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USE OF NEST BOXES BY BARROW'S GOLDENEYES: NESTING SUCCESS AND EFFECT ON THE BREEDING POPULATION

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Nest boxes have been used extensively to enhance production of cavity-nesting waterfowl (Schreiner and Hendrickson 1951, McLaughlin and Grice 1952, Johnson 1967), and to establish populations of wood ducks (*Aix sponsa*) and common goldeneyes (*Bucephala clangula*) (Doty and Kruse 1972, Dennis and Dow 1984). Barrow's goldeneyes (*Bucephala islandica*) are known to use nest boxes (Savard 1982*a*), but there are no reported studies of their breeding success in areas where nest boxes have been provided.

The objectives of my study were (1) to identify and quantify factors influencing the use of nest boxes by Barrow's goldeneyes; (2) to determine the reproductive success of Barrow's goldeneyes in nest boxes; and (3) to assess the effect of nest boxes on size of the breeding population.

METHODS

Between 1981 and 1984, I erected 278 nest boxes in a 100-km^2 area 40 km west of Williams Lake, British Columbia. Boxes erected in 1981 and 1982 were larger ($23 \times 30 \times 61$ cm, hole diam of 12 cm, $n = 183$) than those added in 1983 and 1984 ($19 \times 25 \times 40$ cm, $n = 95$). My analyses combine both types of boxes because Barrow's goldeneyes used them equally ($\chi^2 = 0.078$, 1 df, $P = 0.78$).

Boxes were nailed on trees so the entrance was 4–5 m aboveground. Wood shavings were added as nest material. Trees close to the water's edge were selected whenever possible, but boxes ranged from 0 to 400 m from the water's edge because several ponds were surrounded by open grassland. I added boxes each year to ensure a surplus. I placed these boxes near existing boxes, or in similar habitat, to minimize habitat dif-

Table 1. Number of nest boxes used by breeding wildlife in central British Columbia, 1981–1984.

Breeding species	1981	1982	1983	1984	Total
Barrow's goldeneye	37	90	117	132	376
American kestrel	24	14	10	20	68
European starling	27	5	22	14	68
Red squirrel[a]	6	2	5	3	16
Tree swallow (*Tachycineta bicolor*)		2	2		4
Northern flicker (*Colaptes auratus*)	1		1		2
Bufflehead			1	1	2
Mountain bluebird (*Sialia currucoides*)			1		1
Boxes not used	41	44	37	82	204
Boxes available	136	157	196	252	741

[a] Not always breeding.

ferences between existing (old) and newly installed (new) boxes.

I checked nest boxes twice (during incubation and after hatching) in 1981, and 3–10 times (at least once after hatching) in 1982–1984. In 1984, 30 occupied boxes were visited daily to estimate extent of parasitic egg laying. I estimated clutch initiation dates by assuming an incubation period of 30 days (Palmer 1976), and a laying rate of 1 egg/day.

I counted breeding pairs 4–5 times between 1 May and 20 May each year from 1980 through 1984. Isolated pairs, isolated lone males, and isolated lone females were considered to represent a breeding pair. I averaged these counts to obtain an estimate of the breeding population. Birds were counted from shore with a spotting scope, and each count took from 2 to 2.5 days to complete. After ducklings had hatched, I surveyed ponds 3–4 times to count the number of broods on the study area.

Brood count data were pooled to derive a single yearly estimate of the number of broods because hatching extended over several weeks and some broods were not observed during all surveys. Most broods could be identified individually by a combination of their location, age of the young, and number of young. Broods of Barrow's goldeneyes often use territories for several weeks (Savard 1982*b*). This, along with their habit of swimming to open water when disturbed, greatly facilitated counts. Savard (1981) showed that >80% of broods present in an area could be located after 2 counts.

I defined successful nests as those in which ≥1 egg hatched. Any box containing Barrow's goldeneye eggs was considered to have been used by this species. Unsuccessful nests were classified as either preyed upon (≥1 egg disappeared or destroyed) or deserted (no sign of egg removal).

RESULTS

Use of Nest Boxes

Three species accounted for 96% of 537 nesting attempts recorded in boxes during 4 years: Barrow's goldeneyes (70%), American kestrels (*Falco sparverius*) (13%), and European starlings (*Sturnus vulgaris*) (13%) (Table 1). Only 2 buffleheads (*Bucephala albeola*) nested in boxes, and both were unsuccessful. From 19 to 33% of the boxes were not used each year (Table 1).

Use of nest boxes by Barrow's goldeneyes increased 257% from 1981 to 1984 (Table 1). Barrow's goldeneyes used old boxes, which had been erected for several years, more than new ones (Fig. 1). Nest boxes used by Barrow's goldeneyes were more likely to be used the following year (76%, $n = 225$) than those not used (58%, $n = 234$; $\chi^2 = 17.2$, 1 df, $P < 0.001$). Also, boxes in which Barrow's goldeneyes successfully hatched a brood were reused proportionally more often by goldeneyes (90%, $n = 90$) than boxes in which the reproductive attempt failed (67%, $n = 135$; $\chi^2 = 15.3$, 1 df, $P < 0.001$).

Reproductive Success of Barrow's Goldeneyes

Nesting Success.—On the average over 4 years, 46% (SE = 4) of the Barrow's goldeneye nests were successful, 31% (SE = 3) were preyed upon, and 23% (SE = 3) were deserted. These proportions did not differ among years ($\chi^2 = 10.07$, 3 df, $P = 0.12$).

Predation was an important cause of nest failure. Black bears (*Ursus americanus*) destroyed 27 nest boxes during the study, 17 of them occupied by incubating goldeneyes. Bear predation occurred throughout the study area and probably involved several different bears. Black bears usually attacked occupied nest boxes (85% of attacks) and often left nearby unoccupied boxes intact. There was no predation by black bears in 1980, but in 1982, 1983, and 1984 they accounted for 13, 9, and 32%, respectively, of the predation cases. Black bears may become a significant problem in the future.

Some predators (I suspected pine martens [*Martes americana*] and red squirrels [*Tamiasciurus hudsonicus*]) removed eggs one at a time from boxes and accounted for the remaining cases of predation. Partial predation of a clutch did not necessarily cause desertion, but all nests in which yolk spilled on the other eggs were deserted. Besides the boxes destroyed by black bears, 5 were lost when their support tree fell down naturally, 3 were felled by beavers (*Castor canadensis*), 1 was felled by loggers, and 1 was destroyed by vandals.

Nesting success was independent of the length of time nest boxes had been erected ($\chi^2 = 11.5$, 3 df, $P > 0.05$). Most desertions were not caused by observer interference, as proportionately more desertions occurred either before nest checks or in nests where females were absent during the checks (54%, $n = 136$) than in nests where females were present (9%, $n = 266$; $\chi^2 = 95.4$, 1 df, $P < 0.001$). For nest boxes where clutch initiation dates could be determined, I divided initiation dates each year in 4 equal parts: early, mid-early, mid-late, and late. Because the proportion of successful nests did not differ significantly among years, I pooled data within each category. The proportion of successful nests did not differ between early (66%, $n = 82$) and mid-early (52%, $n = 82$) clutches ($\chi^2 = 3.05$, 1 df, $P = 0.09$) or between mid-late (35%, $n = 80$) and late (33%, $n = 80$) clutches ($\chi^2 = 0.11$, 1 df, $P = 0.74$), but was greater in combined early vs. combined late clutches ($\chi^2 = 20.99$, 1 df, $P < 0.001$). Among the 173 nests that failed, the proportion of deserted nests did not differ among clutch initiation periods ($\chi^2 = 1.70$, 3 df, $P = 0.64$). Of the nest boxes that were used 2 consecutive years by Barrow's goldeneyes, those that were successful the first year were more likely to be successful the second year ($n = 81$, 57% success in year 2) than those that were unsuccessful the first year ($n = 90$, 38% success in year 2; $\chi^2 = 5.78$, 1 df, $P = 0.016$).

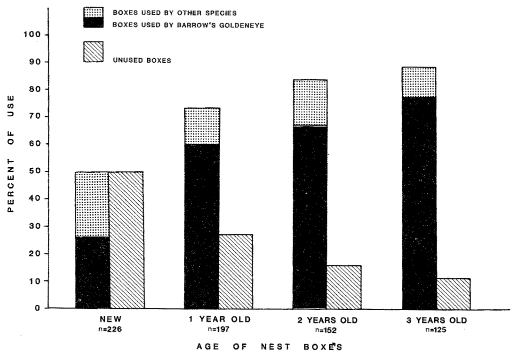

Fig. 1. Age of nest boxes and use by Barrow's goldeneyes and other wildlife in central British Columbia, 1981–1984.

Productivity.—The number of eggs laid in nest boxes increased 6-fold from 1981 to 1984 (Table 2). Average clutch sizes were significantly lower in the first 2 years even if deserted and preyed upon clutches are excluded (Table 2). Clutch sizes in new and 1-year-old nest boxes did not differ significantly, but were smaller than clutches in 2- and 3-year-old boxes (Table 3). A similar result was obtained when only successful nests were compared. The proportion of eggs that hatched was lowest in 1-year-old boxes and highest in 3-year-old boxes. Nest boxes that were not used by Barrow's goldeneyes in the previous year contained smaller clutches ($\bar{x} = 9.1$, SE = 0.5, $n = 50$) than those that had been used, whether the nesting attempt was successful ($\bar{x} = 13.0$, SE = 0.1, $n = 46$) or not ($\bar{x} = 12.2$, SE = 0.7, $n = 35$) (Newman-Keuls multiple range test, $P < 0.05$).

Parasitic Egg Laying.—Parasitic laying was frequent in the monitored population (40%, 12 of 30 boxes). If clutches of >13 eggs are assumed to result from parasitic laying, as in-

Table 2. Number and fate of Barrow's goldeneye eggs in nest boxes in central British Columbia, 1981–1984.

Year	No. of boxes[a]	No. of eggs	% of eggs: Hatched	% of eggs: Preyed upon	% of eggs: Deserted	Clutch size, All nests: $\bar{x}$	All nests: SE	Successful nests only: $\bar{x}$	Successful nests only: SE	Successful nests only: n
1981	33	217	65	10	26	6.6 A[b]	0.6	7.8 A	0.7	19
1982	89	646	42	22	36	7.3 A	0.4	9.2 A	0.7	34
1983	115	1,127	42	13	45	9.8 B	0.4	12.8 B	0.6	42
1984	131	1,265	46	18	36	9.7 B	0.4	11.1 B	0.5	62

[a] Only nest boxes that contained clutches of known fate.
[b] Means with similar letters were not significantly different (Newman-Keuls multiple range test, $P < 0.05$).

dicated by follicle counts of breeding females (J. M. Eadie, Univ. British Columbia, pers. commun.), the frequency of parasitic laying was 7% ($n = 41$) in 1981, 7% ($n = 99$) in 1982, 20% ($n = 124$) in 1983, and 19% ($n = 145$) in 1984. These estimates are conservative, because clutches deserted as a result of parasitism would not be included unless they were deserted after they had >13 eggs. Also, nest parasitism does not always result in larger clutches. Five (42%) of the parasitized nests had clutches <14 eggs. Also, 9 nests (30%) had clutches >13 eggs, and of these, only 1 had no obvious sign of parasitism. Most nests were parasitized during egg laying; only 2 of 12 nests were parasitized after initiation of incubation.

Population Size

In 1980, the year before the erection of nest boxes, the population of Barrow's goldeneyes was estimated at 212 (SE = 10) pairs. By 1984, the Barrow's goldeneye population had increased to 322 (SE = 8) pairs, a significant increase of 52% (ANOVA, $F = 29.4$, $P < 0.001$). There was no significant difference in numbers of goldeneye pairs in 1980, 1981, and 1982; but numbers of Barrow's goldeneye pairs increased significantly in 1983, 2 years after the erection of the first nest boxes, and in 1984 (Newman-Keuls test, $P < 0.05$).

Brood counts reflected the increase in Barrow's goldeneye pairs. The number of broods was similar in 1980 (84) and 1981 (84), but increased in 1982 (87), 1983 (95), and 1984 (110), an increase of 29%.

DISCUSSION

The use of nest boxes by Barrow's goldeneyes was determined by a combination of previous use, outcome of previous breeding attempts, and age of box. Nest boxes used in previous years were likely to be reused the following years, especially when nests were successful. Similar patterns of use were found in common goldeneyes (Eriksson 1979; Dow and Fredga 1983, 1985) and in buffleheads (Erskine 1961). A surplus of nesting cavities is important because females often change boxes

Table 3. Age of nest boxes and Barrow's goldeneye egg production in central British Columbia, 1981–1984.

	% of eggs: Hatched	% of eggs: Preyed upon	% of eggs: Deserted	No. of eggs	Mean clutch size: All nests[a]	n	Successful nests only	n
New boxes	48	14	38	355	6.6 A[b]	54	7.7 A	24
1-year-old boxes	34	21	45	895	7.6 A	118	9.1 A	39
2-year-old boxes	47	12	41	1,023	10.2 B	100	12.6 B	43
3-year-old boxes	53	17	30	974	10.3 B	95	11.8 B	51

[a] Only nest boxes that contained clutches of known fate.
[b] Means with similar letters were not significantly different (Newman-Keuls multiple range test, $P < 0.05$).

after an unsuccessful nesting attempt and as a means of reducing interspecific competition for nest sites.

Boxes erected for >1 year received more use from Barrow's goldeneyes than newly installed boxes. This is because most subadult females and unsuccessful females select nest sites the year before breeding (Eadie and Gauthier 1985). Boxes installed in the spring were therefore not available at the time of nest-site selection. Nest-site philopatry by breeding females, especially those that nested successfully the previous year, also contributes to greater use of old boxes.

Reproductive Success

Early clutches were more likely to hatch than late ones, possibly reflecting earlier breeding by older and more experienced birds (Krapu and Doty 1979, Afton 1984). The average clutch size of Barrow's goldeneyes in nest boxes was lower in the first 2 years than in the last 2 years of my study. Also, clutches were smaller in new and 1-year-old nest boxes, probably because a large proportion of young breeders used new boxes. In some waterfowl species, young breeders are known to produce smaller clutches than older birds (Heusmann 1975, Dow and Fredga 1984).

Intraspecific nest parasitism was frequent. The high rate of desertion observed in this study may have been related to nest parasitism, as with other cavity-nesting waterfowl (Grenquist 1963, Jones and Leopold 1967, Pienkowski and Evans 1982).

The percentage of successful Barrow's goldeneye nests ($\bar{x}$ = 46%, SE = 5, n = 4) was within the range reported for other cavity-nesting waterfowl: common goldeneye, 62% (Johnson 1967), 27% (Eriksson 1979), 42% (Bragin 1981); bufflehead, 78% (Erskine 1972), 46% (Gauthier 1985); wood duck, 75% (Naylor 1960, Morse and Wight 1969), 29% (Jones and Leopold 1967, Strange et al. 1971); and black-bellied whistling duck (*Dendrocygna autumnalis*), 61% (Bolen 1967), 31% (McCamant and Bolen 1979). High variability in hatching success within and between species indicates that nest-box programs should be monitored closely when first implemented to identify potential problems. Predation accounted for approximately 30% of clutch losses in Barrow's goldeneyes; thus, hatching success could be significantly increased by the use of predator-proof nest boxes. Nest success increased from 44 to 77% after installation of predator guards on black-bellied whistling duck boxes (Bolen 1967). However, there is no known deterrent for black bears. Also, it remains to be determined if predator guards would be cost efficient. Erection of nest boxes over water may prove more efficient as water may deter most terrestrial predators.

Population Size

My results suggest that nest boxes increased the number of Barrow's goldeneyes breeding in the area. Pair numbers increased about 50% in 4 years following installation of nest boxes. The increase began in 1983, 3 years after the first erection of boxes. This coincides with the year that young produced in 1981 were old enough to enter the breeding population. Although no direct controls were used in this study, 2 lines of evidence support, to various degrees, the conclusion that the increase in goldeneye numbers was due in part to the erection of nest boxes. First, the number of buffleheads in the study area did not increase during the same period, although survival of bufflehead ducklings was higher than that of Barrow's goldeneyes (Savard 1986). Second, counts conducted by Ducks Unlimited in central British Columbia during the same period and with similar methods (Wishart et al. 1983) did not indicate any increase in the goldeneye population (Table 4). The difference between the number of Barrow's goldeneyes and the number of buffleheads increased steadily in the study area, but not in Ducks Unlimited counts.

Table 4. Breeding pair counts of Barrow's goldeneyes and buffleheads in central British Columbia, 1980–1984.

Area	Year	No. of Barrow's goldeneye pairs	No. of bufflehead pairs	Goldeneye pairs minus bufflehead pairs
A[a]	1980	67	47	20
	1981	69	58	11
	1983	69	46	23
B	1980	28	23	15
	1981	39	43	−4
	1983[b]	60	69	−9
C	1980	26	5	21
	1981	26	9	15
	1982	29	37	−8
	1983	27	8	19
D	1980	33	21	12
	1982	40	67	−27
	1983	43	32	11
E	1982	78	87	−9
	1983	70	115	−45
	1984	49	55	−6
F	1980	212	126	86
	1981	201	125	76
	1982	201	171	30
	1983	265	123	142
	1984	322	155	167

[a] Areas: A = Bald Mountain, 148 Mile House; B = Chilco; C = Rosehill and Merrit; D = 70 Mile House; E = Chilcotin; F = study area. Areas A–E censused by Ducks Unlimited.

[b] Several new ponds suitable for diving ducks probably led to similar increases in both goldeneye and bufflehead numbers.

Thus, whatever caused the increase in the number of Barrow's goldeneyes in the study area did not cause a similar increase in bufflehead or goldeneye numbers in adjacent areas.

Gauthier (1985) and Peterson and Gauthier (1985) found a scarcity of large natural cavities in the aspen parkland of British Columbia; an adequate supply of cavities was present for buffleheads (0.8/ha), but only 12% of 135 cavities had an opening large enough for Barrow's goldeneye (0.1/ha).

Siren (1951) and Johnson (1967) reported an increase in common goldeneye densities after the installation of nest boxes. Gauthier and Smith (1987) found that bufflehead density did not increase with provision of additional nest sites and suggested that territorial behavior limited the population. Territorial behavior did not seem to influence nest-box use by Barrow's goldeneye. Aggression of paired drakes on territories did not deter females from using adjacent nest boxes. Nest boxes a few meters apart were used by different females. Because territorial aggression is centered on the territory and not on the nest site, any impact of territorial behavior on nest-box use will be indirect through an overall limiting effect on the population. Because Barrow's goldeneye can use nest sites >2 km away from their breeding territory (Munro 1939, Savard 1987), the effect of territorial behavior on the number of pairs should be minimal in areas where water bodies are abundant. In my study, because the population apparently was limited by nest sites, it may take a few more years before any influence of territorial behavior on nest-box use is detected.

SUMMARY

I studied reproductive success of Barrow's goldeneyes nesting in boxes and assessed the effect of nest boxes on the population from 1981 to 1984 in central British Columbia. Use of nest boxes by Barrow's goldeneye increased from 37 in 1981 to 132 in 1984. Proportions of nests that hatched, were preyed upon, and were deserted were similar among years and averaged 46, 31, and 23%, respectively. Nest-box use and clutch size were affected by previous use, outcome of previous breeding attempt, and age of nest box. Clutch sizes were significantly lower in the first 2 years of the study than in the last 2 years. Early clutches were more likely to hatch than late ones. Similarly, new nest boxes contained smaller clutches ($\bar{x}$ = 6.6) than old boxes ($\bar{x}$ = 10.2). Intraspecific nest parasitism was common (40%). Breeding pair density of Barrow's goldeneye increased significantly from 212 in 1980 to 322 in 1984, suggesting that nest sites may have been in short supply in the study area before the erection of nest boxes.

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FACTORS AFFECTING NEST-BOX USE BY BUFFLEHEADS AND OTHER CAVITY-NESTING BIRDS

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Secondary cavity-nesting birds use holes excavated by other species, mainly woodpeckers (family Picidae). Because they do not excavate their own cavities, secondary cavity nesters are often limited by the availability of nesting holes (von Haartman 1957, Holroyd 1975). Artificial nesting boxes often increase the breeding density of these species (Hamerstrom et al. 1973, McComb and Noble 1981, Froke 1983). For instance, nest boxes have played a major role in restoring nesting habitat and establishing new breeding populations in species such as wood ducks (*Aix sponsa*) (McLaughlin and Grice 1952, Doty and Kruse 1972), common goldeneyes (*Bucephala clangula*) (Eriksson 1982, Dennis and Dow 1984), and Barrow's goldeneyes (*B. islandica*) (Savard 1986).

Buffleheads (*Bucephala albeola*) are the smallest cavity-nesting duck in North America. In the Cariboo Parkland of British Columbia, holes of the northern flicker (*Colaptes auratus*) are abundant, and natural nest sites do not appear to limit buffleheads (Gauthier and Smith 1987). However, nest sites are likely to be a limiting factor in other parts of this species' breeding range (Erskine 1972). Erskine (1972) reported nest-box use by buffleheads, but quantitative data on the success of nest-box programs or on factors affecting box use in this species are lacking. I, therefore, initiated a study on the use of artificial nest sites by buffleheads to (1) determine if nest boxes can be used successfully by buffleheads, and (2) investigate experimentally some factors (box size, age, previous use, and habitat) affecting nest-box selection and nesting success. I also collected data on box use by other cavity nesters that competed with buffleheads for nest sites.

STUDY AREA AND METHODS

This study was conducted in the Cariboo Parkland of British Columbia, near 100 Mile House (51°46′N, 121°24′W). The study area covered 23 km² and included 26 ponds and lakes. All wetlands were per-

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