SELECTION OF DIFFERENT-SIZED PREY BY SHARP-SHINNED HAWKS (*ACCIPITER STRIATUS*) AND NORTHERN GOSHAWKS (*A. GENTILIS*).

A Thesis

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ABSTRACT

The primary objective of this study was to experimentally test the hypothesis that a positive correlation exists between weight of accipiters and the weight of their prey. Sharp-shinned hawks (Accipiter striatus) and northern goshawks (A. gentilis) were selected for the study due to their abundance during migration, ease of trapping, and differences in weight. Two different-sized prey, European starlings (Sturnus vulgaris) and domestic pigeons (Columba livia), were used as bait. Measures of predator size, other than body weight (wing flat, hallux length, body length, and bill length), were also evaluated. Statistical tests were used to determine if there were between-sex or between-age differences in predator-prey size correlations within each species of raptor. Prey weight was positively correlated with accipiter weight (both species combined) and with goshawk weight, but not with sharp-shinned hawk weight. Some similar patterns were found when other measures of predator size were used. Intraspecific comparisons showed few significant between-sex or between-age differences in predator-prey correlations.

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INTRODUCTION

Predator-prey size relationships have been demonstrated for mammal (Rosenweig, 1968), insect (Mason, 1965), and bird (Betts, 1955; Ashmole, 1968; Schoener, 1969; Leck, 1971) predators. It has long been argued that this relationship exists because of energy cost-benefit expenditures (Hutchinson and MacArthur, 1959; Schoener, 1969). That is to say, as the size of the predator increases, the general size of prey selected increases so that an efficient use of energy in the capture of prey results.

Information regarding relationships about raptors and their prey size have been obtained primarily from the observation of nest remains (Meng, 1959), teathered young (Peterson, 1979), and observations of feeding activity at nesting sites (Bent, 1936; Kennedy and Johnson, 1986). Storer (1966) used the food habit files of the United States Fish and Wildlife Service, which were obtained by recording stomach and crop contents. Storer found that predator-prey size correlations existed in three North American accipiters, sharp-shinned hawks (*Accipiter striatus*), Cooper's Hawk (*A. cooperii*), and northern goshawks (*A. gentilis*).

Significantly, there has been little experimental evidence that a positive correlation between raptor size and prey size exists. In perhaps the most definitive study to date, Mueller and Berger (1970) utilized three different-sized baits for the capture of sharp-shinned hawks. Their results suggested that male sharp-shinned hawks, which are the smaller of the sexes, showed a stronger preference for smaller prey than did females. Also, adults were less likely to attack large prey than were juveniles.

Mueller and Berger's study design appears to be inappropriate in four ways. 1) The study used five baits in the trapping area: two house sparrows (Passer domesticus), two starlings (Sturnus vulgaris), and one domestic pigeon (Columba livia). Because of the unequal representation of bait species, data showing prey preference may have been the result of prey abundance rather than selection. 2) It was unclear if baits were randomly moved to avoid trap selectivety. Therefore, one trap may have been particularly effective in capturing accipiters and would bias the study results. 3) It was not clearly stated if all raptors trapped in the study had equal access to all baits. For example, if a trap had captured a raptor, it would temporarily eliminate the presentation of that bait until the trap was reset. 4) Raptors trapped in mist nets presented the problem of determining which bait the raptor was attempting to capture, if any. It was unclear as to how this problem was resolved.

The primary objective of this study was to test the hypothesis that a positive correlation exists between the size of two North American accipiters, the sharp-shinned hawk and goshawk, and the size of their prey. The two species of accipiters studied were selected due to their ease of trapping, abundance, and interspecific size difference. Weight was selected as the measure of both predator and prey size due to its use in previous studies (see below). A secondary objective is to determine if age or sex affects predator-prey size correlations. For example, is predator-prey size correlation higher in adult goshawks than it is in juvenile goshawks?

Another secondary objective is to explore if predator-prey size correlations are significantly affected when measures of predator size other than weight are used. Hespenheide (1971) used prey weight as a measure of size in describing predator-prey size relationships. Storer (1966) suggested that weight was the best determination of size, although no other measures were used. Though body weight happens to be the most frequently used measure of size, other possible measures of avain size include wing length (Fretwell, 1969), talons length (Mueller, 1986), and bill length (Johnson, 1966; Grant, 1972). In the present study, four other measures of predator size were used: wing flat, body length, bill length, and hallux length.

METHODS AND MATERIALS

Site Description

The trapping site was located approximately thirty five kilometers north of Duluth, Minnesota along the north shore of Lake Superior. The site was selected for its remoteness and its relatively high elevation compared to the surrounding landscape (see Figure 1). The exposed rock outcrops and shallow soil restricted plant growth and presumably increased the visibility of the site to raptors. A major southward migration of raptors occurs through this area beginning in the autumn, as noted by the Duluth Hawk Ridge Count (Ruhme, et al, 1982). The cliffs along the shore provide updrafts, and the lake provides a barrier that raptors do not normally cross. These characteristics, including a high occurrence of cold fronts with northwesterly winds in the fall, combine to cause a "funnelling effect" of raptors moving southward, thus increasing the probability of a large sample.

Traps and Techniques

This study was conducted from August to November, in 1982 and 1983, by luring migrating raptors into a trapping site. Two different-sized prey were simultaneously used as bait. The prey items used for bait were starlings (Sturnus vulgarus) and domestic pigeons (Columba livia).

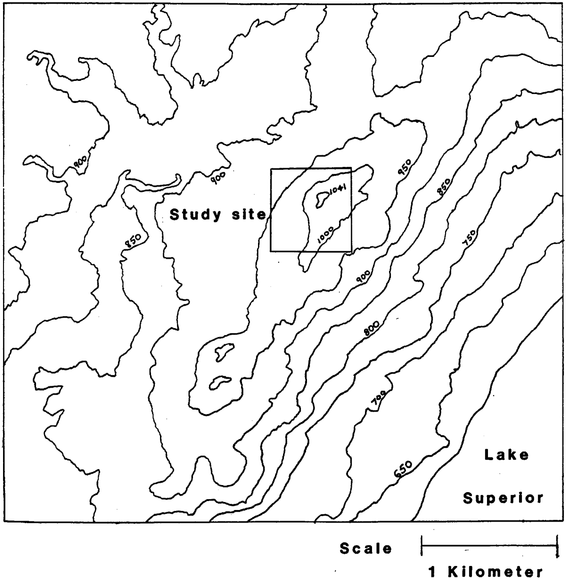

Figure 1. Map of study site.

Raptors were attracted by vigorously moving one of the two baits. As the raptor approached the trapping site, both baits were agitated near the ground to increase the probability that both were equally visible. Raptors that approached from a direction where it was uncertain whether both prey items could be seen, were not used in the study. Any raptor trapped during the time a net had been released and not reset was not used in the study. Trapped raptors were banded with a United States Fish and Wildlife Service band and released after all pertinent information, including prey weight and various predator morphological measurements, had been recorded.

Two spring loaded bow-nets and mist nets were used to trap raptors (Clark, 1971; Keyes and Grue, 1982). Mist nets (61 mm mesh) were set approximately eight meters to the north of the bow-nets and immediately to the south (see Figure 2). Baits were controlled from a blind with a lure line for each bow-net, and were randomly moved to avoid trap bias. The initial bait moved was also randomly selected. Raptors used in this study were either trapped in a mist net while on a direct line of flight to a specific bait, or captured in a bow-net while standing on the bait.

Measurements and Data Analysis

Species, age and sex were recorded for each raptor trapped using USF&WS banding information for this determination (Environmental Conservation Service, 1984). Five morphological characteristics were additionally recorded. These consisted of body weight, body length, wing flat, bill length and hallux length. A detailed description of measurement techniques is found in Appendix A.

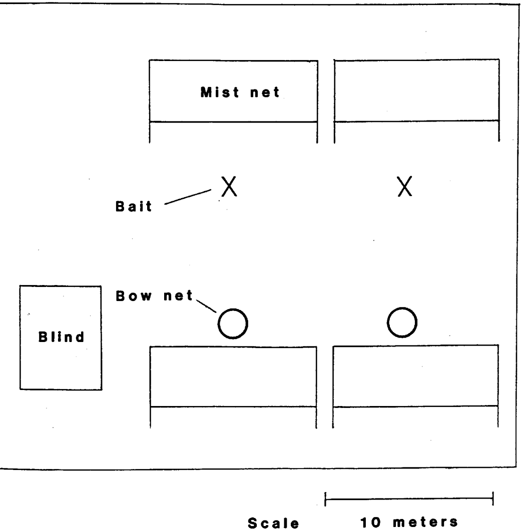

Figure 2. Diagram of study site. Lure lines and poles are not shown.

Standard statistical analysis (chi-square, correlation, and analysis of variance; Zar, 1978) were performed using SPSS-X (SPSS-X INC., 1986) statistical software at the University of Wisconsin - La Crosse Academic Computing Services.

RESULTS

Description of Prey Weight

As shown in Table 1, the starlings and pigeons used as bait were significantly different in size. Pigeons were approximately five times larger than starlings and no interspecific weight overlap occurred. Therefore, raptors trapped in the study clearly had two different-sized prey available at the time of capture.

Predator Size Measurements

Sharp-shinned hawks and goshawks trapped in this study showed statistically significant sexual dimorphism in size. In addition, individuals of each species showed significant age-related size differences (see Table 2).

As shown in Table 2, all females weighed more than males and adult weights averaged more than juveniles in both sharp-shinned hawks and goshawks. This sexual size dimorphism and increase in weight with age is typical for accipiters (Storer, 1966; Snyder and Wiley, 1976; Environmental Conservation Service, 1984).

Other measures of predator size (wing flat, body length, etc.) all showed significant intraspecific differences between sexes for both sharp-shinned hawks and goshawks. Significant differences between ages were apparent in wing flat, bill length and hallux length for sharp-shinned hawks, and in bill length and hallux length for goshawks (see Appendix B. Tables 1-4).

The correlation matrices for sharp-shinned hawks and goshawks (see Table 3) show how well each of the measures for predator size

Table 1. Description of prey weights.

Species	Mean (g)	S.D.	Range (g)	N
Starling	78.1	6.2	66-82	368
Pigeon	362.2	51.5	288-449	362

N = Number of weight measurements

Table 2. Mean weights (g) for sharp-shinned hawks and goshawks. Significant differences were found between age and sex within sharp-shinned hawks and within goshawks (two way analysis of variance; $p < 0.05$).

Sharp-shinned Hawks

	Males	S.D.	N	Females	S.D.	N
Juveniles	96.3	6.0	126	162.8	9.0	116
Adults	101.3	8.1	38	176.6	15.9	116

Goshawks

	Males	S.D.	N	Females	S.D.	N
Juveniles	761.2	57.2	20	1034.7	88.3	16
Adults	901.5	73.4	150	1081.9	77.4	116

Table 3. Correlation matrix for measures of size for sharp-shinned hawks and goshawks. All correlations were statistically significant ($p < 0.05$).

Sharp-shinned Hawks

	Body Weight	Wing Flat	Hallux Length	Body Length
Wing Flat	0.822			
Hallux Length	0.722	0.763		
Body Length	0.790	0.824	0.784	
Bill Length	0.769	0.780	0.785	0.757

Goshawks

	Body Weight	Wing Flat	Hallux Length	Body Length
Wing Flat	0.702			
Hallux Length	0.631	0.676		
Body Length	0.723	0.796	0.793	
Bill Length	0.580	0.502	0.675	0.664

are related to the others. Each of the four measures of predator size was significantly correlated with each other.

General Predator-Prey Comparisons

Table 4 shows prey species selected by sharp-shinned hawks and goshawks. Sharp-shinned hawks clearly selected starlings more than pigeons, while goshawks showed the opposite selection pattern. Given the size data in Table 1 and Table 2, this pattern of prey selection suggests that prey size and predator size are positively correlated.

Intraspecific prey selection patterns for sharp-shinned hawks and goshawks are shown in Table 5. Both sexes in sharp-shinned hawks show a high preference for starlings, but males selected the smaller prey (starlings) proportionately more than females. Interestingly, adult sharp-shinned hawks selected a significantly higher proportion (82.6 %) of smaller prey than did juveniles (71.4 %).

Goshawk males selected a significantly higher proportion (21.2 %) of the smaller prey than did females (6.6 %). Adult goshawks did select larger prey more than did juveniles, unlike the sharpshins noted earlier. Thus, male sharp-shinned hawks and goshawks tended to select smaller prey than females and juvenile and adult selection patterns differ between these two species.

A scattergram was constructed to show the relation-ship of the weight of the prey selected compared to the weight of the raptor (see Figure 3). The data show four areas of concentration, clearly indicating that the data are not normally distributed and reflecting the pattern in prey and predator weight summarized in Tables 1 and 2.

Table 4. Prey species selected by accipiters.

Prey Species	Sharp-shinned Hawks	Goshawks	Total
Starlings	310	44	345
Pigeons	86	248	334
Total	396	292	688

Chi-Square = 266.4 ($p < 0.0001$)
d.f. = 1

Table 5. Prey selection for sharp-shinned hawks and goshawks by sex and age.

Sharp-shinned Hawks

Prey Species	Males	Females	Juveniles	Adults	N
Starlings	144	166	110	200	310
Pigeons	20	66	44	42	86
	Chi-Square = 14.93 ($p < 0.001$)		Chi-Square = 7.64 ($p < 0.01$)		

Goshawks

Prey Species	Males	Females	Juveniles	Adults	N
Starlings	36	8	8	36	44
Pigeons	134	114	18	230	248
	Chi-Square = 16.09 ($p < 0.001$)		Chi-Square = 7.46 ($p < 0.01$)		

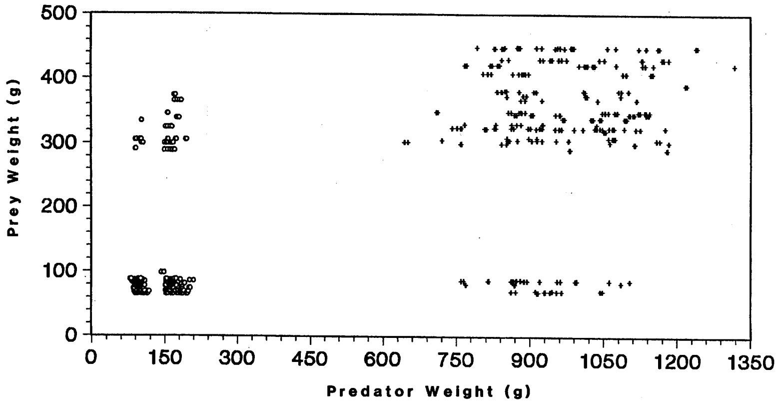

Figure 3. Graph of prey weight (g) versus predator weight (g) for sharp-shinned hawks (O) and goshawks (+).

Because of the non-normal distributions, both prey and predator size measurements were rank-transformed for subsequent statistical analysis. The Spearman Rank correlation procedure, used heavily in subsequent analysis, uses such an approach. The effect of rank-transforming both predator and prey weight is shown in Figure 4. Fisher's Z transformation was used to compare correlation coefficients.

An analysis of predator-prey size correlations is shown in Table 6. When both species are grouped together, a significant positive correlation between prey weight and body weight exists ($r = 0.575$).

Considered separately, sharp-shinned hawks show no significant correlation between body weight and prey weight, while goshawks do show a significant correlation (see Table 6). It should be noted that the correlation coefficients are generally low. This suggests that the amount of variation in prey weight that is explained by the raptor size measurement is rather low, even for goshawks.

Other measures of raptor size (wing flat, hallux length, etc.) all showed significant positive correlation coefficients when sharp-shinned hawks and goshawks were considered as one group. Correlations for sharp-shinned hawks showed significant positive correlations using hallux length and bill length. Goshawks showed significant positive correlations for wing flat, hallux length and body length (see Table 6).

<u>Intraspecific Comparisons -- Sharp-shinned Hawks</u>

Correlation coefficients for sharp-shinned hawks by sex are summarized in Table 7. These coefficients were generally rather low,

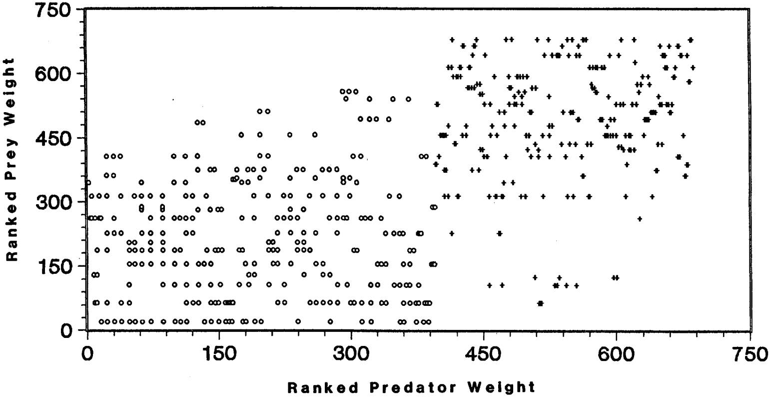

Figure 4. Graph of ranked prey weight versus ranked predator weight for sharp-shinned hawks (O) and goshawaks (+).

Table 6. Predator-prey size correlation coefficients for prey weight and various raptor size measurements.

Species	Body Weight	Wing Flat	Hallux Length	Body Length	Bill Length	N
Both Species	0.575*	0.571*	0.599*	0.578*	0.571*	688
Sharp-shinned Hawks	0.050	0.052	0.179*	0.069	0.090*	396
Goshawks	0.150*	0.188*	0.123*	0.219*	0.092	292

* indicates significant correlation (Spearman Rank; $p < 0.05$)

Table 7. Correlation coefficients for prey weight and various size measurements for sharp-shinned hawks by sex. Coefficients for males and females showed no significant between-sex differences ($p > 0.05$).

Sex	Body Weight	Wing Flat	Hallux Length	Body Length	Bill Length	N
Male	-0.093	-0.019	0.113	-0.038	-0.042	164
Female	-0.144*	-0.167*	0.133	-0.115*	-0.049	232
Between-Sex Difference	No	No	No	No	No	

* indicates significant correlation (Spearman Rank; $p < 0.05$)

and no significant between-sex differences ($p > 0.05$) were found between predator weight-prey weight correlation coefficients.

Furthermore, other measures of size showed no statistical between-sex differences in correlation coefficients. Thus, there is no statistical evidence suggesting that predator-prey correlations are different for male versus female sharp-shinned hawks.

Within each sex, correlations between prey weight and sharp-shinned hawk weight were low (see Table 7). Correlations for prey weight with other measures of predator size similarly showed low values. Interestingly, females had significant negative correlations for three measures of size (body weight, wing flat, and body length).

Both juvenile and adult sharp-shinned hawk correlation coefficients for prey weight and body weight showed no statistical between-age difference (see Table 8). Similarly, correlations of prey weight with other measures of size (wing flat, hallux length, etc.) showed no between-age difference. These results suggest that predator-prey size correlations may not be affected by age in sharp-shinned hawks.

Intraspecific Comparisons -- Goshawks

A summary of correlation coefficients for goshawks by sex is shown in Table 9. Though the correlation coefficient is not high, female goshawks are positively correlated with prey weight when predator size is measured by body weight. However, there was no statistically significant between-sex difference in the correlations for body weight.

Table 8. Correlation coefficients for prey weight and various morphological measurements for sharp-shinned hawks by age. Coefficients for juveniles and adults showed no significant between-age differences ($p > 0.05$).

Age	Body Weight	Wing Flat	Hallux Length	Body Length	Bill Length	N
Juvenile	0.156*	0.140*	0.278*	0.171*	0.157*	242
Adult	0.122	0.118	0.247*	0.100	0.245*	154
Between-Age Difference	No	No	No	No	No	

* indicates significant correlation (Spearman Rank; $p < 0.05$)

Table 9. Correlation coefficients for prey weight and various morphological measurements for goshawks by sex. Coefficients for body length show a significant between-sex difference ($p < 0.05$).

Sex	Body Weight	Wing Flat	Hallux Length	Body Length	Bill Length	N
Male	0.063	0.151*	0.049	0.129*	0.122	170
Female	0.208*	0.352*	0.184*	0.503*	-0.073	122
Between-Sex Difference	No	No	No	Yes	No	

* indicates significant correlation (Spearman Rank; $p < 0.05$)

Positive predator-prey correlations are also present for both males and females using other measures of predator size. The only significant between-sex difference in correlation coefficients was for body length, where correlations were higher in females than males. Thus, in most cases sex appears not to affect the relationship of prey weight and predator size.

Correlation coefficients for goshawks by age are presented in Table 10. Correlation coefficients for prey weight and predator weight for both juvenile and adult goshawks are low and there is no between-age difference. Predator-prey correlations using other measures of predator size showed correlations for hallux length to differ between juveniles and adults. Hallux length in juveniles appears to be more highly correlated with prey weight than hallux length in adults. Although the between-age diference with hallux length occurred, other measures of size show no between-age differences.

Table 10. Correlation coefficients for prey weight and various morphological measurements for goshawks by age. Coefficients for hallux length show a significant between-age difference ($p < 0.05$).

Sex	Body Weight	Wing Flat	Hallux Length	Body Length	Bill Length	N
Juvenile	-0.041	0.133	0.478*	0.338*	0.222	26
Adult	0.092	0.160*	0.061	0.195*	0.034	226
Significant Difference	No	No	Yes	No	No	

* indicates significant correlation (Spearman Rank; $p < 0.05$)

DISCUSSION

Do larger accipiters take larger prey?

The results of this study suggest that, in a number of instances, larger accipiters do take larger prey. Prey species selected by accipiters, using Chi-square analysis (Table 4), show the larger of the two species, goshawks, selected the larger prey (pigeons) and sharp-shinned hawks selected smaller prey (starlings). Furthermore, male goshawks selected smaller prey more often than female goshawks (Table 5). The same trend is shown for male and female sharp-shinned hawks.

Correlation analysis further show a significant positive correlation between prey weight and predator weight for both accipiters as a group (Table 6). Other positive correlations with predator weight were shown for juvenile sharp-shinned hawks (Table 8), female goshawks (Table 9), and goshawks as a whole (Table 6). The study also showed, however, that there are no significant correlations in weight for male goshawks (Table 9), male sharp-shinned hawks (Table 7), and both age classes of goshawks (Table 10).

Interestingly, in several instances there is a negative correlation between predator size and prey size. Juvenile sharp-shinned hawks, which were smaller than adults (Table 2), select larger prey than adults (Table 5). Furthermore, female sharp-shinned hawks show negative predator-prey correlations (Table 7).

These results are inconsistent with the general findings of this study and should be investigated further. A possible explaination for this inconsistency may be in the use of 0.05 or less as the level of statistical significance, which implies at least one out of twenty tests will show significance even though no significance exists. This type of statistical artifact may explain these patterns (also see below).

Other measures of predator size (wing flat, hallux length, body length, and bill length) show positive correlations in many cases and are generally consistent with the correlations for predator weight. Some significant positive correlations are shown with other size measures where significance had not been shown with predator weight. For example, significant positive correlations are shown in sharp-shinned hawk hallux length and bill length (Table 6) and in both age classes of goshawks for body length (Table 10). In several instances, correlations using other measures of predator size often resulted in higher correlation coefficients than did correlations using predator weight.

Though additional study is necessary, it is possible that predator weight may be a less satisfactory measure of size than, say, hallux length. An individual may show short term fluctuations in weight due to changes in the amount of time since food was last consumed, how much food was consumed, if food is present in the crop, percent body fat, etc. It is possible that other size measures (e.g. body length, hallux length, etc.) may be less prone to these short term changes.

The cost-benefit model of energy expenditures (Hutchinson and MacArthur, 1959; Schoener, 1969) implies that predators should forage efficiently and, as a result, larger predators take large prey. The result of these predicted foraging patterns is that food items should be partitioned between differently sized predators within a species as well as between species. Thus, female goshawks should take larger prey than males, and goshawks should take larger prey than sharp-shinned hawks. This model seems to be generally consistent with accipiter prey selection patterns noted in this study, but certainly not all.

For example, some of the results in this study raise the possiblity that size-related food partitioning may also occur that does not agree with the cost-benefit model described above. For instance, juvenile sharp-shinned hawks selected a higher proportion of pigeons than did adults (Table 5). Mueller and Berger (1970) suggested that juvenile sharp-shinned hawks are inexperienced and thereby attempt to capture inappropriate-sized prey. Therefore, the smaller juveniles may select proportionately larger prey than the adults. This suggestion may also explain the juvenile-adult selection pattern for goshawks (Table 5), where juveniles selected a higher proportion of smaller prey than did adults. It may be that adults utilize the more optimally sized prey items and cause an "inadvertent" partitioning of the food resource with juveniles.

Predators may also use cues other than size to select prey. Some of these other cues include fitness of the prey (Mech, 1970), prey abundance, and nutritional value of the prey. The potential complexity of prey selection may explain not only the lack of positive correlations in some groups of accipiters but also the generally low correlations found in most raptor groups considered in this study. It seems likely that there are factors other than size affecting the selection of prey by predators.

A particularly puzzling aspect of this study concerns the negative correlation between prey weight and predator weight for female sharp-shinned hawks (Table 7). This negative correlation may be a statistical artifact as mentioned earlier. Additional observations are neded to verify whether or not this is the case.

Does age or sex affect predator-prey correlations?

Results of this study show that predator-prey size correlations within accipiter sex and age groups are often significant (Tables 7-10). The question which now can be considered is if one sex class (e.g. males) or one age class (e.g. juveniles) is better correlated with prey size than is the other sex or age class.

In general there is little difference between sex or age correlations for all measures of predator size. Hallux length in juvenile goshawks, however, shows a significantly higher correlation with prey weight than did measures for adults (Table 10). Also, body length in female goshawks is better correlated with prey size than in males (Table 9). These differences may be biologically significant, but, given the large number of pair-wise correlation coefficient comparisons, it is possible they may be statistical artifacts. Additional observations would help clarify this.

Conclusions

The two baits used in the study provided non-overlapping prey weights that allowed accipiters to make a clear choice between a small prey item (starling) and a large prey item (pigeon). However, a study more sensitive to subtle predator selection differences may have been possible by using a wider prey weight range and more intermediate sized prey.

Prey weight is positively correlated with accipiter weight (both species combined) and with goshawk weight, but not with sharp-shinned weight. Similar patterns were found when other measures of predator size were used. These results are consistent with less carefully controlled studies of predator-prey size relationships (Mueller and Berger, 1970; Kennedy and Johnson, 1986; Mueller, 1986). Within-species categories designated by age and sex showed fewer significant predator-prey size correlations, particularly for sharp-shinned hawks, suggesting that prey selection is also a function of other, undetermined variables.

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APPENDIX A. Measurement Techniques

Body length was determined by grasping the raptor by the legs and placing the bird on its back while holding the bill forward with the head flat on a table. The measurement was taken from where the tip of the bill touched a vertical bar, to the terminal tip of the rectrices, along a horizontal plane. Weight was determined by placing the raptor in a close fitting metal cylinder and using an Ohaus triple beam balance (Mueller and Berger, 1968) and recorded to 0.1 gram.

Tail length was measured by placing a ruler between the central rectrices to make contact with the body, then sighting across the tips of the two longest rectrices. Wing chord was measured by placing the bend of a closed wing (carpal joint) at the junction of a ninety degree angle on the end of a metric ruler. The wing was pivoted downward until the longest primary touched the ruler. Wing flat was measured by pressing the wing flat. Hallux length was measured from the fleshy end of the toe along the outer edge of the talon to the point, using a flexible plastic ruler. Bill length was measured from where the cere and bill meet anteriorly, along the outer edge, to the terminal point, again with a plastic ruler.

APPENDIX B. Between-age and Between-sex Size Comparisons

Table B1. Mean wing flat measurements (mm) for sharp-shinned hawks and goshawks.

Sharp-shinned Hawks

Significant differences were found for both age and sex (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	173.0	3.6	126	203.1	5.3	116
Adults	174.3	3.6	38	205.7	4.1	116

Goshawks

Significant differences were found for sex but not for age (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	323.8	3.9	20	351.7	10.4	6
Adult		327.3		356.0	13.4	116

Table B2. Mean body length measurements (mm) for sharp-shinned hawks and goshawks.

Sharp-shinned Hawks

Significant differences were found for sex but not age (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	276.1	18.1	126	324.2	7.3	116
Adult	279.1	5.9	38	325.9	9.4	116

Goshawks

Significant differences were found for sex but not for age (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	524.9	6.9	20	580.7	26.1	6
Adult	529.7	14.6	150	587.4	19.4	116

Table B3. Mean bill length measurements (mm) for sharp-shinned hawks and goshawks.

Sharp-shinned Hawks

Significant differences were found for both age and sex (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	11.9	1.4	126	15.1	1.0	116
Adults	12.8	1.0	38	15.7	1.0	16

Goshawks

Significant differences were found for both age and sex (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	25.7	1.5	20	27.0	1.6	6
Adult	26.7	1.6	150	29.4	2.1	116

Table B4. Mean hallux length measurements (mm) for sharp-shinned hawks and goshawks.

Sharp-shinned Hawks

Significant differences were found for both age and sex (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	13.2	1.1	126	17.5	1.3	116
Adults	13.4	1.2	38	17.8	1.1	116

Goshawks

Significant differences were found for both age and sex (two way analysis of variance; $p < 0.05$).

	Male	S.D.	N	Female	S.D.	N
Juvenile	33.2	2.9	20	37.3	2.1	6
Adult	34.6	3.3	150	40.1	2.7	116

APPENDIX C. Prey Weight and Predator Size Measurements

Table C1. Mean prey weight and predator size measurements for sharp-shinned hawks.

Groups	Prey Weight (gm)	S.D.	Predator Weight (gm)	S.D.	Body Length (mm)	S.D.	N
All	137.5	118.2	139.8	37.6	305.1	26.7	396
Males	107.4	85.9	97.5	6.9	276.8	16.1	164
Females	158.9	132.6	169.7	14.7	325.0	8.4	232
Juvenile Males	109.0	84.2	96.3	6.0	276.1	18.1	126
Juvenile Females	177.9	137.8	162.8	9.0	324.2	7.3	116
Adult Males	102.3	92.5	101.3	8.1	279.1	5.9	38
Adult Females	139.8	124.8	176.6	15.9	325.9	9.4	116

Groups	Hallux Length (mm)	S.D.	Bill Length (mm)	S.D.	Wing Flat (mm)	S.D.	N
All	15.8	2.5	14.1	2.1	191.5	16.0	396
Males	13.2	1.1	12.1	1.3	173.3	3.6	164
Females	17.7	1.2	15.4	1.0	204.4	4.9	232
Juvenile Males	13.2	1.1	11.9	1.4	173.0	3.6	126
Juvenile Females	17.5	1.3	15.1	1.0	203.1	5.3	116
Adult Males	13.4	1.2	12.8	1.0	174.3	3.6	38
Adult Females	17.8	1.1	15.7	1.1	205.7	4.1	116

Table C2. Mean prey weight and predator size measurements for northern goshawks.

Groups	Prey Weight (gm)	Predator Weight (gm)	Body Length (mm)	Hallux Length (mm)	Bill Length (mm)	Wing Flat (mm)	N
All	322.4	966.3	553.3	36.7	27.7	339.0	292
Males	308.0	885.0	529.1	34.4	26.6	327.0	170
Females	342.6	1079.6	587.1	40.0	29.2	355.8	122
Juvenile Males	260.9	761.2	524.9	33.2	25.7	323.8	20
Juvenile Females	247.0	1034.7	580.7	37.3	27.0	351.7	6
Adult Males	314.2	901.5	529.7	34.6	26.7	327.3	150
Adult Females	347.5	1081.9	587.4	40.1	29.4	356.0	116

Groups	Prey Weight (gm)	Predator Weight (gm)	Body Length (mm)	Hallux Length (mm)	Bill Length (mm)	Wing Flat (mm)	N
All	322.4	966.3	553.3	36.7	27.7	339.0	292
Males	308.0	885.0	529.1	34.4	26.6	327.0	170
Females	342.6	1079.6	587.1	40.0	29.2	355.8	122
Juvenile Males	260.9	761.2	524.9	33.2	25.7	323.8	20
Juvenile Females	247.0	1034.7	580.7	37.3	27.0	351.7	6
Adult Males	314.2	901.5	529.7	34.6	26.7	327.3	150
Adult Females	347.5	1081.9	587.4	40.1	29.4	356.0	116