WHY MIGRATORY BIRDS OF PREY MAKE GREAT BIOLOGICAL INDICATORS

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Abstract

Numbers of raptors traveling along traditional migration corridors have been monitored at watchsites in North America since the early 1930s (Zalles and Bildstein 2000). Although initially conducted to document the numbers of birds protected from shooting (Broun 1949), eventually, such counts were used to monitor changes in regional (Nagy 1977), continental, and world populations of raptors (Zalles and Bildstein 2000). Since the 1950s, shifts in numbers of migrating birds of prey have been used to reflect environmental change. Rachel Carson (1962), for example, used declines in the annual ratios of juvenile-to-adult Bald Eagles (*Haliaeetus leucocephalus*) migrating past Hawk Mountain Sanctuary in eastern Pennsylvania to document pesticide-era impacts in aquatic environments. Even so, the extent to which counts of migrating raptors serve as useful "indicators" of ecosystem change has never been examined thoroughly. I used a recent list of independent criteria (Woodward et al. 1999) for "ideal" biological indicators to assess the value of annual counts of raptors at raptor-migration watchsites as indicators of environmental change. Migrating raptors meet or exceed 13 of 14 criteria for ideal indicators. I conclude that monitoring numbers of raptors at migration watchsites, particularly when counts are conducted in conjunction with counts at other watchsites, and across large geographic scales, offers considerable potential for assessing which human activities influence local, regional, continental, and global ecosystem processes.

Hawkwatching in the Americas (Bildstein and Klem, Eds.) 2001. Pages 169-179.

Introduction

Monitoring ecological change is fundamental to cost-effective conservation biology (Goldsmith 1991, Spellerberg 1991). This is particularly so when humans are rapidly modifying large areas of the world's remaining natural landscapes (Furness et al. 1993). Unfortunately, many of the ecological end points and processes conservationists consider to be of value (e.g., biodiversity and the resilience of ecosystems to natural and human-induced disasters) are both difficult—indeed sometimes impossible—and costly to survey and monitor (Peterken and Backmeroff 1988, Noss 1990). This being the case, conservationists often track the status of more easily measured surrogates or "indicators" of the ecological goals they seek to achieve.

Chosen correctly, biological indicators serve as low-cost sentinels of ecological change. Chosen incorrectly, indicators can lack sufficient sensitivity, reliability, or even cost effectiveness to serve as early warning signals of the changes in question (Noss 1990, Spellerberg 1991).

Numbers of raptors passing traditional raptor-migration watchsites have long been touted by hawkwatch practitioners and others as ideal biological indicators (Carson

1962, Hickey 1969, Zalles and Bildstein 2000). Here, I use a set of recently developed independent criteria for choosing desirable biological indicators (Woodward et al.1999) to assess the value of counts of migratory raptors as practical and effective environmental sentinels.

Each of the 13 nonexclusive desirable properties of biological indicators that follow is examined in light of raptor biology, the history of raptor migration watchsite activities, or both. Desirable properties are listed in the order in which they appeared in Woodward et al. (1999), and not necessarily in order of importance.

Independent Criteria for Desirable Biological Indicators

Politically appealing

Biological indicators should "reflect what people care about" (Woodward et al. 1999). In part, because of the recent historic and current status of several high-profile migratory raptors (e.g., California Condors [*Gymnogyps californianus*], Bald Eagles [*Haliaeetus leucocephalus*], Peregrine Falcons [*Falco peregrinus*]) as endangered species, and in part because of their status as "charismatic megafauna," many migratory raptors most certainly meet this admittedly sociological criterion (e.g., Broun 1949, Weidensaul 1996, Beans 1996, Winn 1998, Wilcove 1999).

Known statistical properties

Biological indicators should have known "mathematical distribution(s), abundance(s), ranges(s) of variation, and criteria for being out of range" (Woodward et al. 1999). The long-term status of migration counts at traditional watchsites (Broun 1949, Harwood 1973, Brett 1991), the detailed history of their analysis (Haugh 1972, Bednarz et al. 1990, Bildstein 1998a), and the availability of results from similarly conducted concurrent counts across broad geographic regions (Zalles and Bildstein 2000), indicate that raptor-migration watchsite counts most certainly meet this criterion.

Logically linked

Biological indicators should have "connectivity with other elements that are monitored" including the "food chain" (Woodward et al. 1999). Because of their status as top predators on hundreds, if not thousands of prey species—the Peregrine Falcon alone is reported to take well over 250 species of birds worldwide (Palmer 1988)—including insects and other invertebrates, as well as fishes, amphibians, reptiles, birds, and mammals (del Hoyo et al. 1994), migratory raptors most certainly meet this criterion.

Allows scaling

Biological indicators should "be chosen [such] that [they] can be aggregated over the greatest possible range of scales" (Woodward et al. 1999). Intercontinental assemblages of raptor migration watchsites, particularly those at relatively low latitudes along major migration corridors and continental bottlenecks (e.g., the Corpus Christi Hawkwatch at Hazel Bazemore Park in Gulf Coast Texas, Rio-de-Rapaces at the Veracruz Coastal Plain watchsite in Gulf Coast Mexico, and the Southern Panama Canal Zone watchsite in central Panama) (Smith 1980, 1985a, 1985b; Economidy 1996, 1997a, b; Sutton and Sutton 1999), have the combined capacity for monitoring raptor populations continentally. Similarly, regional assemblages of watchsites at higher latitudes (e.g., Hawk Ridge Nature Reserve at the western tip of Lake Superior in eastern Minnesota, the Southeastern Michigan Raptor Research watchsite on Lake Erie in southeastern Michigan, and Hawk Mountain Sanctuary in the central Appalachian Mountains of eastern Pennsylvania) (Hofslund 1966, Cypher and Smart 1995, Bildstein 1998a), working together with other watchsites along branches of these corridors (e.g., Bolton Flats on the eastern edge of the northern Appalachian Mountains in eastern Massachusetts, Beelzebub Street near the Connecticut River in central Connecticut, and Franklin Mountain in the northwestern foothills of the Catskill Mountains in southern New York) (Zalles and Bildstein 2000), have the combined capacity for monitoring raptor populations regionally and locally. Given the current network of more than 380 watchsites worldwide, including more than 150 in North America alone (Zalles and Bildstein 2000), there is no doubt that migratory raptors meet this criterion.

Representative

According to Woodward et al. (1999) "indicators should include representatives of all trophic levels, taxonomic groups, scales, geographic regions, and important substrates," and should offer redundancy. Diurnal birds of prey are limited trophically as predators and, secondarily, as scavengers (Newton 1978, del Hoyo et al. 1994). They also are largely taxonomically distinct (Class Aves, Order Ciconiiformes, Families Accipitridae, Sagittariidae, and Falconidae; and Subfamily Cathartinae) (Sibley and Ahlquist 1990). Raptors do, however, operate over enormous ranges of both spatial and temporal scales, as well as across most habitats, both within and across species (Newton 1978, Kerlinger 1989, del Hoyo et al 1994), making them broadly representative both geographically and temporally.

Leading versus lagging

One of the hallmarks of effective indicators is their ability to provide "early warning(s) of major change" (Woodward et al. 1999). Migratory raptors have long excelled in this area. For example, although we now know that the widespread use and misuse of DDT and other organochlorine pesticides in the mid-20th Century disrupted numerous ecological phenomena across a broad range of terrestrial and aquatic ecosystems in both North America and Europe (Giesy et al. 1995, Simonich and Hites 1995, Blais et al. 1998, and references therein), and although conservationists had warned of this possibility as early as the late 1940s (Gabrielson et al. 1950), documenting the causal relationships remained both difficult and controversial well into the 1960s (Carson 1962, Hickey 1969, Cade et al. 1988).

In North America, several of the earliest "signals" of such disruption came from substantial declines in the reproductive success of southern Bald Eagles in peninsular Florida in the mid- to late 1940s (Broley 1950), together with concurrent declines in ratios of juvenile-to-adult Bald Eagles seen migrating past Hawk Mountain Sanctuary in eastern Pennsylvania (Carson 1962). Reports of the declines, in turn, led to studies of causation involving several species of captive and free-ranging raptors that, eventually, produced a fuller understanding and appreciation of the ability of organochlorine and other relatively persistent fat-soluble pesticides to accumulate and magnify in concentrations across food chains in numerous nontarget organisms, including humans (Cade et al. 1988, Furness et al. 1993).

That raptors also have proved sensitive to many of the organophosphate and carbamate replacements for subsequently banned organochlorines (Goldstein et al.1999, Mineau et al. 1999), together with the fact that pesticide use in the United States has increased at least 33-fold since 1945 (Pimental 1995), suggests a significant continuing role for raptors in this arena for some time.

More recently, reports from the northeastern United States suggest that at least several species of raptors, including both Coopers Hawks (*Accipiter cooperii*) and Red-tailed Hawks (*Buteo jamaicensis*), appear to be particularly vulnerable to the newly arrived West Nile Virus. Carcasses of these relatively large-bodied birds, which are more likely to be found and reported to local and regional health agencies than are those of smaller species of birds, are providing an early-warning signal to the spread of this pathogen, which affects human populations, as well as those of birds.

Clearly identifiable

Biological indicators "must be clearly identifiable and measurable" (Woodward et al. 1999.). Birds of prey are charismatic species that have attracted human attention and admiration for centuries (Olendorff et al. 1995). Their taxonomy is well known (Sibley and Ahlquist 1990), and their identification in the field is particularly well studied and documented (Clark and Wheeler 1987, Wheeler and Clark 1995, Clark 1999, Forsman 1999). Equally important, established protocols exist for documenting their numbers at established watch sites (Hawk Migration Association of North America 1982, Bildstein and Zalles 1995, Zalles and Bildstein 2000). Thus migratory raptors certainly meet this criterion.

Cost-effective

Biological indicators "must be cost-effective and robust so that monitoring will be continued" (Woodward et al. 1999). The daily passage of hundreds and even tens of thousands of migrating hawks, eagles, and falcons along established migration corridors makes them exceptionally attractive watchable wildlife. Hawk Mountain Sanctuary, the world's first and longest-running migration watchsite, has used volunteer counters as part of its workforce for more than half a century. The Hawk Migration Association of North America (HMANA), a group of more than 400 hawkwatch enthusiasts, consists almost entirely of individuals who volunteer their services at over 100 raptor migration watchsites in the United States and Canada. HMANA's accruing databases, archived at Hawk Mountain Sanctuary, include counts from more than 50 watchsites that have been active for more than a decade (Bildstein 1998a). Worldwide, other enthusiasts regularly count and record raptors at more than one hundred additional watchsites on six continents (Zalles and Bildstein 2000). Thus migratory raptors most certainly meet this criterion.

Indicative of cause

When possible, biological indicators "should point to the cause of change. For example, estimating population size may indicate a change, but estimating recruitment might indicate the cause of change" (Woodward et al. 1999). Juvenile and adult plumages differ in most species of raptors, and in many species, young of the year are easily identified as such, making assessments of recruitment possible. And indeed, declines in Bald Eagle recruitment detected at Hawk Mountain Sanctuary in the late 1940s-early 1950s provided one of the earliest signals of the effects of mid-20th Century pesticide misuse (Carson 1962, Bildstein 1998a). Thus migratory raptors meet this criterion.

Sensitive

Biological indicators should be species that are "likely to respond to subtle human-caused perturbations" (Woodward et al. 1999). Aside from the fact that raptors are top predators, and as such depend upon a number of secondary consumers for their survival, the high metabolic rates of birds of prey, together with their recognized sensitivity to most classes of synthetic pesticides (see above), and many heavy metals (Redig et al. 1980, Wiemeyer et al. 1988), make them excellent candidates as canaries for "coal mine earth."

Keystone attributes

Biological indicators should be "keystone species" whose "impacts on their communities or ecosystems are large relative to their abundance" (Woodward et al. 1999). A growing body of evidence indicates that top predators often limit the densities of their prey, and in so doing directly and indirectly affect a number of ecosystem processes via so-called "trophic cascades" (i.e., effects across several trophic levels, many of which can affect primary productivity) (Schmitz et al. 2000). Although better studied in terrestrial carnivores, the removal of top predators often results in "mesopredator release" (i.e., increases in the numbers and effects of smaller predators whose populations are normally lower in the presence of larger predators) (Palomares et al. 1995), which in turn affects the magnitudes of other predation-linked ecological processes (Terborgh et al. 1999). These effects, together with data indicating the potential for more direct prey-population effects (Newton 1993, Redpath and Thirgood 1997, Suhonen et al. 1994), indicate that migratory birds of prey meet this criterion.

Umbrella species

Biological indicators should require habitats that are "home for a large number of associated species," and should be monitored "by determining [their] most important life–history trait" in terms of sensitivity to change (Woodward et al. 1999). Raptors meet both of these criteria. Birds of prey are diverse, highly mobile, and wide-ranging, area-sensitive species whose habitat and spatial requirements span six continents (Newton 1978, Zalles and Bildstein 2000). Overall, the trophic status of raptors, together with the large spatial requirements of many raptors, ensures that protecting them will result in the protection of numerous additional species, many of whose populations are far more difficult to monitor. Many large raptors have particularly large area requirements (Newton 1978, Thiollay 1989), making them particularly useful in this regard.

Because raptors are a particularly well-studied group (Newton 1978, Bildstein 1998b) much is known regarding factors limiting their survival and growth, both within and across species. We know, for example, that while mid-20th Century organochlorine pesticide misuse affected North American Peregrine Falcons, primarily through reduced reproductive success, it affected British Island populations of Peregrine Falcons primarily by reducing adult survival (Cade et al. 1988).

Genetics

"Monitoring programs should consider the practicalities of working at the genetic level" (Woodward et al. 1999). Although many details remain to be studied, the phylogenetic history and current relationships of birds of prey are reasonably well-studied and understood (Amadon and Bull 1988, Sibley and Ahlquist 1990). The cosmopolitan Peregrine Falcon, in particular, has been the subject of numerous historic and recent investigations (Longmire 1988, Morizot 1988, White and Boyce 1988). Other recent analyses include (1) nucleotide sequencing of the mitochondrial DNA of Holarctic raptors (Wink et al. 1998), (2) investigations of the relationships of New Word Cathartid vultures to other raptors (Griffiths 1994a), (3) the use of molecular data and syringeal anatomy in investigations of Falconidae origins and early diversification (Griffiths 1994b; 1999), and (4) mitochondrial DNA studies of Palearctic *Buteos* (Haring et al. 1999).

Given past and current activities in the field, raptors most certainly meet the criterion of genetic information.

Symbiotic associations

Woodward et al. (1999) suggest that species with particularly tight ecological links to other species (e.g., mycorrhizal fungi and their associations with the roots of many species of trees [Hartley and Smith 1983]) may be particularly useful biological indicators because of their direct ability to indicate the status of other species, as well as that of the general environment. Migratory raptors do not meet this criterion.

Discussion

The assessment above suggests that in addition to being eminently attractive and watchable wildlife (Zalles and Bildstein 2000), as well as substantial contributors to many local economies through tourism (e.g., Kerlinger and Brett 1995), migrating birds of prey can serve as valuable indicators of the ecological integrity of natural and human-dominated landscapes (Table 1).

Migratory birds, including migratory raptors, appear to be sensitive to global climate change (Berthold 1993, Viverette et al. 1996). That several watchsites have been counting numbers of migrating raptors for decades or more, suggests that continued and expanded monitoring will make significant contributions toward understanding the impact of this and other large-scale human impacts across the world’s many landscapes.

Although counting migrating raptors and, equally importantly, analyzing, summarizing, and publishing the results of such counts, in and of themselves are not likely to affect the conservation status of the world’s natural areas, combined and coordinated with other conservation efforts, these activities have and should continue to make substantial and significant contributions toward developing a better understanding and appreciation of the ecosystems upon which both we and raptors ultimately depend.

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Table 1. Why migrating birds of prey are great biological indicators. (Nonexclusive desirable properties for biological indicators are presented in the order in which they appeared in Woodward et al. [1999].)

Desirable properties for biological indicators (Woodward et al. 1999)	How raptors rank[a]
Politically appealing	++
Known statistical properties	++
Logically linked	++
Allows scaling	++
Representative	+
Leading versus lagging	++
Clearly identifiable	++
Cost-effective	++
Indicative of cause	++
Sensitive	++
Keystone attributes	++
Umbrella species	++
Genetics	++
Symbiotic associations	-

[a]++ = easily meet or exceed criterion; + = marginally meet criterion; - = do not meet criterion.

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