DECLINING SCAUP POPULATIONS: A RETROSPECTIVE ANALYSIS
OF LONG-TERM POPULATION AND HARVEST SURVEY DATA
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Abstract: We examined long-term databases concerning population status of scaup (lesser [Aythya affinis] and greater scaup [A. marila] combined) and harvest statistics of lesser scaup to identify factors potentially limiting population growth. Specifically, we explored evidence for and against the general hypotheses that scaup populations have declined in association with declining recruitment and/or female survival. We examined geographic heterogeneity in scaup demographic patterns that could yield evidence about potential limiting factors. Several biases exist in survey methodology used to estimate scaup populations and harvest statistics; however, none of these biases likely accounted for our major findings that (1) the continental scaup breeding population has declined over the last 20 years, with widespread and consistent declines within surveyed areas of the Canadian western boreal forest where most lesser scaup breed; (2) sex ratios of lesser scaup in the U.S. harvest have increased (more males now relative to females); and (3) age ratios of lesser scaup in the U.S. harvest have declined (fewer immatures now relative to adults), especially in the midcontinent region. We interpreted these major findings as evidence that (1) recruitment of lesser scaup has declined over the last 20 years, particularly in the Canadian western boreal forest; and (2) survival of female lesser scaup has declined relative to that of males. We found little evidence that harvest was associated with the scaup population decline. Our findings underscore the need for both improvements and changes to population survey procedures and new research to discriminate among various hypotheses explaining the recent scaup population decline.

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In North America, duck breeding populations and habitat conditions are surveyed annually in spring by federal, state, and provincial resource management agencies (Smith 1995). From 1986 to 1993, breeding populations of many duck species were below goals of the North American Waterfowl Management Plan (NAWMP), associated with extended drought throughout the Prairie–Parkland Region (Dubovsky et al. 1997). Numbers of ponds in this region increased markedly in 1994 and remained high through 1997. Accordingly, breeding populations of most duck species have increased since 1993 (Dubovsky et al. 1997).

In spring 1997, breeding populations of 8 of the 10 principal duck species were above NAWMP goals and significantly above their respective long-term averages (Caithamer and Dubovsky 1997). Continental populations of scaup (lesser and greater combined) and northern pintail (Anas acuta), however, remained well below NAWMP goals and their respective long-term averages. The breeding population of northern pintails increased significantly in 1997 over levels observed in 1996, whereas the estimate for scaup has not changed since water conditions improved in 1994 (Caithamer and Dubovsky 1997). The lack of response by scaup is of great concern to resource management agencies and private conservation groups (Afton 1996; Austin et al. 1998, 1999, 2000, 2001).

We examined long-term databases concerning population status of scaup and harvest statistics of lesser scaup to identify factors limiting population growth. Changes in populations over time can be described by the general equation:

\[
\frac{dN}{dt} = B + I - D - E,
\]

where \( N \) = population size, \( t \) = time, \( B \) = birth rate, \( I \) = immigration rate, \( D \) = death rate, and \( E \) = emigration rate (Wilson and Bossert 1971). We focused on potential factors affecting recruitment and survival of lesser scaup, assuming that immigration and emigration could be ignored at large spatial scales. Specifically, we explored evidence for and against general hypotheses that scaup populations have declined in association with declining recruitment and/or female sur-

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vival. We also examined geographic heterogeneity in scaup demographic patterns that could yield evidence about potential limiting factors. Hunting mortality often is proposed as an important factor contributing to population declines in ducks (e.g., Conroy and Kremenz 1990). Thus, we also investigated relationships between (1) annual harvest rate indices and population trajectories; and (2) annual U.S. hunting regulations and harvest of lesser scaup in the Mississippi Flyway.

We provided an early draft of this paper to all attendees prior to a workshop, held in September 1998. Our draft manuscript formed the basis for initial workshop discussions, and our original hypotheses explaining the scaup population decline generally were accepted (Austin et al. 2000:255) and have been discussed in various reports resulting from the workshop (Austin et al. 1999, 2000). In this paper, we provide our original results and interpretations from analyses of long-term population and harvest survey data, discuss potential and known biases in survey methodology, recommend changes and improvements for population surveys, and suggest further analyses and new research to discriminate among various explanatory hypotheses.

METHODS

Waterfowl Breeding Population and Habitat Surveys

We obtained scaup breeding population and May pond data from the Migratory Bird Management Office of the U.S. Fish and Wildlife Service (USFWS, Laurel, Maryland, USA). Duck population data were collected annually on 52 strata in the traditional surveyed area (Fig. 1). Estimates of breeding scaup (lesser and greater scaup combined) in this area were available since 1955, and estimated numbers of May ponds (natural and artificial wetlands expected to retain water for 3 weeks following the survey) were available for prairie Canada (strata 26–40) since 1961, and for northcentral U.S. (strata 41–49) since 1974. The 2 scaup species were combined because of difficulties in separating them during aerial surveys. Survey design and methodology were described in detail by Canadian Wildlife Service (CWS) and USFWS (1987), Johnson and Grier (1988), Smith
We analyzed scaup population trends for individual survey strata, regions, biomes, and the entire traditional surveyed area. Characteristics of individual strata were provided in Smith (1995:3) and Hodges et al. (1996:2–3). Regions of the traditional surveyed area were as described in annual USFWS trends and status reports (Dubovsky et al. 1997, Caithamer and Dubovsky 1997): (1) Alaska–Yukon Territory–Old Crow Flats (strata 1–12); (2) central and northern Alberta–northeastern British Columbia–Northwest Territories (strata 13–20 and 75–77); (3) northern Saskatchewan–northern Manitoba–western Ontario (strata 21–25 and 50); (4) southern Alberta (strata 26–29); (5) southern Saskatchewan (strata 30–35); (6) southern Manitoba (strata 36–40); (7) Montana–western Dakotas (strata 41–44); and (8) eastern Dakotas (strata 45–49). Delination of biomes followed Smith (1995): (1) Prairie–Parkland (strata 26–49 and 75–76); (2) Boreal Forest (strata 1–7, 12–25, 50 and 77); and (3) Tundra (strata 8–11). Population and pond estimates from fixed-wing aerial surveys were adjusted for visibility based on ground transects in the Prairie–Parkland and by helicopter surveys (population estimates only) in the Boreal Forest and Tundra (Smith 1995, Hodges et al. 1996).

We used correlation and regression analyses to detect long-term (1955–1997, n = 43 years) and short-term trends (1978–1997, n = 20 years) in scaup breeding populations (PROC CORR and REG; Cody and Smith 1997). For this and other analyses, we arbitrarily chose the last 20 years of survey data as representative of potential short-term trends prior to inspection of any data. For regression analyses, we examined residuals to check for linearity and other model assumptions (Draper and Smith 1966;86; Freund and Litell 1991). If nonlinear relationships were indicated, we fit up to fourth order polynomial models (Freund and Litell 1991). Given the exploratory nature of our analyses and our search for general patterns, we used $P < 0.10$ as the critical value for all statistical tests.

**Midwinter Waterfowl Survey**

We obtained numbers of scaup (lesser and greater scaup combined) counted during Midwinter Waterfowl Surveys from USFWS flyway representatives who coordinated and compiled annual reports on their respective flyway surveys. We analyzed data from 1955 to 1997 to be consistent among all flyways. The Pacific Flyway data included counts from the west coast of Mexico and Baja; other flyways included data only from the United States. The western portions of Montana, Wyoming, Colorado, and New Mexico were included in the Pacific Flyway, whereas eastern portions of these states were included in the Central Flyway. Survey designs and techniques varied among states and have been described in general by Eggeman and Johnson (1989) and Heusmann (1999). Long-term (1978–1997, n = 20 years) trends in midwinter scaup counts were examined using correlation and regression analyses as previously described.

**U.S. Hunter and Parts Collection Surveys**

We obtained U.S. harvest data for lesser scaup for 1961–1996 (n = 36 years) from the USFWS Section of Harvest Surveys. We estimated total harvest and age and sex ratios from hunter-obtained wings based on standard USFWS procedures (Martin and Carney 1977; Voelzer et al. 1982; E. M. Martin, USFWS, personal communication), except that we did not prorate unknown age or sex wings and then include them in our sex- and age-ratio estimates. The order in which unknown wings are prorated influences final estimates, and thus could add unwarranted variation.

Best estimates of harvest rates generally are derived from banding data, if reporting rates can be estimated accurately (Anderson and Burnham 1976, Trost 1987). Unfortunately, the paucity and poor temporal and geographic distributions of preseason bandings of lesser scaup (Austin et al. 1999), combined with little information available on band reporting rates for this species, precluded a rigorous estimate of harvest rates (Kelly 1990). Consequently, we estimated annual (1961–1996) harvest rate indices for the United States, Canada, and North America using an equation described by Anderson and Burnham (1976:31):

$$\text{Harvest rate index} = \left( \frac{H_A}{N_A} \right) \times (100),$$

where $H_A =$ estimated harvest of adult lesser scaup from Oct-Jan, and $N_A =$ estimated breeding population of lesser scaup from the traditional surveyed area. Our annual harvest rate estimates are indices because some adults die during summer months (Anderson and Burnham 1976). For U.S. data, we summed estimated harvests of adult males, adult females, and adult sex unknowns to obtain the annual harvest of
adult lesser scaup. We obtained total harvest and wing data for lesser scaup in Canada from the CWS Migratory Bird Populations Division; see Cooch et al. (1978) and Levesque and Collins (1999) for descriptions of the National Harvest Survey in Canada. We estimated annual harvest of adult lesser scaup in Canada by multiplying total harvest by the proportion of adult wings in the harvest (B. T. Collins, CWS, personal communication). We multiplied annual scaup breeding population estimates by 0.89 (Austin et al. 1998) to obtain an estimate for lesser scaup and assumed that the estimated proportion of continental scaup comprised of lesser scaup has remained constant.

We used multiple regression analysis (PROC REG; Freund and Littell 1991) to investigate effects of bag limit and season length on U.S. harvest of lesser scaup in the Mississippi Flyway. Historical information on regulations was obtained from the USFWS Mississippi Flyway representative. Bag limits for lesser scaup varied among states within the flyway in some years due to selection of either the point system or conventional bag limits; consequently, for analysis, we used the bag limit selected by most states each year. We used backward elimination procedures to select our final model (Freund and Littell 1991). We log-transformed harvest estimates to meet assumptions of constant variance (Draper and Smith 1966).

RESULTS

Waterfowl Breeding Population and Habitat Surveys

North America.— Breeding populations of scaup (lesser and greater scaup combined) in North America have fluctuated markedly since surveys were initiated (Fig. 2), but annual population estimates were not correlated with northcentral U.S. ($r = -0.18, P = 0.40$), prairie Canada ($r = 0.10, P = 0.56$), or total May pond numbers ($r = 0.03, P = 0.88$). The continental breeding population generally declined during the 1960s, increased during the 1970s and early 1980s, and then declined again (Fig. 2). Scaup breeding population estimates in 1959, 1972, 1979, 1983, and 1984 showed marked increases from previous years, followed by marked declines in subsequent years (Fig. 2), that were biologically unrealistic given the relatively low reproductive rates of the 2 species (Crissey 1975; Austin et al. 1999, 2000). During the last 20 years (1978–1997), the breeding population has declined at a rate of 150,491 scaup per year ($Y = 18,444.288 - 150.491X$, where $Y =$ scaup/1,000 and $X = [\text{year} - 1900]$, $R^2 = 0.67$, $n = 20$, $P = 0.0001$).

Biomes.— On average, 7% of the estimated breeding population of scaup was observed in Tundra, 25% in Prairie–Parkland, and 68% in Boreal Forest biomes during 1955–1997. Estimated populations in the 3 biomes differed markedly in their trajectories over time (Fig. 3). The Tundra population has remained relatively stable. In contrast, Prairie–Parkland and Boreal Forest populations have varied markedly, but annual population estimates in these 2 biomes
were not correlated \((r = 0.22, P = 0.15)\). The Prairie–Parkland population increased by 50% from 1993 to 1997, whereas the Boreal Forest population continued to decline (Fig. 3). During the last 20 years (1978–1997), the Boreal Forest population has declined at a rate of 112,805 scaup per year \((Y = 13,391.843 - 112.805X, \text{where } Y = \text{scaup}/1000 \text{ and } X = [\text{year} - 1900], R^2 = 0.73, n = 20, P = 0.001)\).

The ratio of Boreal Forest to Prairie–Parkland scaup populations fluctuated from 1.38 to 5.17 during 1955–1997, and 36% of the variation in this ratio during 1974–1997 was explained by total May ponds (Fig. 4). Estimated numbers of breeding scaup in the Prairie–Parkland were positively correlated with total May ponds during 1974–1997 \((r = 0.37, P = 0.0735)\), whereas those in the Boreal Forest were unrelated to total May ponds \((r = -0.17, P = 0.44)\).

Regions.—Two of the 8 described regions in the traditional surveyed area showed long-term (1955–1997) declines in scaup populations: (1) central and northern Alberta–northeastern British Columbia–Northwest Territories \((r = -0.39, P = 0.0095)\); and (2) southern Manitoba \((r = -0.42, P = 0.0053)\). The eastern Dakotas showed a long-term increase in scaup populations \((r = 0.71, P = 0.0001)\). The Alberta–British Columbia–Northwest Territories region had a major influence on the continental estimate because, on average, 52% of the estimated population of breeding scaup was observed in this region, whereas only 3% and 1%, respectively, were observed in southern Manitoba and eastern Dakota regions. During the last 20 years (1978–1997), no regions showed increases and 4 showed declines in scaup populations: (1) Alberta–British Columbia–Northwest Territories \((r = -0.85, P = 0.0001)\); (2) southern Alberta \((r = -0.66, P = 0.0016)\); (3) southern Saskatchewan \((r = -0.39, P = 0.0881)\); and (4) Montana–western Dakotas \((r = -0.45, P = 0.0486)\).

Strata.—Seventeen of 52 individual strata in the traditional surveyed area showed long-term (1955–1997) declines in scaup breeding populations, whereas 14 other strata showed long-term increases in scaup populations (Table 1). During the last 20 years (1978–1997), 19 of 52 strata showed declines in scaup breeding populations, whereas only 3 strata showed increases (Table 1).

Midwinter Waterfowl Survey

Midwinter counts of scaup (lesser and greater combined) have declined at a rate of 24,260 scaup per year since surveys were initiated (Fig. 2); however, no short-term (1978–1997) trend was evident \((P = 0.73)\). On average, 40% of scaup were counted in the Mississippi Flyway, 39% in the Atlantic Flyway, 14% in the Pacific Flyway, and 6% in the Central Flyway for 1955–1997.

Numbers of scaup counted during midwinter generally have declined since 1955 in all 4 flyways,

Fig. 4. Relationships of the ratio of Boreal Forest to Prairie–Parkland estimates of breeding scaup (lesser and greater scaup combined) to year (1955–1997, left panel) and total May ponds (1974–1997, right panel).
Table 1. Long-term (1955–1997) and short-term (1978–1997) trends in scap breeding populations (lesser and greater scap combined) for 52 individual survey strata (1–50 and 75–77) in the traditional surveyed area.

<table>
<thead>
<tr>
<th>Long-term decline</th>
<th>Long-term increase</th>
<th>Short-term decline</th>
<th>Short-term increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (r = −0.28; P = 0.0662)</td>
<td>2 (r = 0.52; P = 0.0004)</td>
<td>4 (r = −0.47; P = 0.0365)</td>
<td>1 (r = 0.38; P = 0.0961)</td>
</tr>
<tr>
<td>6 (r = −0.33; P = 0.0284)</td>
<td>8 (r = 0.38; P = 0.0112)</td>
<td>7 (r = −0.65; P = 0.0021)</td>
<td>3 (r = 0.52; P = 0.0181)</td>
</tr>
<tr>
<td>17 (r = −0.29; P = 0.0622)</td>
<td>12 (r = 0.55; P = 0.0001)</td>
<td>14 (r = −0.58; P = 0.0079)</td>
<td>48 (r = 0.59; P = 0.0066)</td>
</tr>
<tr>
<td>18 (r = −0.53; P = 0.0002)</td>
<td>21 (r = 0.36; P = 0.0188)</td>
<td>15 (r = −0.80; P = 0.0001)</td>
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<tr>
<td>25 (r = −0.26; P = 0.0960)</td>
<td>22 (r = 0.33; P = 0.0282)</td>
<td>16 (r = −0.72; P = 0.0003)</td>
<td></td>
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<tr>
<td>27 (r = −0.54; P = 0.0002)</td>
<td>30 (r = 0.28; P = 0.0054)</td>
<td>17 (r = −0.76; P = 0.0001)</td>
<td></td>
</tr>
<tr>
<td>28 (r = −0.37; P = 0.0160)</td>
<td>36 (r = 0.57; P = 0.0001)</td>
<td>18 (r = −0.89; P = 0.0001)</td>
<td></td>
</tr>
<tr>
<td>31 (r = −0.29; P = 0.0827)</td>
<td>42 (r = 0.32; P = 0.0379)</td>
<td>20 (r = −0.82; P = 0.0001)</td>
<td></td>
</tr>
<tr>
<td>32 (r = −0.27; P = 0.0857)</td>
<td>43 (r = 0.28; P = 0.0873)</td>
<td>22 (r = −0.41; P = 0.0731)</td>
<td></td>
</tr>
<tr>
<td>33 (r = −0.35; P = 0.0234)</td>
<td>44 (r = 0.42; P = 0.0054)</td>
<td>26 (r = −0.71; P = 0.0005)</td>
<td></td>
</tr>
<tr>
<td>34 (r = −0.33; P = 0.0332)</td>
<td>45 (r = 0.54; P = 0.0002)</td>
<td>28 (r = −0.42; P = 0.0663)</td>
<td></td>
</tr>
<tr>
<td>35 (r = −0.46; P = 0.0019)</td>
<td>46 (r = 0.61; P = 0.0001)</td>
<td>32 (r = −0.54; P = 0.0142)</td>
<td></td>
</tr>
<tr>
<td>37 (r = −0.46; P = 0.0021)</td>
<td>48 (r = 0.55; P = 0.0001)</td>
<td>35 (r = −0.42; P = 0.0638)</td>
<td></td>
</tr>
<tr>
<td>40 (r = −0.58; P = 0.0001)</td>
<td>49 (r = 0.56; P = 0.0001)</td>
<td>37 (r = −0.50; P = 0.0248)</td>
<td></td>
</tr>
<tr>
<td>41 (r = −0.49; P = 0.0009)</td>
<td>41 (r = −0.63; P = 0.0027)</td>
<td>41 (r = −0.63; P = 0.0027)</td>
<td></td>
</tr>
<tr>
<td>76 (r = −0.55; P = 0.0001)</td>
<td>42 (r = −0.54; P = 0.0140)</td>
<td>45 (r = −0.45; P = 0.0452)</td>
<td></td>
</tr>
<tr>
<td>77 (r = −0.30; P = 0.0499)</td>
<td>77 (r = −0.51; P = 0.0208)</td>
<td>75 (r = −0.55; P = 0.0114)</td>
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</tbody>
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* Individual strata not listed showed no significant trend (P > 0.10).

except for a recent increase in the Atlantic Flyway (Fig. 5). Midwinter counts showed a short-term (1978–1997) increase in the Atlantic Flyway (r = 0.51, P = 0.0207) and a decrease in the Mississippi Flyway (r = −0.45, P = 0.0453); other flyways showed no short-term trends (all P > 0.47). On average for 1955–1997, most scap counted in the Atlantic Flyway were in Florida (48%), followed by New Jersey (12%), New York (11%), and Maryland (8%); no other state comprised >4% of the flyway total. Louisiana and Texas comprised, on average, 91% and 97%, respectively, of scap counted during midwinter in the Mississippi and Central flyways during the same period. On average, Mexico comprised 30% of total scap counted during midwinter in the Pacific Flyway; California (43%) and Washington (19%) were the most important states, and all other states each comprised <6% of the flyway total.

U.S. Hunter and Parts Collection Surveys

**United States**—Annual U.S. harvest estimates for lesser scap ranged from 93,327 in 1962 to 686,752 in 1977, and averaged 343,703 (SE = 28,197, n = 36) for 1961–1996. U.S. harvests increased from 1961 through the 1970s, declined through the 1980s and early 1990s, and then increased again recently (Fig. 6). Sex ratios (males: females) in the U.S. harvest ranged from 1.17 in 1970 to 2.37 in 1977 and averaged 1.42 (SE = 0.04). Sex ratios exhibited no long-term (1961–1996) trend (P = 0.19); however, the 1977 estimate was markedly higher than those of other years (Fig. 6). A long-term increase in sex ratios was indicated when this year was excluded (Sex Ratio = 0.998 + 0.005 [year – 1900], R² = 0.14, n = 35, P = 0.0295). Age ratios (immatures:adults) in the U.S. harvest ranged from 0.46 in 1977 to 2.31 in 1961 and 1966 (mean = 1.46, SE = 0.07), and have declined steadily since surveys were initiated (Fig. 6). The U.S. harvest was positively correlated to sex ratio in the harvest (r = 0.41, P = 0.0133), but was unrelated to age ratio (r = −0.09, P = 0.62). The correlation between harvest and sex ratio was driven primarily by the extreme sex ratio recorded in 1977; harvest and sex ratio were unrelated (r = 0.24, P = 0.17) when this year was excluded from analysis.

Sex ratios of harvested adult lesser scap showed a long-term (1961–1996) increase, where those of immatures showed a long-term decline (Fig. 7). Annual variation in sex ratios was greater for adults than for immatures (Fig. 7). Age ratios of male lesser scap showed a long-
term (1961–1996) decline (Fig. 7), but those of females were unrelated to year \( (P = 0.34) \). Age ratios of females generally were higher than those of males (Fig. 7).

Annual U.S. harvest \( (r = 0.21, P = 0.33) \), sex ratio \( (r = -0.12, P = 0.59) \), and age ratio \( (r = 0.26, P = 0.22) \) of lesser scaup showed no relationship to total May ponds for 1974–1996. Interestingly, the 3 largest harvests (1977, 1981, 1984) occurred following dry springs on the prairies. Annual U.S. harvest of lesser scaup was positively correlated to total May ponds when these 3 years were excluded \( (r = 0.73, P = 0.0002) \).

**Flyways.**—Harvests of lesser scaup varied among flyways during 1961–1996 (Fig. 8). Harvest was greatest and most variable in the Mississippi Flyway, where, on average, 62% of the U.S. harvest occurred. Alaska, Pacific (excluding Alaska), Central, and Atlantic flyways comprised 1%, 8%, 16%, and 13%, respectively, of the total harvest.

Annual sex ratios of harvested lesser scaup showed a long-term (1961–1996) increase in the Mississippi Flyway and a recent increase in the Central Flyway (Fig. 9); no trends (all \( P > 0.50 \)) were evident in other flyways. Annual age ratios of harvested lesser scaup showed a long-term (1961–1996) decline in the Mississippi Flyway (Age Ratio = 3.413 – 0.026 \( \times \) [year – 1900], \( R^2 = 0.30, n = 36, P = 0.0006 \); no trends were evident in other flyways (all \( P > 0.24) \).

Annual flyway harvests of lesser scaup were not correlated with total May ponds for 1974–1996 (all \( P > 0.13) \). As noted for the total U.S. harvest, 3 of the highest annual harvests (1977, 1981, 1984) in the Mississippi Flyway occurred following dry springs on the prairies. Annual harvest in the Mississippi Flyway was positively correlated to May ponds when these 3 years were excluded \( (r = 0.75, P = 0.0001) \). Annual sex and age ratios of harvested lesser scaup were not correlated with total May ponds for any flyway (all \( P > 0.17) \).

**States.**—The top 4 harvest states for lesser scaup were Louisiana (mean \( \pm \) SE, 70,918 \( \pm \) 10,565), Minnesota (57,528 \( \pm \) 5,817), Texas (29,449 \( \pm \)
indices for North America (mean ± SE = 3.4% ± 0.4, n = 23, range from 1.6% to 8.6%) followed closely those of the United States (Fig. 11). Harvest rate indices for the United States and North America generally were low from 1986–1994 (Fig. 11), a period when scaup breeding populations were declining (Fig. 2).

**Hunting Regulations and Harvest.**—Multiple regression analysis indicated that harvest of lesser scaup in the Mississippi Flyway (where on average 62% of U.S. harvest occurred) primarily was influenced by season length for 1961–1996 (Fig. 12). Bag limit was excluded from the final model; however, season length and bag limit were positively correlated ($r = 0.82$, $P = 0.0001$). Second-order polynomial models, estimated for each regulation component separately, significantly (all $P < 0.0001$) predicted lesser scaup harvest, but the season-length model ($R^2 = 0.64$, mean square error = 0.1395) provided a better fit to the data than did the bag-limit model ($R^2 = 0.53$, mean square error = 0.1779).

**DISCUSSION**

**Survey Biases**

**Waterfowl Breeding Population and Habitat Surveys.**—In a review of survey methodology, Smith (1995:20) concluded that a coefficient of variation (CV) of 5.6% for the overall estimated population size of scaup in 1994 was excellent. This conclusion refers to precision of the survey. Precision generally leads to accuracy (i.e., the closeness of an estimated value to the true value), unless there is a bias in the estimation procedure (Sokal and Rohlf 1969). Consequently, a critical question is whether or not the breeding population survey was biased with respect to estimates for scaup. Another major concern with the survey is that population trends could differ between species and not be revealed because estimates for greater and lesser scaup were combined.

Lesser scaup generally migrate later in spring, initiate egg laying later, and nest more synchronously than do most other North American duck species, with peak laying during June throughout most of their breeding range (Austin et al. 1998). The breeding population survey was conducted from 1–25 May in prairie strata and from 12 May to 12 June in boreal forest areas (Smith 1995). Many lesser scaup are still migrating during the period that surveys are conducted (Naugle et al. 2000; Afton, unpublished data; D. Kay, Ducks Unlimited Canada [DUC], personal communica-

3,688), and Wisconsin (22,704 ± 2,229) for 1961–1996 (n = 36 years). Together, these 4 states comprised, on average, 53% of the total U.S. harvest of lesser scaup. Annual state harvests were positively correlated with sex ratios in Louisiana ($r = 0.45$, $P = 0.0062$) and Texas ($r = 0.34$, $P = 0.0433$), but not for the 2 northern states (all $P > 0.24$). Annual state harvests were positively related to age ratios in Minnesota and Wisconsin and negatively related to age ratios in Louisiana and Texas (Fig. 10). The range of age ratios in the harvest in the 2 southern states was much greater than those in the 2 northern states (Fig. 10).

**Harvest Rate Indices.**—U.S. harvest rate indices for lesser scaup ranged from 0.8% in 1962 to 8.2% in 1977 (mean ± SE = 2.9% ± 0.3, n = 36) for years 1961–1996; no long-term trend was evident (Fig. 11). Harvest rate indices for lesser scaup in Canada (mean ± SE = 0.47% ± 0.02, n = 23, range from 0.31% to 0.67%) generally remained stable for 1974–1996 and were markedly lower than those in the United States. Accordingly, harvest rate
tion); consequently, the potential is high for errors in estimating both distribution and numbers of breeding scaup. Depending on timing of surveys and scaup migration chronology (both of which are influenced by spring weather conditions), the probability of multiple counting of the same individuals is high when scaup and survey crews move north at the same time (see also Crissey 1975:20; Austin et al. 1998, 2001; Naugle et al. 2000).

Anecdotal observations and some quantitative data (Naugle et al. 2000) suggest that overestimation of the scaup population was a major problem in some years. For example, observations on a marked population of lesser scaup breeding near Erickson, Manitoba (Afton 1983, 1984), indicated that large numbers (10–20 times the resident population) of unmarked migrants were present when USFWS transects in the area were flown in 1979. These migrants moved the day after the survey was completed (Afton, unpublished data) and may have been counted again on more northerly transects. Similarly, Naugle et al. (2000) reported that ground counts of lesser scaup showed an 11-fold decrease 2 weeks after transects were flown in eastern South Dakota in 1996.

In other years, the probability of underestimation of the population is high when large numbers of migrating scaup are observed south of surveys already underway (Afton, personal observations). Such observations may represent mainly nonbreeders (Johnson and Grier 1988), but could include some birds en route to breed in northern areas. Repeated pair counts on several study areas in the Northwest Territories indicated that resident scaup arrived after the breeding population survey was completed in some years (D. Kay, DUC, personal communication); thus, estimates of resident populations there were biased low in those years.

Other evidence that migrant scaup sometimes were counted on transects where they did not stay to nest include observations that (1) visibility correction factors <1 for scaup occur only in
Fig. 8. Annual U.S. harvests of lesser scaup for each flyway, 1961–1996. For regression equations shown, \( X = [\text{year} - 1900] \).

Fig. 9. Annual sex ratios of lesser scaup in the U.S. harvest for the Mississippi (left panel) and Central (right panel) flyways, 1961–1996. For regression equations shown, \( X = [\text{year} - 1900] \).
southern strata (41–44 and 50) and some states outside the traditional surveyed area (e.g., Minnesota; J. S. Lawrence, Minnesota Department of Natural Resources, personal communication); and (2) proportions of scaup counted in groups (39% for Prairie–Parkland, 31% for Boreal Forest) were markedly higher than for other duck species in these areas (Smith 1995). Finally, Hodges et al. (1996) excluded from their analysis the exceptionally high count of tundra scaup (assumed to be primarily greater scaup) in the 1994 Alaska survey because migration was delayed due to a late spring, and consequently, many of the scaup were believed en route to breed in other areas.

One known bias is the different way that northern and prairie survey crews have recorded unidentified ducks (Crissey 1975:5). Southern survey crews recorded 60–65% of ducks as unidentified, whereas northern crews apparently recorded all unidentified ducks as scaup. This procedural difference resulted in many other prairie duck species being recorded as scaup during drought years, such as 1959 when several species moved into northern areas (Crissey 1975:5). We previously noted 4 other years (1972, 1979, 1983–1984; Fig. 2) that showed biologically unrealistic population increases, and we suspect that these high estimates also resulted from differential recording of unidentified ducks and/or multiple counting of individuals.

In conclusion, the breeding population survey clearly is conducted too early to accurately estimate site-specific breeding populations of lesser scaup. We strongly recommend that surveys be repeated during mid- to late June, on transects within important lesser scaup breeding areas, to more accurately estimate breeding populations (Naugle et al. 2000). We also strongly encourage the development of separate population estimates for the 2 scaup species, perhaps through complementary ground surveys at periodic intervals on selected transects where the species might overlap. We are skeptical that simple stratifica-
Scaup population estimates for many strata, especially those within the Canadian western boreal forest, have been declining steadily during the last 20 years. We would expect that systematic under- and overestimates of the scap population, as affected by varying spring weather, water conditions, and migration chronology, should vary randomly in a temporal sequence. Consequently, despite our strong concerns about survey bias, we believe that the indicated breeding population decline is not due solely to biased population estimates.

**Midwinter Waterfowl Survey.**—Eggeeman and Johnson (1989) evaluated the midwinter waterfowl survey in the Atlantic Flyway and concluded that past counts contained substantial amounts of unmeasured error and cautioned against comparisons of duck numbers among states or years. Heusmann (1999) questioned whether midwinter waterfowl survey should be continued in the Atlantic Flyway, but stated that scap counts in that flyway were relatively good. Crissey (1975:22) and Jessen (1981) discussed problems and biases with the midwinter survey for scap and noted little resemblance between combined midwinter and breeding population estimates for the 2 species. We also found little correlation between annual estimates shown by the 2 surveys; breeding population estimates showed a marked short-term decline, whereas midwinter counts showed no trends during the same period.

Crissey (1975) pointed out that the annual midwinter survey total was strongly affected by the number of scap recorded in Louisiana. The 2 lowest counts in Louisiana occurred recently due to weather preventing a large-scale survey effort (1993) and unavailability of survey aircraft (1997); thus, annual estimates clearly do not indicate winter population changes in some years. We conclude, as have others (Crissey 1975, Jessen 1981), that the midwinter survey as presently conducted should not be used to represent population status of scap. We recommend that the sampling design of the midwinter survey be strengthened and standardized, and that transects be added in the Gulf of Mexico, where large flocks of scap frequently occur (Crissey 1975; Afton, personal observations). Greater and lesser scap also should be estimated separately during midwinter surveys, perhaps by subsampling important areas in each state periodically by ground or boat surveys.

**U.S. Hunter and Waterfowl Surveys.**—Crissey (1975), Martin and Carney (1977) and Couling et
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al. (1982) previously discussed weaknesses and potential biases in the U.S. waterfowl hunter and parts collection surveys. Here, we highlight 2 important concerns regarding the parts collection survey that could result in large underestimates of the harvest of lesser scaup: (1) hunters may deplete their supply of wing envelopes early in the season and then not request more (Crissey 1975, Martin and Carney 1977, Cooch et al. 1978); and (2) hunters may lose interest in sending in wings as the hunting season progresses (D. F. Caithamer, USFWS retired, personal communication). Lesser scaup are 1 of the latest species to migrate in fall (Austin et al. 1998); consequently, the proportion of duck harvest comprised by lesser scaup increases later in the season (Geis and Carney 1961). Accordingly, we suspect that harvest estimates of lesser scaup are highly sensitive to seasonal changes in wing reporting rates and recommend investigation of the magnitude of this potential bias.

Major Trends in Scaup Populations and U.S. Harvests

Our retrospective analysis of long-term population and harvest survey data indicated that (1) the continental scaup breeding population has declined over the last 20 years, with a geographically widespread and consistent decline within surveyed areas of the Canadian western boreal forest where most lesser scaup breed; (2) sex ratios of lesser scaup in the U.S. harvest have increased (more males now relative to females); and (3) age ratios of lesser scaup in the U.S. harvest have declined (fewer immatures now relative to adults), especially in the midcontinent region. We interpreted these major findings as evidence that (1) recruitment of lesser scaup has declined over the last 20 years, particularly in the Canadian western boreal forest; and (2) survival of female lesser scaup has declined relative to that of males.

Factors Affecting Recruitment of Lesser Scaup.—Declines in recruitment could result from any combination of reduced breeding propensity, clutch size and renesting rates among hens, lower hatching and nesting success, or lower brood survival (Afton 1984). Factors affecting recruitment, through changes in reproductive parameters, could originate on breeding areas or at other locations used during the annual cycle (Afton 1984; Austin et al. 1999, 2000).

Boreal forest wetlands traditionally have been considered stable, productive, and protected from human disturbance because of their remoteness (Jessen 1981). However, commercial forestry, mineral extraction, and agriculture have increased markedly in this region (Ducks Unlimited 1999). Surface water in this region is more variable than generally appreciated, and substantial areas of the western Canadian boreal forest apparently were in drought conditions through much of the 1980s and early 1990s (a period when the scaup population declined in this region) following climatic shifts that began in the northern Pacific Ocean in 1976 (Graham 1994, Hayward 1997). We recommend a finer-scale analysis of scaup breeding population data at the transect and segment levels to determine whether the population decline has varied within strata in the boreal forest region, and if so, whether this variation corresponds with any known changes in land use or environmental variation. We also recommend an analysis of long-term weather and river-flow patterns (e.g., magnitude, timing, and duration of flood events) in the western Canadian boreal forest, and an assessment of spatial and temporal correspondence with trends in scaup populations.

Annual variation in food resources on wintering and spring migration stopover areas probably influences body condition of females upon arrival on breeding areas (Afton 1984; Afton et al. 1989, 1991; Austin et al. 1998). Poor body condition upon arrival should have a greater effect on recruitment of female lesser scaup breeding in northern boreal areas than in the prairie-parklands because of the shorter time between arrival and egg-laying in the north (Austin et al. 1998). Declines in food resources on nonbreeding areas, therefore, could affect northern breeders more than southern breeders, consistent with the geographic differences in population trends that we observed. Simultaneous studies of body condition and reproductive performance of northern and southern breeding populations of lesser scaup would be informative.

Accumulation of contaminants can affect recruitment rates by reducing breeding effort, clutch size, egg viability, or hatching and fledging success (Austin et al. 1998, 1999, 2000). Assays of eggs or embryos and females collected at various breeding sites might yield initial clues about the prevalence and distribution of contaminants affecting offspring quality and allow testing of geographic variation in contaminant loads among breeding populations showing different population trends. Sampling of nonbreeding
birds will be necessary to evaluate possible effects of contaminants on breeding propensity.

Factors Affecting Survival of Female Lesser Scaup.— In theory, declines in female survival could be caused by any mortality factor; however, hunting often is the first mortality factor suspected to be the cause of a population decline in ducks. Results from our analysis of annual harvest rate indices, however, were not consistent with the hypothesis that overharvest has caused the recent decline of lesser scaup. Some of the lowest harvest rate indices occurred from 1986–1994 (Fig. 11), a period when scaup populations declined markedly (Fig. 2). Based on reviewed available data, Austin et al. (1999:5) also suggested that hunting has not played an important role in the population decline of lesser scaup.

Our analysis of the relationship between hunting regulations (bag limit and season length) and harvest of lesser scaup in the Mississippi Flyway, where most harvest occurs, has implications for harvest management. Our results suggested that season length may be more effective in controlling harvest of lesser scaup than would changes in bag limits. Moreover, extreme reductions in season length (or bag limits) would be required to effectively regulate harvest of lesser scaup (Fig. 12). We suspect that recent increases in U.S. harvest (Fig. 6) and U.S. harvest rate indices for lesser scaup (Fig. 11) primarily have resulted from long seasons (>50 days) associated with liberal regulation packages prescribed by adaptive harvest management for midcontinent mallards (Anas platyrhynchos; USFWS 2000).

U.S. harvests of lesser scaup fluctuated markedly among years (Fig. 6) and showed little relationship to annual population estimates (Fig. 2). Interestingly, the U.S. harvest of lesser scaup in 1977 differed markedly from all other years. The highest sex ratio (2.37), lowest age ratio (0.46), and highest estimated harvest (686,752) all occurred in 1977, which was 1 of 3 years (1977, 1981, 1984) in which harvest was extremely high following dry springs on the prairies (Fig. 6). We found some evidence that the U.S. harvest was positively correlated with total May ponds; however, the 3 aforementioned dry years with high harvests were marked exceptions to this trend. Consequently, we believe that this erratic phenomenon of high U.S. harvest of lesser scaup in some years, following dry springs on the prairies, reflects some unique aspect about the fall migration of lesser scaup and/or their vulnerability to hunting, which deserves further investigation.

Furthermore, relationships between harvest levels and sex and age ratios varied markedly among northern and southern states with high harvests of lesser scaup. These differences also suggest unique geographic variation in hunting vulnerability among various sex and age classes that deserves study.

In conclusion, we do not understand the population dynamics of lesser scaup sufficiently well, or have sufficient quantitative data to rigorously assess the effects of harvest rate variation on female survival. Nor can we rigorously assess the degree to which population change is sensitive to variation in female survival. Development of a population model for lesser scaup and subsequent sensitivity analysis of various vital rates is needed and would help direct future field studies of lesser scaup demography.

We also recommend that period-specific survival rates of lesser scaup be estimated using radiotelemetry or other techniques. Informative periods for contrasting male and female survival rates would be (1) during the nesting season (when predation on hens could be high); (2) during molt and early fall migration (when late-nesting or successful females might be more vulnerable to hunting and nonhunting mortality); (3) during late fall migration when natural mortality appears high for immatures and late-nesting adult females (Afton, personal observations); and (4) during winter when sexes often are segregated (Afton, personal observations) and perhaps differentially exposed to mortality risks.

Finally, affinities of major breeding and wintering populations are not well defined for scaup because of the paucity of banding data for birds marked on breeding areas. Understanding these distributions and geographic relationships will be important for evaluating scaup population dynamics and discriminating among various explanatory hypotheses (Austin et al. 1999, 2000). For instance, the apparent different trajectories for scaup breeding populations in the western Canadian boreal forest compared to those in Alaska may reflect flyway differences in scaup population dynamics. Likewise, greater declines of wintering scaup populations in the Mississippi Flyway as compared with other flyways might be better understood if breeding-area affinities of birds wintering in each flyway were known. More preseason banding of scaup also would allow better estimates of male and female annual survival rates, insights about sources of variation in survival rates, and rigorous estimates of harvest
rates. Obtaining such data would require major increases in preseason banding effort in several breeding areas, including remote areas not previously sampled. Finally, deployment of satellite transmitters on scaup in late winter could provide important information on spring migration routes and breeding areas of various wintering populations and allow an assessment of the magnitude of bias in breeding population estimates related to survey timing and scaup migration chronology (Afton 1996).

MANAGEMENT IMPLICATIONS

We urgently need to determine causes of the scaup breeding population decline to identify what, if anything, waterfowl managers can do to reverse the decline. We believe that suggested improvements and changes to survey procedures, to more accurately assess harvest and inventory populations of both scaup species separately, are long overdue and should be implemented quickly. A major new banding program and/or large-scale telemetry studies should be implemented immediately to assess female survival, harvest rates, and affiliations among various breeding, migration, and wintering areas. Research to contrast scaup recruitment and survival between regions of population declines (e.g., Canada’s Mackenzie Valley) and population stability (e.g., central Alaska) would be especially informative.

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