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ABSTRACT — The incidence of lead shot in 1,687 lesser scaup (*Athya affinis*) and 416 ring-necked ducks (*Athya collaris*) in spring migration in Minnesota and the implications as related to the bird population and hunting harvest the preceding fall are considered in this study. The ducks, which were examined for shot by photofluorographic radiography had died as a result of oil pollution on the Mississippi River in the vicinity of Red Wing in the spring of 1963. The birds were separated into two age groups and by sex. Yearling lesser scaup had a body shot incidence (proportion of birds containing shot) of 5.5 per cent and yearling ring-necked ducks 17.8 per cent. For both species, yearling males had a higher incidence of shot than yearling females, and the most common location of shot was just beneath the skin on the back and abdomen. By using shot incidence in conjunction with other data, the harvest rate during the preceding hunting season (1962) was estimated as being 15 to 20 per cent of the population for yearling lesser scaup of both sexes; 30 to 35 per cent for yearling female ring-necked ducks, 60 to 70 per cent for yearling males, and 45 to 55 per cent for yearlings of both sexes of ring-necked ducks combined. Incidence of ingested shot in the digestive tracts of the birds (mostly gizzard) was low, being 1.7 per cent for lesser scaup and 1.6 per cent for ring-necked ducks.

In December 1962 an estimated million gallons of fuel oil were lost from an oil storage facility at Savage, Minnesota. The spilled oil largely remained under the snow until spring melt waters carried the oil into the adjacent Minnesota River. On January 23 the same winter, during a period of extremely cold weather, there also had been an accidental release of 1 to 1.5 million gallons of soybean oil from storage facilities at Mankato on the Blue Earth River, a tributary of the Minnesota River. Subsequently, this oil flowed into the Mississippi River (Moyle *et al.*, 1963).

Following breakup of ice in March and early April 1963, many waterfowl (especially ducks) were killed by coming in contact with these oils on the backwaters of the Mississippi River. Other birds became uncapable of flying as their feathers became coated with oil. Waterfowl losses were estimated at about 10,000 birds and were noted for about 60 miles from the mouth of the Minnesota River downstream to Lake Pepin.

In rescue operations 1,369 live and 1,842 dead birds were recovered. Many of the live birds died later even though they were washed with detergent and housed in warm quarters. As a result, 2,745 dead birds became available for examination for incidence of body shot that they had previously received.

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Most of the waterfowl were diving ducks (*Tribe Aythyini*). Of the 2,388 ducks originally examined, only 49 were dabbling ducks (*Tribe Anatini*). The few dabbling ducks killed indicate a differential response to oil pollution by the two groups of birds. Of the diving ducks, 76 percent were lesser scaup and 19 percent ring-necked ducks. These two species were the most numorous spring migrants at the time.

Methods of Investigation

In August 1963 all dead birds were taken from cold storage, examined, and individually marked with metal leg bands. The birds were then tallied according to species, sex, relative amount of oil on the feathers, and condition of the carcass. Two examinations were then undertaken: (1) photofluorographic images from two projections to determine the presence and location of lead pellets; and (2) internal examination for identifying the yearling birds.

Photofluorographic images were prepared by use of an automatic sequencing 70 mm Westinghouse photofluorographic unit. The primary beam was provided by a Picker radiograph activated at 66 kilovolts peak and 90 milliampere seconds. Anode focal spot to screen distance was 100 centimeters. These units had been designed to military specifications. Great care in establishment of exposure routine, equipment location, and lead shielding was necessary. This care was needed to reduce the occupational exposure below 6.25 milliroentgens per hour of x-ray production received by any of the technical assistants.

Two photofluorographs were taken of each bird. A lateral (L-R) and a dorsal to ventral view provided for three-dimensional localization of pellets within the birds. This method also provided a check for occasional pellets found within areas of heavy bone density as projected on the photofluorographs.

Sex determination was made on the basis of external

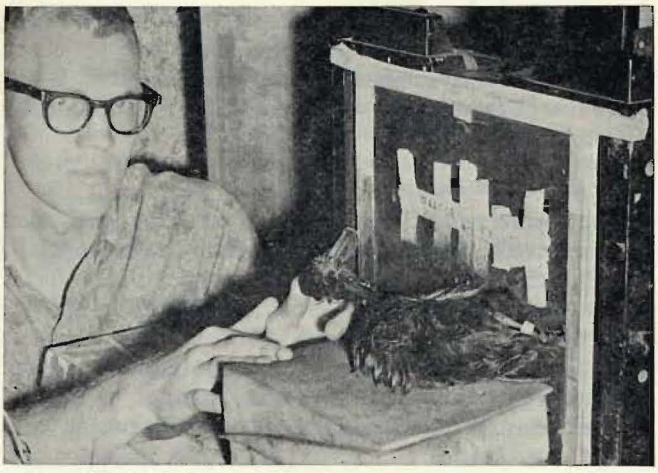

FIGURE 1. X-raying oil-killed duck for incidence of shot in body tissues and intestinal tract.

plumage characteristics. Age criteria were those established by Anderson (1966) and used by him on these birds. Birds having relative bursa depths of 29 or less were considered to be at least 20 months old, and those having a relative bursa depth of 32 or more, yearling birds. Relative bursa size is the product of greatest width and greatest length as measured in millimeters.

Birds in which body parts were missing or tissue decay prevented age identification are not included in the tabulations. In all, 1,687 lesser scaup and 416 ring-necked ducks were satisfactorily aged and sexed. In the calculations it is assumed that there was no differential response by sex of the birds coming in contact with the oils and that there was no differential survival of rescued birds related to sex, age, or condition.

Incidence and Location of Shot

Of the yearling lesser scaup 5.5 percent were found to have one or more imbedded lead shot pellets per bird (Table 1). Adult scaup that had survived two or more hunting seasons had a 9.1 percent incidence. There was a slightly higher incidence of pellets in adult males (9.6 percent) than in females (7.1 percent). The higher occurrence of shot pellets in males is similar to that reported for this same species by Elder (1955), and this suggests that male lesser scaup are selected as targets by some hunters. A small portion of this difference may be due to the somewhat larger size of the males—30 as compared to 28 ounces average weight.

TABLE 1. Percentage of spring migrant ducks killed by oil pollution in 1963 which had one or more lead shot pellets imbedded in their bodies.

Species and age	Males	Females	Both
Ring-necked ducks			
Adult	20.7 (N=193)	23.4 (N=94)	21.6
Yearling	25.4 (N=71)	8.6 (N=58)	17.8
Lesser scaup			
Adult	9.6 (N=1087)	7.1 (N=309)	9.1
Yearling	5.8 (N=156)	5.2 (N=135)	5.5

Ring-necked ducks had a substantially higher shot incidence than did lesser scaup for both age groups. Adults had a 21.6 percent shot incidence (Table 1). Yearling birds had a 17.8 percent shot incidence and showed a significant difference in shot incidence between the sexes, the well-marked males having a 25.4 percent and females 8.6 percent (t value 2.60 at the 1 percent level).

The number of shot pellets per bird varied considerably. The most found in a single bird was eight. Sixty-seven percent of the birds carrying shot had only one pellet; 20 percent, two pellets; and 7 percent, three.

The location of lead pellets in the bodies of birds was generally similar for ring-necked ducks and lesser scaup (Table 2). The most frequent site of lodged shot was the back (23.8 percent) and abdomen (22.5 percent). Other common sites of lodging were breast (14.3 percent), head (11.2 percent), neck (10.6 percent), and wings (10.5 percent). Many pellets were lodged just beneath the skin, where they presumably stopped without having done much physical damage to the birds. The distribution of lodged pellets is remarkably similar to that recorded by Bellrose (1953) in live-trapped mallard ducks. He found 22.2 percent of the body shot lodged in the back and 15.6 percent in the belly and flank area. Most pellets in these mallards were externally lodged—that is, in skin or flesh without having broken bones. Bellrose was handicapped in his classification by use of a fluoroscope which allowed only one view of the birds, so his classifications of the shot locations were somewhat arbitrary.

Scarcity of shot in the massive breast muscles of the oil-sticken birds is strong evidence that birds wounded

TABLE 2. Location of shot pellets in birds killed by oil pollution.

Location	Lesser scaup			Ring-necked ducks			All birds	
	Number of birds		Percentage [1]	Number of birds		Percentage [1]		
	Male	Female	both	Male	Female	both	Number	Percentage
Head	16	4	10.0	16	1	13.3	37	11.2
Neck	16	6	11.0	10	3	10.2	35	10.6
Breast	22	6	14.0	10	9	14.8	47	14.3
Back	37	12	24.5	19	10	22.6	78	23.8
Wings	15	2	8.5	15	3	14.0	35	10.5
Thorax	4	1	2.5	1	0	0.8	6	1.8
Abdomen	40	6	23.0	19	9	21.8	74	22.5
Legs	4	1	2.5	0	0	0.0	5	1.5
Side	7	1	4.0	2	1	2.3	11	3.4

[1] Percentage of birds containing shot that had at least one shot in a particular location.

in this area are unable to complete their migration and are taken by hunters or predators. The high incidence of pellets in the abdomen is indicative of the non-essential functions of this area to flight and a high resistance to peritonitis among these ducks.

Ingested Shot

The examination showed ingested lead shot in 1.6 percent of the male lesser scaup and in 1.8 percent of the females (Table 3). Similar examination of ring-necked ducks disclosed an average of 0.8 percent for males and 3.3 percent for females. This is a statistically significant higher occurrence in the females (t value 1.85 with a 6 percent level of significance).

TABLE 3. Proportion of ducks containing one or more ingested lead shot.

Species	Number examined	Number with shot	Percentage with shot
Ring-necked duck			
Male	264	2	0.8
Female	152	5	3.3
Lesser scaup			
Male	1243	20	1.6
Female	444	8	1.8
All kinds	2103	35	1.7

The presence of ingested shot pellets in 1.7 percent of the lesser scaup and 1.6 percent of the ring-necked ducks is somewhat similar to that reported for wintering ducks in Michigan, where Whitlock and Miller (1947) reported 1.0 percent for all species. It is considerably less than that reported by Bellrose (1959) for lesser scaup and ring-necked ducks in the fall (usually in excess of 10 percent). Reid (1947) has also reported a high incidence of ingested shot in fall migrant ducks in Minnesota—14 percent for diving ducks and 8 percent for dabbling ducks.

In the sample of birds available for photofluorographic radiography there were two sources of bias. First, birds that have ingested lead shot are less capable of survival because of the stress of lead poisoning. Secondly, some of the birds rescued from the oil pollution, 900 in total, survived for various lengths of time before dying and may have eliminated shot pellets from their digestive tracts (especially the lumen of the gizzard) prior to death. These two biases tend to mitigate each other, but the magnitude of each is unknown.

The significantly higher occurrence of ingested lead shot in female ring-necked ducks (3.3 percent) than in males (0.8 percent) is apparently associated with the females seeking greater amounts of grit prior to laying eggs. Such behavior has been reported for the ring-necked pheasant by Kopischke (1966). The lack of a marked difference between male and female scaup is probably because many yearling scaup do not breed, and the egg laying period of those that do is later than for ring-necked ducks.

In general these spring migrant ducks did not have an unusually high incidence of ingested lead shot even though they had traversed heavily used public hunting grounds. Bellrose (1959) suggests that lethal poisoning does not occur until birds have ingested 4 to 5 pellets of lead shot, varying somewhat with diet. Therefore, it appears few of these ducks would have died of lead poisoning from ingested shot.

Body Shot and Hunting Kill

The incidence of imbedded shot in game birds that have survived a hunting season has long been recognized as being related to hunting pressure and kill (Whitlock and Miller, 1947; Elder, 1950). This relationship is most amenable to interpretation for young-of-the-year birds that have gone through only one hunting season. However, the authors know of no attempt to express this relationship quantitatively. Such a relationship cannot be exact, but it can serve as a useful indicator and perhaps as a wildlife management tool. To relate the incidence of body shot to the proportion of the population killed by hunting (total hunting mortality) requires information of several kinds, each of which has associated error.

In the following calculations, population and kill statistics are used at face value, and crippling loss is assumed to equal 30 percent of the birds bagged. The latter assumption is based on the work of Mendall (1958) on ring-necked ducks as is supported by Minnesota data of Lee *et al.* (1964).

The basic question to be considered is—"What is the general quantitative relationship between the percentage of living birds containing one or more lead shot in body tissues after a hunting season to the percentage of birds in the hunted population that were killed by hunters?"

In an attempt to interpret shot incidence found in lesser scaup and ring-necked ducks and relate this to hunt-

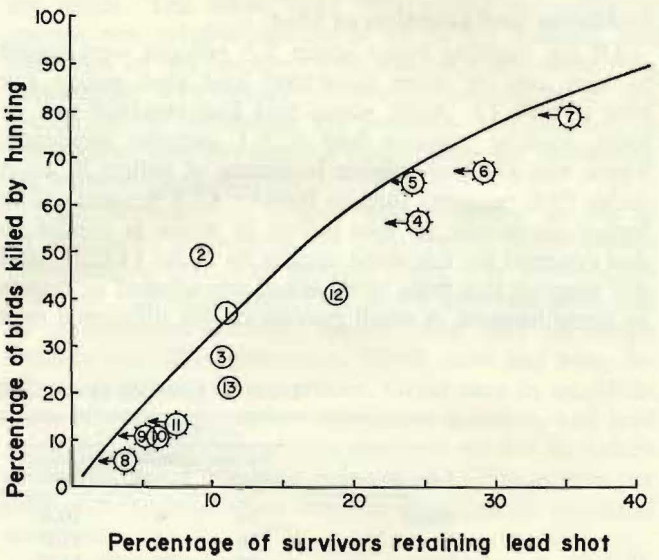

FIGURE 2. Percentage of surviving yearling game birds (ducks and pheasants) retaining body shot after the hunting season as related to the percentage of birds killed by hunting (including crippling loss). Circles with rays are based on data for pheasants; those without rays on data for ducks. Arrows signify data for birds of mixed ages and that the true value for yearling birds lies to the left; absence of arrows indicates young-of-the-year birds. Data are from sources cited in Table 4.

ing kill, similar data were compiled or calculated from other sources (Table 4). These represent situations in which incidence of shot in surviving birds is known and where information on hunting kill (including crippling loss) is available or can be calculated and in which data is also available or can be calculated on the size of the population hunted. Using this information, the percentage of birds (ducks and pheasants) in a population that were killed by hunting has been plotted against the percentage of survivors carrying body shot (Figure 2). The unmodified circles in this graph represent values for young-of-the-year birds (birds hunted in the same year they were hatched), and circles with arrows pointing to the left are values for populations of birds of mixed ages. The arrows indicate that the values are too high when applied to yearling birds and that the true value lies to the left. It should be pointed out, however. that in all cases a large part of the hunting kill was of yearling birds.

After plotting the data, several curves or mathematical models were calculated to obtain a curve that would best represent the data, and that shown in Figure 2 was selected. It is based on hunting mortalities (including crippling loss) ranging from 5 to 80 percent of the population hunted and incidence of body shot ranging from 3 to 35 percent of the surviving birds. The curve selected in this model represents a relationship in which the number of birds that survive with embedded pellets is equivalent to 25 percent of the hunting kill. That is. for every three birds killed, one bird will be struck, survive its wound, and carry at least one lead pellet in its body. The slope of the curve represents a series of segments each representing 2.5 percent of the total kill and flattens out as the population is thinned by hunting. It was calculated in this way since such population thinning occurs as ducks migrate down the flyway or, in the case of pheasants, as the hunting season progresses.

From this curve, for example, it can be estimated that if 20 percent of the birds surviving the hunting season carry shot, it is likely that 60 percent of the birds in the population were killed by hunting. Applying it to the incidence of shot already given for yearling lesser scaup and ring-necked ducks, it is estimated that the hunting kill of yearling scaup in the fall of 1962 was about 20 percent of the population and that for ring-necked ducks about 55 percent. The kill figure for ring-necked ducks suggests overshooting of this type.

Body Shot and Population Size

Theoretically, the curve in Figure 2 can also be used to estimate the size of the population from which the hunting kill came providing that the following pieces of information are known: (1) the hunting take of yearling birds; (2) crippling loss as a percentage of the hunting take; (3) the proportion of yearling to adult birds taken by hunters; and (4) the post-season incidence of shot in surviving yearling birds. These relationships will be considered for lesser scaup and ring-necked ducks and compared with estimates obtained in other ways.

Lesser Scaup

It will be recalled that 5.5 percent of the yearling lesser scaup examined carried body shot. Referring to Figure 1, this indicates a take hunting kill of about 20 percent of the pre-season population. The total U.S. hunting kill of yearling lesser scaup in 1962 was estimated by Glover and Smith (1963) to be 55,000 birds, to which should be added a crippling loss of 30 percent plus an estimated 12,000 kill in Canada. This gives an estimated total kill of 85,000 birds. Since the curve indicates this represents 20 percent of the total pre-season population of yearling birds the total population is estimated at 425,000 (5 x 85,000) birds.

The population of lesser scaup of all ages (other than ducklings) on the breeding grounds the previous summer (1962) as tallied by aerial counts was estimated as 2.7 million birds (Glover and Smith, 1963). This is probably too low. Martinson (personal communication) estimated that if it is corrected on the basis of ground counts, the real population size may have been 4.4 million. Lesser scaup populations contain more male than female ducks. The ratio was 3.5 males to 1.0 females for adult oil-killed birds, but was nearly equal for yearling birds. From these data and findings of other workers (Erickson, 1943; Bellrose *et al.*, 1961:419; and Benson, 1963) it

TABLE 4. Reference to estimates of game birds harvests and body shot incidence in the surviving population used in Figure 1.

Code [1]	Population	References	Comment
1	— Continental mallard population, 1963	Several sources [2]	Immature males only
2	— Continental mallard population, 1964	Several sources [2]	Immature males only
3	— Continental mallard population, 1965	Several sources [2]	Immature males only
4	— Cock pheasants, South Dakota, 1952 & 1959	Chesness & Nelson, 1964	Includes adults
5	— Cock pheasants, North Dakota, 1957-59	Chesness & Nelson, 1964	Includes adults
6	— Cock pheasants, Minnesota, 1958-60	Chesness & Nelson, 1964	Includes adults
7	— Cock pheasants, Wisconsin, 1953-56	Chesness & Nelson, 1964	Includes adults
8	— Hen pheasants, South Dakota, 1952-59	Chesness & Nelson, 1964	Includes adults
9	— Hen pheasants, North Dakota, 1957-59	Chesness & Nelson, 1964	Includes adults
10	— Hen pheasants, Minnesota, 1958-60	Chesness & Nelson, 1964	Includes adults
11	— Hen pheasants, Wisconsin, 1953-56	Chesness & Nelson, 1964	Includes adults
12	— Mallards, Illinois, 1949-52	Bellrose, 1953	Immature males
13	— Mean of six species, early 1950's	Elder, 1955	Calculations from table 4

[1] Numerals shown in Figure 2.
[2] Especially Brakhage, 1966; Hansen, 1964; Crissey, 1967; Hansen and Hudgins, 1965; and Grieb, personal communication.

appears likely that about 70 percent of the lesser scaup population on the breeding grounds was of male ducks. On this basis the number of paired breeding birds on the breeding grounds would be about 2.6 million (using the corrected aerial count as a base) of which about 0.8 million were yearling birds (based on the age ratio of the oil-killed ducks and further corrected for seasonal changes as reported by Benson, 1963). This estimate for yearling birds (750,000) is considerably higher than that already calculated from incidence of shot (425,000) by use of Figure 2.

If, however, the figures for the original aerial count were used as a base without any corrections, the estimate for yearling birds on the breeding grounds in 1962 becomes 460,000—a figure quite comparable to the 425,000 calculated from shot incidence.

Ring-necked Ducks

The incidence of body shot found in yearling ring-necked ducks killed by the oil spill was 24.5 percent for males, 8.6 percent for females and 17.8 percent for both sexes combined. Again referring to the curve in Figure 1, a hunting kill of about 55 percent is indicated among yearling ring-necked ducks both sexes combined.

The 1962 hunting kill (including that estimated for Canada and the crippling loss) is estimated at about 230,000 birds, of which about 60 percent (138.000) were young-of-the-year. It is estimated, as was done in the previous section, that the fall population was about 250,000 yearling birds. Judging from the ratio of the yearling to adult birds in the U. S. hunter's bag (1.36:1) and making allowance for immatures being more easily shot (1.7 times as reported by Lee *et al.*, 1964, p. 86), it appears that the adult population was around 275,000 in a total of about 500,000 birds in the fall flight. Probably almost half were killed.

The surviving population as estimated from shot incidence is in fairly close agreement with the uncorrected aerial counts made in 1963, when there were 313,000 ring-necked ducks counted on the wintering grounds and 216,000 on spring breeding grounds (Glover and Smith, 1963). It should be emphasized that the uncorrected aerial counts are minimal because of the difficulty of seeing the birds from the air.

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