AGE AND SEX VARIATION IN THE SIZE OF GOSHAWKS

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We have shown that it is possible to determine the sex of live Goshawks (*Accipiter gentilis*) and identify most birds as belonging to one of three age classes (Mueller and Berger, 1967, 1968). We now have a considerably larger sample allowing us to present criteria that permit an inexperienced bander to determine age and sex of Goshawks with an error of less than 2%. Our data also provide some observations on sexual dimorphism and changes in size with age in the species.

We trapped 354 Goshawks in the autumns of 1950 through 1974 at the Cedar Grove Ornithological Station, on the western shore of Lake Michigan about 70 km north of Milwaukee, Wisconsin. Sample sizes for the various measurements differ slightly because we inadvertently neglected to record some measurements on 9 birds. Although we have data from only one bird trapped in spring, we believe our age criteria would be applicable through early summer when the birds begin the next molt. We will use both the age terminology given in our previous papers and the terminology used by the Bird Banding Laboratory.

AGE CRITERIA

Because of slight variation in size with age, a bander should first determine the age of a Goshawk. A bird entirely in the brown (juvenal) plumage is a juvenile or HY-SY (HY until 31 December, SY after 1 January). The entire dorsal surface, including the head, back, wings and tail are brown and the underside is whitish with brown streaks. The postjuvenal or prebasic molt into the first gray plumage may begin quite early; on 24 March we trapped one juvenile that had 7 adult feathers on the lower breast and flanks. However, the postjuvenal molt is usually not completed until the very late fall or winter of the bird's second year.

Adults are gray above and the feathers of the underside are whitish with gray barring; some individuals show dark gray shaft streaks on the breast. A gray-plumaged bird with any brown feathers is more than one, but less than two years old, and was designated Adult I in our previous papers or SY-HY by the Bird Banding Laboratory.

An entirely gray-plumaged bird with two generations of gray feathers (feathers produced by two different molts presumably in two different years) is an Adult II or ASY-ATY.

A gray-plumaged bird with only one generation of feathers is an adult of unknown age or AHY. Only 1% of the 185 adults that we trapped fell into this category. The age of some of these individuals can be determined by eye color (see below).

Extremely careful examination of the bird, in good light, is necessary to differentiate ASY from AHY. Each flight feather (remex and rectrix) should be examined closely for differences in wear and coloration. Feathers of a previous generation usually show noticeably more wear on the tips, particularly in the rectrices, and a subtle fading sometimes can also be seen. Goshawks take several months to complete a molt, and feathers molted early (innermost primaries) may show more wear than feathers molted later (outermost primaries). Rectrix molt appears to be somewhat erratic; the central (No. 1) and outer (No. 6) pairs are almost invariably replaced by October or November while numbers 2 and 5 appear to be the last to be molted. The presence of few feathers of another generation, particularly in the body plumage, may not be the result of a molt because feathers pulled out in an accident are replaced without delay by feathers of the next plumage. Thus, the juvenile we trapped on 24 March may have accidentally lost the 7 breast feathers, which were replaced with adult feathers.

The eye color of the three North American species of *Accipiter* changes with age, progressing from gray to pale yellow, orange, red, and finally a very dark red. This color change is poorly understood and shows considerable individual variation. The color change appears to occur more rapidly in males than females. All juveniles had irides that were varying shades of yellow, occasionally with some or considerable gray. We subjectively assigned the eye color of each adult to one of six categories. These are listed below, along with approximate equivalents from Smithe (1975): light orange (color 18, orange yellow of Smithe), orange (17, spectrum orange), dark orange (16, chrome orange), light red (15, flame scarlet), red (14, scarlet), dark red (11 spectrum red). Table 1 shows the incidence of these colors in Adult I and II Goshawks.

TABLE 1

Iris color in Goshawks[1]

	light orange	orange	dark orange	light red	red	dark red
Adult I male	91.2	70.0	0	0	0	0
Adult II male	8.8	30.0	100	100	100	100
Adult I female	73.1	21.1	0	0	0	0
Adult II female	26.9	78.9	100	100	100	100

[1]The number given is the percent of that iris color which is of that age. Thus, 8.8% of the males with light ornage irides are adult II.

It can be seen that the age of birds with light orange or orange eyes cannot be determined by eye color alone with any degree of certainty. All birds with irides colored dark orange or any of the three categories of red were Adult II. In our sample, this would permit age determination of 75 percent of the adult males and 26 percent of the adult females by the use of eye color. Only one of the three birds that we could not place in Adult I or II on the basis of plumage had a sufficiently dark eye that we could place it in Adult II. Eye color thus can be used as a supplement to determine the age of Goshawks, but first, attention should be paid to plumage.

SEX CRITERIA

We measured wing chord and tail length on all but a few of the birds we captured. Wing chord was measured by placing the wrist (bend) of the closed wing at the zero point on a rule and pivoting the wing downward until the longest primary just touched the rule. Pressing the wing firmly against a stop at the zero point, as practiced by many banders, would result in slightly shorter measurements. Carelessly letting the wing lie on the ruler (as practiced by many banders) would result in slightly longer measurements. Perhaps these two commonly used practices cancel each other out. Tail length was measured by carefully inserting a very thin metal rule between the central rectrices and sighting across the tips of the longest rectrices.

All birds were subjectively sexed at the time of banding. To an experienced hawk bander, all female accipiters of a given species appear larger than the males. Indeed, the size dimorphism is sufficiently pronounced that an expert can often determine the sex of a bird with little more than a fleeting glimpse in the field. The wing and tail measurements for each age and (subjectively determined) sex class were graphed, and each of the six distributions resembled a normal (bell-shaped) curve. Within a given age class, the distributions for the two sexes almost met, and in one case (juvenile wing chord) actually overlapped slightly. The mean and standard deviation were calculated for each set of measurements for each age and sex class (Table 2).

A normal curve was calculated for each of the six distributions and a chi-square analysis indicated that each observed distribution did not differ significantly from a normal distribution (see, e.g., Sokal and Rohlf, 1969). For both tail and wing, we then added the standard deviations for the two sexes (in each age class) and divided this sum into the difference between the means. For the juvenile tail, this calculation yielded 2.43 standard deviations, which would include 49.25% of the area of the upper half of the normal curve for males and 49.25% of the lower half of the normal curve for females. The percentage of the area of the normal curve included within a given number of standard deviations can be obtained from a table in, e.g., Rohlf and Sokal (1969). Multipiying the standard deviation for males by 2.43 and adding the product to the mean yields 253.85. Multiplying the standard deviation for females by 2.43 and subtracting the product from the mean yields 253.67. The resulting slight overlap can be eliminated by using 2.37 standard deviations which includes 49.11% of half of each curve and yields a maximum tail measurement of 253 for males and a minimum of 254 for females. The area under the normal curve represents the percentage of the total population that will be included within these bounds. Thus far, we have considered only the adjacent halves of the curves for males and

TABLE 2

Measurements of Goshawks[1]

Measurement	Age	N	Males Mean + SD (Range)	N	Females Mean + SD (Range)	Difference in means
Tail length (mm)	Juvenile	106	239 ± 6.11 (221-252)	53	272 ± 7.54 (255-286)	33.2
	Adult I	39	232 ± 5.28 (223-242)	45	267 ± 6.56 (251-279)	34.0
	Adult II	41	230 ± 5.37 (219-240)	60	266 ± 7.69 (249-281)	35.5
Wing Chord (mm)	Juvenile	109	319 ± 6.36 (301-334)	52	346 ± 6.93 (330-361)	27.1
	Adult I	39	324 ± 5.26 (314-335)	45	350 ± 6.34 (337-367)	25.9
	Adult II	41	323 ± 4.75 (309-336)	60	353 ± 6.22 (339-365)	29.4
Weight (g)	Juvenile	105	808 ± 66.75 (664-988)	52	1,005 ± 79.03 (878-1,253)	197.4
	Adult I	39	900 ± 69.19 (756-1,029)	44	1,118 ± 103.75 (845-1,345)	217.1
	Adult II	38	925 ± 61.30 (735-1,099)	59	1,152 ± 77.50 (1,005-1,364)	226.8

[1]Within each age class, males differ significantly from females in every measurement (t-test, $P < 0.0001$). Within each sex, both adult I and II differ significantly in every measurement from the juveniles (t-test, $P < 0.0001$).

females, and the total percentage of males that have a tail length of 253 mm or less is twice 49.11% or 98.2%. Similarly, 98.2% of the females have a tail length of 254 mm or greater. The results of calculations for tail length and wing chord for the three age classes are given in Table 3.

TABLE 3

Sexing criteria and confidence intervals

Measurement	Age	Confidence interval (%)	Upper limit for males	Lower limit for females
Tail (mm)	Juvenile	98.2	253	254
	Adult I	99.5	247	248
	Adult II	99.2	244	245
Wing (mm)	Juvenile	95	331	332
	Adult I	96.8	336	337
	Adult II	99	336	337

Tail length appears to be the best indicator of sex in Goshawks (which surprised us), but in the case of birds with tail measurements near the dividing line a bander may wish to use wing length as a supplement to sex determination. Adults of unknown age can be sexed by using either, or a combination, of the calculations for Adult I and II, since the differences between the two are slight. The means and limits might change slightly for a different or larger sample, but it is highly unlikely that these differences would be of even marginal significance. Very few birds have measurements falling near the point of division between the sexes, and it would not matter much if this point were moved a few mm.

The statistical techniques used in determining these sex criteria are applicable to any species that is strikingly sexually dimorphic in size. Measurements in most books are based on dead birds, and shrinkage probably results in shorter measurements than those taken from live birds; for example, the wing arcs of Goshawk skins measured by Storer (1966) averaged 5 to 9 mm (2%) shorter than live birds measured by Mueller and Berger (1968). As Storer (1966) noted, collectors sometimes err in making sex determinations, and the ranges of measurements listed for a given sex taken from museum specimens may include incorrectly sexed birds. Analyzing a reasonably large sample of measurements of birds of unknown sex may result in a more accurate determination of sex dimorphism than measurement of museum specimens of "known" sex if the dimorphism of the species is sufficiently pronounced to yield two normal distributions without appreciable overlap.

VARIATIONS IN WEIGHT DURING THE AUTUMN

Goshawks tend to show increased weight as the fall progresses (Fig. 1). Although the regression coefficients (r) are not high, all but the ones for Adult I male and female are statistically significant (*t*-test, $P < 0.004$). Possibly weight increase through the fall is not rectilinear, but the high variability in weights precludes attempts to fit a more exact function to the data. Our data were gathered over a 25-year period and interannual variations in weight can occur (Mueller et al., in press), although our sample for a given year is usually too small to prove or demonstrate this point. But year-to-year and seasonal variation encompasses only a small part of the total variation in weight. For example, in the Adult I females, for which the regression line offers the poorest fit of all, we captured 19 of these birds in the brief interval of 13-17 October 1972, with a mean weight of 1,128.1 g, a standard deviation of 94.05, and a range of 987-1,310. A comparison of these calculations with those for all Adult I females (Table 2) reveals that the variation in these five consecutive days is nearly as great as for the entire sample. Furthermore, the mean for the 19 birds is slightly higher than the mean for the entire sample, even though the 19 were taken very early in the season. The extremely flat curve for Adult I females is largely a result of the peculiar sample of 13-17 October 1972. We are unable to explain the large variance

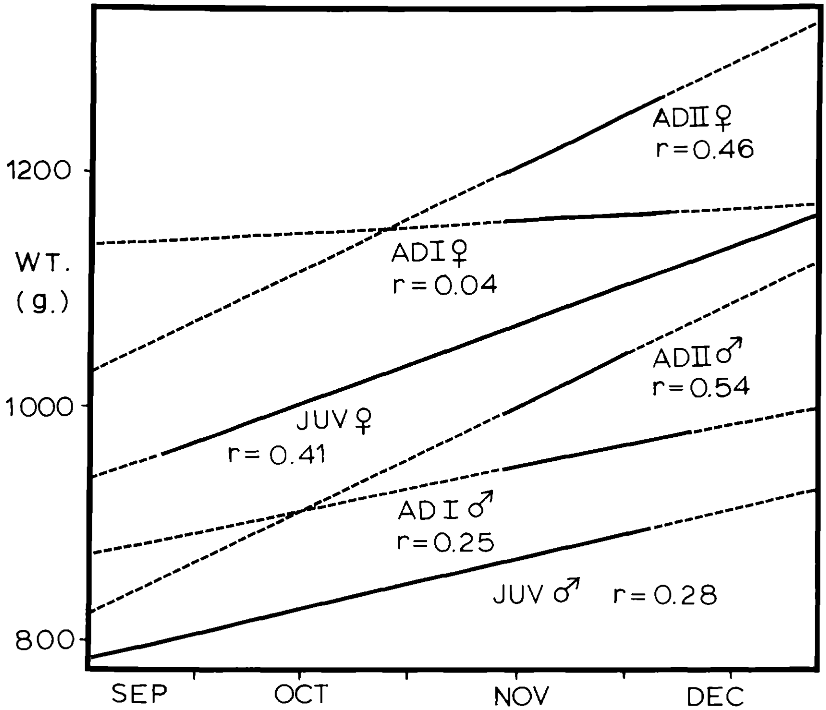

FIGURE 1. Linear regressions of weight on date of capture. Dotted lines indicate extrapolations beyond dates on which any captures made.

in weight of Adult I females; it is significantly larger than the variance of either Adult II or juvenile females (F test, $P < 0.05$).

The regression lines suggest that Goshawks increase in weight 2% (Adult I females) to 35% (Adult II males) in the period 15 September-27 December. If we eliminate the Adult I birds from consideration because of the poor fit of the regression lines, then the range becomes 17% (juvenile males) to 35%. These estimates should be viewed with caution because all regression lines involve at least some extrapolation beyond dates for which we have data. Although the graph suggests that Adult II birds increase in weight more rapidly than juveniles, the differences in slope are not significant.

CHANGES IN SIZE WITH AGE

Adult Goshawks have longer wings, shorter tails and weigh more than juveniles (Table 2). All these differences are very highly significant (*t*-test, $P < 0.0001$). These differences may be of significance in the relative abilities to pursue and capture prey and in agonistic encounters between birds. Greenewalt (1962) presented formulae that permit us to use wing chord to obtain an estimate of wing area. Table 4 presents estimated mean wing area for the six age and sex classes, along with the average wing loading. It should be noted that our estimates of wing area are lower, and wing loading is higher, than the measurements of one specimen of each sex presented by Storer (1955). The constants used in the formulae of Greenewalt (1962) are the probable source of error in our estimates. Since we used the same formulae in all of our calculations, comparisons between our age and sex groups are probably valid, but our estimates of wing area and wing loading should not be compared with those of other species or with those derived by different methods.

TABLE 4

Estimated mean wing area and wing loading

	Males		Females	
Age	Wing area[1] (cm^2)	Wing loading (g/cm^2)	Wing area (cm^2)	Wing loading (g/cm^2)
Juvenile	1,371.6	0.589	1,613.7	0.623
Adult I	1,415.0	0.636	1,651.2	0.677
Adult II	1,406.3	0.658	1,679.6	0.686

[1]Estimated by the formulae from Greenewalt (1962): wing area = (wing chord/0.62)^2/1.93.

Wing loading increases more with age than any other measure except weight (Table 5). A bird with a heavier wing loading will

TABLE 5

Percent changes in measurements with age

	Males				Females			
	wing chord	weight	wing load	tail length	wing chord	weight	wing load	tail length
Juvenile-Adult I	1.6	11.4	8.0	−2.9	1.2	11.2	8.7	−1.8
Juvenile-Adult II	1.3	14.5	11.7	−3.8	2.0	14.6	10.1	−2.2
Adult I-Adult II	−0.3	2.8	3.5	−0.9	0.8	3.0	1.3	−0.4

have a higher stalling speed and will have to fly more rapidly. A heavier bird will have a greater impact in a strike on prey (or on a conspecific) than a lighter bird; the more rapid flight of an adult will increase this difference (cf. Storer, 1966). These considerations should give an adult an advantage over juveniles in dealing with large prey or in fights with conspecifics. If, as we suspect, the increase in weight of adults is primarily an increase in the size of the flight musculature, the adults have an even greater advantage because the increase in power available would result in greater acceleration and maneuverability. Within an age class, females have greater weight and wing loading than males and presumably have a competitive edge over males in dealing with them or with large prey. It is interesting to note that although juvenile females weigh more than adult males (Table 2), adult males have a slightly higher wing loading than juvenile females (Table 4). We have presented data and arguments elsewhere (Mueller et al., in press) that females dominate males and adults dominate younger birds in agonistic encounters.

The long tail and lighter wing loading of the juveniles aid maneuverability, permit easier utilization of updrafts (particularly weak ones), and generally reduce the energy expenditure necessary for flight and perhaps even for pursuit of small, elusive prey. We believe that the low weight and low wing loading of juveniles are an adaptation to minimize energy expenditure and thus reduce need for prey. Adults, with their greater experience in finding, pursuing and capturing prey (see, e.g., Mueller and Berger, 1970), can afford the advantages conferred by heavier wing loadings. We are assuming that each individual Goshawk increases in size with age because it seems unlikely that our data reflect a higher survival rate of larger, heavier birds in both sexes.

We have searched the literature, unsuccessfully, for a previous account showing an increase in size with age in a flying, altricial bird after the young become independent of the parents. We are currently examining our data from other species, and an increase in size with age seems to be characteristic for all three species of North American accipiters. We suspect that at least an increase in weight with age may exist in other bird-eating hawks and falcons and perhaps even in other species of Falconiformes.

The dimorphism between sexes shows a general trend to increase with age (difference in means, Table 2). These differences, however, are not statistically significant (t-test: tail, $P = 0.22$; weight $P = 0.13$). A larger sample of birds collected within a few days, rather than over many years, might show the increase in dimorphism of weight to be statistically significant. This increase in dimorphism in weight might have some biological significance but it probably has arisen fortuitously as a result of increases of the same proportion in the two sexes. Adult II males are 117 g or 14.48% heavier than juvenile males and Adult II females are 147 g or 14.62% heavier than juvenile females. The increase in dimorphism with age is thus 30 g but only 0.14%, which is probably insignificant.

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SUMMARY

All but a few Goshawks can be assigned to one of three age classes by an examination of plumage and molt. Eye color is a further aid in age determination. The sex of Goshawks can be established with an error of no more than 1.8% by tail measurement. Wing chord is an additional criterion in difficult cases. Adults have significantly shorter tails, longer wings, greater weight, and higher wing loadings than juveniles. Females are significantly larger than males in all of the above measures. Females probably have a competitive edge over males, and adults over juveniles in capturing large prey and in intraspecific agonistic encounters. The long tails, low weights, and low wing loadings in juveniles are probably an adaptation for less energy-consuming flight until sufficient experience is gained in capturing prey.

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