harvest rate (in 0.01 unit increments) that does not produce a decline in the number of breeding adults in the modeled populations; we refer to harvest levels below this rate as sustainable. "Moffat's equilibrium" is the stable age structure at equilibrium population size for a given set of demographic parameter values (Hunt 1998). When we report population size at Moffat's equilibrium we include all age classes, unless otherwise noted. Demographic parameters of interest are productivity, defined as the mean number of young fledged per occupied nest site annually (ρ) as recommended by Steenhof (1987), and the juvenile (θj), subadult (θ_s), and adult (θ_a) annual survival rates (proportions alive at fledging time each year).

Falconry harvest

Falconers who take raptors from the wild are generally required to do so either by removing eyases from nests or by trapping passage birds during their first year of life. Because of difficulties distinguishing age classes, current regulations do not restrict harvest of American kestrels and great horned owls to first-year individuals. In addition, golden eagles older than 1 yr may be taken, but all harvest of golden eagles is restricted to depredating individuals under special circumstances by provisions in the Bald and Golden Eagle Protection Act (16 U.S.C. 668-668d). Each falconer must report to the FWS and the respective state fish and wildlife agency all acquisitions and dispositions of raptors taken or otherwise acquired under his or her falconry permit (50 CFR 21). FWS regional migratory bird permit offices input all data on raptors taken from the wild into the FWS's permit tracking database. We used data for 2003 and 2004 from this database to assess the number of raptors removed from the wild by species for the purposes of our analyses. Some wild take may go unreported each year, but we believe such actions are infrequent enough to be considered inconsequential in the context of this analysis.

We used the harvest statistics reported above and modified population size estimates for continental North America from the Partners in Flight North American Landbird Conservation Plan (Rich et al. 2004) to estimate the proportion of the year-1 cohort removed from the wild by falconers in 2003 and 2004. These estimates are for Canada and the United States, which is the appropriate geographic scale for this assessment because migrant raptors from Canada are undoubtedly included in the United States harvest of passage raptors. We eliminated the ad hoc visibility correction factor employed by Rich et al. (2004) that doubled population estimates derived from Breeding

Bird Survey (BBS) counts under the general assumption that 50% of individuals were not detected because they were incubating or brooding on nests. This assumption is likely not valid for raptors because most species have large young that do not require brooding by the time BBS routes are run in May and June, and delayed maturation and nest site limitations result in large numbers of subadult and floaters in most populations (Newton 1979). We agree that the probability of detection for raptors is certainly less than 1.0 on BBS routes, but in the absence of an empirically derived visibility correction factor we chose to use the more conservative unadjusted estimates of population size. For the peregrine falcon, opportunities for falconry harvest are currently restricted to a portion of the species' North American range. Accordingly, we used population estimates for the peregrine falcon for the portion of the species' geographic range that is subject to harvest from U.S. Fish and Wildlife Service (2004).

Demographic effects of harvest

We modeled the effects of falconry harvest at different rates on hypothetical closed raptor populations using the best demographic data available for each species. We gave preference to findings from long-term mark-recapture or radio-tracking studies where emigration probabilities were estimated, because such studies yield less biased estimates of juvenile and adult survival rates than simple band recovery or mark-recapture analyses (Kenward et al. 2000). For species lacking intensive long-term demographic studies that accounted for emigration rates, we used the mid-points of ranges for estimates of demographic parameters reported in applicable Birds of North America accounts.

We selected the following species for analysis because they are harvested regularly by United States falconers or they are biologically similar to harvested U.S. species: (1) Eurasian sparrowhawk (*A. nisus*), biologically similar to the Cooper's hawk (*A. cooperii*) and sharp-shinned hawk (*A. striatus*), using data from a marked population in Southern Scotland from 1971 – 1984 (Newton 1986); (2) a radio-tagged and banded population of northern goshawks (*Accipiter gentilis*) from the Baltic island of Gotland, Sweden, using demographic data from 1980 – 1987 (Kenward et al. 1999); (3) Harris's hawk (*Parabuteo unicinctus*), using summarized demographic data from Bednarz (1995); (4)) red-tailed hawk (*Buteo jamaicensis*), using summarized demographic data in Preston and Beane (1993); (5) American kestrel (*Falco sparverius*) using summarized demographic data in Smallwood and Bird (2002); (6) peregrine falcon, using demographic data from a color-marked population in Colorado, USA, collected from 1973 – 2001 (Craig et al. 2004); (7) prairie falcon, using summarized demographic data in Steenhof (1998); and (8) golden eagle, using age-specific survival rate estimates from a long-term radio-tracking study in California by Hunt (2002) and composite productivity values from Kochert et al. (2002) (Table 1). It is important to note that there are differences among species in how occupied nest sites were defined. In the case of the Eurasian sparrowhawk, occupied nests were defined as nests in which at least 1 egg was laid (Newton 1986). For other species, occupied nest sites were sites with a territorial pair in attendance, but the likelihood of detecting pairs whose nests fail early in the nesting cycle varies among species (Steenhof 1987). These differences affect strict comparability of productivity estimates among species, but we believe the bias does not compromise our overall conclusions.

To estimate how falconry harvest likely affects raptor populations, we used a deterministic, Excel-based matrix model (Hunt 2003) that limited the number of adults that could breed annually to 2,000 (i.e., we assumed 1,000 suitable breeding sites for each hypothetical population). The algebraic formulas used to compute equilibrium stage structure are given in Hunt (1998). Models were run for 100 years using point estimates of mean values for ρ, θ_j, θ_s (for species with delayed maturation), and θ_a from the peer-reviewed literature for the 8 species of raptors. We used the model output to estimate population size and structure at Moffat's equilibrium. We fixed parameters of the model that, in reality, would likely shift to buffer declines (e.g., a decrease in age at first breeding, an increase in mean productivity as nest sites of lesser quality became unoccupied and interference competition relaxed; Newton and Mearns 1988; Ferrer and Donazar 1996). However, we also made no effort to account for demographic or environmental stochasticity, nor did we account for potential lowered reproductive success of first-time breeders (Newton 1979), both factors that could affect population structure and growth rates. We recognize that not incorporating these features of raptor populations in our models oversimplifies what likely occurs in nature, but we believe the model outputs adequately illustrate the probable impacts of harvest on wild raptor populations.

In our initial model runs, we incorporated harvest effects by decreasing first-year survival rates in 0.01 unit increments, which would be the case if all harvest was of passage raptors. For comparison purposes, we also simulated an eyas-only and adult-only harvest of peregrine falcons by decreasing productivity values, and by increasing adult mortality values, by 0.01 unit increments, respectively. Response variables of interest at Moffat's equilibrium after 100 years of harvest at the specified rates included resultant numbers of breeders (N_b), juveniles (N_j), subadults (N_s), and floating adults (N_f); the annual rate of population change (λ) if all breeding-age adults were able to breed and produce young at the rate of the population mean; and the floater to breeder ratio (ζ), which is the ratio of nonbreeding adults to breeders. In general, λ is a useful way of gauging the impacts of harvest in a non-saturated population where growth is possible, and ζ is the more useful metric when the population is at equilibrium and all breeding sites are occupied (Hunt 1998). We also developed MSY curves with harvest rate as the variable of interest for golden eagles, peregrine falcons, and American kestrels. These three species represent the range of harvest potential based on the available data.

To estimate actual harvest rates, we divided the number of individuals of each species harvested by the estimated size of the juvenile population of each species. We used the average of the number of individuals of each species harvested in 2003 and 2004 as the numerator. We estimated the denominator by multiplying the overall population estimate for each species by an estimate of the proportion of the population that was ≤ 1 yr old (and therefore subject to harvest). We based our estimate of the proportional size of the ≤ 1 yr-old age class on the species-specific population structure from our models at the 0% harvest rate at Moffat's equilibrium. For species for which we lacked data to develop specific models, we used the model output for the species with the most similar life history characteristics. Estimates for sharp-shinned hawks and Cooper's hawks are from the model for the Eurasian sparrowhawk; estimates for the red-shouldered hawk, ferruginous hawk, great horned owl, and snowy owl are from the model for the red-tailed hawk; the estimate for the merlin and Eastern screech-owl are from the model for the American kestrel.

Results

Actual falconry harvest in 2003 and 2004

Falconers harvested 922 and 1,062 raptors of 15 species from the wild in the United States in 2003 and 2004, respectively (Table 2). Although the most frequently harvested species was the red-tailed hawk, the estimated harvest rate was greater for the Harris's hawk, peregrine falcon, and prairie falcon. For all species, the estimated harvest rate was below 1.0% of the juvenile cohort.

Modeled impacts of harvest on populations

Passage harvest models for all 8 example raptor species at Moffat's equilibrium showed that numerical effects of harvest are primarily restricted to the subadult and floating adult components of populations (Fig. 1). When higher harvest rates compromise the equilibrium, floaters are absent because all adults are able to acquire breeding sites. At the highest levels of harvest, equilibrium population size of all age classes are predicted to be substantially below that at MSY, and the degree of reduction is related to the degree to which harvest rate exceeds MSY. The harvest rate at MSY differs considerably depending on the age classes included in the harvest and, as expected, is greatest for a harvest of eyases and lowest for a harvest of adults (Table 3; Fig. 2). MSY passage harvest rates varies among species in accordance with variation in vital rates (Fig. 3), and this variation is also apparent in changes in λ for unsaturated populations of those species (Fig. 4).

Discussion

Our results suggest that the sustainability of falconry harvest varies among raptor species in accordance with variation in vital rates. Model predictions indicate a comparatively low relative harvest potential for several species (Eurasian sparrowhawk, red-tailed hawk, American kestrel, prairie falcon). We suspect that this is largely due to the underestimation of vital rates for these species because survival rates for them were derived from banding or marking studies that did not include unbiased correction for emigration, and to a lesser degree for the effects of differential mortality among age classes, which can affect reporting rates (Newton 1979, Kenward et al. 2000). In contrast, vital rate estimates for goshawks, golden eagles, and to a lesser degree, peregrine falcons, were based on radio-tracking or marking studies that allowed for estimation and correction for these biases. As Kenward et al. (2000) showed, banding and marking typically greatly underestimate survival in raptors relative to findings for the same populations from radio-tagging studies. Our findings highlight the need for better information on vital rates of these raptors.

Our model output confirms, at least for the peregrine falcon, that the impacts of harvest are proportional to the age of the cohort harvested, with nestling harvest having the least impact. This is consistent with findings of many previous studies that show raptor populations are most sensitive to changes in adult mortality rates (Newton 1979). Changes in raptor populations in response to sustainable harvest are largely restricted to the subadult and floating adult components of the populations, neither of which is amenable to population monitoring by traditional methods of counting breeding adults and young at nest sites. Overharvest would initially produce a decrease in the number of floating adults, which would likely increase the number of younger breeders at nests (Newton 1979, Ferrer et al. 2003), and could eventually cause a decrease in nest site occupancy. Monitoring trends in the age of breeders at nests could provide an early indication of decline (Ferrer et al. 2003), but such a pattern also would also be expected in an unsaturated population that was increasing (Newton and Mearns 1988, Tordoff and Redig 1997).

Our models oversimplify what would be expected to occur in nature, and ideally our predictions should be tested experimentally with wild populations. We encourage study in this area, but recognize that the logistics of such work will be daunting given the difficulty measuring population responses among nonbreeders. Previous attempts to estimate sustainable harvest rates for raptor populations have examined empirical data on rates of recovery of depleted populations, sustainability of populations under persecution, or, in one case, population responses to experimental harvest (Conway et al. 1995, Kenward 1997). The conclusions of these analyses generally mirror what we found: that many raptor populations can sustain eyas or passage harvest rates of 10% - 20%, and sometimes higher. This increases our confidence in the results presented here. That said, we also believe a degree of caution is warranted in applying these results. MSY approaches to harvest management frequently overestimate sustainability, and monitoring capabilities are often not adequate to determine when harvest rates need to be reduced or modified (Ludwig et al. 1993). Moreover, deterministic models can produce overly optimistic projections of sustainability by masking the consequences of stochastic events that can temporarily depress production or elevate mortality (Beissinger and Westphal 1998).

In our models we used demographic values that, while realistic for the species, are not likely representative of all populations of those species at all times. Though this justifies caution in applying our findings to local populations, we believe that our overall findings are representative for raptor populations in healthy condition. In declining populations, harvest would amplify declines commensurate with harvest rate. However, to determine the ultimate effects of falconry harvest on a declining raptor population, it would be important to know the cause of the decline. For example, we doubt that raptor populations declining due to locally deteriorating habitat conditions or declines in food availability would be appreciably impacted over the long term by falconry harvest if the proportion harvested remained constant through the range of changes in population size. This is because once the population reached carrying capacity under the new conditions, demographic values would be expected to stabilize at healthy levels. On the other hand, population declines in species experiencing excessive mortality or reproductive failure would be exacerbated by harvest at any level, and unless the underlying cause of the decline was remedied or the harvest stopped, extirpation or extinction would occur more rapidly than would otherwise be the case.

Our analyses, which assume that raptor harvest constitutes an irrevocable additive mortality effect on populations, are conservative for 2 reasons. First, not all raptors harvested by falconers are permanently removed from the wild. Mullenix and Millsap (1998) reported that about 40% of falconer-harvested red-tailed hawks and American kestrels are either purposefully or accidentally returned to the wild each year. Survival rates and fitness of these birds are unknown, but some almost certainly survive and return successfully to the wild population. For example, in Great Britain, the northern goshawk was reestablished as a breeding species from escaped falconry stock (Kenward 1974, Kenward et al. 1981). Second, Conway et al. (1995) found that nestling prairie falcons left in nests from which siblings were harvested had higher survival and breeding recruitment rates than nestlings from unharvested nests. This suggests that in the case of eyas harvest there may be a compensatory effect of harvest on survival of remaining nestlings.

Management implications

Our results suggest that harvest strategies employed by agencies seeking to regulate the take of raptors by falconers should manage take based on each species' ability to sustain harvest, recognizing that for some species, the state of current knowledge probably underestimates that capacity. Further, we believe that harvest rates should be conservative given the potential for MSY-based analyses to overestimate sustainability and the impracticality of measuring the actual effects of harvest on wild raptor populations. Finally, limiting take to eyas and passage raptors, as is currently the case for most species, is an effective strategy for limiting effects of harvest on populations.

As a practical guide, we recommend that in the USA, harvest of juvenile raptors be limited to ½ of the estimated MSY up to a maximum of 5%, depending on species-specific estimates of capacity to sustain harvest. We suggest that the available information on vital rates are sufficient to justify harvest rates of up to 5% for northern goshawks, Harris's hawks, peregrine falcons, and golden eagles; species with estimated MSYs greater than twice this value. We advocate harvest rates of ½ MSY for other North American species we assessed, and harvest rates of 1% for species without adequate demographic data to estimate MSY until better estimates of vital rates confirm greater harvest potential (Table 2). We believe that harvest rates below these levels are unlikely to produce discernible effects on raptor numbers or the sustainability of otherwise healthy populations, and are probably inconsequential in declining populations if those declines are caused by a reduction in the amount of suitable habitat or prey availability.

One obvious difficulty in this approach is the lack of reliable annual information on abundance for raptor species from which to calculate harvest rates. The BBS-based abundance estimates we used here are likely conservative for most species, particularly with the modification we employed that eliminated the visibility correction factor used by Rich et al. (2004). Given this, and considering that most raptor populations tend to be fairly stable from year-to-year (Newton 1979), annual estimates of abundance may not be necessary for management of falconry take. Rather, we suggest the approximate annual harvest rate estimates derived from known annual harvest divided by the estimated number of juveniles in Table 1 should suffice to identify species for which harvest might be approaching the thresholds identified here. Under this approach, we suggest that juvenile population size estimates for species with declining BBS trends be recalculated every 3 yr, and that those for other species be revised every 6 yr. While BBS-based population estimates will never be ideal for raptors, they could be improved if future recalculations included some measure of annual variation so that confidence intervals could be constructed for the estimates.

The approach outlined above seems particularly appropriate when one considers that estimated harvest rates in 2003 and 2004 for all raptor species in the U.S. were well below the recommended thresholds. The primary harvest regulation mechanism in effect in these years was a 2-bird per falconer limit on the number of raptors that could be removed from the wild each year, in conjunction with an overall maximum possession limit of 3 birds. Thus, even with some 4,250 licensed falconers in the U.S. (U.S. Fish and Wildlife Service files) and a potential harvest of up to 8,500 raptors, harvest rates were extremely conservative under this regulatory framework; only 11.7% of the recommended allowable take occurred.

Although we include golden eagles in our analysis, harvest of golden eagles is regulated differently than other falconry species. The Bald and Golden Eagle Protection Act (16 U.S.C. 668-668d) provides added restrictions specific to the take of golden eagles: only falconers with >7 yr of overall falconry experience and eagle handling experience may take golden eagles from the wild, and only in certified depredation areas. Therefore, take of golden eagles for falconry is far more limited than is other falconry harvest.

Our assessment indicates take of wild raptors for falconry is very unlikely to have a significant adverse impact on wild raptor populations in the U.S. Because of the limited participation in falconry, and because nearly half of all raptors used in the sport are produced through captive breeding and not taken from the wild (Peyton et al. 1995), we believe impacts are unlikely to increase. Nevertheless, our recommendations provide a relatively easy and cost effective way to track the potential national impact on an annual basis using harvest reports already being provided by falconers. Only if the potential for impacts increase, either through substantial growth in the number of licensed falconers or an increase in harvest rates for a particular species, would additional safeguards be necessary.

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Table 1. Species, data sources, and demographic input to models used to assess effects of falconry harvest on wild raptor populations in the United States.

Species	Data source	Geographic locale	Annual juvenile survival	Annual subadult survival[a]	Annual adult survival	No. young per occupied nest site	Age at first breeding (yr of age of limiting sex)	Maximum age[b]
Eurasian sparrowhawk	Newton 1986	Southern Scotland	0.45	-	0.61	2.30	1	13
Northern goshawk	Kenward et al. 1999	Baltic Islands, Sweden	0.58	0.65	0.81	1.45	2	17
Harris's hawk	Bednarz 1995	Composite, USA	0.70	0.64	0.82	2.10	2	17
Red-tailed hawk	Preston and Beane 1993	Composite, USA	0.46	0.80	0.80	1.40	2	17
American kestrel	Smallwood and Bird 2002	Composite, USA	0.31	--	0.55	3.30	1	11
Peregrine falcon	Craig et al. 2005	Colorado USA	0.54	0.67	0.80	1.66	2	17
Prairie Falcon	Steenhoff 1998	Composite, USA	0.25	--	0.75	2.78	1	14
Golden Eagle	Survival rates from Hunt (2002), productivity from Kochert et al. 2002	California, USA for survival; composite USA for productivity	0.84	0.90	0.91	0.80	5	25

[a]For species indicated as breeding at 1 yr of age, there is no subadult age class in the models. For others, the subadult age class includes years after year 1 (juvenile) and the age at first breeding. Most species indicated as first breeding at age 2 do occasionally

breed at age 1, particularly females (Newton 1979), but we used the values reported here in our models as we felt they were appropriately conservative.

[b]Maximum age as calculated in models. We assumed no breeding senescence, so maximum breeding age equals maximum age.

Table 2. Number of raptors removed from the wild by licensed falconers in the United States in 2003 and 2004 according to U. S. Fish and Wildlife Service records. Population size estimates are from Rich et al. (2004). Percent harvest estimates use the mean number harvested.

Species	North American population size[a]	Estimated % juveniles[b]	Number juveniles[b]	Number Harvested			% juveniles harvested	Recommended maximum harvest rate
				2003	2004	Mean		
Sharp-Shinned Hawk	291,500	0.50	145,750	15	15	15	0.0103	1.0%
Cooper's Hawk	276,450	0.50	138,225	67	72	69.5	0.0503	1.0%
Northern Goshawk	120,050	0.30	36,015	52	46	49	0.1361	5.0%
Harris's Hawk	19,500	0.25	4,875	50	32	41	0.8410	5.0%
Ferruginous Hawk	11,500	0.30	3,450	7	6	6.5	0.1884	1.0%
Red-Shouldered Hawk	410,850	0.30	123,255	3	3	3	0.0024	1.0%
Red-tailed Hawk	979,000	0.30	293,700	527	645	586	0.1995	4.5%
American Kestrel	2,175,000	0.60	1,305,000	100	101	100.5	0.0077	1.5%

Merlin	325,000	0.60	195,000	48	52	50	0.0256	1.0%
Gyrfalcon	27,500	0.30	8,250	8	19	13.5	0.1636	1.0%
Peregrine Falcon	9,870[c]	0.30	2,961	1[c]	18	18	0.6079	5.0%
Prairie Falcon	17,280	0.50	8,640	31	42	36.5	0.4225	1.0%
Eastern Screech-Owl	369,600	0.60	221,760	1	0	0.5	0.0002	1.0%
Western Screech-Owl	270,100	0.60	162,060	0	3	1.5	0.0009	1.0%
Great Horned Owl	1,139,500	0.30	391,850	6	7	6.5	0.0020	1.0%
Snowy Owl	72,500	0.30	21,750	1	1	1	0.0046	1.0%
Total				922	1,062	992		

[a]Unless otherwise noted, taken from Rich et al. (2004), but modified as described in the Methods. Units are total number of individuals.

[b]The percent juveniles was estimated from observed population structure in species-specific population models at equilibrium (see Fig 1 and Table 1). Estimates for sharp-shinned hawks and Cooper's hawks are from the model for the Eurasian sparrowhawk;

estimates for the red-shouldered hawk, ferruginous hawk, great horned owl, and snowy owl are from the model for the red-tailed hawk; and estimates for the merlin and Eastern screech-owl are from the model for the American kestrel.

[c]Harvest of peregrine falcons is limited to states west of the 100th meridian, and the is the population included here. This population size estimate is from U.S. Fish and Wildlife Service (2004), based on direct counts from states. Harvest of wild peregrine falcons for falconry was authorized only in Alaska in 2003, but was expanded to include other western states in 2004.

Table 3. Summary of model output for 8 species of raptors using demographic data in Table 1. The floater-to-breeder ratio (ζ) is descriptive of saturated populations at Moffat's equilibrium, whereas the annual rate of population change (λ) is applicable for populations that are below carrying capacity and still capable of growth. The harvest rate at maximum sustainable yield (MSY) assumes populations are at Moffat's equilibrium, and likely are not representative of maximum sustainable harvest rates for all populations of the species.

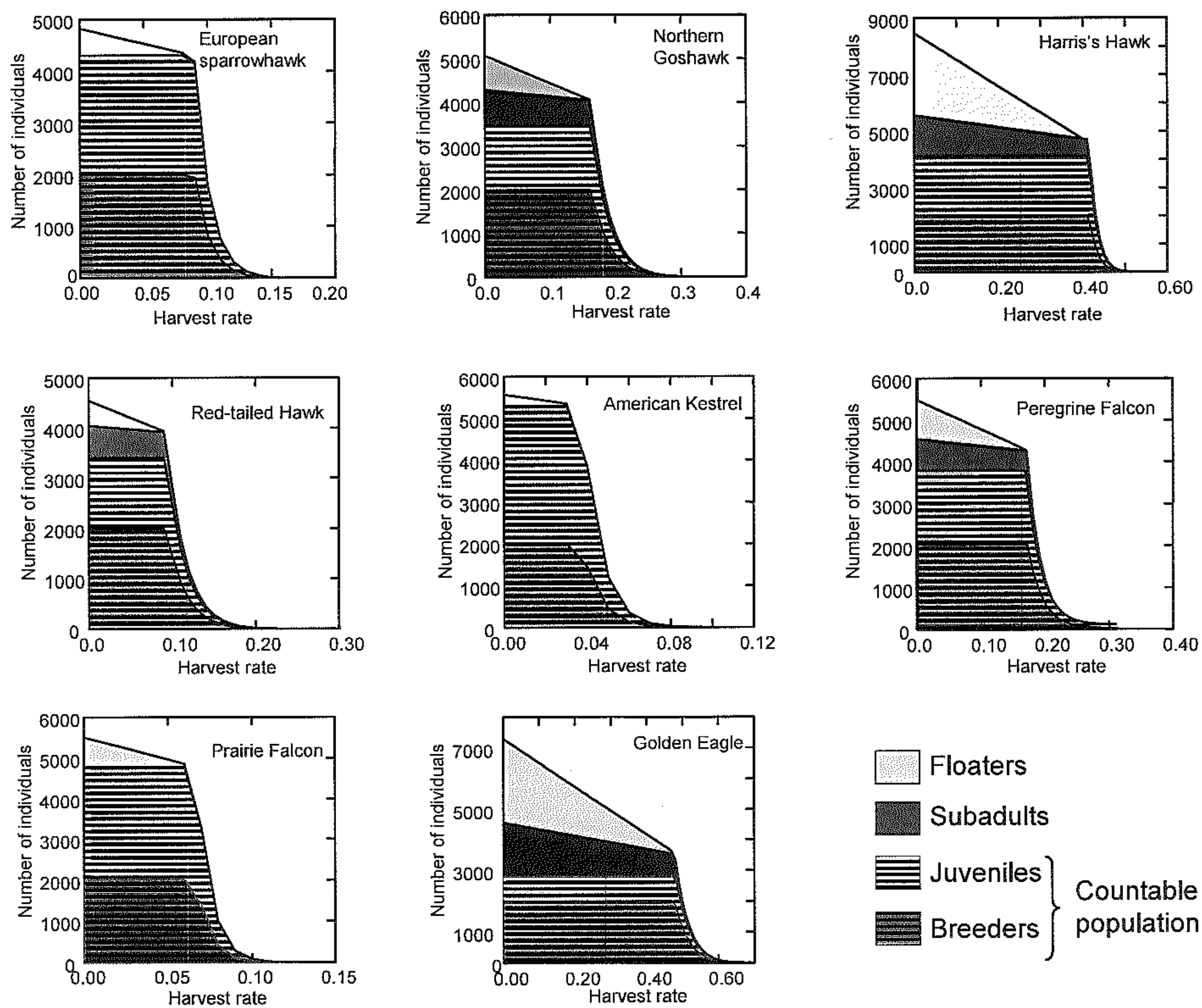
Species	Age of harvest	Initial ζ	Initial λ	Harvest rate at MSY
Eurasian sparrowhawk	Passage	0.26	1.07	0.06
Northern goshawk	Passage	0.39	1.05	0.16
Harris's hawk	Passage	0.45	1.45	0.41
Red-tailed hawk	Passage	0.25	1.03	0.09
American kestrel	Passage	0.14	1.04	0.03
Peregrine falcon	Eyas	0.46	1.06	0.31
Peregrine falcon	Passage	0.46	1.06	0.16
Prairie Falcon	Passage	0.37	1.07	0.06
Golden Eagle	Passage	1.35	1.07	0.31

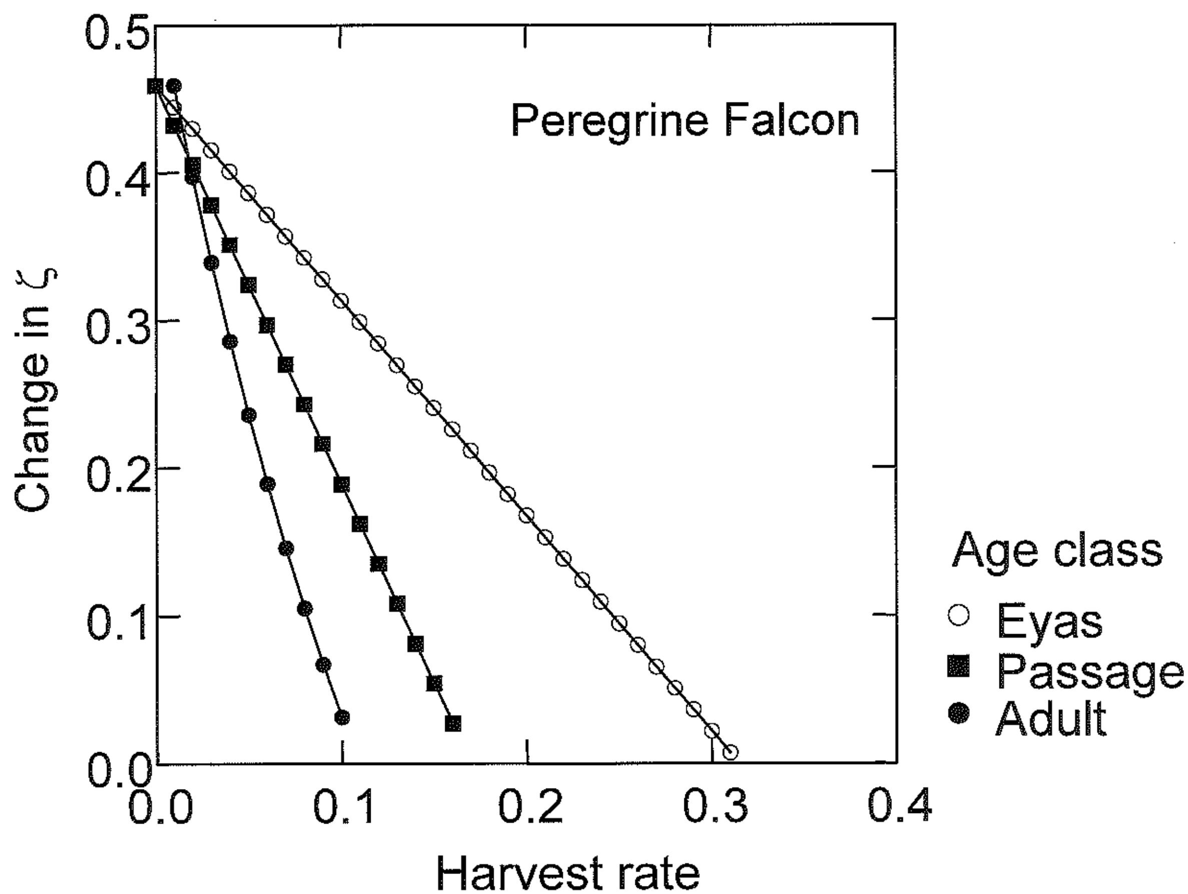
Figure 1. Estimated population structure of 8 raptor species at various passage harvest rates (% of juvenile cohort taken by falconers). See Methods section in text for definitions. Data sources are given in Table 1. The component of the population that can be accounted for through nest-site monitoring is cross-hatched. For all species, effects of harvest on populations below the harvest rate at maximum sustainable yield (MSY) are primarily in population segments that are not associated with nest sites. Above the MSY harvest rate, nest site occupancy and production are maintained at lower equilibrium levels than would otherwise be supportable.

Figure 2. Change in floater-to-breeder ratio (ζ) with increasing harvest rate in a hypothetical peregrine falcon population at Moffat's equilibrium, using demographic data in Table 1. Under these demographic parameter values, the harvest rate at maximum sustainable yield is 3 times greater for an eyas-only harvest compared to a harvest of adults.

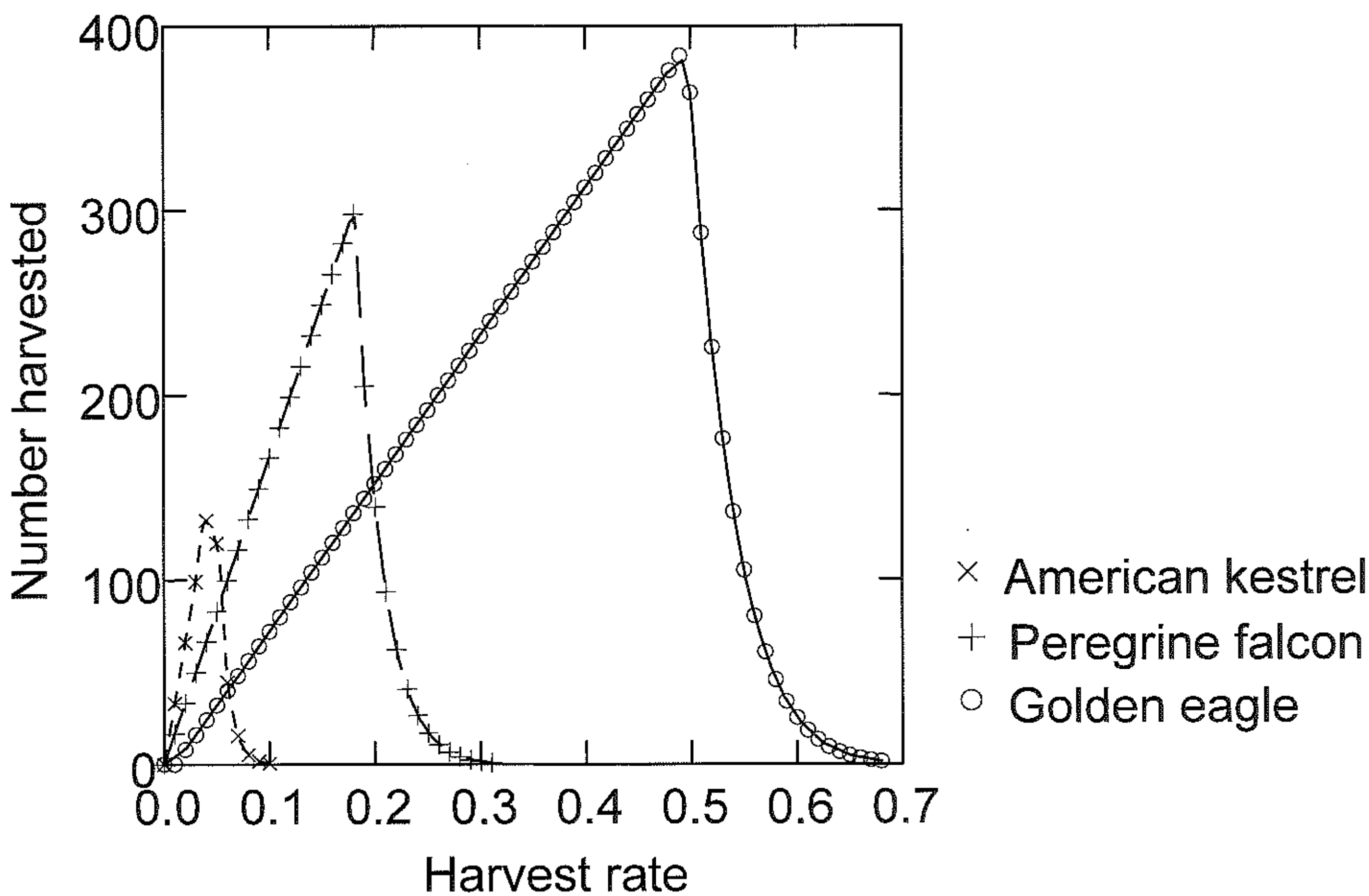
Figure 3. Harvest equilibrium curves for 3 species of raptors representing the range of harvest potential observed. Modeled harvest is of passage individuals, and models use the demographic data for each species from Table 1.

Figure 4. Change in population growth rate (λ) with changing passage harvest rate for 8 species of raptors at harvest levels below maximum sustainable yield, using demographic parameter values from Table 1.

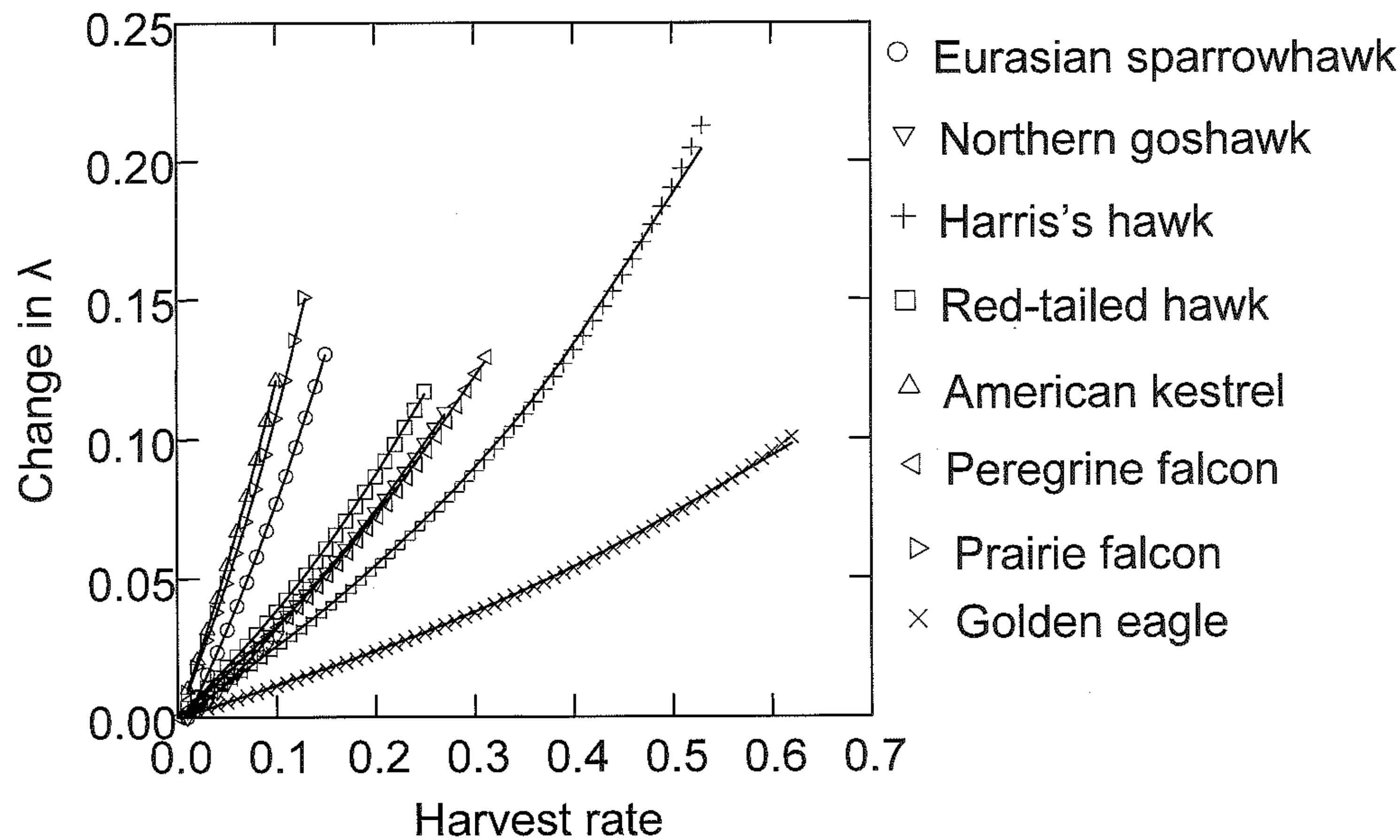

European sparrowhawk
Northern Goshawk
Harris's Hawk
Red-tailed Hawk
American Kestrel
Peregrine Falcon
Prairie Falcon
Golden Eagle
Number of individuals
Harvest rate
Floaters
Subadults
Juveniles
Breeders
Countable population



Peregrine Falcon
Change in ζ
Harvest rate
0.0
0.1
0.2
0.3
0.4
0.5
Age class
Eyas
Passage
Adult



400
300
200
100
0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
Number harvested
Harvest rate
American kestrel
Peregrine falcon
Golden eagle


Change in λ
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Harvest rate
Eurasian sparrowhawk
Northern goshawk
Harris's hawk
Red-tailed hawk
American kestrel
Peregrine falcon
Prairie falcon
Golden eagle