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REPRODUCTION AND DISTRIBUTION OF BALD EAGLES IN VOYAGEURS NATIONAL PARK, MINNESOTA, 1973–1993

By

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and

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Reproduction and Distribution of Bald Eagles in Voyageurs National Park, Minnesota, 1973–1993

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Abstract. The bald eagle (*Haliaeetus leucocephalus*) is classified as a threatened species in Minnesota. In 1973, the National Park Service began monitoring the distribution and reproduction of bald eagles in and immediately adjacent to Voyageurs National Park to obtain data that park management could use to protect bald eagles from the effects of use of the park by visitors and from the expansion of park facilities. Thirty-seven breeding areas were identified during 1973–93. Annual productivity ranged from 0.00 to 1.42 fledglings/occupied nest and averaged 0.68 during the 21 breeding seasons. The annual number of breeding pairs tripled, the mean number of fledged eaglets increased 5 times, and reproductive success doubled during the study. However, in more than 15 of the breeding seasons, the mean productivity and the annual reproductive success in Voyageurs National Park were below the 1 fledgling/occupied nest and the 70% reproductive success that are representative of healthy bald eagle populations. We suspect that toxic substances, human disturbance, severe weather, and lack of food in early spring may have kept bald eagles in Voyageurs National Park from achieving a breeding success that was similar to that of conspecifics in the nearby Chippewa National Forest. The cumulative effect of these variables on reproduction and on habitat of bald eagles in Voyageurs National Park is unknown and should be determined.

Key words: Bald eagle, population dynamics, threatened species, ecological contaminants, wildlife management, human disturbance.

Most records of the distribution, population size, and reproduction of bald eagles (*Haliaeetus leucocephalus*) in the Voyageurs National Park area before the park was created in 1971 were anecdotal accounts by explorers, timber cruisers, loggers, surveyors, geologists, natural historians, or bush pilots. Cole (1979) obtained information on bald eagles and other wildlife in the park by reviewing literature and historical documents and by interviewing longtime residents. Although these records provided background information, they could not be used to determine the population size and distribution of the local bald eagles.

The only exception to the anecdotal accounts were annual surveys of nesting bald eagles by Superior National Forest biologists from 1962 to 1974 in areas (Kabetogama, Namakan, and Sand Point lakes) that became part of the park in 1971. Three breeding areas were on Namakan Lake and two each on Kabetogama Lake and on Sand Point Lake. The number of observed nests ranged from one in 1962 to nine in 1972. During 13 breeding-season surveys, 14 eaglets fledged on Namakan Lake and 1 each on Kabetogama Lake and on Sand Point Lake. The reproductive success was highest in 1968 when four bald eagle eaglets fledged from five occupied nests. Parkwide surveys in cooperation with the Superior National Forest and the Minnesota Department of Natural Resources began in 1973. In 1975, the park assumed sole responsibility for the bald eagle survey.

Annual aerial surveys have been conducted by the National Park Service since 1973 to monitor the reproduction and the distribution of the bald eagle in Voyageurs National Park. The original purpose for monitoring the bald eagle population was compliance with the management guidelines of the Endangered Species Act of 1973 (16 U.S.C., 1531 et seq.), the Northern States Bald Eagle Recovery Plan (*[1]Grier et al. 1983), and the management policies of the National Park Service (*U.S. National Park Service 1988). The results were to be used to protect bald eagles from park visitors and from expansion of park facilities and to manage bald eagle habitat in the park.

Monitoring during several years revealed that breeding success was obviously lower of bald eagles in the park than of bald eagles in the nearby Chippewa National Forest in north-central Minnesota (*Mathisen 1975). Several explanations were advanced, including human disturbance, severe spring weather, lack of food in early spring (Cole 1979), and environmental contaminants (W. Bowerman, Michigan State University, personal communication).

In early spring (late March to late April), park visitors may disturb bald eagles that are feeding on carrion on ice surfaces or eagles that are courting, building nests, and laying and incubating eggs. Later in spring, while eagles are incubating and brooding eaglets, concentrations of visitors on water near nests may cause eagles to respond in ways that could adversely affect reproduction (Gerrard and Bortolotti 1988). Motorboats that passed close to a nest site during June and July 1992 accounted for most of the responses of eagles to human presence and may have contributed to the death of an eaglet (*Fink 1992). During critical periods in the nesting cycle, eagles may abandon nests in response to nearby (unauthorized) camping.

The National Park Service tried to reduce the human disturbance of eagles. Before the creation of Voyageurs National Park, visitors were not excluded from areas close to bald eagle nests during critical periods of the breeding cycle. After the park was established in 1975, 0.4-km buffer zones around nest sites were initiated to keep out visitors. After 1983, the guidelines for nest-site protection of the Northern States Bald Eagle Recovery Plan (*Grier et al. 1983) were followed.

Severe spring weather periodically reduces reproduction in bald eagles (Gerrard and Whitfield 1979; Swenson et al. 1986). Voyageurs National Park is subjected to continental polar air throughout most of the year and to freezing temperatures into June (National Oceanic and Atmospheric Administration 1993). Heavy snows may occur as late as May. Cole (1979) suggested that declines in the numbers and kinds of native cervids reduced the amount of late-winter and early-spring food sources from carrion for scavengers such as bald eagles. He estimated the cervid biomass was reduced by two-thirds from pre-1920 levels.

Studies that K. Kozie, park wildlife biologist, and W. W. Bowerman of the Pesticide Research Center and Institute for Environmental Toxicology of the Michigan State University initiated in 1989 indicated that environmental contaminants may also be suppressing the reproduction of bald eagles in Voyageurs National Park. The polychlorinated biphenyl (PCB) level in a blood sample from one eaglet in the park in 1989 was among the highest in a study of bald eagles from the Great Lakes states (*Bowerman et al. 1991).

Mercury, which seems to be widespread in the aquatic ecosystem of the park, also may be a problem. Mercury levels were elevated in common loons (*Gavia immer*; *Ensor et al. 1992), in river otters (*Lutra canadensis*; *Route and Peterson 1988), and in fishes from 14 park lakes (*Minnesota Department of Health 1993).

We identified long-term trends in the reproduction of bald eagles in Voyageurs National Park and its vicinity; evaluated the distribution of bald eagle nests and breeding areas by administrative, biotic, and physiographic features of the park; and analyzed the influence of weather on reproduction. Results from our study will be used to improve the management of bald eagles in Voyageurs National Park and to facilitate research into the cumulative effects of environmental contaminants and human disturbance on the reproduction and the distribution of the bald eagles in the park.

Study Area

The study area (Fig. 1) was Voyageurs National Park in Minnesota and an adjacent 3-km-wide periphery along

[1] An asterisk denotes unpublished material.

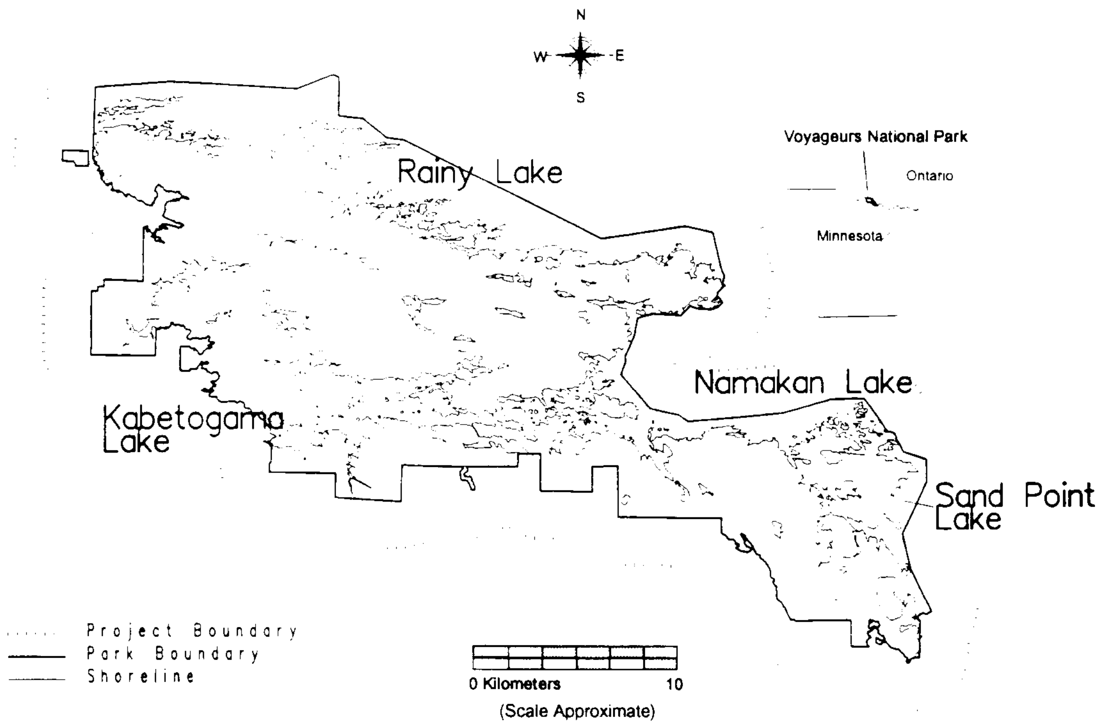


Fig. 1. Study area of bald eagles (*Haliaeetus leucocephalus*) in Voyageurs National Park, Minnesota, 1973–1993.

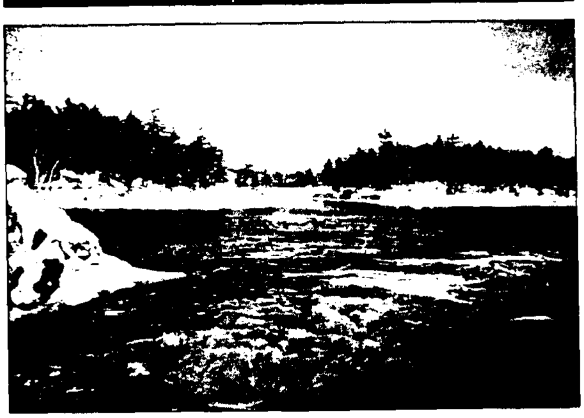
the international border between Minnesota in the United States and Ontario in Canada. The bald eagle population in Voyageurs National Park is contiguous with the populations of the Superior National Forest and the Kabetogama State Forest in Koochiching and St. Louis counties, Minnesota, and the Rainy River District, Ontario. The area is between latitude 48° 20′ and 48° 40′ N and longitude 92° 25′ and 93° 15′ W and encompasses 30 named park lakes. Four major lakes (Rainy, Kabetogama, Namakan, Sand Point) are 39% of the park's total area of 88,628 ha and 96% of the park's total lake area. About 37% of the 858 km^2 area of Rainy Lake is in the study area. Seventy percent of the watershed and 75% of the Rainy Lake area is in Ontario (Chevalier 1977). About half of Namakan and Sand Point lakes are in Ontario, but Kabetogama Lake is entirely in Minnesota. Hundreds of islands, numerous bays, and about 1,000 km of shoreline are inside the park boundaries (*Route and Peterson 1988). Twenty-six small lakes, hundreds of bogs, and more than 1,000 beaver ponds are dispersed in 54,359 ha of mainland and peninsular land of the park (Naiman et al. 1988). Land elevations in the study area range from 337 to 430 m above mean sea level. Three dams, which were built in 1909 and 1914, significantly elevated water levels and changed shoreline configurations and the aquatic ecosystem of the park's four major lakes (Kallemeyn et al. 1988).

The park, which is almost completely forested, is considered part of the Great Lakes Forest Region (Morley 1969). Cole (1987) and Pastor and Mladenoff (1992) described the study area as being part of the southern boreal–northern hardwood forest border. Dominant southern boreal–forest species on mineral soils are the quaking aspen (*Populus tremuloides*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), and paper birch (*Betula papyrifera*). Black spruce (*Picea mariana*) grows on peat soils (Kurmis et al. 1986). Dominant species of the northern hardwood zone are green ash (*Fraxinus pennsylvanica*), red maple (*Acer rubrum*), American basswood (*Tilia americana*), red pine (*Pinus resinosa*), and eastern white pine (*Pinus strobus*). Before logging, larger stands of eastern white, red, and jack pines were more common and widely distributed because of natural fire (Heinselman 1973). Anthropogenic activities altered much of the forest, and seral species such as aspens and balsam firs are now widespread (Heinselman 1973; Coffman et al. 1980).

The geologic landscape consists of early Precambrian metamorphic and igneous formations of the Superior Subprovince of the Canadian Shield (Minnesota Geological Survey 1979; Ojakangas and Matsch 1982). Most bedrock in the park is strongly oriented on a northeast-to-southwest strike and influences lake basin and island orientation and characteristics. Mineral soils are

Aerial photograph of Voyageurs National Park, Minnesota, showing interspersion of land and water areas that bald eagles (*Haliaeetus leucocephalus*) use. *Photo from Voyageurs National Park files.*

A bald eagle (*Haliaeetus leucocephalus*) nest on Pine Island in Kabetogama Lake, Voyageurs National Park, Minnesota. *Photo by T. G. Grubb.*



Early ice-out area around which bald eagle (*Haliaeetus leucocephalus*) nesting and feeding is centered before ice-out on the main lakes in Voyageurs National Park, Minnesota. *Photo by R. S. Evans.*

relatively young and unweathered and derived from the till and outwash of the recent glaciation.

Methods

Terminology

The terminology and definitions of Berger (1961), Thomson (1964), Postupalsky (1974), and Grubb et al. (1975) were followed.

Breeding pair	A breeding pair of bald eagles that laid or incubated eggs or brooded eaglets in a nest (sometimes synonymously reported as an active nest).
Alternate nest	One of several nests in a breeding area of one pair of breeding bald eagles; also called supernumerary nest.
Eaglet	A young bald eagle before it is fully grown and able to fly.
Fledgling	A young bald eagle from the time it leaves its nest until it is independent of all parental care (Berger 1961). Bald eagle fledglings remain dependent on parental care for several weeks and often return to the nest for food (Sprunt et al. 1973).
Mean brood size	The number of eaglets per active pair.
Nest years	The number of years a specific nest existed in the study area; i.e., a nest that was in the study area during 21 breeding seasons has a longevity of 21 nest years.
Occupied breeding area	An area with one occupied nest or with one occupied nest and one or more alternate nests.
Occupied nest	Any nest where a breeding pair is present irrespective of whether the female laid eggs.
Productivity	The number of fledglings per occupied nest.
Reproductive success	The proportion of breeding pairs in occupied breeding areas that raised one or more fledglings per breeding season (sometimes synonymously reported as percent nesting success or nest success).
Active pair	A breeding pair of bald eagles at an occupied nest that raised at least one young to an advanced stage of development (sometimes synonymously reported as a successful nest).
Unactive pair	A breeding pair of bald eagles at an occupied nest that failed to raise young because of any cause (sometimes synonymously reported as an unsuccessful nest or nest failure).

Surveys

The reproduction and distribution of the bald eagles in Voyageurs National Park were monitored annually. Two sets of data were annually collected from fixed-winged aircraft. In 1973, traditional survey guidelines by the Minnesota Department of Natural Resources and by biologists of the Chippewa National Forest and the Superior National Forest were followed. When appropriate, minor changes were made when new guidelines for aerial surveys of bald eagles (Postupalsky 1974; Leighton et al. 1979; Grier et al. 1981; Fraser et al. 1983, 1984) became available. Such changes were made for the pilot's and observer's safety and did not affect the experimental design. One survey was conducted on about 10 April to determine occupancy of the breeding areas, and the other survey was conducted on about 10 July to determine productivity and reproductive success. The same observer conducted 41 of the 42 aerial surveys during 21 breeding seasons (personal observation). The park pilot flew a Piper Super Cub or Christen Husky in 17 of the 21 survey seasons. Long-term familiarity with the survey area and with the breeding areas in the survey area raised the probability of consistent monitoring that we think accounted for more than 90% of the annual breeding population.

Analysis

Geographic Information System

The Geographic Information System (GIS) was used to prepare maps of the study area, the park boundary, park lakeshores, nest-site locations, breeding areas, open-water areas in early spring, nesting sites of gulls (*Larus* spp.), the year of establishment of breeding areas of bald eagles, and the average reproductive success and average productivity of bald eagles by breeding area. The base maps for GIS were the 7.5-min topographic quadrangle series and the Voyageurs National Park topographic map by the United States Geological Survey. Survey data and Universal Transverse Mercator coordinates of all nests were entered into dBase III Plus (Ashton–Tate Corp. 1987) and linked to PC ARC/INFO. 3.4D Plus (Environmental Systems Research, Inc. 1992). Linking the database information to GIS laid the groundwork for more extensive analysis of the reproduction and distribution of bald eagles in Voyageurs National Park.

Identification of Bald Eagle Breeding Areas

The locations and sizes of bald eagle breeding areas in Voyageurs National Park were estimated from information collected by the same observer during 21 breeding seasons. The variables for determining the locations of breeding areas included the location of all nests during 21 breeding seasons, the distances between nests that were simultaneously occupied by breeding bald eagles, the distances between simultaneously occupied nests and alternate nests, the patterns of simultaneous occupancy and use of nests during 21 breeding seasons, the location and accumulation of alternate nests, the location and use of perching and feeding sites, the location of territorial interactions between bald eagles, the density of breeding pairs, and the longevity and habitat characteristics of traditional breeding areas.

Stratification of Breeding Areas

To evaluate the variability of reproduction between breeding areas over time, we stratified the breeding areas by three ranges of productivity (0.0–0.69, 0.70–0.99, 1.00–2.00 fledglings/occupied nest) and by four ranges of reproductive success (0–25, 26–49, 50–69, and 70–100%).

Breeding-pair Densities

Densities of breeding pairs per 10 km^2 of total lake area (water and land area) were compared among the four large lake districts. Each district consisted of its water and island areas. This unit of density was used because bald eagles built nests on islands throughout the large lakes and along the primary shorelines that define the peripheries of the lakes. The land and water areas of each lake district were obtained from the Minnesota–Ontario Boundary Waters Fisheries Atlas for Lake of the Woods, Rainy River, Rainy Lake, and Namakan Lake (*Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources 1992).

Climate Variables

Weather records were obtained from the International Falls Station of the U.S. Department of Commerce, Environmental Data and Information Service (National Oceanic and Atmospheric Administration 1993). Distances from the station, which is 19 km west of the western boundary of Voyageurs National Park, to nesting areas ranged from about 15 to 80 km. We determined mean temperature, coefficient of variation of temperature, total degree-days below 0° C, mean windchill, maximum windchill, total snowfall, and total precipitation. Mean windchill was calculated from the monthly means of temperature and monthly means of wind speed. Maximum windchill values in each month were selected from daily windchill maximums that were computed from daily minimum temperatures and daily maximum wind speeds. Dates of ice-outs were obtained from the *International Falls Daily Journal*, a local newspaper that has published local ice-out data for more than 40 years.

Nest Longevity

Nest longevity was determined by annual monitoring of the presence and condition of each nest.

Nest Distribution

The distributions of nests and breeding areas during the study were evaluated by lake district, geographic features, tree species, forest cover types, aspect (orientation to open water), distance from open water, relation to early ice-out areas, and proximity to breeding colonies of gulls.

Forest cover types that breeding bald eagles used in Voyageurs National Park during 1973–93 were compared with the distribution of forest cover types to determine if the birds had a preference for certain cover types. A map by Steigerwaldt (*1973) of 12 generalized forest and nonforest cover types in Voyageurs National Park was digitized by the Natural Resources Research Institute, University of Minnesota–Duluth. The sizes of the various cover types were then calculated with PC ARC/INFO.

The aspects (north, east, south, and west) of nests that were within 100 m of open water were determined with a compass. Distances from ice-free areas to nest sites were computed with GIS.

Because gulls may be an important prey item for bald eagles in Voyageurs National Park, we determined the proximity of eagle nests to 26 breeding colonies (>10 breeding pairs/area) of herring gulls (*Larus argentatus*) on the park's major lakes. Distances from herring gull colonies to nest sites of bald eagles were computed with GIS.

Statistical Analyses

Standard summary statistics, paired *t*-tests, linear regression analyses, and analysis of variance (ANOVA) were calculated on a microcomputer with the software package SYSTAT (Wilkinson 1990). Significance was accepted at $P \leq 0.05$ for all tests.

The instantaneous rate of growth (r) in breeding pairs was calculated with $r = [\ln(N_t/N_0)]/t$, where N_t is the population size at time t, N_0 is the initial population size, and t is the number of time periods (Ricklefs 1973).

Paired *t*-tests were used to compare the densities of bald eagle breeding pairs in the four large lake districts; and bald eagle productivity, reproductive success, and mean brood size in Voyageurs National Park and Chippewa National Forest.

Unpaired *t*-tests (Steel and Torrie 1960) were used to determine the significance of differences of reproduction and nest distribution parameters in unequal time periods. The comparisons included the number of nests in older with the number of nests in younger breeding areas, productivity and reproductive success in the four breeding seasons with the latest ice-out dates with all other breeding seasons, productivity during 1973–81 with productivity during 1982–93, and breeding pair densities in Kabetogama and Rainy lakes during 1973–81 with those in 1982–93. The test was also used to assess differences in slopes from linear regression analysis of number of breeding pairs during 1973–81 and during 1982–93.

Significance of changes in 12 reproductive parameters in three equal comparison periods (1973–79, 1980–86, and 1987–93) was determined with a one-way analysis of variance (ANOVA). Linear regression analysis was used to examine possible relations between weather in April, May, and June; ice-outs on Kabetogama and Rainy lakes; and productivity of bald eagles.

The likelihood that frequencies of occurrence of bald eagle nests may be influenced by the frequencies of occurrence of early ice-out areas and herring gull colonies was determined with a chi-square test. The analyses were conducted with the Geographic Information System software GRASS. Each test was based on the number of nests in eight distance intervals—500-m increments to 3,000 m; nests above 3,000 m were pooled—originating at either an early ice-out area or at a herring gull colony. The actual number of nests in these intervals was compared with the number of nests in the study area that were expected in each interval if all nests were evenly distributed.

A chi-square goodness-of-fit test was used to determine whether the difference between the expected use of forest cover types by bald eagles for nest sites and the actual frequency of usage of the different forest cover types was significant. Expected values for lowland and upland brush and rock outcrop cover types were pooled to meet the commonly accepted minimum sample size of five for each expected usage (Steel and Torrie 1960).

Results

Breeding Areas and Nests

From 1973 to 1993, the number of breeding areas (Table 1; Fig. 2) increased from 15 to 37; it remained constant on Namakan (6) and Sand Point (3) lakes but increased from 4 to 9 on Kabetogama Lake and from 9

Table 1. An annual summary of bald eagle (*Haliaeetus leucocephalus*) reproduction in Voyageurs National Park, Minnesota, 1973–1993.

Variable	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Breeding areas	15	16	15	17	18	17	15	15	16	18	21
Occupied nests	12	8	7	7	10	5	9	9	9	11	13
Breeding pairs	12	6	7	7	10	4	7	8	8	8	12
Active pairs	9	1	1	3	5	1	0	4	2	4	9
Fledglings	17	1	1	4	6	1	0	6	3	5	16
Productivity	1.42	0.13	0.14	0.57	0.60	0.20	0.00	0.67	0.33	0.45	1.23
Eaglets/active pair	1.42	0.16	0.14	0.57	0.60	0.25	0.00	0.75	0.38	0.63	1.33
Brood size	1.89	1.00	1.00	1.33	0.83	1.00	0.00	1.50	1.50	1.25	1.78
Total nests	17	18	19	23	23	21	21	25	26	29	34

Variable	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Breeding areas	22	24	24	29	29	29	31	31	34	35
Occupied nests	18	18	13	23	21	22	28	25	29	33
Breeding pairs	14	17	13	19	19	20	22	22	23	33
Active pairs	6	10	7	13	12	9	17	16	16	29
Fledglings	9	18	13	15	18	13	23	22	26	47
Productivity	0.50	1.00	1.00	0.65	0.86	0.59	0.82	0.88	0.90	1.42
Eaglets/active pair	0.64	1.06	1.00	0.79	0.95	0.65	1.05	1.00	1.13	1.42
Brood size	1.50	1.80	1.86	1.15	1.50	1.44	1.35	1.38	1.63	1.62
Total nests	39	42	40	49	49	42	43	42	50	58

Bald eagle (*Haliaeetus leucocephalus*) eaglets in Voyageurs National Park, Minnesota, were marked with color-coded bands after morphological measurements and blood and feather samples were collected for genetic and toxicological analysis. *Photo by T. G. Grubb.*

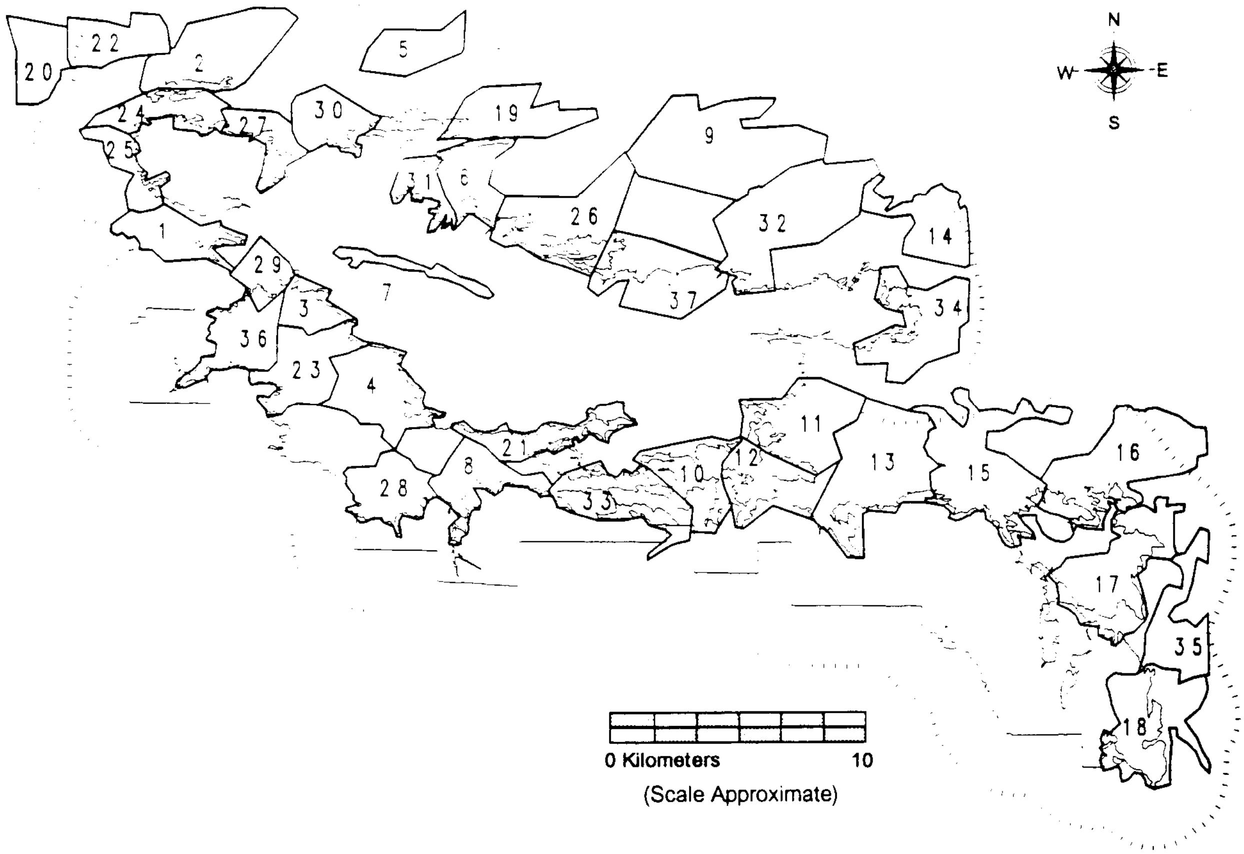


Fig. 2. The distribution of 37 breeding areas of bald eagles (*Haliaeetus leucocephalus*) in Voyageurs National Park, Minnesota, 1973–1993.

to 18 on Rainy Lake. The increases primarily occurred during 1982–93.

Ninety-nine percent of nests and 97% of breeding areas were on the four major lakes (Table 2). The largest numbers of nests and breeding areas were on Rainy Lake, which was the largest lake in the study area. Only one breeding area with one nest was on 1 of the 26 small, interior lakes that are dispersed throughout the mainland and peninsular areas of the park. Among the 37 breeding areas, the orientation of 18 (49%) was north, of 13 (35%) south, of 4 (11%) west, and of 2 (5%) east.

The number of nests per breeding area ranged from 1 to 9 (mean 3.49, SD = 2.14). More nests were in the older breeding areas than in breeding areas that were established during the last 10 years (Table 3; $t = 4.5622$, $df = 35$, $P < 0.05$). Eagles did not occupy 25 of the 129 nests.

Table 2. The distribution of nests and breeding areas of bald eagles (*Haliaeetus leucocephalus*) by lake districts in Voyageurs National Park, Minnesota, 1973–1993.

Parameter	Lake district				
	Interior	Kabetogama	Namakan	Rainy	Sand Point
Total area (ha)	1,278	10,425	11,480	33,463	3,690
Percent of area	2	17	19	56	6
Water area (ha)	1,269	9,800	10,000	30,104	3,400
Number of nests	1	30	33	52	13
Percent of nests	<1	23	26	40	10
Breeding areas	1	9	6	18	3
Percent of areas	3	24	16	49	8

Table 3. A summary of reproduction in 37 bald eagle (*Haliaeetus leucocephalus*) breeding areas in Voyageurs National Park, Minnesota, 1973–1993.

Breeding area number	Nests: Years observed	Nests: Years occupied	Pairs: Years breeding	Pairs: Years successful	Total number eaglets	Fledglings /occupied nest	Percent of successful pairs	Nests per area
1	21	14	11	6	10	0.71	43	7
2	18	12	12	5	7	0.58	42	3
3	21	18	17	11	18	1.00	61	7
4	12	12	10	6	10	0.83	50	6
5	12	11	10	6	9	0.82	55	3
6	21	13	13	8	12	0.92	62	2
7	20	0	0	0	0	0.00	0	1
8	21	9	8	7	10	1.11	78	5
9	11	11	11	9	14	1.27	82	2
10	21	19	17	9	13	0.68	47	6
11	21	9	8	3	4	0.44	33	2
12	21	13	12	7	9	0.69	54	6
13	21	13	12	8	13	1.00	62	3
14	21	13	10	5	9	0.69	38	4
15	21	17	13	3	4	0.24	18	9
16	20	6	2	1	2	0.33	17	6
17	19	18	17	10	14	0.78	56	2
18	21	13	12	10	18	1.38	77	7
19	15	13	13	7	10	0.77	54	4
20	11	11	11	7	9	0.82	64	3
21	21	7	4	3	4	0.57	43	4
22	9	2	2	0	0	0.00	0	3
23	7	5	5	4	7	1.40	80	2
24	7	6	5	3	3	0.50	50	1
25	21	11	8	6	10	0.91	55	6
26	7	6	6	4	5	0.71	67	1
27	3	3	1	1	2	0.67	33	1
28	4	4	4	3	4	1.00	75	1
29	4	3	3	2	3	1.00	67	2
30	18	8	8	5	7	0.88	63	4
31	21	1	1	1	2	2.00	100	1
32	10	9	8	5	8	0.89	56	3
33	21	5	5	3	4	0.80	60	2
34	21	6	5	1	2	0.33	17	3
35	21	3	3	2	4	1.33	67	4
36	4	4	3	2	3	0.75	50	2
37	1	1	1	1	1	1.00	100	1

Longevity and Use of Nests

The mean nest longevity was 5.5 years (SD = 4.76, range 1–21, N = 129, 715 nest years; Table 4). The mean occupancy was 3.17 years (SD = 2.78, range 1–12, n = 104, 330 occupied nest years), and the mean number of years that nests were used by breeding pairs was 3.06 (SD = 2.64, range 1–11, n = 95, 291 breeding pair years). Seventy-four percent of all nests were used by breeding pairs at least 1 year. Although nests with 1–5 years longevity were 63% of the 129 nests, eaglets fledged from 3 of 6 nests that were older than 16 years (Table 4). About 60% of the occupied nests and of the nests used by breeding pairs were used for only 1 or 2 years. Eight (22%) of the 37 breeding areas and 47 (36%) of the 129 nests were established after 1987.

Population Size and Population-size Trends

Population Size

The population of breeding adults and fledged bald eagles ranged from 11 (1978) to 113 (1993) during 21

Table 4. The longevity and use of 129 bald eagle (*Haliaeetus leucocephalus*) nests in Voyageurs National Park, Minnesota, 1973–1993.

Longevity in years	Nests Number	Nests Percent	Nests Occupied	Percent occupied	Breeding pairs	Percent active
1	25	19.4	41	39.0	38	40.0
2	18	13.9	21	20.0	21	22.1
3	11	8.5	10	9.5	6	6.3
4	18	13.9	6	5.8	7	7.4
5	9	7.0	6	5.8	6	6.3
6	7	5.4	4	3.8	3	3.2
7	9	7.0	3	2.9	5	5.3
8	6	4.7	5	4.8	3	3.2
9	3	2.3	4	3.8	3	3.2
10	2	1.6	3	2.9	2	2.1
11	5	3.9	0	0.0	1	1.1
12	3	2.3	1	0.9	0	0.0
13	3	2.3	0	0.0	0	0.0
14	3	2.3	0	0.0	0	0.0
15	0	0.0	0	0.0	0	0.0
16	0	0.0	0	0.0	0	0.0
17	1	0.8	0	0.0	0	0.0
18	3	2.3	0	0.0	0	0.0
19	1	0.8	0	0.0	0	0.0
20	0	0.0	0	0.0	0	0.0
21	2	1.6	0	0.0	0	0.0
Total	129	100.0	104	100.0	95	100.2

breeding seasons (Table 1). These figures do not include nonbreeding adults and immature eagles, which were not systematically surveyed every year. The breeding population in 1993 consisted of 33 pairs (66 adults) that had 47 known fledglings (Table 1).

Population-size Trends

The mean numbers of breeding pairs, occupied breeding areas, and fledglings increased significantly from 1973 to 1993 (Table 5; ANOVA, $P < 0.05$). During 1973–81, the breeding population was low (5–12 pairs, mean = 8.4) and variable. During 1982–93, 14 new breeding areas were established and the number of breeding pairs rose from 11 in 1982 to 33 in 1993 (mean = 21.2). Changes in the number of breeding pairs, as indicated by the slopes of the linear regressions of the number of breeding pairs on breeding season year (1973–81, slope = −0.117; 1982–93, slope = 1.783) differed significantly among the two periods ($t = 4.66$, $df = 17$, $P < 0.05$). Breeding pairs increased during 1982–93 at an annual instantaneous rate of growth (r) of 0.10.

Reproduction

Changes in Reproduction Parameters

The arithmetic means of 10 of 12 reproduction parameters from the three equal comparison periods 1973–79, 1980–86, and 1987–93 were marked by significant increases (Table 5; ANOVA, $P < 0.05$). The only two parameters that did not increase significantly were the mean number of fledglings per occupied nest (productivity) and the mean percent of breeding areas with breeding pairs.

Productivity and Reproductive Success

The average annual productivity during 21 breeding seasons was 0.68 fledglings/occupied nest (Table 5). The average annual productivity was significantly greater during 1982–93 (0.86 fledglings/occupied nest) than during 1973–81 (0.45 fledglings/occupied nest; $t = 2.264$, $df = 19$, $P < 0.05$). The number of fledglings annually increased more than 9 times during 1982–93.

The average reproductive success was 45% during 21 breeding seasons (Table 5). The average reproductive success increased significantly from 31% during 1973–79 to 44% during 1980–86 and to 61% during 1978–93 ($F = 4.169$, $df = 2.18$, $P = 0.033$).

Unsuccessful Nesting Attempts by Breeding Pairs

The number of unsuccessful nesting attempts by breeding pairs during 1973–79, 1980–86, and 1987–93 did not differ (Table 5; ANOVA: $F = 1.759$, $df = 2.18$, $P = 0.201$). However, during the same periods, the annual number of breed-

Table 5. Mean values of bald eagle (*Haliaeetus leucocephalus*) reproduction parameters in Voyageurs National Park, Minnesota, during 1973–1979, 1980–1986, 1987–1993, and 1973–1993 and summary of results of one-way analysis of variance of changes in the parameters during the three equal comparison periods.

Parameter	1973–79	1980–86	1987–93	1973–93	Range	*df*	*F*	*P*
Mean number of breeding areas	16.1	20.0	31.0	22.3	15–35	2,18	59.86	0.000
Mean number of occupied areas	8.3	13.3	25.7	15.7	5–33	2,18	45.26	0.000
Mean percent of occupied breeding areas	52	64	82	66	29–94	2,18	11.85	0.001
Mean number of breeding pairs	7.6	11.4	22.4	13.9	4–33	2,18	29.50	0.000
Mean percent of breeding areas with breeding pairs	90	88	87	89	73–100	2,18	0.22	0.807
Mean percent of occupied nests with active pairs	31	44	61	45	0–88	2,18	4.17	0.033
Mean percent of successful pairs	32	51	69	51	0–88	2,18	6.83	0.006
Mean number of active pairs	2.9	6.0	15.9	8.2	0–29	2,18	16.72	0.000
Mean number of fledglings per occupied nest	0.44	0.74	0.87	0.68	0–1.42	2,18	2.46	0.113
Mean number of eaglets per breeding pair	0.45	0.82	1.00	0.76	0–1.42	2,18	4.19	0.032
Mean number of eaglets per active pair	1.01	1.60	1.44	1.35	0–1.89	2,18	4.93	0.020
Mean number of annual fledglings	4.30	10.00	23.40	12.6	0–47	2,18	10.23	0.001

ing pairs increased from 4 to 33. As a result, the mean percent of unsuccessful nesting attempts by breeding pairs decreased significantly from 68% during 1973–79 to 49% during 1980–86 and to 32% during 1987–93 (ANOVA: $F = 6.832$, $df = 2,18$, $P = 0.006$).

Productivity and Reproductive Success by Breeding Area

Mean productivity among the 37 breeding areas of Voyageurs National Park ranged from 0.00 to 2.00 fledglings/occupied nest (Table 3). Mean productivity in 13 of the 37 breeding areas was between 0.00 and 0.69 fledglings/occupied nest, between 0.70 and 0.99 in 13 breeding areas, and greater than 0.99 in 11 breeding areas (Fig. 3). Seven of those 11 breeding areas were observed during more than 10 years. At least one breeding area where the mean productivity value was greater than 0.99 fledglings/occupied nest was in all the lake districts except in the interior district (the district with the 26 small lakes of the park).

The mean reproductive success among the 37 breeding areas of Voyageurs National Park ranged from 0 to 100% (Table 3). The mean reproductive success in 5 of the 37 breeding areas was between 0 and 25%, between 26 and 49% in 7 breeding areas, between 50 and 69% in 18 breeding areas, and greater than 70% in seven (19%) of the breeding areas (Fig. 4). The average reproductive success was greater than 70% in at least one breeding area in each of the Rainy, Kabetogama, and Sand Point lake districts.

Comparison of Reproduction by Lake Districts

During the study, 183 (69%) eaglets were hatched at Rainy and Kabetogama lakes, which were the only lake districts where the number of occupied breeding areas increased (Fig. 5). The largest number of occupied breeding areas (151) and the number of fledglings (120) during the 21 breeding seasons were in the Rainy Lake District (Fig. 5). The total number of occupied breeding areas on

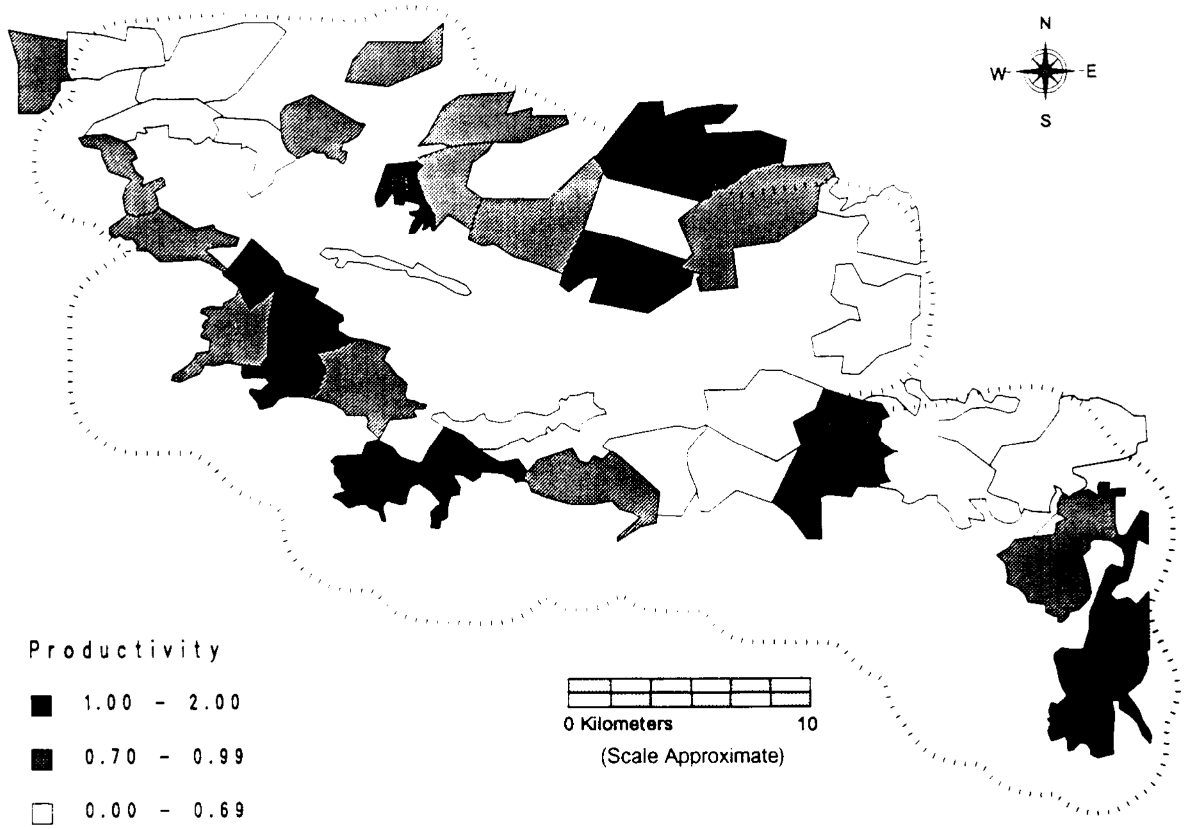


Fig. 3. The distribution of breeding areas of bald eagles (*Haliaeetus leucocephalus*) according to the average number of eaglets per occupied area in three ranges in Voyageurs National Park, Minnesota, 1973–1993.

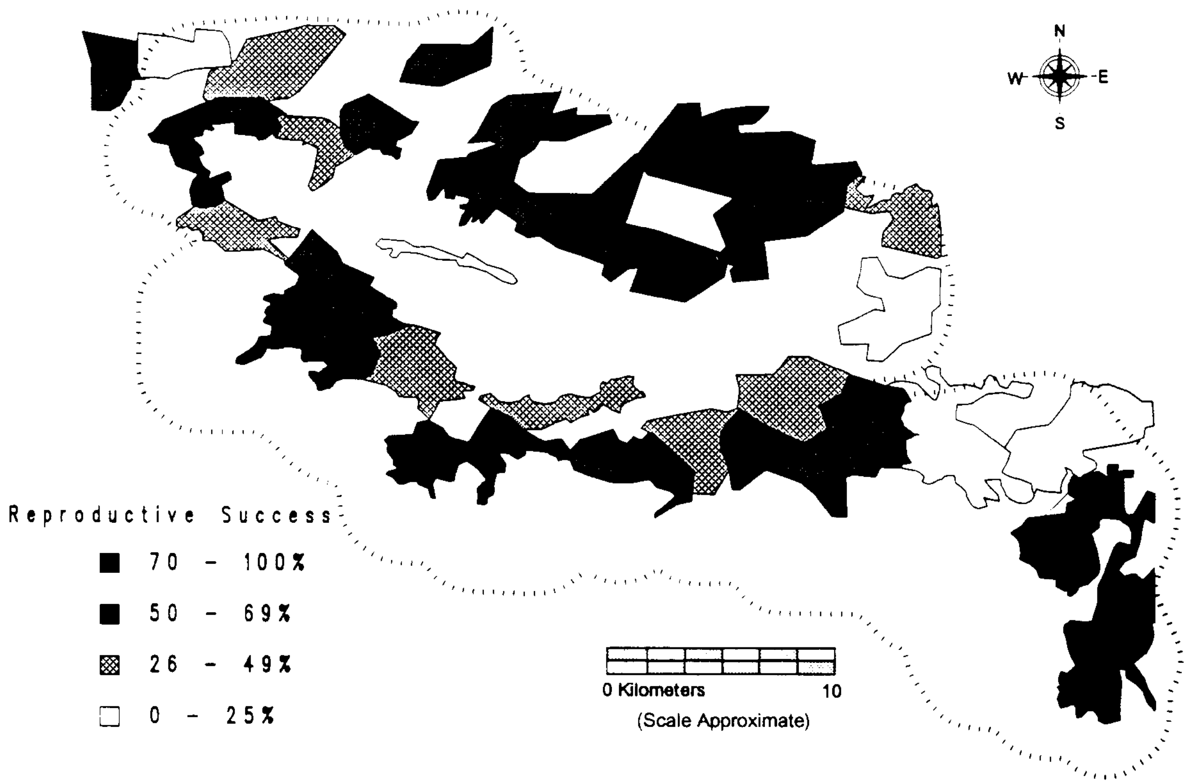


Fig. 4. The distribution of breeding areas of bald eagles (*Haliaeetus leucocephalus*) according to reproductive success in four ranges in Voyageurs National Park, Minnesota, 1973–1993.

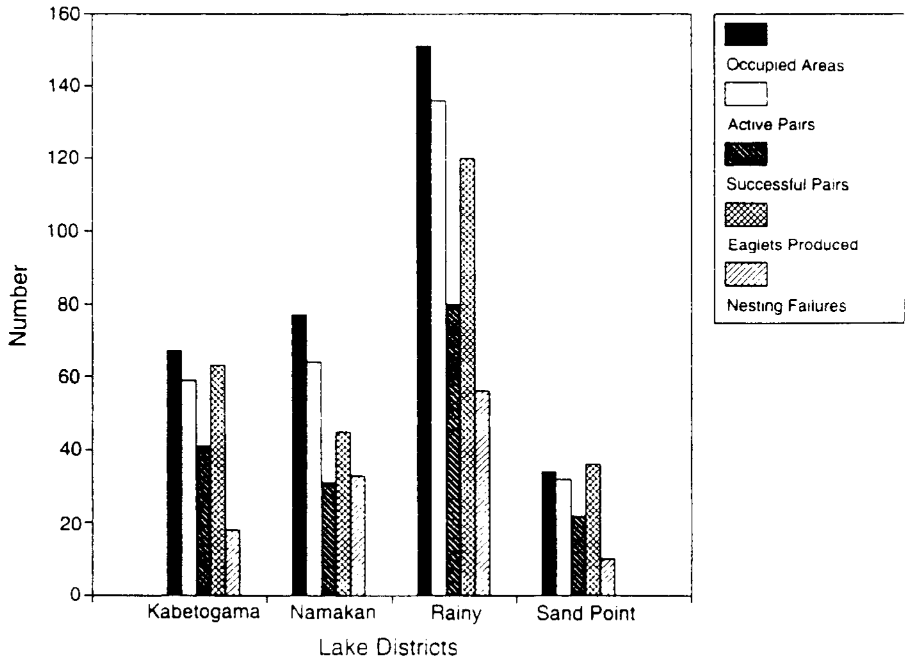


Fig. 5. A comparison of five reproductive parameters of bald eagles (*Haliaeetus leucocephalus*) by major lake districts in Voyageurs National Park, Minnesota, 1973–1993.

Namakan Lake (77) was similar to that on Kabetogama Lake (67). However, more pairs (41) were successful and more eaglets (63) fledged at Kabetogama Lake than at Namakan Lake (31;45). Unsuccessful nesting attempts were high (33, 52%) at the Namakan Lake; the mean productivity was only 0.58 fledglings/occupied nest (Fig. 6). The highest average number of fledglings per occupied nest (1.06) and the highest average reproductive success (65%) were at Sand Point Lake, where the number of breeding areas was only three. Brood size throughout the four major lake districts was relatively consistent (1.45–1.64 eaglets/successful breeding pair; Fig. 6).

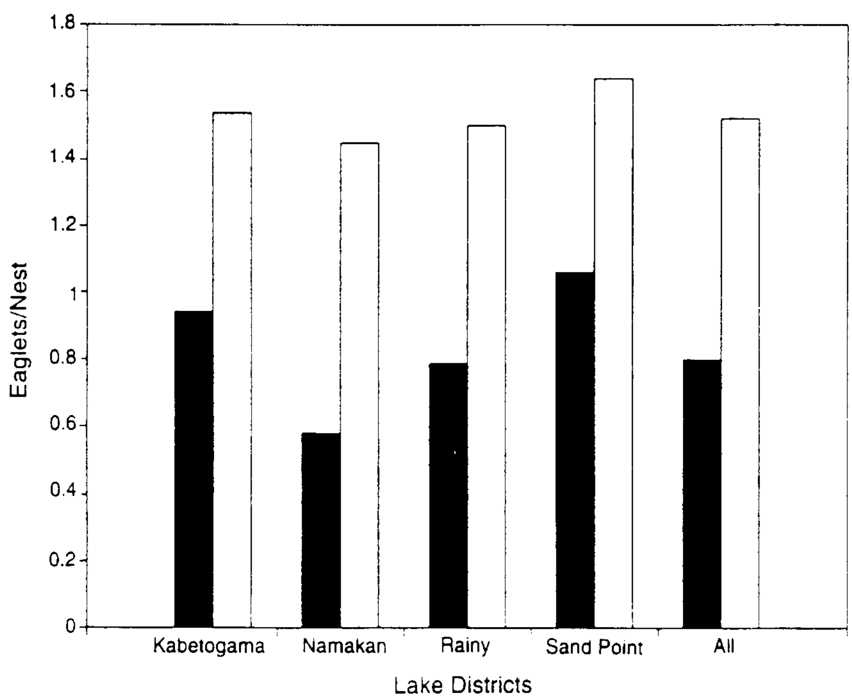


Fig. 6. A comparison of productivity (■) and mean brood size (□) of bald eagles (*Haliaeetus leucocephalus*) by major lake districts in Voyageurs National Park, Minnesota, 1973–1993.

Climate Effects

Relations were significant between only two of the seven climate-related variables and the reproduction of bald eagles, although the degree of interrelation between the temperature variables was high. Inverse relations were significant between number of fledglings per occupied nest and the total number of degree-days that were below 0° C in April, May, and June ($r = -0.438$, $P = 0.047$, $N = 21$) and the ice-out date of Rainy Lake ($r = -0.443$, $P = 0.045$, $N = 21$). The relation with ice-out on Kabetogama Lake, which usually occurs 4 to 5 days before ice-out of Rainy Lake, approached significance ($r = -0.394$, $P = 0.077$, $N = 21$). On Rainy Lake, the latest observed ice-out dates were 10 May (1975, 1978), 11 May (1974), and 12 May (1979). Productivity and reproductive success in these years when ice-out was 10 to 12 days later than average were 0.13 and 13% (1974), 0.14 and 14% (1975), 0.20 and 20% (1978), and 0.00 and 0% (1979). Productivity and reproductive success were significantly lower in these four breeding seasons than in all other breeding seasons (productivity: $t = 4.4529$, $df = 19$; $P < 0.001$; reproductive success: $t = 5.0962$, $df = 19$; $P < 0.001$).

Nest Distribution

Density

The mean density of breeding pairs in all lake districts and in all breeding areas (1973–93, $N = 330$) was 0.3 pairs/10 km^2 (Table 6). The density of breeding pairs ranged from less than 0.1 to 0.9 pairs/10 km^2. The mean breeding-pair densities during 1973–93 ranged from 0.43 pairs/10 km^2 on the smallest lake, Sand Point Lake, to 0.23 pairs/10 km^2 on the largest lake, Rainy Lake. The mean breeding pair densities were significantly higher during 1973–93 on Sand Point Lake than on Namakan Lake ($t = 2.129$, $df = 20$, $P = 0.046$) and on Rainy Lake ($t = 6.093$, $df = 20$, $P = 0.000$). The mean breeding pair densities were also significantly higher on Kabetogama and Namakan lakes than on Rainy Lake (Kabetogama Lake: $t = 2.630$, $df = 20$, $P = 0.016$; Namakan Lake: $t = 3.746$, $df = 20$, $P = 0.001$). The average densities of breeding pairs on Rainy and Kabetogama lakes were significantly higher (Rainy Lake: $t = 6.1839$, $df = 19$, $P < 0.05$; Kabetogama Lake: $t = 4.230$, $df = 19$, $P < 0.05$) during 1982–93 than during 1973–81. The highest densities (0.7–0.9 pairs/10 km^2) were on Kabetogama Lake during 1990–93. The densities in the Namakan and Sand Point lake districts during 1973–93 were relatively stable without evident trends. No breeding pairs occupied the 26 interior lakes.

Tree Species and Forest Cover Types

Of the 23 tree species identified by Kurmis et al. (*1979) in Voyageurs National Park, bald eagles built nests in 4 species. Eastern white pines were selected for most nests (116, 90%) and red pines (10, 8%), aspens (2, 1%), and white

Table 6. The density of bald eagle (*Haliaeetus leucocephalus*) breeding pairs per 10 km^2 by lake district in Voyageurs National Park, Minnesota, 1973–1993.

Year	Lake district				Total
	Kabetogama	Namakan	Rainy	Sand Point	
1973	0.1	0.4	0.2	0.5	0.2
1974	0.1	0.4	0.03	0.3	0.11
1975	0.1	0.4	0.03	0.3	0.1
1976	0.2	0.3	0.03	0.3	0.1
1977	0.2	0.3	0.1	0.3	0.2
1978	0.0	0.0	0.1	0.3	0.1
1979	0.0	0.4	0.1	0.5	0.2
1980	0.1	0.4	0.1	0.3	0.2
1981	0.1	0.3	0.1	0.5	0.2
1982	0.1	0.3	0.2	0.5	0.2
1983	0.3	0.4	0.2	0.3	0.2
1984	0.3	0.4	0.3	0.3	0.3
1985	0.3	0.3	0.3	0.8	0.3
1986	0.3	0.2	0.2	0.5	0.2
1987	0.4	0.5	0.3	0.5	0.4
1988	0.5	0.4	0.3	0.5	0.4
1989	0.4	0.4	0.4	0.5	0.4
1990	0.9	0.3	0.4	0.5	0.5
1991	0.7	0.4	0.4	0.3	0.4
1992	0.8	0.4	0.5	0.5	0.5
1993	0.9	0.5	0.5	0.5	0.6

Table 7. Forest cover types used by bald eagles (*Haliaeetus leucocephalus*) for nests in Voyageurs National Park, Minnesota, 1973–1993.

Forest cover type[a]	Nests: Number	Nests: Percent	Percent of type	Difference
Aspen/paper birch	27	20.9	46.4	−26.4
Balsam/white spruce	25	19.4	11.2	+ 8.2
Pine/red, eastern white, jack	71	55.0	16.5	+38.5
Lowland brush	3	2.3	9.4	−7.1
Upland brush	1	0.8	0.1	+ 0.7
Rock outcrop	2	1.6	0.1	−1.5
Other cover types	0	0.0	16.3	−16.3
Total	129	100.0	100.0	

[a] Vegetation classification by Steigerwaldt 1973.

spruce (1, <1%) for the remaining nests. All trees were in the supercanopy stratum and alive when the nests were built.

Nests were built in 6 of the 12 forest cover types (Table 7). Pine cover types were selected for 71 (55%) nests. The observed use of pine and balsam/spruce cover types for nests was greater than the expected use (Table 7; chi-square test for goodness of fit: $\chi^2 = 170.61$, $df = 4$, $P < 0.001$). In the 37 breeding areas, breeding pairs used pine cover types in 15 areas (41%), the balsam/spruce cover type in 7 areas (19%), and the aspen/birch cover type in 5 areas (14%). The cover in 10 breeding areas (27%) were mixtures of types.

Geographic Location

In the four major lake districts, bald eagles built 82 (64%) nests on islands and 46 (36%) nests on the mainland shorelines of those lakes. Islands with nests were part of island clusters near shallow bays and narrows. Mainland sites were on points and peninsulas similar to islands that were in juxtaposition to island clusters near shallow bays and narrows. The only nest on an interior lake was located on the mainland. Ninety-one of the 129 nests were inside the park boundaries. No nests were found near the Browns, Grassy, and Staege bays of Sand Point Lake or at the Johnson, Little Johnson, and Spring lakes, all of which are along the southeastern border of the park. Neither were nests found in the Mica Bay and in the Squaw and Squirrel narrows regions above the Kettle and Squirrel Falls dams on Namakan Lake.

Distance and Orientation to Open Water

In Voyageurs National Park, breeding bald eagles are usually seen over the water, near shorelines, and on land within 200 m of shorelines of the major lakes where the nests and breeding areas are concentrated. The mean distance from all 129 nests to a lake shoreline was 92.5 m (SD = 140, range 6–805 m). One hundred five (81%) nests were within 100 m, and 118 (92%) nests were within 200 m of a lake shoreline (Fig. 7). The mean distance to the shoreline of the nests within 100 m was 41.6 m (SD = 21.7, range 6–100 m), and the mean distance of those within 200 m was 56.7 m (SD = 48.6, range 6–200 m). Two-thirds of 105 nests within 100 m of open water had south- or west-facing aspects (Table 8).

Proximity to Early Ice-out Areas

Nests were not randomly distributed relative to the location of areas that become ice-free early in the spring (chi-square test: $\chi^2 = 150.775$, $df = 7$, $P < 0.001$). Forty-three (40%) nests were within 0.5 km of early ice-free areas, 59 (46%) within 1.0 km, and 78 (60%) within 1.5 km (Fig. 8). Only 20 nests (16%) were more than 3.0 km from the ice-free areas.

Proximity to Herring Gull Colonies

Nests were also not randomly distributed relative to the location of herring gull colonies (chi-square test: $\chi^2 = 66.979$, $df = 7$, $P < 0.001$). Twenty-two of the 129 bald eagle nests were within 1,000–2,000 m of herring gull colonies. Only five nests were expected to occur in this distance interval if all nests had been evenly distributed in the study area.

Discussion

Population Dynamics and Reproductive Biology

Although the population dynamics of bald eagles are probably more sensitive to changes in survival rates than to changes in reproduction (Young 1968; Grier 1980; Buehler

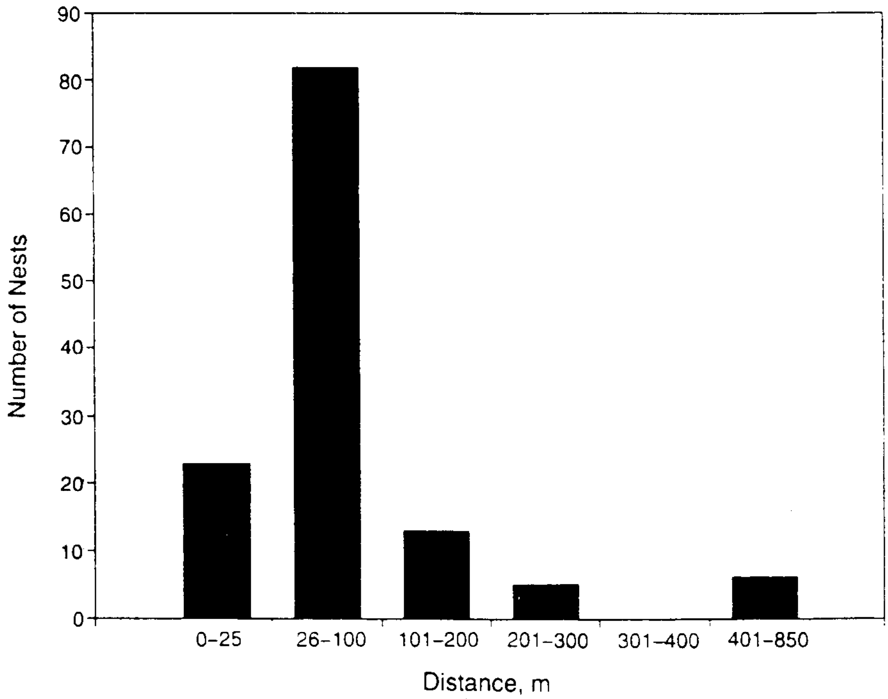


Fig. 7. The distance of nests (N = 129) of bald eagles (*Haliaeetus leucocephalus*) to lake shorelines in Voyageurs National Park, Minnesota, 1973–1993.

et al. 1991), there is a continued need for information on reproduction. Grier (1980), while emphasizing the need for survival estimates, stressed that additional information on reproduction is needed to assess temporal variation and to improve our understanding of this component of the species' life history.

Biologists, although debating what levels of reproduction and survival are needed to sustain eagle populations for long periods, agree that trends in reproduction such as we observed are more accurate indicators of population status than annual productivity and reproductive success values (Wiemeyer et al. 1984). Annual surveys are more suitable than surveys at less frequent intervals for assessing trends (Grubb et al. 1983). Trends, however, must be applied with caution when they are of small bald eagle populations such as the population in Voyageurs National Park (Kozie and Anderson 1991) because chance events may determine the fate of small populations (Grier 1980).

The bald eagles in Voyageurs National Park are part of an expanding regional population in the states and provinces that are adjacent to the Great Lakes basin (Bowerman 1993) that we believe contributed significantly to the threefold increase of the bald eagle population in the park during the study. The number of breeding and fledgling bald eagles increased from 41 to 113 between 1973 and 1993. The entire population was probably larger because it included nonbreeding adults and immature birds we did not survey. Large numbers of nonbreeding adults in some bald eagle populations have been reported (Hansen and Hodges 1985). Although the specific source of new breeders to the park's population is unknown, Lewis (*1992) suggested that the birds' emigration to Voyageurs National Park may affect the recovery of the regional bald eagle population by stripping away the productivity from adjacent more productive and successful subpopulations. If this is true, the regional subpopulations could be viewed as source populations and the park population as a sink population (Wiens and Rotenberry 1981). Whether the emigration to the park is adversely affecting the regional population as Lewis (*1992) suggested, however, is debatable. Pulliam (1988) argued that active dispersal from productive source populations can maintain large sink populations and that such dispersal may

Table 8. Aspect[a] of bald eagle (*Haliaeetus leucocephalus*) nests (n = 105) within 100 m of lakeshore in Voyageurs National Park, Minnesota, 1973–1993.

	North	South	East	West	Total
Number of nests	25	35	10	35	105
Percent	23.4	33.3	10.0	33.3	100

[a] The direction from the nest site to open water.

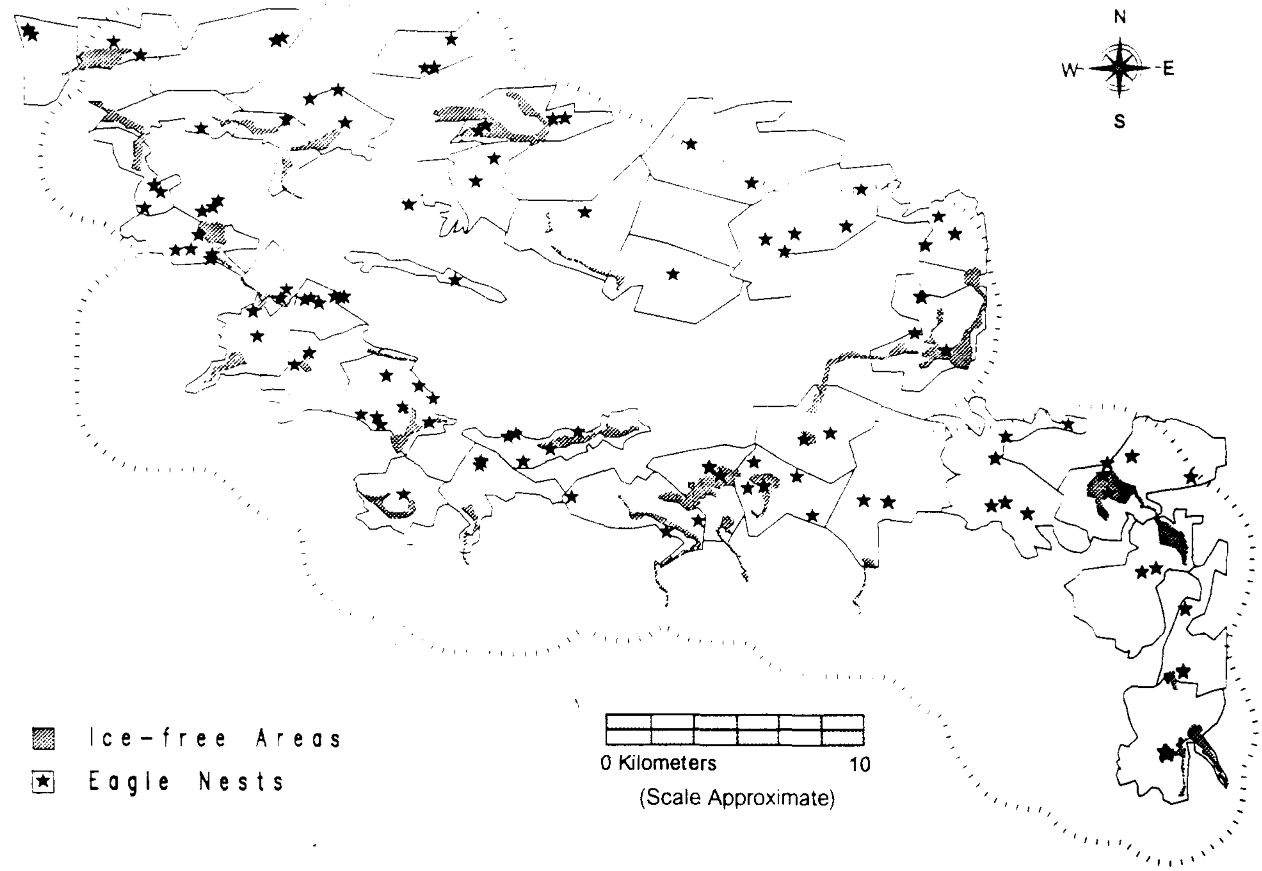


Fig. 8. The distribution of nests of bald eagles (*Haliaeetus leucocephalus*) relative to areas in the major lakes that become ice-free before ice-out in Voyageurs National Park, Minnesota, 1973–1993.

even be evolutionarily stable. To actually determine whether such a source–sink relation exists requires detailed demographic studies (Wiens and Rotenberry 1981).

The increase of the bald eagle population in Voyageurs National Park was concurrent with the establishment of 14 new breeding areas, significant reductions in unsuccessful nesting attempts by breeding pairs, and substantial increases in average productivity and reproductive success. Most improvements occurred during 1982–93. In 1993, the average productivity and the average reproductive success were the highest recorded in 21 breeding seasons. Despite these increases, the average productivity (0.68 fledglings/occupied nest) and the average reproductive success (45%) from 1973 to 1993 did not meet the reproduction criteria of Sprunt et al. (1973) for stable bald eagle populations (0.70 fledglings/occupied nest and 50% reproductive success). Neither did they meet the suggested criteria of Wiemeyer et al. (1984) and Sindelar (*1988) for a healthy bald eagle population (1 fledgling/occupied nest and 70% reproductive success). Productivity and reproductive success in Voyageurs National Park were below the criteria of Sprunt et al. (1973) in 57% and 52% of the survey years and below the criteria of Wiemeyer et al. (1984) and Sindelar (*1988) in 76% and 90% of the survey years.

Although Sprunt et al.'s (1973) reproductive standards for population stability are generally accepted, we believe the standards that Wiemeyer et al. (1984) and Sindelar (*1988) suggested are more applicable to Voyageurs National Park. Their standards were based on the reproduction of the bald eagles that were repopulating Wisconsin's historical inland breeding range. This situation seems analogous to that in Voyageurs National Park. Standards of Sprunt et al. (1973) were based on six widely dispersed populations from throughout the United States, three that were declining and three that were considered stable. Their criteria were also developed when the nationwide bald eagle reproduction was being suppressed by organochlorine pesticides (Grier 1982).

The average productivity and the average reproductive success of the bald eagles in Voyageurs National Park were also well below the average values of bald eagle populations in northwestern Ontario (Grier 1982), in inland Wisconsin (*Sindelar 1988), and in the nearby Chippewa National Forest, Minnesota (*Mathisen 1993). In the Chippewa National Forest, a steadily growing population, which had an

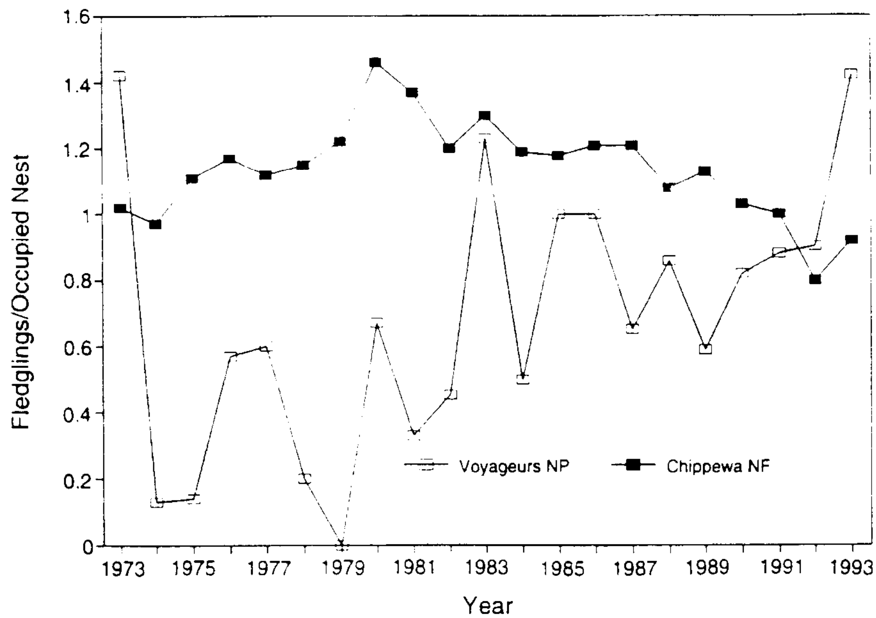


Fig. 9. A comparison of productivity of bald eagles (*Haliaeetus leucocephalus*) in Voyageurs National Park (□) and in the Chippewa National Forest (■), Minnesota, 1973–1993 (Chippewa data from Mathisen 1993).

average productivity and reproductive success well above that considered necessary for population stability, exceeded the average productivity of bald eagles in Voyageurs National Park in 18 of 21 breeding seasons and the average reproductive success in 17 of 21 breeding seasons. Comparisons of three reproduction parameters during 1973–93 of bald eagles from the two areas revealed lower productivity ($t = 4.438$, $df = 20$, $P = 0.000$; Fig. 9), brood size ($t = 3.089$, $df = 20$, $P = 0.006$; Fig. 10) and reproductive success ($t = 4.297$, $df = 20$, $P = 0.000$; Fig. 11) of bald eagles in Voyageurs National Park. Most exceptions occurred in the latter portion of the comparison period when productivity was increasing in Voyageurs National Park and decreasing in the Chippewa National Forest. The recent decline of productivity of the population in the Chippewa National Forest may be the result of high population densities and may be an example of animals responding to an expanding population (*Mathisen 1992).

Although 10 of 12 reproduction parameters increased consistently throughout the last 11 years of our study, the average annual productivity of the bald eagle population in Voyageurs National Park was below the overall average

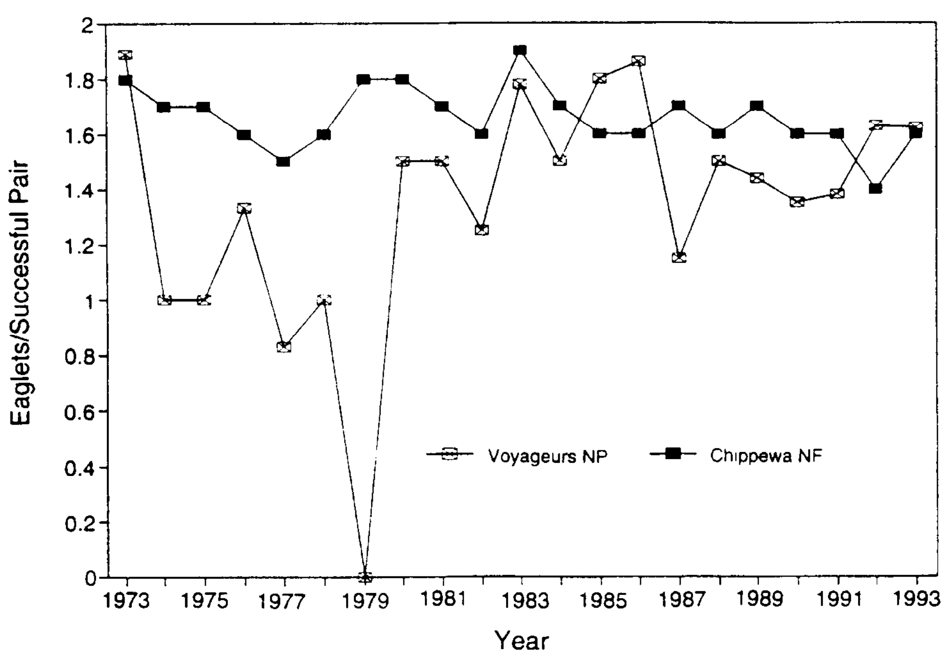


Fig. 10. A comparison of brood sizes of bald eagles (*Haliaeetus leucocephalus*) in Voyageurs National Park (□) and in the Chippewa National Forest (■), Minnesota, 1973–1993 (Chippewa data from Mathisen 1993).

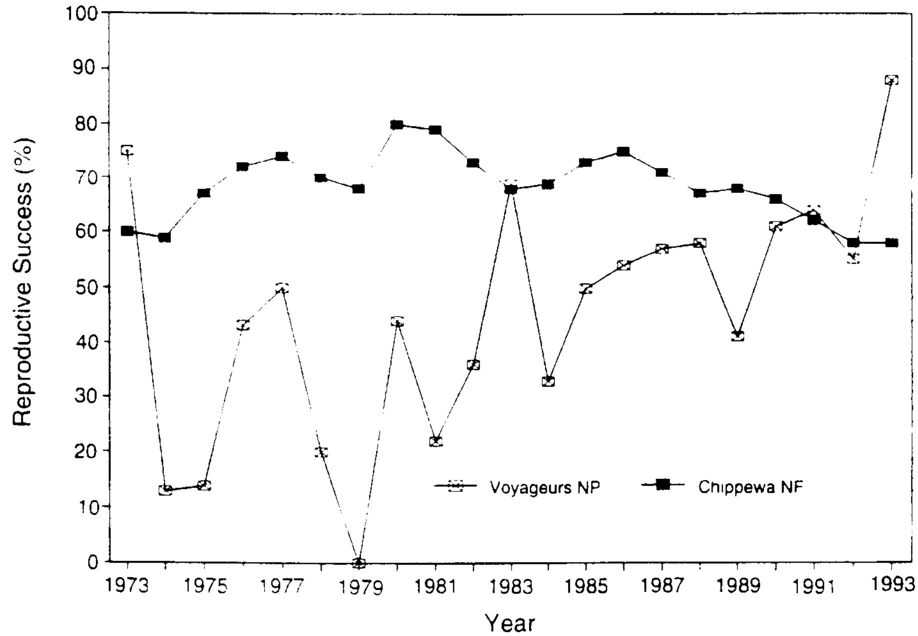


Fig. 11. A comparison of reproductive success of bald eagles (*Haliaeetus leucocephalus*) in Voyageurs National Park (□) and in the Chippewa National Forest (■), Minnesota, 1973–1993 (Chippewa data from Mathisen 1993).

annual productivity of the regional population (Bowerman 1993). For the bald eagle population in Voyageurs National Park to be self-sustaining and healthy, we believe that productivity and reproductive success will have to consistently reach or exceed the levels in the latter portion of our study. Until such levels are sustained, future increases in the park's population will seemingly remain dependent on emigrants from the more productive and successful regional population. Population sustainability and health will also be dependent on adequate survival rates and ultimately on the carrying capacity of Voyageurs National Park for bald eagles.

Because specific data (survival and mortality rates, emigration and immigration) were not available, the carrying capacity for bald eagles in the study area was not determined. However, the fact that the breeding-pair densities per 10 km^2 and number of breeding areas on Namakan and Sand Point lakes remained constant for 21 breeding seasons, suggested a realized carrying capacity on those lakes. The increases in density on the Kabetogama and Rainy lakes suggested their carrying capacities were not realized during the study. Conceivably, if the population continues to grow at the rate that was observed from 1982 to 1993, the carrying capacities of the major lake districts could be realized, and as a result, new breeding areas may be established in previously unoccupied areas. The small sizes of the interior lakes in Voyageurs National Park may preclude the use of these lakes by breeding bald eagles. In central Saskatchewan and Manitoba, where habitats are similar to those in the park, lakes with less than 11 km of shoreline did not provide primary breeding habitat for bald eagles (Whitfield et al. 1974).

Nest Distribution

The bald eagles in Voyageurs National Park were particular about where they established breeding areas and nests. Like nests throughout the range of the bald eagle (Gerrard and Bortolotti 1988), nests in the study area were concentrated along the shorelines of major lakes; only one nest was on 1 of the 26 small, interior lakes. Two-thirds of the nests were on islands in island clusters in the northern portions of the four major lakes. The remaining nests were on island-like points and peninsulas on the mainland, usually near offshore island clusters. The aspects of eagle nests to open water were primarily to the south and west, reflecting the strong influence of bedrock orientation on lake basin and island orientation and characteristics. A preferred westerly aspect was also observed of bald eagle nests in northern Saskatchewan and in Manitoba (Gerrard et al. 1975), whereas aspects of nests in the Chippewa National Forest seemed to be random (Mathisen 1983).

Most nests are in park areas that are proposed for wilderness designation (*U.S. National Park Service 1992). Bald eagles did not nest in three areas in the Voyageurs National Park study area (Mica Bay; Squirrel and Squaw narrows on Namakan Lake; Browns, Grassy, and Staege bays on Sand Point Lake; and Johnson, Little Johnson, and Spring lakes at the park's southeastern boundary) with similar habitats. No explanation for this was apparent.

Ninety percent of the bald eagle nests were in supercanopy eastern white pines, and 55% of the nests were in pine forest cover. The areas and trees that are currently used are the result of past natural fires and apparent lack of logging. Large volumes of pine were removed by logging in the early 1900's; however, the intensity and extent of logging varied throughout the park (Coffman et al. 1980). Fire management by the park includes provisions for prescribed burns and prescribed natural fire (fires that are started by a natural source and allowed to burn as long as they meet prescription standards; U.S. National Park Service 1989). Both fire types should accelerate the initiation or generate the growth of the pine forest cover and the nest trees that bald eagles prefer.

The well documented preference of bald eagles for nests near water that becomes ice-free early in spring (Swenson 1975; Swenson et al. 1986; Gerrard and Bortolotti 1988) was also apparent in Voyageurs National Park. More than 60% of the nests were within 1.5 km of lake areas where ice-out occurs earlier than on the main lakes. Ice-out in these preferred areas typically occurs in late March or in early April, whereas the main portions of the lakes are usually not ice-free before 1 May (range 17 April to 16 May). In mild winters, the preferred areas, which are commonly in narrows and in other areas with substantial currents, often remain ice-free throughout much of the winter.

The disproportionately large number of bald eagle nests within 1–2 km of herring gull colonies suggests that bald eagles in Voyageurs National Park are opportunistic feeders, exploiting the available food resources. Bald eagles that perch and forage in the gull colonies are commonly observed, and the proportion of avian prey in the bald eagle diet in the park was closer to that of bald eagles nesting along ocean and Great Lakes coasts than that of bald eagles in inland areas (Todd et al. 1982; Bowerman 1993).

Possible Limiting Factors of Bald Eagle Reproduction

Toxic Contaminants

Birds such as bald eagles that are terminal consumers in aquatic communities can bioaccumulate contaminant residues at levels that can impair reproduction (Niemi et al. 1986). Some chlorinated hydrocarbon compounds can impair a bird's ability to produce viable eggs or may be teratogenic (Wiemeyer et al. 1984; Kubiak et al. 1989; Gilbertson et al. 1991; Bowerman 1993). North American bald eagle populations declined substantially during the 1950's and—concurrent with the use of persistent organochlorine contaminants—remained depressed well into the 1970's (Wiemeyer et al. 1972, 1984; Kozie and Anderson 1991). The bald eagle population in Voyageurs National Park, like those that Grier (1982) observed in nearby northwestern Ontario, were probably also included in this pervasive trend. During 1958 and 1961, approximately 5,265 ha of forest land, now in Voyageurs National Park, were treated with 1,1,1-trichloro-2,2-bis(4-chlorophenyl)-ethane (DDT) to control the eastern spruce budworm (*Choristoneura fumiferana* [Clem.]; *Minnesota Department of Agriculture and United States Forest Service 1973). After the United States banned the use of DDT in 1972, bald eagle populations throughout North America began recovering from depressed reproduction and began returning to healthy population sizes (Grier 1982; Wiemeyer et al. 1984).

However, the population recovery was not uniform throughout the bald eagle's range. Sindelar (*1988), Bowerman et al. (1990), Bowerman (1991), and Kozie and Anderson (1991) documented that populations on the Great Lakes shoreline like the population in Voyageurs National Park consistently failed to produce young at the population static of 1.0 fledglings/occupied nest, the productivity level that Wiemeyer et al. (1984) attributed to healthy, uncontaminated populations. Concentrations of PCBs and 1,1-dichloro-2,2-bis(p-chlorophenyl)-ethane (DDE) in blood and egg samples from bald eagles at the Great Lakes shorelines were greater than known threshold concentrations related to reproductive problems (Bowerman 1991). Productivity and reproductive success were consistently higher in nearby inland populations, which had lower contaminant levels (Wiemeyer et al. 1984; Kozie 1986; *Sindelar 1988).

Organochlorine contaminants may have also limited bald eagle reproduction in Voyageurs National Park (Bowerman et al. 1993). Geometric mean concentrations of p,p′-DDE and PCBs in plasma samples from bald eagle eaglets in Voyageurs National Park—although lower than levels in eaglets from the Great Lakes—were higher than in eaglets from other inland populations in the Great Lakes basin (Table 9; Bowerman 1993). The productivity and reproductive success of bald eagles that nested at the Great Lakes and in Voyageurs National Park were significantly less than the productivity and reproductive success of bald eagles that used interior nests in Michigan or in Minnesota (Bowerman 1993).

Productivity and reproductive success in 10 subpopulations in the Great Lakes basin, including Voyageurs National Park, significantly and inversely correlated with geometric mean concentrations of PCBs and p,p′-DDE in plasma of bald eagle eaglets (Bowerman 1993). Overall productivity significantly and inversely correlated with geometric mean concentrations of PCBs ($R^2 = 0.869$, $P = 0.0003$) and p,p′-DDE ($R^2 = 0.945$, $P = 0.0001$). Overall reproductive success rates significantly and inversely correlated with geometric mean concentrations of PCBs ($R^2 = 0.840$, $P = 0.0005$) and p,p′-DDE ($R^2 = 0.923$, $P = 0.0001$). An abandoned bald eagle egg collected in 1990 in the park had p,p′-DDE and PCB concentrations that were above the threshold for reproductive failure. A bald eagle eaglet with a bill

Table 9. Geometric mean, standard deviation, range, and frequency of detectable concentrations of total polychlorinated biphenyls (PCBs) and 1,1-dichloro-2,2-bis(p-chlorophenyl)-ethane (p,p-DDE) in plasma of 309 bald eagle (*Haliaeetus leucocephalus*) nestlings from 10 subpopulations in the upper Midwest, 1987–1993 (Bowerman 1993).

		Total PCBs				p,p-DDE			
Area[a]	*n*	Geometric mean (μg/kg)	SD	Range	Frequency (%)	Geometric mean (μg/kg)	SD	Range	Frequency (%)
CNF	43	7	2	<10–67	23	3	2	<5–29	19
SNF	15	5	1	<10–18	7	3	1	<5–8	13
VNP	21	47	4	<10–1,615	91	20	3	<5–206	95
LP	49	31	2	<10–200	96	10	2	<5–193	86
EUP	16	32	2	<10–146	94	12	2	<5–24	94
WUP	48	25	3	<10–177	88	10	3	<5–245	79
LS	45	127	2	12–640	100	25	3	<5–306	89
LM	25	154	2	14–628	100	35	2	<5–235	100
LH	12	105	3	5–928	100	25	3	<5–78	92
LE	35	199	2	81–1,325	100	22	3	<5–429	100

[a] Areas were the Chippewa National Forest (CNF) and the Superior National Forests (SNF), and Voyageurs National Park (VNP), Minnesota; Lower (LP), eastern Upper (EUP), and western Upper (WUP) peninsulas of Michigan; and Lakes Superior (LS), Michigan (LM), Huron (LH), and Erie (LE).

deformity commonly related to high contaminant levels was observed at a Namakan Lake nest site in 1989 (K. Kozie, park wildlife biologist, personal communication).

Concentrations of p,p′-DDE and PCBs in the plasma of eaglets reflect exposure to these compounds from the prey species in the breeding area (Frenzel 1985). In 1993, potential fish and bird prey species were collected in Voyageurs National Park to assess the possible level of exposure to bald eagles from contaminants in their preferred prey (K. Ensor and S. Smith, U.S. Fish and Wildlife Service, personal communication). Herring gulls, which contributed to elevated contaminant levels in bald eagles at the Apostle Islands National Lakeshore on Lake Superior (Kozie and Anderson 1991), were collected from several Voyageurs National Park colonies. The colonies, some of which contain hundreds of breeding gull pairs, are in U.S. and Canadian waters in the study area. Gulls are seemingly an important prey item because about 34% of Voyageurs National Park eagle nests visited during banding of eaglets contained gull remains (Bowerman 1993). Fishes, which may also contribute to elevated contaminant levels in eagles (Frenzel 1985), were collected from areas adjoining active eagle nests.

High mercury levels have also been a concern in regard to bald eagle reproduction in Voyageurs National Park. Total mercury levels in eaglet breast feathers collected in Voyageurs National Park in 1989 averaged 20.2 mg/kg and ranged from 5.2 to 27.0 mg/kg (n = 8; Bowerman 1993). The mean level from Voyageurs National Park was 2 to 6 times higher than levels in samples from the Great Lakes and from the Upper and Lower peninsulas of Michigan (Bowerman 1993). The source of the mercury seemed to be the fishes on which eagles prey. High mercury levels in fishes from many lakes in northeastern Minnesota, including 14 lakes in Voyageurs National Park, have caused the Minnesota Department of Health to issue fish consumption advisories (*Minnesota Department of Health 1993). Mercury levels in the northern pike (*Esox lucius*), a preferred prey of eagles (Bowerman 1993), exceed 1.0 mg/kg in three of the park's four major lakes (*Minnesota Department of Natural Resources 1994).

Assessing the effects of elevated mercury levels on populations of nesting bald eagles is complicated by the presence of organochlorine compounds (Frenzel 1985). Although Bowerman (1993) found significant correlations between the number of young per occupied nest and percent of successful breeding attempts and PCB and p,p′-DDE levels in bald eagles in the Great Lakes and in Voyageurs National Park, he observed no significant correlations with mercury concentrations. Research findings that linked problems with reproduction in white-tailed eagles (*Haliaeetus albicilla*) to mercury levels (Berg et al. 1966) were subsequently refuted when information on p,p′-DDE and PCB concentrations became available (Koivusaari et al. 1980; Helander et al. 1982). The lack of information on additive or synergistic effects of the three contaminants, however, precludes the certainty that mercury does or does not affect bald eagle reproduction. The effects of mercury, particularly in areas with relatively high concentrations such as Voyageurs National Park, may become evident if organochlorine concentrations in the environment decrease (Frenzel 1985).

The importance of a vulnerable, relatively uncontaminated forage base is imperative to successful reproduction in bald eagles. Despite the fact that PCB and DDT use has ceased in North America and concentrations of most halogenated hydrocarbons in the prey of bald eagles has decreased in the Great Lakes region (Giesy et al. 1993), current concentrations of PCBs and p,p′-DDE are high enough to affect reproduction of bald eagles in the Great Lakes and in Voyageurs National Park (Bowerman 1993). Management that controls populations of prey species of bald eagles must take into account the effect that increases or decreases in contaminated species has on bald eagle reproduction. The need to maintain uncontaminated populations of preferred fish species is imperative for maintaining the continuing recovery of bald eagles.

Human Disturbance

Human activity in breeding and wintering areas of bald eagles is one of many cumulative, potentially detrimental effects on breeding-area occupancy, reproduction, perching, foraging, and nest placement (Grubb and King 1991; McGarigal et al. 1991). However, not all human activities are detrimental. Studies of human disturbance in the Chippewa National Forest where breeding areas have buffer zones revealed that logging, recreation, and research adjacent to primary buffer zones did not harm bald eagle reproduction (Mathisen 1968; Fraser et al. 1985). Investigator-induced effects from approaching and climbing to nests have also not harmed reproduction of bald eagles (Grier 1969; Bortolotti et al. 1985). Disturbance thresholds in bald eagles are more commonly exceeded by a multivariate complex of disturbance factors (Grubb and King 1991).

During the bald eagle breeding season, more than 95% of the annual human visitation of Voyageurs National Park takes place on the major lake surfaces and on land within 200 m of the shoreline (*Eibler 1991). Because most eagle nests and breeding areas are in these areas, they are susceptible to disturbance by visitors, park staff, and private property owners. Visitor action–eagle response was monitored at two nests with eaglets in June and July of 1992 (*Fink 1992). Human disturbances at the sites were from motorboats (68%), fishing boats (13%), aircraft (15%), camping (2.5%), and unknown sources (1.5%; $n = 248$). Disturbance thresholds to each activity varied. The smaller of two eaglets at one site died during the observation period. Whether or not human disturbance contributed to its death is unknown; its sibling was healthy and fledged. Fink's observations did not cover all the critical periods of the bald eagle breeding cycle, and therefore the potential effects of human disturbance earlier in the breeding cycle were not assessed. Vulnerability of bald eagles and other raptors to disturbance is greatest in the earlier stages of egg laying and during incubation (Mathisen 1968; Fyfe and Olendorff 1976).

Kabetogama Lake—although only 17% of the park's water area—receives 60% of the park's total visitation (*Eibler 1991; Voyageurs National Park public use statistics, unpublished). As a result, the probability for human disturbance of eagles is highest there. However, the relatively high level of human use of Kabetogama Lake seemingly did not harm the productivity and the reproductive success of the bald eagles from 1982 to 1993. The number of breeding areas increased by 125%, and breeding-pair densities increased from 0.4 to 0.9 pairs/10 km^2. Productivity increased from 0.22 to 1.05 fledglings/occupied nest, and reproductive success increased from 22 to 66%; unsuccessful nesting of breeding pairs, however, decreased from 77 to 24%. These improvements occurred although the number of motorized vehicles, aerial surveys, and research and management activities increased (*Eibler 1991).

Despite these improvements, long-term studies are needed to test the effectiveness of the reduction of human-eagle interactions by management. Since the establishment of the park in 1975, management—as recommended by the Northern States Bald Eagle Recovery Plan (*Grier et al. 1983)—has primarily consisted of establishing 0.4-km buffer zones around occupied nests to exclude visitors. Because the responses by bald eagles to disturbances vary among populations, management must be determined by population (Grubb et al. 1992).

Bald eagles may also benefit from management guidelines that the U.S. Fish and Wildlife Service and the National Park Service developed in 1992 for the protection of the threatened eastern gray wolf (*Canis lupus*). The guidelines were designed to protect the wolves from human disturbance on the major lakes in Voyageurs National Park during winter and spring, before ice-out (*Lewis 1992). The guidelines directed the park administration to close portions of the major lakes to motorized vehicles, primarily snowmobiles, so that the wolves would not be distracted from hunting and killing prey near shorelines or on the ice surfaces. Bald eagles that search for food or have breeding areas inside these closed zones would also benefit from the reduction of needless energy drains from responses to human activity (Stalmaster 1983). In winter, bald eagles may not return to a food source from which they were displaced by human activity for several hours or for the remainder of that day (Stalmaster and Newman 1978; Skagen et al. 1991).

Food Availability

The importance of food availability for bald eagles before egg laying and during incubation and brooding was documented by Swenson et al. (1986), Gerrard and Bortolotti (1988), and Kozie and Anderson (1991). Correlations have been reported between food abundance and nesting and earlier laying (Hansen 1987), reproductive success (Bowerman 1991), and bald eagle densities (Dzus and Gerrard 1993). Clutch size was not related to food availability in a bald eagle population in southeastern Alaska (Hansen 1987). Whether food availability reduces bald eagle productivity and reproductive success by limiting the initiation of breeding activity or clutch abandonment is an unresolved issue (Gerrard and Bortolotti 1988).

Bortolotti (1986) concluded that the growth rates of bald eagle eaglets were determined by the quantity of energy in food and that the frequency with which prey was brought to the nest was an indicator of available prey. Regular placement of food supplements in foraging areas significantly improved the survival of bald eagle eaglets (Hansen 1987).

Severe environmental conditions, such as those that commonly occur in Voyageurs National Park in winter and spring, may limit food availability. The importance of ungulates and fishes as a food supply for bald eagles in the park has been recognized (Cole 1987). Eagles frequently feed on white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) that were killed by eastern gray wolves and on beaver (*Castor canadensis*) carcasses that trappers leave on ice surfaces. Offal on the ice from recreational fishing also attracts eagles to certain areas. During their egg laying and incubation period, bald eagles prey on herring gulls, which return to their breeding colonies in late March and early April or about 30 days before ice-out of the major lakes. A rapidly increasing ring-billed gull (*Larus delawarensis*) population in Voyageurs National Park provides eagles with an additional prey base that was not present in the park before the mid-1980's. Waterfowl, common loons, and double-crested cormorants (*Phalacrocorax auritus*), previously observed as prey items of bald eagles (Gerrard and Bortolotti 1988), concentrate in early open water areas where eagles frequently forage. Eagles also frequently capture and feed on white suckers (*Catostomus commersoni*) that are making their spawning run up small streams.

The only quantitative information about food habits of bald eagles in Voyageurs National Park was based on prey remains from in and around 44 eagle nests (Bowerman 1993). The most frequent prey items were suckers, northern pikes, and gulls. Remains of suckers and northern pikes were in about two-thirds of the nests and remains of gulls, in about one-third of the nests. The relative importance of fishes and gulls in the diet of bald eagles may not be accurately portrayed by this sampling method because mammalian and avian bones, fur, feathers, and other remains are more persistent than fishes. Consequently, fish prey tends to be underestimated and mammalian and avian prey overestimated from ocular examinations (Mersmann et al. 1992).

Our qualitative information and Bowerman's (1993) results are not adequate to test Cole's (1987) hypothesis on food as a limiting factor of productivity and reproductive success in the bald eagles in Voyageurs National Park. To test that hypothesis, quantitative studies of food availability, particularly in early spring and throughout the time eagles are in the park, are needed.

Climate

Severe spring weather has been implicated as a factor that can reduce reproduction in bald eagles by either its effect on food availability or by direct physical harm of the adult birds or their offspring (Gerrard and Whitfield 1979; Swenson et al. 1986; Gerrard and Bortolotti 1988). The bald eagles in Voyageurs National Park are commonly exposed to severe weather during egg laying and incubation and until eaglets gain thermal regulatory independence (late March to mid-June). Climatic effects on bald eagle reproduction in Voyageurs National Park were primarily related to temperature variables; reproduction was significantly reduced in years with the latest ice-out dates and the highest number of degree-days below 0° C during early spring. Spring weather was most severe, ice-outs were latest, and productivity was lowest in the 1970's. Productivity in 1975, a year with severe spring weather, was low not only in Voyageurs National Park but also in northern Saskatchewan, Canada (Gerrard and Whitfield 1979), and in the Yellowstone National Park area (Swenson et al. 1986). Spring snows, which reduce reproduction of bald eagles in Yellowstone National Park (Swenson et al. 1986), seemed not to be a factor in Voyageurs National Park.

Conclusions

We suspect that a complex of variables in Voyageurs National Park and in its vicinity kept the bald eagle population from realizing higher average productivity and reproductive success during 1973–93. Toxic contaminants, human disturbance, severe weather in early spring, and low prey availability may be to blame. An expanding regional population probably contributed to the recent increase of the population size of bald eagles at Voyageurs National Park. To sustain those gains requires adequate levels of reproduction and survivorship or continued recruitment from the regional population.

Recommended Management

Implementation of the resources management action plan of Voyageurs National Park is imperative to inform park visitors, private landowners, concessionaires, and neighbors of the ecology of bald eagles and to reduce adverse human effects on the bald eagle population. In coordination with the bald eagle resources management action plan, technological aids such as GIS should be used for the management of the bald eagles in the park. A full complement of GIS tools such as spatial analysis and surface modeling should enable park managers to develop and implement site-specific management for each breeding area to protect bald eagles from park developments and disturbance by visitors. GIS is expected to enhance the efficacy of integrating monitoring and future research, thereby helping with the identification of habitat availability and suitability in the park.

Recommended Research

Long-term monitoring of nesting and nest placement by bald eagles should be continued. Other aspects of the bald eagle life cycle in Voyageurs National Park must be investigated to better understand the relation between humans and eagles and their environment. Information about the total bald eagle population in the park, including the breeding and nonbreeding individuals, should systematically be gathered throughout the year.

Survivorship and emigration and immigration in the Voyageurs National Park population should be determined. Quantitative studies of the amount and timing of food availability, particularly in early spring, are needed. Data that allow the determination of carrying capacity for bald eagles in the study area should be gathered.

The potential effects of human disturbance during all the critical periods of the bald eagle life cycle in Voyageurs National Park must be assessed. Specific studies are needed to identify essential perching and foraging areas of bald eagles in summer and in winter to develop strategies for closing buffer zones around these areas and in water areas adjacent to nests. Existing models (Grubb and King 1991; Montopoli and Anderson 1991) could be used to assess the influence of human disturbance on bald eagles and define new management criteria that further minimize adverse human–bald eagle interactions.

The differences in productivity and reproductive success of the bald eagles in the major lake districts could be assessed with the habitat suitability index model developed by Peterson (1986). However, a more thorough analysis could be made by combining the results of the food, disturbance, and contaminant studies with more detailed information on forest characteristics. Measurements of availability of potential nest trees and nest-tree heights above the canopy are needed to assess the significance for nest site selection and for modeling viewsheds. The research results could then be used to assess the cumulative effects of the complex of variables that we suspect kept the park's bald eagle population from realizing higher average productivity and average reproductive success during 1973–93.

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