for this, however, is anecdotal or poorly documented. For example, some cold-intolerant species such as opossums (*Didelphis* spp.) and armadillos (*Dasypus novemcinctus*) have expanded their range significantly northward during the last 50 years, and some heat-sensitive species, such as white birch (*Betula papyrifera*), have receded northward during the same period. Data from some recent studies also suggest that global warming may be influencing the distribution or physiology of other plants and animals. Although these data are not sufficient to determine cause and effect relationships, they are intriguing enough to identify future research needs.

The articles that follow all investigate interesting trends between one aspect of climate change—global warming—and plant and animal behavior. Root and Weckstein document long-term change in the winter distribution of some birds; global warming is one possible explanation for these changes. LaRoe and Rusch's article shows change in onset of hatching behavior in selected populations of geese; and Oglesby and Smith's contribution shows a long-term trend in migratory behavior of some birds and in blooming of some plants. Finally, Morse et. al. use existing models to provide a preliminary assessment of patterns of plant vulnerability to climate change.

All four articles are subject to the complexities common to most work on global change; all the trends show dramatic year-to-year variation in response to short-term temperature changes and all have multiple possible explanations; and while all show intriguing statistical correlations, none demonstrates a cause-and-effect relationship. Moreover, these trends do not affect all species, because different species have different sensitivities to temperature and because global climate change is not the only factor affecting species. As discussed in Root and Weckstein's article, a number of competing hypotheses can be used to explain these changes. Nonetheless, together these articles suggest that global warming should be considered as a contributing factor.

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# Changes in Winter Ranges of Selected Birds, 1901-89

*by*
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Over time the ranges of species expand and contract, and abundance patterns shift. Ranges can expand when suitable new habitat becomes available or when population pressure forces migration to new areas. Contractions can occur when populations decline and individuals abandon less-than-ideal habitats, which are often along the edges of species' ranges.

We wish to compare historical and recent range and abundance patterns of selected wintering birds, categorize the type of changes that occurred, and speculate on possible causes of the changes. We found range expansions in most birds examined; only a few species exhibited contractions, and patterns of abundance shifted in almost all species.

## Sources of Data

We used data collected by volunteers for the National Audubon Society's Christmas Bird Counts. Wing (1947) summarized data from 1901-40 (from winter 1900-01 to winter 1939-40), which included 6,853 censuses. We obtained data for 32,167 censuses from the U.S. Fish and Wildlife Service for 1960-89, excluding those for 1969, which were not available at time of analysis. For more information on how we used these data, *see* Root and Weckstein (1994).

## Changes in Ranges

We found extensive changes in the ranges and abundance patterns of the birds we examined. Environmental changes that facilitate rearrangements in species' ranges and abundances can be due to natural factors, such as hurricanes transporting cattle egrets (*Bubulcus ibis*) to North America (Bock and Lepthien 1976). In the fairly recent past, however, such changes have been primarily precipitated by humans, including breaking sod in the prairies for farming, which allowed the western spread of American robins (*Turdus migratorius*; Bent 1949), and building cooling ponds for waste heat from power plants, which provided open water for various wintering ducks in the northern states (Root 1988a).

Over the last several decades most ecological studies examining range and abundance changes have focused primarily on investigating direct natural and human-induced effects of habitat change. Consequently, by reading the

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literature one gets the impression that such changes are the most common and most important.

Indirect effects of habitat change, however, are probably just as common and important, and perhaps even more so, although obtaining clear obvious evidence for indirect effects is difficult given the fact that other factors are changing at the same time. One such effect is the biotic response to the abiotic changes induced by human disturbance. A good example is changes in birds' ranges in response to increasing temperature.

## Range Expansion

One way to examine the possible importance of global warming on changing ranges is examining possible physiological mechanisms constraining birds' ranges to warm areas. Previous work has shown that 50 species of songbirds (e.g., sparrows and warblers) have range boundaries apparently dictated by average minimum January temperatures (Root 1988b). Ongoing studies of a few of these key species have shown significant changes in the location of northern range boundaries from year to year, and these correspond to annual climate changes.

Preliminary studies on northern cardinals (*Cardinalis cardinalis*) suggest that the lack of stored fat, which is needed to fuel increased metabolic rates in colder areas (Root 1991), is the primary factor restraining this bird's range. Consequently, as the earth warms, we expect birds with ranges restricted by low temperatures to readily expand their ranges. Such expansions may indeed be already occurring.

Successfully managed birds show extensive range expansions. Up to 1940, the mute swan (*Cygnus olor*) was recorded only in Pennsylvania and Michigan (Fig. 1a), but since then, programs to introduce and establish it—primarily in parks—have allowed it to spread to 19 states (Fig. 1b).

The wild turkey (*Meleagris gallopavo*) shows even a more dramatic change (Fig. 2). It originally occurred in the Southwest and in all the states east of the 100th meridian, except for North Dakota (Schorger 1966). Hunting pressures, habitat loss, and disease spread by domestic poultry all contributed to its dramatic range contraction (Schorger 1966; Hewitt 1967; Lewis 1973). From 1901 to 1940 it was recorded in only 10 states (Fig. 2a). Turkeys were reintroduced into all but three states within its original range and introduced into all the states outside its original range (Fig. 2b). Obviously, management has had a major effect on this gamebird.

Similarly, people may have contributed to a change in both ranges and abundances of various seed-eating birds (Fig. 3). On average, a third of the households in North America provide about 60 lb of bird food a year, with the average being even higher in New England (Ehrlich et al. 1988). Consequently, feeders may have contributed to the expansion of winter ranges of some birds into the northeastern part of the country (e.g., mourning dove [*Zenaida macroura*] Fig. 3; tufted titmouse [*Parus bicolor*]; northern cardinal; and evening grosbeak [*Coccothraustes vespertinus*]).

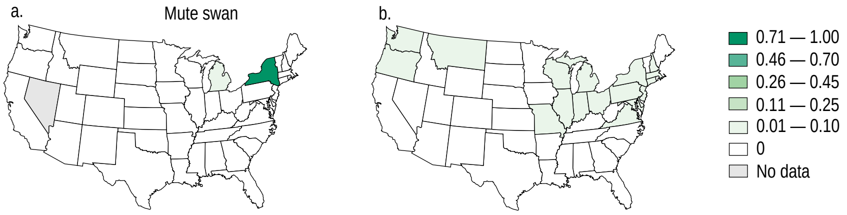

**Fig. 1.** Range and abundance patterns of the mute swan. (a) Data from 1901 to 1940, (b) Data from 1960 to 1989 (except 1969).

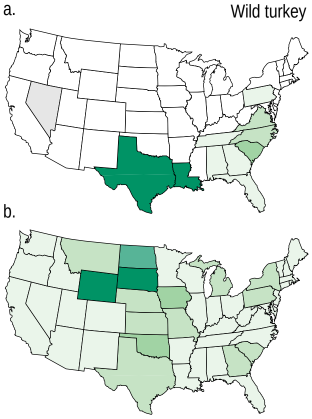

**Fig. 2.** Range and abundance patterns of the wild turkey. (a) Data from 1901 to 1940, (b) Data from 1960 to 1989 (except 1969).

Habitat change due to logging may have contributed to the extensive and recent range changes of the barred owl (*Strix varia;* Fig. 4), which tends to prefer mixed-aged forests. Before 1972 no northern populations of this owl were reported west of the 100th meridian (Root 1988a). The recent expansion is of concern because this owl's range is now partly sympatric with that of the endangered northern spotted owl (*S. occidentalis caurina*), which prefers ancient forests. The consequences of competition between these two species are not understood well yet, but nesting sites, foraging, and diet are similar, particularly in the Northwest (Taylor and Forsman 1976). Anecdotal evidence, however, suggests the larger, more aggressive barred owl may be able to displace the smaller spotted owl (Sharp 1989).

Other raptors (e.g., northern harrier [*Circus cyaneus*] and ferruginous hawk [*Buteo regalis*]) have also significantly expanded their ranges. In particular, the golden eagle (*Aquila chrysaetos*) has moved east, while the bald eagle (*Haliaeetus leucocephalus*; Fig. 5) has spread into the center of the continent.

Over the years humans have strongly influenced the expansion of the bald eagle's range through water-management programs (Root 1988a). Large lakes and impoundments built in the 1930's, locks placed on major waterways,

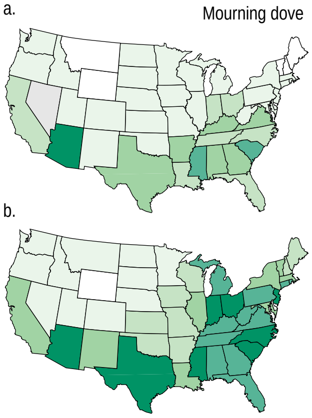

**Fig. 3.** Range and abundance patterns of the mourning dove. (a) Data from 1901 to 1940, (b) Data from 1960 to 1989 (except 1969).

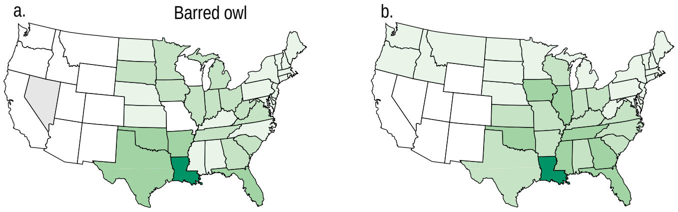

**Fig. 4.** Range and abundance patterns of the barred owl. (a) Data from 1901 to 1940. (b) Data from 1960 to 1989 (except 1969).

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# Changes in Nesting Behavior of Arctic Geese

*by*
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As part of the joint United States-Canada efforts to monitor populations of Arctic geese and to provide data necessary to set hunting regulations, scientists have recorded not only goose population levels, but also nesting behavior. MacInnes et al. (1990) analyzed data from four long-term studies of five different Arctic goose populations. These studies documented the date the eggs hatched and the clutch size (number of eggs per nest) over 35 years (Fig. 1).

The dates of nest initiation and hatch are clearly affected by climate and are delayed by cold weather. The records not only show wide fluctuations from year to year in response to annual variations in climate, but also demonstrate a consistent trend toward earlier hatching over the period (Fig. 2). Young Arctic geese today, on the average, hatch about 30 days earlier than they did 35 years ago; during the same time, average clutch size has shrunk (Fig. 3). MacInnes et al. (1990) suggest the change in nest date is a result of climatic amelioration, that is, warming (although whether from a long-term trend or short-term cycle is unclear), and the change in clutch size is a result of habitat deterioration.

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**Fig. 1.** Location of four monitoring sites. Sites chosen represent localities with information for 5 or more years. Site 1–McConnell River (60˚ 50’N, 94˚ 25’W; snow goose [*Chen caerulescens*] and small Canada goose [*Branta canadensis*]); 2– La Pérouse Bay (58˚ 24’N, 94˚ 24’W; snow goose); 3–Cape Churchill (58˚ 25’N, 93˚W; medium Canada goose); and 4–Southhampton Island (63˚ 60’N, 86˚W; snow goose).

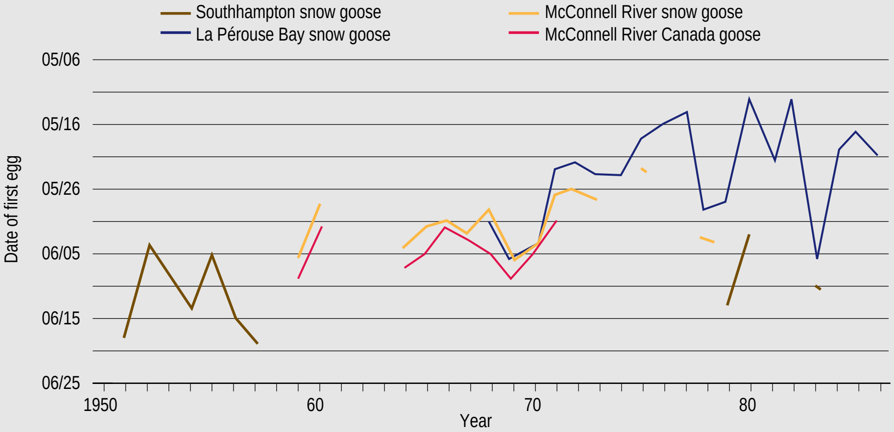

**Fig. 2.** Date of first egg. Although all sites displayed large fluctuations, both the date of first egg and the mean (average) hatch date became significantly earlier during the period 1951-86. There were no significant differences in the slopes of trends among sites or species.


Courtesy E.T. LaRoe

Canada goose (*Branta canadensis*).

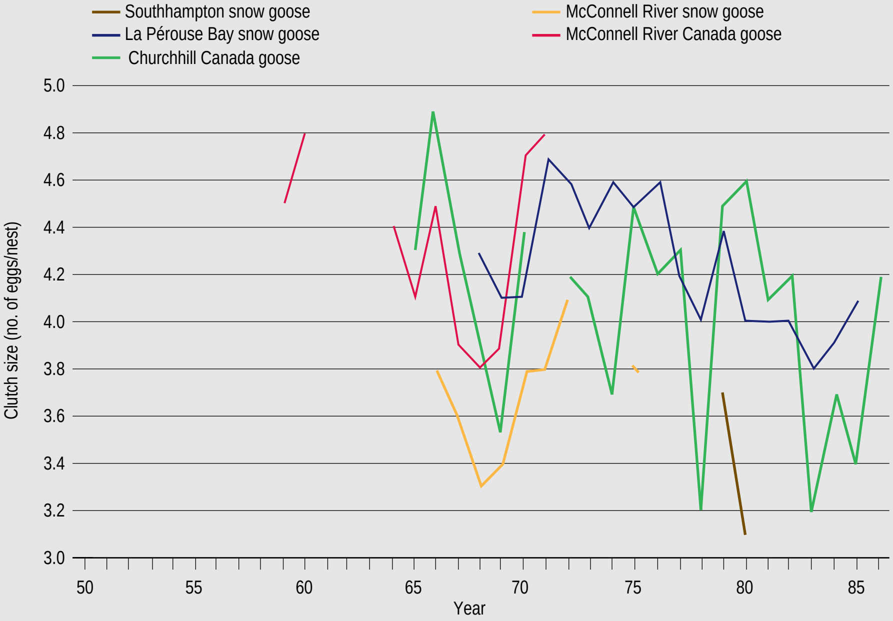

**Fig. 3.** Clutch size of nests of snow and Canada geese at Hudson Bay.

and numerous hydroelectric plants built with cooling ponds provide open water in winter, which this eagle needs for hunting (Southern 1963).

The winter abundance of the bald eagle throughout most of the contiguous United States dropped by about a third from 1957 to 1970 because of the use of persistent insecticides (e.g., DDT) and habitat destruction (Brown 1975). Since World War II, population declines in the East have been blamed on habitat destruction due to human disturbances (waterfront housing and outdoor recreation; Sprunt 1969). Shooting by ranchers from small planes from the late 1930's to the early 1960's could have depressed their abundance during this period and later (USFWS 1992).

### Range Contractions

Of the 58 species examined, only 4 showed range contractions. This result could have been partly an artifact of our sample: we did not examine species that have very restricted ranges. It may also be due to our methods of examination because species had to abandon entire states, not just part of them, before we recorded a contraction. Of the four species showing range contractions, one is the brown-headed cowbird (*Molothrus ater*) and the other three depend on open water: pied-billed grebe (*Podilymbus podiceps*), northern pintail (*Anas acuta*), and common merganser (*Mergus merganser*).

The contraction of the northern pintail is of particular concern (Fig. 6). This game species has been extensively managed, yet estimates of its breeding population have shown a fivefold decrease since the mid-1900's (USFWS 1992). The reasons for this large decline are not yet understood.

## Conclusion

The data collected by volunteers for the National Audubon Society's Christmas Bird Counts provide excellent information to examine the ranges and abundance patterns of wintering North American birds over both a very broad spatial scale and a long temporal scale. The changes that we found were primarily due to human activity, both purposeful (e.g., management of game species) and accidental. Some of these changes could be viewed as being beneficial (e.g., water management programs increasing bald eagle numbers), while others could be viewed as negative (e.g., logging allowed barred owls to invade spotted owl territories).

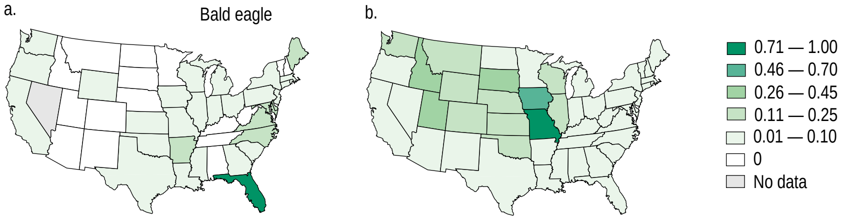

**Fig. 5.** Range and abundance patterns of the bald eagle. (a) Data from 1901 to 1940. (b) Data from 1960 to 1989 (except 1969).

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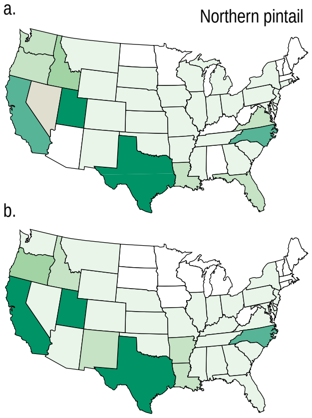

**Fig. 6.** Maps showing range and abundance patterns of the northern pintail. (a) Data from 1901 to 1940. (b) Data from 1960 to 1989 (except 1969).

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