Wilson Bull., 106(3), 1994, pp. 431-447

POPULATION TRENDS OF SHOREBIRDS ON FALL MIGRATION IN EASTERN CANADA 1974–1991

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ABSTRACT.—Analysis of data from the Maritimes Shorebird Survey, involving counts of shorebirds made during fall migration in the Atlantic Provinces of Canada, indicated declines in a number of shorebird populations during the period 1974–1991. Significant declines were recorded most consistently for Least Sandpiper (*Calidris minutilla*), Semipalmated Sandpiper (*C. pusilla*), and Short-billed Dowitcher (*Limnodromus griseus*), and decreases for Red Knot (*C. canutus*) and Black-bellied Plover (*Pluvialis squatarola*) approached statistical significance in some analyses. Population trends were not constant but varied consistently across species during different phases of the study period. Declines occurred in most of the 13 species analyzed during the latter part of the 1970s, followed by increases during the first half of the 1980s, with a less marked tendency towards declines in recent years. A series of cold summers on the breeding grounds during the 1970s may have led to the observed population declines at that time. Statistical power analysis indicated that population changes of 2–5% should be detected at 80% power for the number of sites and years of coverage for which data were available. *Received 26 Aug. 1993, accepted 14 Dec. 1993.*

Many Nearctic shorebird populations undertake very long migrations, some species moving between breeding grounds in the Canadian Arctic and wintering areas near the southern tip of South America (Morrison 1984, Morrison and Ross 1989). Many species, especially those that depend on coastal wetlands, concentrate to a marked degree both during migration and on the wintering grounds, with large proportions of the population occurring at only a restricted number of sites (Morrison and Ross 1989, Morrison 1991). Shorebirds are particularly vulnerable to loss or degradation of habitat in such areas (Myers et al. 1987). Extensive loss of wetlands has occurred in North America during the past and present centuries (Senner and Howe 1984). Wetland habitats used by shorebirds elsewhere in the Western Hemisphere are also increasingly threatened by industrial and recreational developments (Bildstein et al. 1991).

Little information is available on how shorebird populations are being affected by such threats. Analysis of International Shorebird Survey data collected in the eastern United States between 1974 and 1982–83 indicated that three of the 12 species analyzed had declined significantly (Howe et al. 1989). Six of the remaining nine species showed declines which, although not statistically significant, were substantial in terms of annual (3–12%) or cumulative (up to 75%) changes. Declines in shorebird

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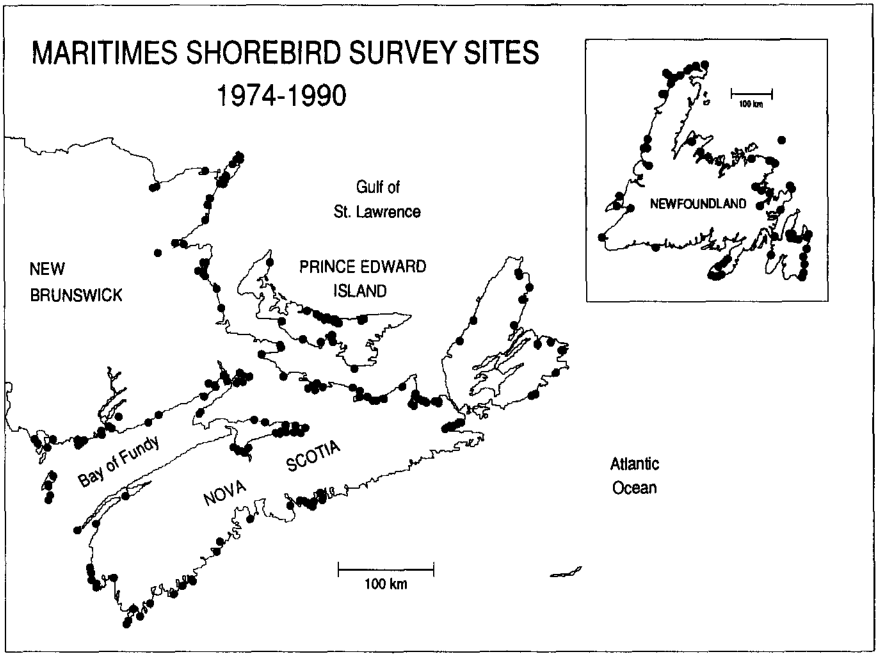

FIG. 1. Locations of sites surveyed during Maritimes Shorebird Survey operations 1974–1991.

numbers have also been suggested by data from James Bay, the St. Lawrence River system, and other parts of eastern Canada (Lariveé 1989, Morrison 1991, Morrison et al. 1991, Erskine et al. 1992).

The present paper uses data from the Maritimes Shorebird Survey to assess changes in numbers of shorebirds recorded on southward migration at sites in the Atlantic Provinces of Canada during the period 1974–1991.

METHODS

Field survey procedures.—The Maritimes Shorebird Survey (MSS) consists of a network of volunteers who count shorebirds at regular intervals at sites in the Atlantic Provinces of Canada (Fig. 1). Surveys during southward migration of shorebirds in the fall have been organized annually by the Canadian Wildlife Service since 1974. Sites in eastern and central U.S.A. and regions farther south are covered by the complementary International Shorebird Survey (ISS) organized by the Manomet Bird Observatory, Massachusetts. Although both schemes were designed to identify stopover areas and migration routes used by shorebirds, the data collected may also be used to examine trends in shorebird populations (Howe et al. 1989, Howe 1990).

Volunteers were provided with forms and detailed instructions to standardize survey protocols as much as possible. Participants were asked to adopt a clearly defined study area

TABLE 1
AVERAGE MAIN ADULT MIGRATION PERIODS FOR 13 SPECIES OF SHOREBIRDS IN ATLANTIC CANADA, 1974–1990

Species[a]	Main adult migration period
Black-bellied Plover (*Pluvialis squatarola*)	31 July–4 September
Lesser Golden-Plover (*P. dominica*)	26 July–30 August
Semipalmated Plover (*Charadrius semipalmatus*)	21 July–20 August
Willet (*Catoptrophorus semipalmatus*)	6 July–5 August
Whimbrel (*Numenius phaeopus*)	6 July–10 August
Ruddy Turnstone (*Arenaria interpres*)	21 July–18 August
Red Knot (*Calidris canutus*)	16 July–15 August
Sanderling (*C. alba*)	21 July–20 August
Semipalmated Sandpiper (*C. pusilla*)	16 July–15 August
Least Sandpiper (*C. minutilla*)	6 July–15 August
White-rumped Sandpiper (*C. fuscicollis*)	10 August–14 September
Dunlin (*C. alpina*)	9 Sept–9 October
Short-billed Dowitcher (*Limnodromus griseus*)	6 July–5 August

[a] Species identifications: It was not possible to check every bird in large flocks of Semipalmated Sandpipers. Such flocks may have contained a few small sandpipers of other species, but errors from this source were thought to be negligible. Long-billed Dowitchers are rare in the Atlantic Provinces and are not likely to have affected counts of Short-billed Dowitchers.

and to carry out counts in a consistent manner at the same stage of the tide on each survey. Surveys were conducted either at high tide, to count flocks of roosting shorebirds, or at intermediate tidal levels when shorebirds were concentrated on feeding areas. Counts were scheduled every second weekend from late July to late October to coordinate data collection. Participants were encouraged to conduct extra surveys. Direct counts were made wherever possible. Instruction sheets included suggestions for estimating numbers in large flocks (e.g., extrapolation from counting parts of flocks, estimation from size of flock and/or density of birds in flock). Emphasis was placed on obtaining reliable counts of the more common species of shorebirds. All observers were requested to provide basic information on survey conditions, species, and numbers and to record supplementary information on age and plumage of birds if possible. The latter information was used to determine migration phenology of adults and juveniles of each species and to associate age groups with peaks in counts.

Analytical procedures.—The 13 species of shorebirds selected for analysis (Table 1) were considered to have an ecological preference for coastal stopover sites with intertidal feeding areas rather than inland, freshwater habitats and thus likely to use MSS sites on a regular as opposed to opportunistic basis. Some 276 sites were censused during the period 1974–1991 (Fig. 1), although many received only limited coverage in terms of numbers of surveys or number of years of coverage. Effective sample sizes of sites available for population trend analyses for the different species generally fell in the range 30–80 (see Results).

For each species, the annual index used for investigating population trends of adults at each site was the mean number occurring during the main period of adult migration. Average main migration periods were determined for each species by calculating the mean number occurring at each site, and then overall, for each five-day period between 1 July and the end of the season. Many species showed two or more peaks. Field observations of age/plumage confirmed that the first peak normally consisted of adult birds. The main period of adult migration was determined by visual inspection of the graphs. This period was defined as lying between the dates at which counts rose above or fell below 10–15% of the maximum count in the first peak. The annual index was the mean of all counts falling within the main migration period. Preliminary investigations showed that the mean count, rather than the maximum count, was the most suitable index for trend analysis. Occasional atypically high counts at a site, resulting perhaps from unusually higher numbers of birds occurring because of weather conditions, tended to distort results obtained using maximum count indices (unpubl. data).

Three techniques were used to assess changes in shorebird abundance, as follows:

(1) Route regression analysis. This method was developed by Geissler and Noon (1981) for analysis of data from the Canadian and U.S. Breeding Bird Surveys and has been adapted for analysis of shorebird counts made at migration areas (Howe et al. 1989; Howe 1990, present paper). Population trends are first estimated for individual sites through linear regression of log-transformed annual population indices. The overall trend is then calculated as a weighted average of the individual site trends. Log transformations produce a linear trend when a constant annual percentage change occurs in a population and also stabilize the variance of the slope estimates. For MSS analyses, annual population indices were log-transformed (natural log) after addition of a constant (0.23) to allow handling of zero counts, and trends for individual sites were calculated through linear regression. Two weighting procedures were applied to individual site trends before calculation of the overall mean trend for the species (Collins and Wendt 1989, Collins 1990). The first involved weighting solely by the precision of the slope estimate. The weighting factor in this case is inversely proportional to the square root of the variance of the estimate. This procedure downweights sites for which there is an imprecise slope estimate or which have only been covered for a limited number of years. The second procedure involved weighting by the product of the precision of the slope estimate and the mean (geometric) number of adult birds at the site. This method gives greatest weights to sites with large numbers of birds. The trend, or rate of change of the population, is defined as the slope of the linear regression line on the log scale; this may be back-transformed (Bradu and Mundlak 1970), or, since its value is not easy to intrepret biologically, may be presented, for instance, as half-lives, yearly, or 10-yearly rates of change (Collins 1990). There were few changes of observers at sites, and subsetting of routes for this reason was not considered necessary.

Trend analyses were also performed for the period 1974–1983 to enable a direct comparison to be made with the results reported by Howe et al. (1989) and for the subsets of years used in the paired t-test comparisons (see below).

(2) Theil's non-parametric trend test. Theil's estimate of the slope coefficient (Hollander and Wolfe 1973) is a non-parametric method which produces unbiased and robust estimates of the slope. Trend estimates for individual sites were combined to produce an overall estimate across all sites and significance levels computed through a randomization test based on 1000 permutations of the data. This procedure was applied to 15 sites which had received coverage in at least eight of the 17 years of surveys between 1974 and 1990.

(3) Paired t-test comparisons. Route regression methods assume a constant rate of change of population during the period of the survey. This assumption, however, is not likely to be met in practice. Changes in the mean abundance of each species at each site were investigated directly using a paired t-test procedure. The 18-year span of the study was divided into three equal time blocks: 1974–1979, 1980–1985, and 1986–1991. The annual index values for each site were averaged for each time block and compared using a paired t-test procedure.

Statistical significance and power analysis.—The significance level for statistical tests, also known as the Type I error rate, may be regarded as the probability of declaring that a significant trend exists when there is no underlying trend in the population. Results are conventionally regarded as being statistically significant when this probability is less than 5%, i.e., $P < 0.05$. In the present work, the highly variable nature of the count data suggests that the 0.05% level of significance may be unduly restrictive, and we have adopted the convention of describing results where P is in the range 0.05–0.10 as being of "borderline significance".

The Type II error rate is the probability of declaring that there is no trend in the population when in fact a trend does exist. The statistical power of a test is defined as 1 minus the probability of a Type II error. Whereas one can control the critical value for the Type I error only using the sample size, the power of the test can be adjusted using both the sample size and magnitude of the effect that is being examined. The statistical power of the survey scheme will depend on two components making up the sample size, i.e., the number of sites being covered and the number of years which they are covered, as well as on the magnitude of the trend to be detected. Methods for calculating statistical power of Breeding Bird Surveys have been developed by Collins (1990) and adapted for shorebird surveys in the present work.

RESULTS

Migration phenology.—Main adult migration periods generally lasted 4–5 weeks (Table 1). About half of the 13 species occurred principally between mid-July and mid-August. Willets (see Table 1 for scientific names) and Short-billed Dowitchers migrated mostly in July, the two large plovers in August, White-rumped Sandpipers between mid-August and mid-September, and Dunlin, which complete a wing molt before moving south to the Atlantic coast (see Morrison 1984), not until September. The two-weekly sampling protocol usually resulted in three counts during the main adult migration period of most species at each site.

Route regression analysis.—Using slope precision × mean count weighting, route regression analysis showed that nine of the 13 species decreased between 1974 and 1991 (Table 2). Most (9 out of 13) of the calculated trends were less than 3%/year and were not statistically significant. Only the Least Sandpiper showed a statistically significant decline, although the large annual rate of decrease recorded for the Red Knot (−15.3%) was notable.

With slope-precision-only weighting, 10 of the 13 species showed negative trends (Table 3). This represented a significant tendency towards declines across species (Wilcoxon signed rank test, $P < 0.05$). The majority of calculated trends (8 out of 13) were again less than 3%/year and not statistically significant. The larger negative trends for Semipalmated Sandpipers, Least Sandpipers, and Short-billed Dowitchers were all statistically significant. A substantial, although not statistically significant, rate of decline (−5.24%/year) was again noted for Red Knots.

Trend estimates produced by the two weighting methods were generally

TABLE 2

POPULATION TRENDS CALCULATED USING ROUTE REGRESSION METHODS FOR SELECTED SHOREBIRD SPECIES DURING THE PERIOD 1974–1991[a]

Species	No. sites	Trend ± SE[b]	Annual change (%)	10-yr change (%)	Range of mean counts	*P*
Black-bellied Plover	85	−0.040 ± 0.039	−3.90	−32.8	0.2–278	0.32
Lesser Golden-Plover	27	−0.003 ± 0.016	−0.33	−3.24	0.2–1.4	0.84
Semipalmated Plover	82	+0.036 ± 0.049	+3.62	+42.7	0.4–623	0.47
Willet	38	−0.011 ± 0.024	−1.06	−10.1	0.3–55	0.66
Whimbrel	33	+0.007 ± 0.044	+0.74	+7.61	0.3–18	0.87
Ruddy Turnstone	66	+0.012 ± 0.025	+1.21	+12.7	0.3–39	0.63
Red Knot	37	−0.166 ± 0.132	−15.3	−80.9	0.3–26	0.22
Sanderling	50	−0.015 ± 0.039	−1.48	−13.9	0.2–380	0.70
Semipalmated Sandpiper	77	−0.011 ± 0.032	−1.10	−10.5	0.3–47,691	0.73
Least Sandpiper	71	−0.142 ± 0.061	−13.2	−75.8	0.3–153	0.02
White-rumped Sandpiper	57	−0.030 ± 0.038	−2.94	−25.8	0.3–203	0.44
Dunlin	40	−0.013 ± 0.031	−1.32	−12.4	0.3–53	0.68
Short-billed Dowitcher	55	+0.014 ± 0.056	+1.39	+14.9	0.3–73	0.81

[a] Based on mean counts during peak adult migration periods. Site weighting factors include precision of estimate and geometric mean of mean counts at site during survey period.
[b] Weighted mean slope on log scale.

TABLE 3

WEIGHTED POPULATION TRENDS CALCULATED USING ROUTE REGRESSION METHODS FOR SELECTED SHOREBIRD SPECIES DURING THE PERIOD 1974–1991[a]

Species	No. sites	Trend ± SE[b]	Annual change (%)	10-yr change (%)	Range of mean counts	*P*
Black-bellied Plover	85	+0.009 ± 0.024	+0.90	+9.37	0.2–278	0.71
Lesser Golden-Plover	27	−0.006 ± 0.010	−0.63	−6.15	0.2–1.4	0.53
Semipalmated Plover	82	−0.028 ± 0.025	−2.76	−24.5	0.4–623	0.27
Willet	38	−0.0002 ± 0.027	−0.02	−0.18	0.3–55	0.99
Whimbrel	33	−0.001 ± 0.018	−0.12	−1.19	0.3–18	0.95
Ruddy Turnstone	66	+0.004 ± 0.023	+0.42	+4.30	0.3–39	0.86
Red Knot	37	−0.054 ± 0.044	−5.24	−41.6	0.3–26	0.23
Sanderling	50	−0.043 ± 0.026	−4.16	−34.6	0.2–380	0.11
Semipalmated Sandpiper	77	−0.084 ± 0.033	−8.08	−56.9	0.3–47,691	0.01
Least Sandpiper	71	−0.077 ± 0.028	−7.43	−53.8	0.3–153	0.007
White-rumped Sandpiper	57	−0.0003 ± 0.030	−0.03	−0.27	0.3–203	0.99
Dunlin	40	−0.005 ± 0.022	−0.54	−5.23	0.3–53	0.81
Short-billed Dowitcher	55	−0.068 ± 0.030	−6.52	−49.1	0.3–73	0.03

[a] Based on mean counts during peak adult migration periods. Sites weighted by precision of estimate only.
[b] Weighted mean slope on log scale.

TABLE 4

WEIGHTED POPULATION TRENDS CALCULATED USING ROUTE REGRESSION METHODS FOR SELECTED SHOREBIRD SPECIES DURING THE PERIOD 1974–1983

Species	No. sites	Range of mean counts	Percent annual change		
			A[a]	B[b]	C[c]
Black-bellied Plover	54	1–278	−8.49*	−8.29	−5.4*
Lesser Golden-Plover	18	0.2–1.4	+0.14	−0.69	
Semipalmated Plover	57	0.7–573	+2.77	−7.50	−9.5
Willet	33	0.3–66	−2.83	−4.52	+0.2
Whimbrel	26	0.3–24	−15.4	+1.15	−8.3***
Ruddy Turnstone	46	0.3–61	+4.74	−3.87	−8.5
Red Knot	31	0.3–53	−25.9	+4.74	−11.7
Sanderling	39	0.2–380	−4.37	−6.83	−13.7***
Semipalmated Sandpiper	57	0.3–63,963	−9.64	−10.6*	−6.7
Least Sandpiper	51	0.3–968	−14.7	−1.87	+2.9
White-rumped Sandpiper	32	0.3–28	−16.2	−3.65	
Dunlin	26	0.3–43	−12.2	−7.63	
Short-billed Dowitcher	45	0.3–525	−7.80	−7.92	−5.5**

* $0.1 > P > 0.05$; ** $P < 0.05$; *** $P < 0.01$.
[a] Slope precision × mean count weighting.
[b] Slope precision only weighting.
[c] Howe et al. 1989.

highly and significantly correlated. Differences resulted from the two weighting procedures emphasizing trends from different sets of sites.

Trends during the period 1974–1983.—Route regression analysis using slope precision × mean count weighting (Table 4) indicated that 10 of the 13 species had negative trends ranging from −2.83%/year for the Willet to −25.9%/year for the Red Knot. Calculated trends were generally larger (10 of 13 were greater than 3%/year) than those derived from the entire study period 1974–1991, reflecting the larger changes which appeared to be taking place in populations during the 1970s (see below). The strong overall negative trend across species was significant using a two-tail Wilcoxon signed rank test ($P < 0.01$). When trends were weighted by slope precision only, 11 of the 13 species showed declines (significant trend across species, Wilcoxon signed rank test, $P = 0.01$), although only that for the Semipalmated Sandpiper reached borderline statistical significance ($0.01 > P > 0.05$, see Methods) (Table 4).

Trend estimates derived by Howe et al. (1989) from ISS data for the period 1972–1984 are compared with those calculated from MSS data for the comparable period 1974–1983 in Table 4. A borderline significant negative trend was noted for Black-bellied Plovers in both studies. The significant negative trends found by Howe et al. for Whimbrel, Sander-

TABLE 5

TRENDS IN SHOREBIRD POPULATIONS AT 15 MSS SITES COVERED FOR EIGHT OR MORE YEARS DURING THE 17-YEAR PERIOD 1974–1990 USING THEIL'S NON-PARAMETRIC TEST BASED ON LOG-MEAN COUNT ANNUAL INDICES

Species	Score	*P*
Black-bellied Plover	−5	0.08
Lesser Golden-Plover	−37	0.24
Semipalmated Plover	+51	0.40
Willet	−20	0.65
Whimbrel	+72	0.11
Ruddy Turnstone	+9	0.90
Red Knot	−69	0.10
Sanderling	−22	0.68
Semipalmated Sandpiper	−146	0.02
Least Sandpiper	−115	0.05
Dunlin	−14	0.79
Short-billed Dowitcher	−88	0.08

ling, and Short-billed Dowitchers were also negative, although not significantly so, in the present study. Four of the trend estimates differed in sign between the two studies, although the differences did not reach statistical significance.

Trend estimates using Theil's test.—Two species, the Semipalmated Sandpiper and Least Sandpiper, showed significant declines during the period 1974–1990. Three other species showed declines which were of borderline significance, the Black-bellied Plover, Short-billed Dowitcher and Red Knot. The Whimbrel showed borderline increase (Table 5).

Changes in mean abundance: paired t-*test comparisons.*—Most species decreased in abundance during the study (Table 6), particularly between early and middle years, when 12 of the 13 species declined on average, a significant tendency across species (Wilcoxon signed rank test, $P < 0.01$). Three species showed significant or borderline significant declines, and the average mean decrease across all species was significantly different from zero.

Differences were less consistently negative between recent and middle counts. Eight of the 13 species showed declines (not a significant tendency across species, Wilcoxon signed rank test), only one of which was of borderline significance.

Recent counts were generally lower than those made in early years. Declines were noted in eight of the 13 species, an almost significant ($0.1 > P > 0.05$, Wilcoxon signed rank test) tendency across species. Four

TABLE 6

DIFFERENCES IN AVERAGE LOG-MEAN COUNTS OF SHOREBIRDS AT MSS SITES DURING "EARLY" (1974–1979), "MID" (1980–1985) AND "RECENT" (1986–1991) YEARS OF THE STUDY PERIOD USING PAIRED *T*-TEST COMPARISONS

		Difference in average log-mean counts					
		Mid–early		Recent–early		Recent–mid	
	N		*P*		*P*		*P*
Black-bellied Plover	223	−0.372	0.14	+0.226	0.51	+0.018	0.92
Lesser Golden Plover	221	−0.239	0.22	+0.096	0.44	+0.010	0.90
Semipalmated Plover	207	−0.160	0.63	−0.196	0.54	−0.085	0.78
Willet	159	+0.215	0.26	+0.128	0.38	−0.059	0.61
Whimbrel	177	−0.116	0.17	+0.004	0.98	−0.117	0.48
Ruddy Turnstone	198	−0.354	0.18	−0.026	0.92	+0.317	0.17
Red Knot	188	−0.013	0.94	−0.611	0.02	−0.281	0.10
Sanderling	207	−0.616	0.07	−0.494	0.13	−0.107	0.54
Semipalmated Sandpiper	188	−0.347	0.16	−1.246	0.00	−0.329	0.25
Least Sandpiper	197	−0.410	0.29	−1.037	0.005	−0.214	0.35
White-rumped Sandpiper	195	−0.722	0.02	+0.184	0.49	+0.255	0.26
Dunlin	124	−0.150	0.60	−0.064	0.87	+0.135	0.58
Short-billed Dowitcher	159	−0.655	0.03	−0.757	0.03**	−0.097	0.62
Mean difference		−0.303		−0.292		−0.043	
SD		0.267		0.489		0.191	
N		13		13		13	
t^a		−4.096**		−2.153*		−0.804 ns	

[a] Comparison of mean difference with 0, ns = not significant, * = 0.1 > *P* > 0.05; ** = *P* < 0.05.

species declined significantly, and the average decrease for all species approached statistical significance ($t = -2.153$, $P = 0.052$).

These results suggest that numbers of shorebirds declined during the study period, with the greatest decreases occurring during the early years of the study.

Population trends during early, middle and recent years of the study period.—Route regression analysis showed that population trends differed considerably in both rate and direction during different phases of the study period (Table 7). Results using slope precision × mean count weighting showed that nine of the 13 species declined during the early (1974–1979) period. Two species showed significant negative trends, two showed borderline significant declines, and one showed a borderline increase. In contrast, during the middle period (1980–1985), 11 of the 13 species analyzed showed positive trends, five of which were statistically significant. The overall positive trend across species was statistically significant (Wilcoxon signed rank test $0.02 < P < 0.05$). During more recent years (1986–1991), declines and increases were more evenly matched, with one sig-

TABLE 7

SHOREBIRD POPULATION TRENDS (ANNUAL PERCENT CHANGE) CALCULATED USING ROUTE REGRESSION ANALYSIS FOR EARLY (1974–1979), MID (1980–1985) AND RECENT (1986–1991) SUBSETS OF YEARS

	1974–1979			1980–1985			1986–1991		
		Trend			Trend			Trend	
Species	N	A[a]	B[b]	N	A[a]	B[b]	N	A[a]	B[b]
Black-bellied Plover	42	−6.77*	−15.9*	25	+2.15	+19.0	31	−2.41	+1.44
Lesser Golden-Plover	12	+46.6	−1.36	8	−10.8	−7.46	12	−32.6	−16.9
Semipalmated Plover	46	−5.40	−16.8*	24	+29.3**	+10.5	35	+16.8***	+1.85
Willet	28	−3.44	−10.1	12	+5.31	+22.8	12	+2.44	−3.71
Whimbrel	21	+20.7*	+12.0	12	+30.9	−1.12	14	−3.43	−16.4
Ruddy Turnstone	38	+8.46	−4.02	20	+33.4***	+30.4**	27	−0.49	+9.46
Red Knot	24	+51.4	+8.43	13	+3.37	+4.72	14	−21.3***	−0.65
Sanderling	31	−25.4***	−16.2*	18	+24.4***	+17.3	17	+0.15	−3.68
Semipalmated Sandpiper	44	−14.0	−23.6*	23	+8.80**	+6.85	31	+33.7	−14.2
Least Sandpiper	40	−23.0	−12.0	21	+9.68	+13.1	30	+3.06	−6.92
White-rumped Sandpiper	27	−39.1*	−4.21	19	−21.5	+14.8	26	+8.87	−3.21
Dunlin	24	−13.3	−7.89	9	+39.5	−3.61	15	−15.0	−7.07
Short-billed Dowitcher	39	−16.2	−4.62	17	+54.8**	−1.02	17	−5.54	+22.4

* $0.1 > P > 0.05$; ** $P < 0.05$; *** $P < 0.01$.

[a] Weighted by slope precision estimate × mean count.

[b] Weighted by slope precision estimate only.

nificant trend in each direction. There was no overall statistically significant trend across species.

Analysis using slope-precision-only weighting indicated that 11 of the 13 species declined during the early period, a significant trend across species (Wilcoxon signed rank test, $P < 0.05$). Four of the declines were of borderline statistical significance. In contrast again, nine of the 13 species increased during the middle period, also a significant tendency across species (Wilcoxon signed rank test, $P = 0.02$). One positive trend was statistically significant. Although nine of the 13 species registered negative trends during recent years, none of the trends or the tendency across species was statistically significant.

Statistical power of the surveys.—Power analysis showed that a plus or minus 2% annual population change would be detected at 80% power for all species except Lesser Golden-Plover and Whimbrel for coverage of 40–50 sites for the number of years on which the trend analyses were based (18). A 5% population change would be detected at 80% power for all species for this degree of coverage. Coverage required to achieve 80% power varied between species and was typically 12–18 years for 40 sites to detect a 2% change and 9–15 years for 20 sites to detect a 5% change. Slightly longer coverage (approx. one year) was often required to detect decreases compared to increases. The present MSS coverage should thus be adequate to detect the levels of changes found in the trend analysis.

DISCUSSION

Data analysis.—Route regression methods use log-transformations of data and assume that trends are constant both during the study period and at different sites and that changes are representative of the population being sampled. Assumptions that ISS data were log-normally distributed were tested by Howe et al. (1989) and found to be generally acceptable. While they were not formally tested in the present study, analysis (unpubl. data) has shown that the MSS data mostly conform to a negative binomial distribution for which log-transformations would be reasonable. Log-transformations are also advantageous in stabilizing variance estimates and producing linear regressions for constant annual population trends.

Assumptions that trends are constant across sites or through time are unlikely to be met. There is no a priori reason to assume that population trends will be constant over time. Indeed, route regression analysis of data from subsets of years of the present study indicated that trends of very different magnitude and direction were taking place. Analysis of data from individual sites also showed that trends were not constant either in time or direction (unpubl. data). Where short-term variations are part of an underlying long-term trend, route regression methods will still be valid in assessing the direction and magnitude of the long-term trends.

Use of several statistical techniques and weighting methods offers a more complete perspective on population trends for conservation purposes than use of a single method, since different aspects of the data are emphasized. With route regression analysis, weighting by slope precision is always desirable, since sites with imprecise slope estimates, which could otherwise exert a considerable effect on the overall trend calculation (larger values of slopes were always associated with imprecise estimates), are effectively downweighted or removed. Slope-precision-only weighting, however, also results in many types of sites, including ones with high and low numbers of birds, contributing effectively to the trend estimate. Results from this method thus reflect trends occurring across a broad range of sites. With mean count × slope precision weighting, on the other hand, results principally reflect trends occurring at sites with large numbers of birds, especially where such sites have both high numbers of birds and a precise slope estimate.

Results from both types of analysis provide complementary information for conservation purposes. Detection of changes occurring across a broad range of sites is of basic importance, because declines may first be seen at sites with peripheral habitat before they become apparent at sites with optimal habitat. On the other hand, changes occurring at sites that support particularly high numbers of birds, and which might be masked in the former analysis, may reflect habitat changes or other problems which could affect a significant proportion of the population.

Theil's analysis and paired *t*-tests, in contrast to regression techniques, do not make any assumptions about the direction or rate of change of populations. Theil's slope analysis involves a non-parametric ranking procedure and may be less sensitive to outliers in the data resulting from unrepresentative counts being obtained in a given year at a particular site. Neither Theil's or paired *t*-test analyses use weighting procedures and may thus reflect trends occurring across a broad range of sites, although *t*-test comparisons could be affected by an unrepresentative high count affecting a site mean.

These considerations suggest that a combination of analytical methods will be most appropriate for examining population trends based on count data obtained from the volunteer survey network operation.

Population trends.—All three methods used for analyzing Maritimes Shorebird Survey data indicated declines in shorebird populations in eastern Canada during the period 1974–1991. The species for which declines were most consistently recorded were the Least Sandpiper, Semipalmated Sandpiper, and Short-billed Dowitcher. Decreases for Red Knot and

Black-bellied Plover approached statistical significance in some analyses. The preponderance of declines across the 13 species analyzed was often significant. Declines occurred in most species during the latter part of the 1970s, whereas most species increased during the first half of the 1980s. Changes since 1985 do not appear to have been as marked in either direction.

Causes of declines in shorebird populations are potentially complex and may occur at many points during the annual cycle of the birds. In eastern North America, possible causes of declines include loss of critically important habitat which may result from man-induced or natural causes, pollution, weather, and increased disturbance from human activities or predators. In Europe, Goss-Custard and Moser (1988) reported that decreases in numbers of Dunlin wintering in the U.K. was most pronounced on estuaries where the spread of cord grass (*Spartina anglica*), which is known to hold reduced densities of prey (Millard and Evans 1984), had been greatest. Increased levels of disturbance to roosting Bar-tailed Godwits and Red Knots were thought to be the principal cause of major declines in numbers of those species roosting on the Dee Estuary (Mitchell et al. 1988). Disturbance was also thought to be a major factor affecting the quality of roost sites and hence numbers and distribution of shorebirds on the Firth of Forth (Furness 1973). Shorebirds on migration are particularly vulnerable to such changes owing to their need to store fat reserves for long onward flights, especially those species making very long distance movements (Evans 1991, Evans et al. 1991). Some species may need to accumulate sufficient energy reserves not only for migration but also for subsequent survival and reproduction on High Arctic breeding grounds (Morrison and Davidson 1990).

Widespread losses have occurred in wetland habitats in eastern North America during the present century (Senner and Howe 1984, Bildstein et al. 1991). Such losses would not necessarily affect different species to the same extent, since the main migration areas for different species are found in different areas (Harrington and Morrison 1979, Morrison 1984, Harrington et al. 1989, Morrison and Harrington 1992). There are, in fact, many differences in the migration patterns and characteristics of the species analyzed in the present study. Their breeding ranges occupy wide regions of the Arctic, from middle and high latitudes to low Arctic and boreal areas, stretching from the eastern to the central Arctic. Their wintering grounds lie from the southern tip of South America through its northern coast to the southern United States. They feature long-, middle- and relatively short-distance migrants. They are of a wide variety of sizes and morphologies. All occur in large concentrations during migration and on the wintering areas, making them vulnerable to environmental change.

Apparent decreases (or increases) in shorebird populations in eastern Canada might result from shifts in distribution of shorebirds either within the Atlantic Provinces of Canada themselves or on a broader scale over the eastern seaboard of North America. Possible shifts in distribution of Semipalmated Sandpipers within the upper Bay of Fundy are suggested by the contrast between declining counts at Mary's Point, N.B. (unpubl. data) and apparent increases at other nearby sites in recent years (P. Hicklin, pers. comm.). Declining counts at Mary's Point will have contributed strongly to the negative trend (not significant) found during route regression analysis of MSS data using mean × slope precision weighting, owing to the large numbers of birds which occur there. However, the analysis using slope-precision-only weighting, which reflects trends occurring at a much broader range of sites, showed an even more negative (and statistically significant) trend for the species, suggesting decreases had occurred over a wide area.

Other considerations indicate that the MSS protocol should detect trends that are representative of those occurring over a wider area and that similar populations of shorebirds are being sampled from year to year. The wide distribution of sites across the Atlantic Provinces of Canada in itself provides a broad geographical basis for analyzing population trends. Trends at MSS and ISS sites (Howe et al. 1989) were similar during the 1970s, indicating a consistent pattern over much of the eastern seaboard of North America. Sites were not selected on a random basis but were chosen by participants for a variety of reasons, including use by large numbers of shorebirds and convenience of coverage. However, many species of shorebirds are highly consistent in their use of stopover areas on migration (Morrison 1984, Smith and Houghton 1984), indicating that similar populations are being sampled at a given site from year to year. The possibility that birds might overfly the Maritime Provinces and make a direct flight to wintering areas farther south (e.g., in South America) in years in which they were in unusually good condition seems unlikely on the basis of their potential flight range capabilities from sites in the interior or farther north (e.g., James Bay, Morrison 1984). They might, however, pass through farther south on the eastern seaboard of the United States, although there is currently no evidence that this occurs. Distribution patterns appear consistent from year to year, and few major concentrations of shorebirds are found in other parts of eastern Canada (Morrison et al. 1991).

Weather on the breeding grounds might affect shorebird populations on a broad scale. Boyd (1992) noted that mean June temperatures at locations in the eastern Canadian High Arctic were particularly low during the 1970s and that numbers of Red Knots from these breeding areas wintering in the U.K. tended to fall after cool Junes and rise after warm ones. In 1974, severe weather in mid-June on Ellesmere Island and in other parts of the High Arctic zone in Greenland resulted in many knots and turnstones dying of starvation (Morrison 1975). Similarly severe weather occurred in other parts of the Arctic during the latter part of the 1970s (unpubl. data) and may have affected shorebird populations passing through the eastern seaboard of North America. Increases in populations during the early 1980s occurred during a period of less severe weather across the Arctic (unpubl. data).

Shorebirds face threats from a variety of sources throughout their migration ranges (Morrison 1991). While weather on the Arctic breeding grounds may currently appear to be one of the most likely factors to have influenced shorebird populations migrating through the eastern seaboard of North America over the past 15–20 years, the possible impact of other potential threats must not be ignored. Ongoing shorebird surveys and monitoring schemes have an important role to play not only in assessing the health of shorebird populations but also in determining the processes influencing population levels and in designing conservational initiatives based on an understanding of the biology of the species concerned.

ACKNOWLEDGMENTS

We thank the many volunteers who have contributed data to the Maritimes Shorebird Survey scheme, especially those who covered survey sites faithfully for many years during the period 1974–1991. Key contributors at sites used in the trend analysis included Roger Burrows, David Christie, Shirley Cohrs, Brian Dalzell, Peter de Marsh, Henk Deichmann, Sylvia Fullerton, Marion Hilton, Clive MacDonald, Mary Majka, Peter Pearce, Ulysse Robichaud, Eric and Barbara Ruff, Sid and Betty Smith, Francis and Eric Spalding, Harry Walker, Mary Willms, and David Young. Special thanks to Barbara Campbell for her many contributions with the administration and organization of the surveys and analysis of data. We thank Hugh Boyd for his continued encouragement for the work and support of the need for long-term studies.

LITERATURE CITED

BILDSTEIN, K. L., G. T. BANCROFT, P. J. DUGAN, D. H. GORDON, R. M. ERWIN, E. NOL, L. X. PAYNE, AND S. E. SENNER. 1991. Approaches to the conservation of coastal wetlands in the Western Hemisphere. Wilson Bull. 103:218–254.

BOYD, H. 1992. Arctic summer conditions and British knot numbers: an exploratory analysis. Wader Study Group Bull. 64, Suppl.:144–152.

BRADU, D. AND Y. MUNDLAK. 1970. Estimation in lognormal linear models. J. Am. Stat. Assoc. 65:198–211.

COLLINS, B. T. 1990. Using rerandomizing tests in route-regression analysis of avian population trends. Pp. 63–70 *in* Survey designs and statistical methods for the estimation of avian population trends (J. R. Sauer and S. Droege, eds.), Biol. Report 90(1). U.S. Fish & Wildlife Service, Washington, D.C.

——— AND J. S. WENDT. 1989. The Breeding Bird Survey in Canada 1966–83: analysis of trends in breeding birds populations. Can. Wildl. Serv. Tech. Rept. Series No. 75.

ERSKINE, A. J., B. T. COLLINS, E. HAYAKAWA, AND C. DOWNES. 1992. The cooperative Breeding Bird Survey in Canada, 1989–91. Can. Wildl. Serv. Progress Notes No. 199. Canadian Wildlife Service, Ottawa, Canada.

EVANS, P. R. 1991. Seasonal and annual patterns of mortality in migratory shorebirds: some conservation implications. Pp. 346–359 *in* Bird populations studies: relevance to conservation and management (C. M. Perrins, J.-D., Lebreton, and G. J. M. Hirons, eds.). Oxford Univ. Press, Oxford, England.

———, N. C. DAVIDSON, T. PIERSMA, AND M. W. PIENKOWSKI. 1991. Implications of habitat loss at migration staging posts for shorebird populations. Acta XX Congressus Internationalis Ornithologici, pp. 2228–2235.

FURNESS, R. W. 1973. Wader populations at Musselburgh. Scottish Birds 7:275–281.

GEISSLER, P. H. AND B. R. NOON. 1981. Estimates of avian population trends from the North American breeding bird survey. Stud. Avian Biol. 6:42–51.

GOSS-CUSTARD, J. D. AND M. E. MOSER. 1988. Rates of change in the numbers of Dunlin, *Calidris alpina,* wintering in British estuaries in relation to the spread of *Spartina anglica.* J. Appl. Ecol. 25:95–109.

HARRINGTON, B. A. AND R. I. G. MORRISON. 1979. Semipalmated Sandpiper migration in North America. Studies in Avian Biol. 2:83–100.

———, J. M. HAGAN, AND L. E. LEDDY. 1989. Site fidelity and survival differences between two groups of New World Red Knots *Calidris canutus.* Auk 105:439–445.

HOLLANDER, M. AND D. A. WOLFE. 1973. Nonparametric statistical methods. John Wiley and Sons, New York, New York.

HOWE, M. A. 1990. Methodology of the International Shorebird Survey and constraints on trend analysis. Pp. 23–25 *in* Survey designs and statistical methods for the estimation of avian population trends (J. R. Sauer and S. Droege, eds.), Biol. Report 90(1). U.S. Fish & Wildlife Service, Washington, D.C.

———, P. H. GEISSLER, AND B. A. HARRINGTON. 1989. Population trends of North American shorebirds based on the international shorebird survey. Biol. Conserv. 49:185–199.

LARIVEÉ, J. 1989. Variation des observations d'oiseaux du Québec méridional de 1969 à 1988. Les Carnets de zoologie 49:83–90.

MILLARD, A. V. AND P. R. EVANS. 1984. Colonization of mudflats by *Spartina anglica*; some effects on invertebrate and shorebird populations at Lindisfarne. Pp. 41–48 *in Spartina anglica* in Great Britain (P. Doody, ed.), Focus on Nature Conservation No. 5. Nature Conservancy Council, Peterborough, England.

MITCHELL, J. R., M. E. MOSER, AND J. S. KIRBY. 1988. Declines in midwinter counts of waders roosting on the Dee estuary. Bird Study 35:191–198.

MORRISON, R. I. G. 1975. Migration and morphometrics of European Knot and Turnstone on Ellesmere Island, Canada. Bird-Banding 46:290–301.

———. 1984. Migration systems of some New World shorebirds. Pp. 125–202 *in* Shorebirds: migration and foraging behavior (J. Burger and B. Olla, eds.), Behav. Marine Anim. Vol. 6. Plenum Press, New York, New York.

———. 1991. Research requirements for shorebird conservation. Trans. 56th N.A. Wildl. & Nat. Res. Conf. (1991):473–480.

——— AND N. C. DAVIDSON. 1990. Migration, body condition and behaviour of shorebirds during spring migration at Alert, Ellesmere Island, N.W.T. Pp. 544–567 *in* Canada's missing dimension, science and history in the Canadian Arctic Islands, Vol. 2 (C. R. Harington, ed.). Canadian Museum of Nature, Ottawa, Canada.

——— AND B. A. HARRINGTON. 1992. The migration system of the Red Knot *Calidris canutus rufa* in the New World. Wader Study Group Bulletin 64, Suppl.:71–84.

——— AND R. K. ROSS. 1989. Atlas of Nearctic shorebirds on the coast of South America. Canadian Wildlife Service Special Publication. 2 vols. Canadian Wildlife Service, Ottawa, Canada.

———, R. W. BUTLER, H. L. DICKSON, A. BOURGET, P. W. HICKLIN, AND J. P. GOOSSEN. 1991. Potential Western Hemisphere Shorebird Reserve Network sites for migrant shorebirds in Canada. Can. Wildl. Serv. Tech. Rept. Series No. 144, Canadian Wildlife Service, Ottawa, Canada.

MYERS, J. P., R. I. G. MORRISON, P. Z. ANTAS, B. A. HARRINGTON, T. E. LOVEJOY, M. SALLABERRY, S. E. SENNER, AND A. TARAK. 1987. Conservation strategy for migratory species. Am. Sci. 75:19–26.

SENNER, S. E. AND M. A. HOWE. 1984. Conservation of nearctic shorebirds. Pp. 379–421 *in* Shorebirds: breeding behavior and populations (J. Burger and B. Olla, eds.), Behav. Marine Anim. Vol. 5. Plenum Press, New York, New York.

SMITH, P. W. AND N. T. HOUGHTON. 1984. Fidelity of Semipalmated Plovers to a migration stopover. J. Field Ornithol. 55:247–249.

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