MIGRATION COUNTS OF RAPTORS AT HAWK MOUNTAIN, PENNSYLVANIA, AS INDICATORS OF POPULATION TRENDS, 1934–1986

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ABSTRACT.—Counts of migrating hawks were initiated in 1934 at Hawk Mountain and, except for 1943–1945, have continued to the present. We analyzed the data from 1934–1986 by a standardized sample period appropriate for each species. Counts of several species known to be susceptible to detrimental effects of organochlorine pesticides crashed between 1946–1971. All of these populations recovered subsequently. The immature-age classes and the species with the shortest generation times recovered first after DDT use diminished in North America. These observations mostly conform to predictions made on the basis of the adverse effects of DDT and metabolites on raptors. We suggest that standardized migration counts reflect qualitative trends of most raptor populations that pass over Hawk Mountain in the autumn. Currently, populations of many species appear to be either stable or recovering from the effects of organochlorines. Possible exceptions are eastern populations of the Red-tailed Hawk (*Buteo jamaicensis*), American Kestrel (*Falco sparverius*), Broad-winged Hawk (*B. platypterus*), Red-shouldered Hawk (*B. lineatus*), and Golden Eagle (*Aquila chrysaetos*), which may be decreasing. *Received 15 November 1988, accepted 28 July 1989.*

ANALYSIS of the population trends of birds has received attention recently because of observed and predicted regional or global changes in the environment and the availability of data suitable for long-term trend assessment (e.g. Robbins et al. 1986, Holmes and Sherry 1988). Evaluations of population trends are critical to understanding population dynamics on a broad scale and are relevant to the conservation of avian species faced with human alterations to landscapes or climate. Effective censuses of breeding raptors (eagles, hawks, and owls) over large expanses of habitat, however, are generally prohibitive because of the massive resources required (Fuller and Mosher 1987). An alternative cost-effective approach to monitoring regional populations of raptors may be to sample visible bird migration.

Counts of migrating raptors are commonly made from "lookouts" (e.g. Broun 1935, 1939; Allen and Peterson 1936) located along landscape features that funnel or direct migrants into a relatively narrow corridor (Mueller and Berger 1967). These data may indicate population trends (e.g. Spofford 1969, Hackman and Henny 1971, Nagy 1977, Dunne and Sutton 1986). Still, the merit of migration counts in reflecting population trends and, for that matter, understanding any aspect of migration biology has been questioned (Svensson 1978, Newton 1979, Fuller and Mosher 1981, Smith 1985, Kerlinger and Gauthreaux 1985, Craig 1986). Potential weaknesses include the lack of standardization among years, variation in observers' abilities to detect or identify raptors within or between sample periods (Hussell 1985), observer fatigue (Sattler and Bart 1985), different count locations (Kochenberger and Dunne 1985), temporal fluctuations in effort in terms of coverage time and observer number (Hussell 1985, Kochenberger and Dunne 1985, Titus et al. 1989), the influences of weather on the behavior of migrants (Haugh 1972, Alerstam 1978, Richardson 1978, Hussell 1985), and the proportion of migrating birds missed (Clark 1985, Smith 1985). The last item is not a serious concern if counts are considered to be just a sample of the populations that pass overhead (Hussell 1985, Titus et al. 1989). Some of the other difficulties can be corrected by use of standardized methods to collect data (Bednarz and Kerlinger 1989) or by analytical techniques (Hussell 1985). The most difficult factor to compensate for is the influence of weather on migrants (but see Hussell 1985).

Data are usually reported as total numbers of birds observed per year (e.g. Nagy 1977, Dunne and Sutton 1986, Ward et al. 1988, Titus et al.

in press) or as numbers of birds observed per hour of effort (Hackman and Henny 1971), with little or no adjustment for temporal variation in the volume of migration. This manner of data presentation is deceptive, because the volume of migration varies seasonally. Total numbers or measures of hourly movement, therefore, depend on when samples were taken. A common bias of hawk-count data in recent years is that coverage has increased in the early and late portions of the migration season when the volume of movement is low. When such data are compared with numbers per hour in earlier years, erroneous declines may appear (Titus et al. 1989).

We attempted to determine if hawk-count data could be used to infer population trends of raptors and to identify trends in the numbers of hawks recorded at Hawk Mountain, Pennsylvania, in the past 53 years. Some resolution of the first question is crucial before interpretations of migration data can be undertaken.

As a preliminary test of the usefulness of migration information, we standardized the data and compared the response of hawk-count indices with known patterns of decline and recovery in certain raptor populations affected by organochlorine pesticides (e.g. Porter and Wiemeyer 1969; Wiemeyer and Porter 1970; Spitzer et al. 1978; Grier 1982; Wiemeyer et al. 1984, 1988). Because application of organochlorines differed geographically and the sources of populations sampled over Hawk Mountain are not well known, we restricted our evaluation to qualitative predictions. Specifically, we predicted that counts of immature eagles (especially Bald Eagles, *Haliaeetus leucocephalus*) would reflect organochlorine contamination sooner than counts of adults. This prediction is based on the finding that organochlorine contaminants primarily interfere with the reproductive physiology of birds (Porter and Wiemeyer 1969, Wiemeyer and Porter 1970, Risebrough 1986). Because eagles have high survival rates as adults and are normally 5 yr of age before attaining adult plumage (Clark and Wheeler 1987), the adult component of the population should reflect population fluctuations (crashes and recoveries) caused by changes in the recruitment of young only after a suitable lag period.

We also predicted that the smaller accipiters, presumably with shorter generation times and more rapid population turnover, should respond to, and recover more quickly from, the presence and removal of DDT/DDE than the large accipiter, Northern Goshawk (*Accipiter gentilis*). An assumption of this evaluation is that the populations of the three species of accipiters seen at Hawk Mountain originate from the same geographical breeding area. This premise may be partially violated because the breeding ranges of both Sharp-shinned Hawks (*Accipiter striatus*) and goshawks extend farther north into Canada than does the nesting range of the Cooper's Hawk (*A. cooperii*) (Palmer 1988). At present, we do not know the specific origins of the populations sampled at Hawk Mountain.

Methods

Raptors have been counted from the North Lookout at Hawk Mountain since 30 September 1934. Beginning in 1935, migrants were counted on most days from early September through late November. This coverage has been expanded over the years, and counts are now made daily (weather permitting) from mid-August to mid-December. Counts were suspended for 3 yr during World War II (1943–1945). Therefore, our analysis covers 50 yr of data collected in a 53-yr period (1934–1986).

Maurice Broun was the primary counter between 1934 and 1966. During those years, Broun often recorded "full" or "half" days of coverage rather than exact times. Based on Broun's descriptions of his own activities (unpublished field notes archived at Muhlenberg College, Pennsylvania) and hawk flight patterns, we assumed that a full day of coverage was 8 h of observations in August, November, and December, and 9 h in September and October. Based on Broun's journals, we converted a "half" day of coverage to 4 h of observations. Since 1966, exact hours of coverage have been tallied. The primary responsibility of counting has been given to one experienced staff member or volunteer on each sample day throughout the study. Hawk Mountain Sanctuary attracts large crowds on weekends, and interpretive personnel are stationed at North Lookout to answer questions and to prevent visitors from distracting the counter.

Hours of daily coverage have remained remarkably similar for most of the 50 yr that observations were made. Observations typically extend from 0800–1700 and may be continued later in the day or terminated earlier depending on whether migrants are present or absent. The mean hours ($\bar{x} \pm$ SD) sampled per day varied from a low of 6.8 ± 2.72 h (n = 86 days) in 1957 to a high of 8.49 ± 2.37 h (n = 83 days) in 1941. Average daily coverage for the entire sample period was 7.74 ± 0.43 h (n = 50 annual means).

Binoculars were used to detect and identify migrants. Telescopes were also used shortly after counts were initiated. All raptors were counted if they were

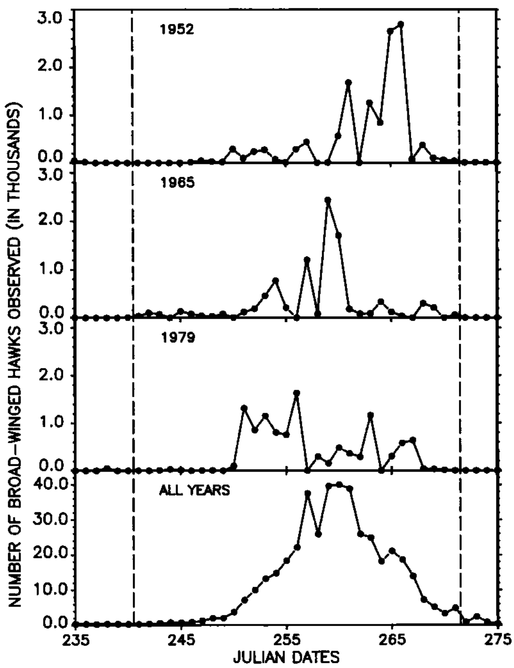

Fig. 1. Numbers of Broad-winged Hawks at Hawk Mountain in relation to Julian dates for the years 1952, 1965, 1979, and all years combined (50 yr). The dashed lines denote the sample period used for the computation of the hawks-observed-per-10-hours-of-observation index for each individual year sampled.

clearly moving south or southwest past North Lookout. Throughout the study, eagles were classified into adult and immature plumage categories (adult Bald Eagle = white head and tail, otherwise immature; adult Golden Eagle (*Aquila chrysaetos*) = no white on tail or wings, otherwise immature).

To standardize the data, we summed all counts over all years for each species (Fig. 1). We then defined the sample period of passage for each species (Table 1) by eliminating approximately *equal* percentages of the total number of birds counted from each extreme of the distribution. For all species, we originally intended to define the sample periods by eliminating 2% of the total hawk-count distribution (1% from each tail). This approach to discarding the "tails" of the migration could not be strictly achieved because entire count days must be either included or excluded from the defined sample periods. Rather, the discarded portion of the data varied from 1–2% of the total birds sampled, depending upon species. The sample period for each species was constant for all years of the study (Table 1). This approach should negate potential biases caused by seasonal changes in the migration volume. Also, the selected sample period permits adequate sampling when the timing of migration varied. For example, in 1979 most Broad-winged Hawks (*Buteo platypterus*) migrated relatively early (the second week in September; Fig. 1), but in 1952 most movement was relatively late (last week in September). Compare this with 1965, which was more typical of the Broad-winged Hawk migration (Fig. 1). In all cases, the major flight was well within the selected sample period (Fig. 1).

One important concern is the effect of weather on counts (Haugh 1972, Kerlinger 1984, Kerlinger and Gauthreaux 1985). Winds perpendicular to the ridge that are deflected upward tend to concentrate hawks near ridges. On windless days, hawks seem to move in a broader front; and a smaller fraction of the population is detected from ridge lookouts. A bias in the sampling of migrating hawks could occur, for instance, if the weather conditions in one year were conducive to funneling hawks near the ridge line and, in the following year, tended to disperse migrants.

For this analysis, we accept that weather affects both the volume of movement and the detectability of hawks from North Lookout. We assume (in the sense of Burnham et al. 1980) that the effects of weather on our sample were random with respect to the population size in any given year. This assumption seems reasonable because the migration volume over time for each species approaches a normal distribution when all 50 yr of data are combined (e.g. Fig. 1). The Broad-winged Hawk distribution shown for all years (Fig. 1) deviates significantly from normal ($P < 0.01$, Kolmogorov-Smirnov test; Sokal and Rohlf 1981) because of the immense sample size (429,245 birds), which makes goodness-of-fit tests extremely sensitive.

Alternatively, the normality assumption can be examined with an analysis of residuals by removing the effects of the overall linear trends. Distributions of residuals significantly differed from normal for 4 of the 18 data sets evaluated (Kolmogorov-Smirnov tests): total Bald Eagles, Cooper's Hawks, and Merlins (*Falco columbarius*) at the $P < 0.05$ level, and goshawks at the $P < 0.01$ level. Log transformations of these data do not differ significantly from a normal distribution. For the most part, our data conformed to a normal distribution, which supports the assumption that yearly weather patterns affected counts at Hawk Mountain in a random fashion. Therefore, our data should depict trends that are manifested over the long-term period (>10 yr), but they may not reliably reflect short-term population fluctuations.

We divided the 50 yr of data into three sample periods: the pre-DDT period (1934–1942), the DDT period (1946–1972), and the post-DDT period (1973–1986). For Bald Eagles, Sharp-shinned Hawks, and Cooper's Hawks, we expected no significant trends in the pre-DDT period, a population crash in the DDT period, and a recovery in the post-DDT period. In North America, DDT was used widely from 1946 until

TABLE 1. Sample periods and mean hours of sample effort for raptor species recorded during the autumn migration at Hawk Mountain.

Species	Sample period	Annual coverage (h)	
		$\bar{x}$	C.V.[a]
Osprey (*Pandion haliaetus*)	25 Aug.–21 Oct.	386.3	17.4
Bald Eagle (*Haliaeetus leucocephalus*)			
Total	11 Aug.–1 Dec.	616.3	19.6
Adult	10 Aug.–29 Nov.	613.4	19.3
Immature	11 Aug.–3 Dec.	618.7	19.6
Northern Harrier (*Circus cyaneus*)	23 Aug.–23 Nov.	579.8	22.6
Sharp-shinned Hawk (*Accipiter striatus*)	9 Sept.–5 Nov.	410.4	17.9
Cooper's Hawk (*A. cooperii*)	4 Sept.–18 Nov.	513.0	17.4
Northern Goshawk (*A. gentilis*)	17 Sept.–5 Dec.	474.1	18.9
Red-shouldered Hawk[b] (*Buteo lineatus*)	22 Sept.–26 Nov.	417.7	18.4
Broad-winged Hawk[b] (*B. platypterus*)	23 Aug.–30 Sept.	245.5	16.8
Red-tailed Hawk (*B. jamaicensis*)	14 Sept.–28 Nov.	479.5	18.0
Rough-legged Hawk (*B. lagopus*)	6 Oct.–9 Dec.	331.6	20.8
Golden Eagle (*Aquila chrysaetos*)			
Total	16 Sept.–3 Dec.	472.7	18.7
Adult	19 Sept.–3 Dec.	447.6	19.4
Immature	6 Sept.–5 Dec.	550.5	18.3
American Kestrel (*Falco sparverius*)	11 Aug.–26 Oct.	440.5	24.2
Merlin (*F. columbarius*)	3 Sept.–9 Nov.	476.8	22.2
Peregrine Falcon (*F. peregrinus*)	25 Aug.–17 Nov.	548.7	22.6

[a] C.V. = coefficient of variation, SD × 100/mean.
[b] Only 48 yr of data were suitable for analysis.

its ban in 1972, but use within specific geographical areas started later and was curtailed much sooner than 1972 (e.g. Prebble 1975, Klaas and Belisle 1977). In fact, many of the raptors sampled at Hawk Mountain probably originated in Canada, which prohibited the use of DDT in 1969. The strict adherence to the expectation that the decrease in hawks observed should span the entire DDT period is not a valid test of the index value of count data. Rather, the question is whether the most susceptible species or age groups declined and recovered in the predicted chronological order. Hawk Mountain is the only location in the world where raptors were sampled in a systematic fashion before and during the introduction of organochlorines into the environment.

Trends were determined by standard linear regression analyses. Log-transformations of the data produced no differences in the statistical results. For consistency and ease of interpretation, we present only results of the analyses on the standardized raw data (hawks per 10 h of observation).

For selected species affected by organochlorines, *inflection points* (years in which trends changed direction) were estimated by calculating pairs of linear regressions bracketed around the years in which noticeable changes in slopes were detected. The inflection year was identified by the highest combined r^2 value from all reasonable pairs of regressions computed. Combined r^2 values were weighted by the sample sizes used to compute the individual regressions for each pair (i.e. combined $r^2 = [r_1^2 \times n_1/n_{total}] + [r_2^2 \times n_2/n_{total}]$). Between 9 and 16 pairs of regressions were computed to identify each of 12 inflection points of interest. For this analysis, subsets of the entire samples were selected to define the inflection points of interest. Sample periods used to isolate downward inflection points, presumably induced by DDE/DDT, were 1934–1972 for eagles, 1934–1965 for Sharp-shinned Hawks, and 1946–1965 for Cooper's Hawks. Sample periods used to define upward inflection points, presumably influenced by the disappearance of DDE/DDT compounds from the environment, were 1950–1986 for all species.

RESULTS

From 1934 through 1946 no strong pattern of change was observed in the numbers of Bald Eagles detected over North Lookout ($P > 0.1$). Eagle counts dropped sharply from the 1940s through 1972 (Fig. 2; $P < 0.01$). The estimated downward inflection in numbers of immature eagles, 1942 (probably between 1942 and 1946; no data were collected 1943–1945), precedes the point of decline observed in adult numbers, 1949 (Table 2, Fig. 2). Observations of migrating immature eagles increased significantly in the post-

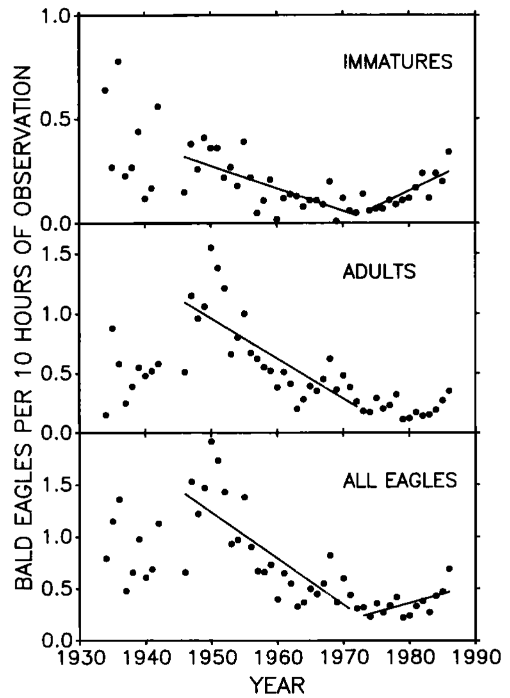

Fig. 2. Autumn counts of immature, adult, and total (immatures + adults) migrant Bald Eagles, 1934–1986. Lines represent significant linear relationships within the a priori selected periods of analysis (1934–1942, 1946–1972, and 1973–1986).

DDT era (Table 3), and this rebound began abruptly in the 1970s (estimated inflection year = 1974). Numbers of adult Bald Eagles increased steadily from the early 1980s (estimated inflection year = 1982; Table 2), although this change was not statistically significant.

Adult and total (immatures + adults) Golden Eagle observations declined significantly in the a priori selected DDT period (Fig. 3, Table 3). A decrease in numbers of immature Golden Eagles occurred from 1940 through 1960, which was followed by a recovery (Fig. 3). Because a major portion of both the decline and recovery occurred within the DDT period, there was no overall statistical trend (Table 3). The slope computed for the earliest years indicated a rather severe decline of immatures in progress (slope = −0.020, 1934–1948) before the primary DDT era. The first inflection point for immatures represents a year (1948; Table 2) in which the decline began to stabilize (slope = 0.002, 1948–1972). Consistent with our original prediction, the decline in immature Golden Eagles anticipated that of adults, but this decrease began before the DDT period (1946–1972).

Both Sharp-shinned and Cooper's hawks were observed to decrease in the DDT period (Fig. 4). Estimated inflection years suggest that the Sharp-shinned Hawk numbers started to drop (1949) slightly before Cooper's Hawk numbers (1950; Table 2). Similar to the pattern shown by the immature Golden Eagle data, Sharp-shinned Hawk numbers crashed and increased within the preselected DDT period (1946–1972); and hence no significant trend resulted. Although the Cooper's Hawk increase probably began before the end of the DDT period, this pattern continued and is statistically significant in the post-DDT period (Table 3). Both Sharp-shinned and Cooper's hawks began to recover at approximately the same time in the mid-1960s (Table 2, Fig. 4).

Northern Goshawk trends were probably

TABLE 2. Estimated inflection points in hawk-trend data determined by paired linear-regression analysis (see Methods). Combined $r^2 = (r_1^2 \times n_1/n_{total}) + (r_2^2 \times n_2/n_{total})$. Scientific names are in Table 1.

	Downward inflection point		Upward inflection point	
	Year	Combined r^2	Year	Combined r^2
Bald Eagle				
Immature	1942	0.476	1974	0.570
Adult	1949	0.637	1982	0.702
Golden Eagle				
Immature	1948[a]	0.176	1959	0.468
Adult	1946	0.374	1971[a]	0.397
Sharp-shinned Hawk	1949	0.367	1961, 1964[b]	0.440
Cooper's Hawk	1950	0.613	1964	0.550

[a] Not downward or upward inflection points. Inflection years (1948 for immatures and 1971 for adult Golden Eagles) represent points where a negative slope changes and approaches zero.

[b] The combined r^2 reached the greatest value (0.440) for both 1961 and 1964.

TABLE 3. Effects of DDT usage on selected raptors sampled at Hawk Mountain, Pennsylvania. Number of years included in regression analyses are shown in parentheses. Levels of significance: * = $P < 0.05$; ** = $P < 0.01$. Scientific names are in Table 1.

	Pre-DDT 1934–1942 (9)			DDT 1946–1972 (27)			Post-DDT 1973–1986 (14)		
	Slope	r^2	P	Slope	r^2	P	Slope	r^2	P
Osprey	0.127	0.05	0.58	0.162	0.37	<0.01**	0.383	0.30	0.04*
Bald Eagle									
Immature	−0.029	0.12	0.36	−0.011	0.52	<0.01**	0.015	0.62	<0.01**
Adult	0.012	0.02	0.69	−0.034	0.55	<0.01**	0.002	0.02	0.65
Total	−0.022	0.04	0.62	−0.045	0.59	<0.01**	0.017	0.33	0.03*
Sharp-shinned Hawk	−1.877	0.02	0.75	0.501	0.04	0.34	−0.604	<0.01	0.88
Cooper's Hawk	−0.719	0.40	0.07	−0.077	0.24	<0.01**	0.390	0.29	0.05*
Northern Goshawk	−0.678	0.71	<0.01**	0.153	0.28	<0.01**	−0.208	0.25	0.07
Golden Eagle									
Immature	−0.031	0.42	0.06	0.001	0.01	0.66	0.013	0.21	0.10
Adult	−0.002	<0.01	0.96	−0.027	0.46	<0.01**	−0.011	0.12	0.23
Total	−0.048	0.17	0.27	−0.023	0.26	<0.01**	0.004	0.01	0.74
American Kestrel	0.145	0.12	0.35	0.398	0.62	<0.01**	−0.556	0.45	<0.01**
Merlin	−0.001	<0.01	0.99	−0.003	0.02	0.51	−0.040	0.22	0.09
Peregrine Falcon	0.081	0.02	0.73	−0.083	0.24	0.01*	0.057	0.07	0.35

confounded by irruptive population years in the mid-1930s and early 1970s (Fig. 4; Mueller et al. 1977). Despite these outlying points, goshawk numbers generally increased during the DDT period (Table 3). This pattern was nearly the inverse of the trends seen in the other accipiters (Fig. 4).

The Peregrine Falcon (*Falco peregrinus*), a species sensitive to pesticide contamination (Craig 1986), declined precipitously in numbers of migrants throughout the DDT period (Fig. 5). More Peregrine Falcons were observed beginning ca. 1980. Ospreys (*Pandion haliaetus*), on the other hand, increased significantly through the pesticide years (Fig. 5, Table 3). Neither the American Kestrel (*Falco sparverius*) nor Merlin showed a pattern of change consistent with an adverse response to DDT (Table 3, Fig. 6).

Over the entire study period, only counts of the Bald Eagle, Golden Eagle, and Peregrine Falcon migrants declined significantly (Table 4). Of these, only Golden Eagle numbers continued to decrease (1971–1986), but not significantly (Table 4). Species that were most susceptible to organochlorine contamination (Osprey, Bald Eagle, Sharp-shinned Hawk, Cooper's Hawk, and Peregrine Falcon) showed positive trends in recent years, although most were not significant (Table 4). For the species that were most severely affected (Bald Eagles and Peregrine Falcons), upward trends should become significant if the recent pattern continues for a few more years.

Declines in numbers of Northern Goshawks, Broad-winged Hawks, Red-tailed Hawks (*Buteo jamaicensis*), Rough-legged Hawks (*B. lagopus*), Golden Eagles, and American Kestrels occurred from 1971 through 1986 (Figs. 3, 4, 6, and 7; Table 4). Of these, statistically significant patterns were seen in the Northern Goshawk, Red-tailed Hawk, and American Kestrel (Table 4). Numbers of most other raptor species were nearly stable or have shown slight positive trends in recent years (Table 4).

DISCUSSION

Migration counts as indicators of population trends.—The predictions of population trends deduced from the established effects of DDT and its metabolites on raptors were detected in our hawk count data. Both age classes of Bald Eagles dropped significantly in numbers coincident with the DDT years (Table 2). Immatures began to recover nearly 10 yr before adults (Fig. 2). These results are consistent with data from nesting and wintering surveys (Sprunt et al. 1973; Grier 1974, 1982; Wetmore and Gillespie 1976; Gerrard 1983; Swenson 1983).

A few authors (Newton 1988, Nisbet 1988)

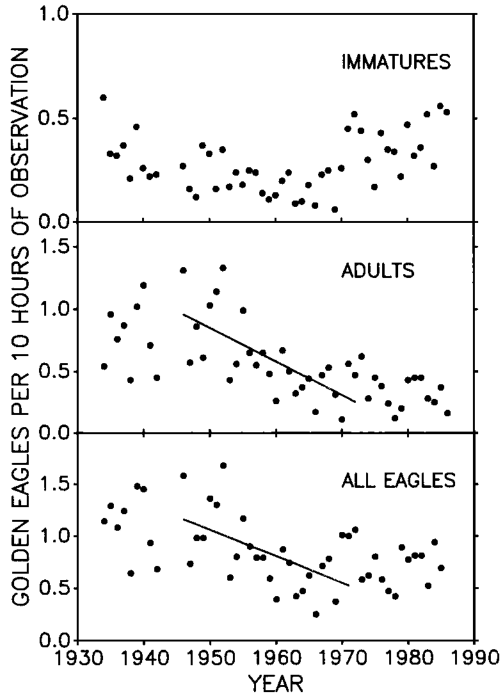

Fig. 3. Autumn counts of immature, adult, and total (immatures + adults) migrant Golden Eagles, 1934–1986. Lines represent significant linear relationships within the a priori selected periods of 1934–1942, 1946–1972, and 1973–1986.

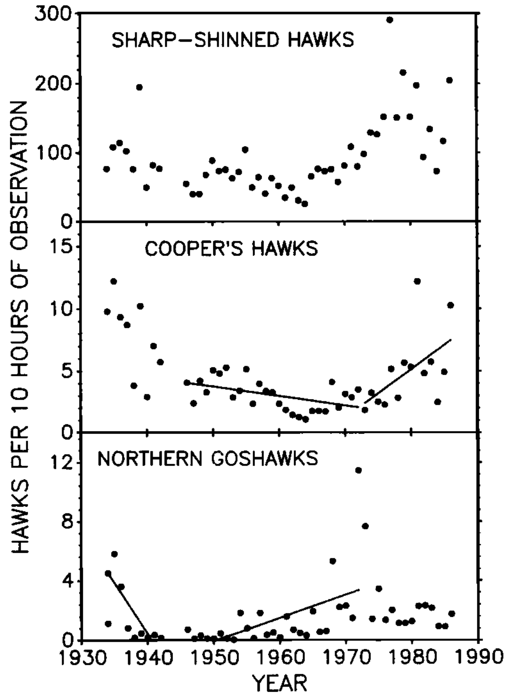

Fig. 4. Autumn counts of *Accipiter* hawks at Hawk Mountain, 1934–1986. Lines represent significant linear relationships within the a priori selected periods of 1934–1942, 1946–1972, and 1973–1986.

suggested that declines in some populations of Peregrine Falcons and other species occurred primarily because cyclodiene insecticides, such as dieldrin, may have caused direct mortality in adults. No data support this possibility in North America. Consistent with our analysis, all evidence to date strongly implicates DDT/DDE as the predominant factor that induced reproductive failures and population crashes of many bird species (Wiemeyer et al. 1984, Risebrough 1986, Risebrough and Peakall 1988, Wiemeyer et al. 1988, and others).

We found that different age classes may be influenced by differing possibly opposite trends. For example, during the 1970s immature Bald Eagles increased while adults declined slightly (Fig. 2). The high proportion of young individuals in the later years of the study suggests a continued recovery. From the age classes of an adequate sample of migrants, the dynamics of populations may be better inferred and changes detected more quickly. When migration count data are used to monitor population trends, we recommend that this practice of recording age classes be adopted for all species that may be classified according to age by plumage.

During the late 1970s and 1980s, wild populations of Bald Eagles and Peregrine Falcons were augmented artificially (Barclay and Cade 1983, Barclay 1988) in the northeastern United States. We presume that some of the birds counted at North Lookout were released as part of management programs and that these influenced the patterns of recovery seen in the post-DDT period.

A noticeable drop in immature Golden Eagles preceded that of adults, although this decline apparently began before the DDT period. A recovery of the immatures followed in the 1960s (Fig. 3). These results are perplexing, in part because Golden Eagles are reported to feed primarily on mammals (e.g. Collopy 1983), which do not accumulate organochlorine insecticides. The limited data from the relict Golden Eagle nesting population in the northeastern United States indicate that water birds are often taken (especially American Bitterns, *Botaurus lentigi-*

TABLE 4. Overall and recent trends in counts of 14 species of diurnal raptors observed at Hawk Mountain, 1934–1986. Levels of significance: * = $P < 0.05$; ** = $P < 0.001$.

	Overall trend (1934–1986)			Recent trend (1971–1986)		
	Slope	r^2	P	Slope	r^2	P
Osprey	0.131	0.50	<0.001**	0.181	0.09	0.250
Bald Eagle	−0.018	0.41	<0.001**	0.011	0.19	0.087
Northern Harrier	0.029	0.22	<0.001**	0.023	0.02	0.631
Sharp-shinned Hawk	1.420	0.17	0.003*	1.940	0.03	0.553
Cooper's Hawk	−0.049	0.07	0.062	0.335	0.31	0.026*
Northern Goshawk	0.023	0.03	0.242	−0.303	0.26	0.046*
Red-shouldered Hawk	−0.005	<0.01	0.816	0.023	0.01	0.781
Broad-winged Hawk	2.421	0.04	0.159	−12.054	0.06	0.341
Red-tailed Hawk	−0.264	0.02	0.324	−2.033	0.39	0.010*
Rough-legged Hawk	0.004	0.11	0.017*	−0.010	0.14	0.152
Golden Eagle	−0.010	0.22	0.001**	−0.071	0.03	0.530
American Kestrel	0.190	0.47	<0.001**	−0.518	0.50	0.002*
Merlin	0.003	0.03	0.219	0.034	0.22	0.065
Peregrine Falcon	−0.093	0.58	<0.001**	0.004	<0.01	0.941

nous, and Great Blue Herons, *Ardea herodias;* Todd 1989). Consumption of avian piscivores implies that Golden Eagles were susceptible to organochlorine contamination. Contrary to our predictions, immature eagles began to decline before 1946, and the numbers of adults failed to rebound after organochlorine use subsided (Fig. 3). We surmise that DDT may have been partially responsible for this pattern, but that other factors may have been important also in regulating the population of Golden Eagles migrating over Hawk Mountain. Alternatively, the Golden Eagle sample may represent a mix of vagrant western individuals and the remnant eastern population, which confounds the capability of counts to track population trends.

We believe that accipiter populations were affected by DDT and its metabolites. Declines occurred in both the Sharp-shinned and Cooper's hawks in the DDT era. The drop and recovery in Sharp-shinned Hawks may have preceded by a short period of time that of Cooper's Hawks (Table 2, Fig. 4). Although quantitative estimates of the points when these two accipiters began to increase were similar (Sharp-shinned Hawk: 1961–1964; Cooper's Hawk: 1964), the early increase of Cooper's Hawks was more gradual than the rapid recovery of Sharp-shinned Hawks (Fig. 4). In fact, considerable Sharp-shinned Hawk recovery occurred before the end of the DDT period, which balanced the decline. No statistically significant trend was seen in the a priori DDT period, but post hoc tests of the decline and recovery periods were significant (1950–1964, slope = −0.389, $r^2 = 0.63$, $P < 0.001$; and 1965–1986, slope = 0.472, $r^2 = 0.27$, $P = 0.01$). The post hoc analyses may be most suitable because Sharp-shinned Hawks should exhibit a rapid response that is due to high population turnover and the fact that, within their primary Canadian range, heavy DDT use was initiated in the early 1950s and phased out by the mid-1960s (Prebble 1975).

There is a direct relationship of generation time to the size of accipiter hawks. First, clutch size is related inversely to body size (mean Sharp-shinned Hawk clutch = 3.9, Cooper's Hawk = 3.5, and Northern Goshawk = 2.7 in North America; Apfelbaum and Seelbach 1983). Yearling Sharp-shinned Hawks of both sexes may breed with some regularity, whereas yearling female Cooper's Hawks and goshawks nest only rarely (Palmer 1988). Finally, life-table analysis of limited banding data suggests that mortality rates of these species are directly correlated with size. The average estimated annual mortality rate of Sharp-shinned Hawks at ages 2–7 yr was 47% (life-table analysis of data reported by Palmer 1988), the mean mortality of Cooper's Hawks at ages 2–8 yr, was 34% (Henny and Wight 1972), and the annual mortality rates of European goshawks at ages 2 yr and older varied between 11 and 35% (Palmer 1988). The productivity of Cooper's Hawk populations was affected adversely by organochlorine pesticides (Schriver 1969, Henny and Wight 1972). Spofford (1969) and Snyder et al. (1973) also concluded that numbers of Sharp-shinned and

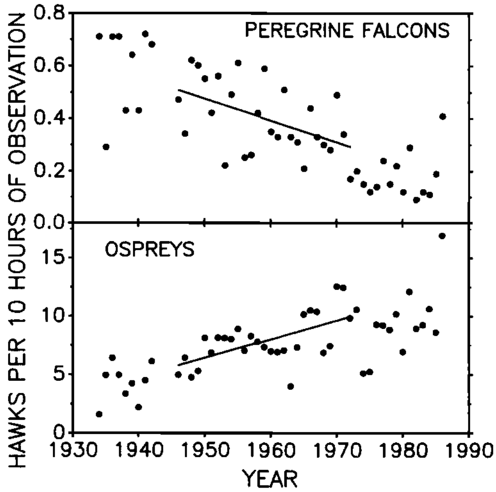

Fig. 5. Autumn counts of Peregrine Falcons and Ospreys, 1934-1986. Lines represent significant linear relationships within the a priori selected periods 1934-1942, 1946-1972, and 1973-1986.

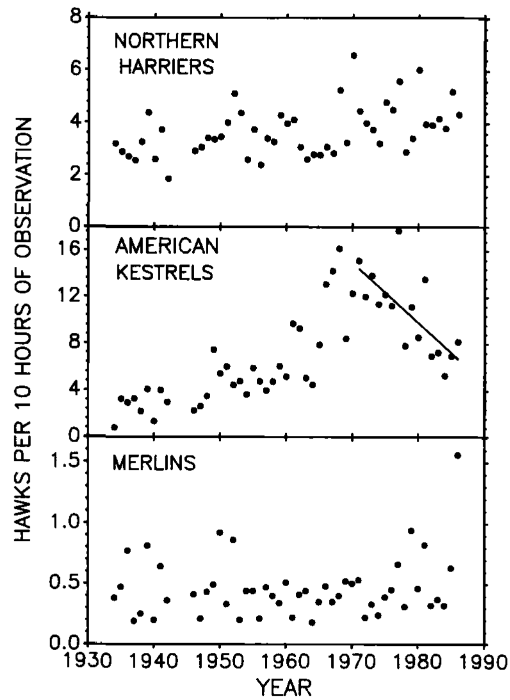

Fig. 6. Autumn counts of Northern Harriers, American Kestrels, and Merlins observed at Hawk Mountain, 1934-1986. A regression line for the most recent 16 yr (1971-1986) is shown if the trend is significant ($P < 0.01$).

Cooper's hawks declined based on analyses of migration data collected at Hawk Mountain.

The Northern Goshawk population went against the common trend and increased during this period (Fig. 4). Northern Goshawks nest in mature forested areas (Reynolds et al. 1982, Palmer 1988), which were probably some distance from where pesticides were frequently applied. Further, goshawks prey commonly on mammals (Storer 1966, Snyder et al. 1973), which are not likely to accumulate organochlorine contaminants. The recent trend in Northern Goshawk (Table 4) numbers may be influenced by irruptive invasions (Mueller et al. 1977) that occurred in the early 1970s (Fig. 4). We propose that the population fluctuations in this species may not be adequately monitored by migration counts, unless some adjustment can be made for invasion years. In addition, because annual mean counts of Rough-legged Hawks were low ($\bar{x}$ = 8.7; n = 50 yr), we suggest that population changes in this species would not be detected at Hawk Mountain unless they were of great magnitude. For the other 12 species regularly observed at Hawk Mountain (with the possible exception of the Golden Eagle), we submit that hawk counts may be used to detect qualitative changes in regional populations.

Population trends.—Migrant Peregrine Falcons decreased through the 1950s and 1960s, stabilized, and then recovered (Fig. 5). This pattern is similar to trends reported for this species elsewhere (e.g. Cade 1985, Craig 1986, Ward et al. 1988, Mueller et al. 1988).

At first glance, trends in Osprey numbers at Hawk Mountain discount the premise that hawk counts accurately reflect population fluctuations. Declines in nesting success and numbers of Ospreys have been reported in certain regions of the country (Ames and Mersereau 1964, Henny and Wight 1969, Spitzer et al. 1983), but data from Hawk Mountain show a steady and significant increase through the pesticide years (Fig. 5). The available nesting survey data indicate that faltering reproductive success in Ospreys was restricted to local populations near to major pesticide applications (Peterson 1969, Henny and Ogden 1970, Wiemeyer et al. 1975, Spitzer et al. 1978, Spitzer and Poole 1980, Henny 1983). Indeed, several Osprey populations were unchanged or only weakly influenced during the DDT era (e.g. Wiemeyer et al. 1975, Henny et al. 1977, Postupalsky 1977, Grier et al. 1977, Reese 1977).

Because Ospreys migrate mostly along coasts (Poole and Agler 1987), we believe we counted in inland Pennsylvania very few, if any, of the severely affected Ospreys that nest along the Atlantic Coast. We have no precise data on the origins of the Ospreys sampled at Hawk Mountain, but most of this population probably breeds in inland northeastern North America (Poole and Agler 1987). In the early 1970s, shortly after the peak pesticide years, nesting Ospreys were relatively abundant in southeastern Canada (Wetmore and Gillespie 1976, Bider and Bird 1983, Greene and Freedman 1986, Seymour and Bancroft 1983, Stocek and Pearce 1983). In summary, we found no independent information to suggest that our study population ever declined during the pesticide era. These results underscore the point that hawk counts from one lookout are regionally dependent and cannot be safely extrapolated to other regions or populations.

We submit that most raptors in northeastern North America are either stable or increasing from small populations that were probably reduced by organochlorine compounds (Figs. 2–7). Significant decreases were noted in numbers of the American Kestrel and Red-tailed Hawk from 1971 through 1986. These declines might be explained by conversion of pasture lands to residential developments or intensive row-crop agriculture in the northeastern U.S. (Brooks in press). Reduction in pasture land would account for a gradual loss of the prime foraging habitats used by both species (cf. Bednarz and Dinsmore 1982, Sferra 1984).

Data from the U.S. Fish and Wildlife Service's Breeding Bird Survey (BBS) are, in some cases, slightly contrary to trends inferred from migration counts. For example, Red-tailed Hawks increased slightly from 1966 through 1987 (U.S. Fish and Wildlife Service unpubl. data), but trends within 3 of 5 northeastern strata (southern New England, central New England, Adirondack Mountains, St. Lawrence Plain, and spruce-hardwood forest; see Robbins et al. 1986) were not significant (C. Robbins pers. comm.). A significant decline of American Kestrels occurred in one strata of the BBS, while a significant increase was seen in another (also see Fuller et al. 1987). The breeding data from the northeastern United States suggest no obvious pattern in either species. The migration data suggest a recent decrease in numbers (Table 4; also see Dunne and Sutton 1986). We believe

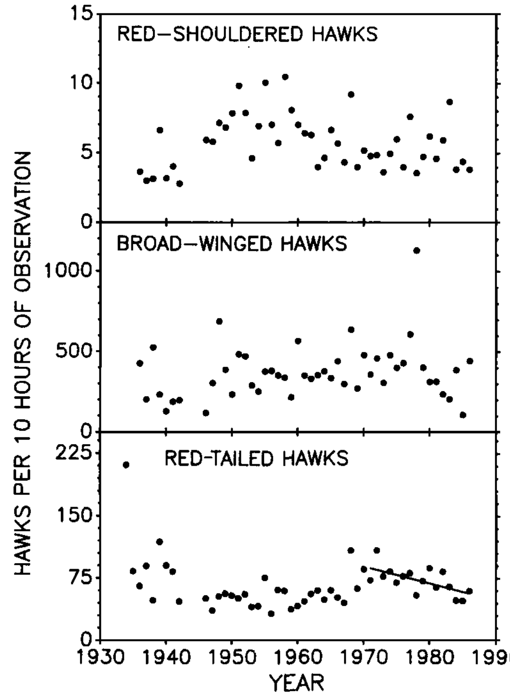

Fig. 7. Autumn counts of three common *Buteo* hawks at Hawk Mountain, 1934–1986. A regression line for the most recent 16 yr (1971–1986) is shown if the trend is significant ($P = 0.01$).

that road counts may not adequately reflect population changes in these species because roads are typically associated with the mosaic of landscape types (fields, pastures, and small woodlots) that would attract these species. The effects of potentially pervasive changes away from roads may therefore be overlooked.

The Broad-winged Hawk, Red-shouldered Hawk, and the Golden Eagle merit attention. The Broad-winged Hawk may have declined (Table 4), albeit not significantly. This is contrary to our expectation of an increase based on limited evidence that recent reforestation may have increased the area of suitable upland-forest nesting habitat (Brooks 1989). If the Broad-winged Hawk population is declining, it may be related to changes in wintering or migratory habitat. The Breeding Bird Survey data suggest slight increases in 4 of the 5 northeastern strata for this species, but only one of these was significant. These differences are minor. Migration counts imply a decrease (not significant); road counts imply an increase (also not significant). Broad-winged Hawks on the BBS are relatively rare (Robbins et al. 1986), and the reliability of this sampling technique for woodland raptors is not clear. In addition, migrant Broad-winged Hawks rely heavily on development of thermal updrafts (Kerlinger et al. 1985) and are probably less dependent on ridge-lines than are other species. Consequently, the slight trend in Broad-winged Hawks at Hawk Mountain may be related to some long-term change in weather patterns.

The Red-shouldered Hawk (*Buteo lineatus*) migration data suggest a long-term, nonsignificant decline (Table 4, Fig. 7). A post hoc analysis suggests that numbers declined significantly between 1946 and 1986 (slope = -0.07, $r^2 = 0.22$, $P = 0.002$). Consistent with this trend, Red-shouldered Hawks decreased in all five northeastern BBS strata. Observations of fewer migrants were also compatible with reports from isolated study areas that suitable habitat decreased because of deforestation and selective logging in floodplains (Bednarz and Dinsmore 1981, 1982; Armstrong and Euler 1982; Bryant 1986).

The adult Golden Eagle numbers have declined slowly at Hawk Mountain. If we assume that this index is not confounded by vagrant western eagles, this pattern is worrisome. More data are needed on the specific origin and the seasonal movements of these birds.

Patterns in some hawks, especially accipiters and eagles, were probably confounded by heavy shooting (cf. Henny and Wight 1972) in the early years of data collection (Figs. 2-4). The consequences of shooting are impossible to estimate accurately (Senner 1984). With protective legislation and changing human attitudes, we conclude that shooting has had little influence on recent counts (ca. 1972-1986).

We suggest that populations of most raptors in eastern North America are either near stable or recovering from the effects of organochlorine contaminants. Exceptions are Red-tailed Hawks and American Kestrels, which seem to have declined recently, possibly because of changes in habitat or land use. Decreases in the numbers of Broad-winged Hawks, Red-shouldered Hawks, and Golden Eagles may be in progress, and we recommend that populations of these species particularly warrant further investigation.

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