

RESEARCH ARTICLE

Determination of the Relationship Between Beak Length and Body Weight of Juvenile Northern Bald Ibis (*Geronticus eremita*) and Estimating Body Weight from Beak Length

Adil UZTEMUR ¹ (*)  Abdülkadir ORMAN ¹ 

¹ The University of Bursa Uludag, Faculty of Veterinary Medicine, Department of Animal Science, TR-16059 Bursa - TÜRKİYE



(*) **Corresponding author:** Adil UZTEMUR

Cellular phone: +90 534 726 6337

E-mail: vet.hek.adiluztemur@gmail.com

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Abstract

The aim of the study is to measure the body weight and beak measurements of the juvenile bald ibis birds breeding in Türkiye and try to find out whether there is a comparative relationship between them and compare them with the measurements in the other studies. In this direction, beak measurements and body weights of total 460 bald ibis chicks, including 197 male chicks and 263 female chicks, were determined in an 11-year period from 2012 to 2022. Average upper beak length was found 15.68 cm, lower beak length was 11.34 cm and average body weight was 1.11 kg in male bald ibis juveniles. Average upper beak length was found to be 15.08 cm, the average lower beak length was 10.84 cm and the average body weight was 1.07 kg in female bald ibis juveniles. A positive and moderate significant relationship was found between upper beak length and body weight ($P<0.001$). It was determined that the average body weight of male bald ibis juveniles was higher than the body weight of female bald ibis juveniles ($P<0.001$). Body weight variation could be explained by using only upper beak and lower beak measurement in 26% and 29% respectively. No significant variation was observed in the live weight of bald ibis chicks over the years.

Keywords: Bald ibis juveniles, Beak length, Body weight, Estimating weight

INTRODUCTION

The northern bald ibis (*Geronticus eremita*) belongs to the Threskiornithidae family of the order Pelecaniformes ^[1]. According to IUCN 2018 data, there are an estimated 200-249 mature individuals of the northern bald ibis, classified as endangered ^[2,3]. Historically, nomadic northern bald ibis birds were found in the Middle East and Central Europe during the spring and summer months. During winter, they had a large distribution area extending from the Arabian Peninsula to the African Red Sea coast, reaching Eritrea and Ethiopia ^[4]. However, their numbers have decreased significantly in recent years due to factors such as destruction of their natural habitats, excessive use of pesticides (especially DDT), and hunting ^[5,6]. For this reason, conservation and breeding centers have been established to ensure the survival of the northern bald ibis species ^[7].

There are breeding centers in many different places in the world such as Türkiye, Syria, and Morocco. The bald ibises of Moroccan origin are resident, and those at the Breeding

Center in Birecik are semi-wild ^[8]. They are also known to exist as two wild populations on the Atlantic coast of Morocco and near Tamri ^[9]. Moroccan and Turkish-origin northern bald ibis birds are genetically different from each other ^[10]. The northern bald ibis is described as a large, glossy black bird with a length of 70-80 cm (28-31 in), a wingspan of 125-135 cm (49-53 in), and an average weight of 1.0-1.3 kg (35-46 ounces) ^[11]. In Northeast Africa and Northwest Africa, western individuals of a certain species have an average beak length of 14.1 cm in males and 13.3 cm in females ^[10,11]. A study has reported that eastern ones in Türkiye of the same species have a shorter beak length, averaging 12.9 cm in males and 12.3 cm in females. A study reported a strong positive correlation between upper beak length and lower beak length in male western cattle herons ^[12]. Beak length plays an important role in the nutrition of the northern bald ibis. These birds use their beaks to catch creatures such as fish in the water, worms in the soil, and insects, etc. ^[12]. Birds with longer beaks survived better during the drought period by reaching larger seeds compared to species with shorter



beaks^[13]. The length of the beak undergoes modifications according to the diet of the species^[14]. Birds fed efficiently and in a balanced way will reach a sufficient body size for migration^[15]. In a different study, the body mass of adult males of the northern bald ibis was 1.28 kg, and females were 1.17 kg, while the average weight of both male and female offspring was reported to be 1.02 kg^[16]. Body weight plays an important role in migratory birds. During the migration period, birds must reach sufficient body size and complete their energy reserves for successful migration^[17]. Young northern bald ibis birds that do not reach maturity before migration have a low chance of survival. Adults are more likely to survive compared to juveniles^[18]. Young northern bald ibis birds must reach sufficient body size to be able to migrate together with adults. It is understood that beak length and body weight have an important role in feeding and migration. Based on this information, it will be attempted to determine whether the body weights and beak measurements of juvenile northern bald ibis at the semi-wild breeding station in Türkiye differ from the reported measurements in previous studies. With this study, the body weights and beak lengths of male and female Northern bald ibis chicks will be determined again and evaluated to find out whether there is a relationship between body weights, beak lengths, and genders. It is revealed that the beak lengths and body weights of Northern bald ibis chicks have changed over the last 11 years. With these findings, we also aimed to reveal the unknown features of the species due to the decrease in the number of bald ibises in recent years. This study will increase interest in the protection and breeding of the species and will open the door for further new studies^[4,19,20]. With the obtained results, we will determine whether the northern bald ibis juveniles have reached a sufficient size to migrate.

MATERIAL AND METHODS

Ethical Statement

This study was carried out after obtaining ethical approval from the Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks, dated 11.01.2023, with approval number E-21264211-288.04-8468166.

Ethical approval was also obtained from the Harran University Animal Experiments Local Ethics Committee Presidency with decision number 2024/001/01 and approval number 296272 dated 15/01/2024.

Study Area and Number of Individuals

The study was performed at the Bald ibis Breeding Center, located in Birecik district of Şanlıurfa Province in southern Türkiye (37°02'N, 37°59'E), situated 3 km north of the Fırat River. In the study, the initial body weights and beak

lengths of northern bald ibis juveniles born between 2012 and 2022 were measured when they were taken into cages. Over the course of 11 years, beak measurements and body weights were recorded for a total of 460 northern bald ibis juveniles, 197 males and 263 females. Adult and young northern bald ibis birds are released into the wildlife for breeding in the second week of February each year. They breed in artificial wooden nests mounted on high walls within the Breeding Center and in natural rock nests that were crafted by hand in the same location.

Feeding and Care Program

Each northern bald ibis bird was fed a diet consisting of 100 g of ground beef, 14 g of cheese, 44 g of chick feed, 44 g of carrots, and 0.125 eggs. Additionally, adults and young birds were provided with feed ad-libitum from outside once they began to fly. The main components of their natural diet include insects, spiders, scorpions, worms, snails, fish, amphibians, lizards, and small vertebrates such as snakes, small rodents, and birds^[7,21,22]. The chicks hatched after an incubation period of 27-28 days^[7]. Male chicks are typically incubated for longer periods than females^[23]. Approximately after 45-50 days they can leave the nest and fly^[12]. Any northern bald ibis birds that were not sent for migration due to various reasons were returned to the cage in June-July of the same year.

Measurement Process

While all individuals were placed into cages, the gender analysis of the juveniles born in that year was initially conducted at the Biology Department of the Middle East Technical University by collecting their blood in separate 3 mL EDTA tubes from each individual. In recent years, gender analysis has also been conducted at the Harran University Genetic Research Center. After attaching a colored plastic ring to one foot and a metal ring to the other foot of each newborn chick, their body weights were measured using an electronic handheld scale (Portable electronic scale WH-A08) with a sensitivity of 5 g for weights ranging from 1-10 kg. Upper and lower beak measurements were taken using a 50 cm metal L ruler with a precision of 1 cm or 10 mm. Subsequently, the chicks were returned to the main cage. After determining the genders of northern bald ibises chicks, they were recorded. The procedures conducted throughout the working year continued in the same program without any changes.

Statistical Analysis

The relationship between beak lengths and body weights was assessed using the Pearson correlation test. Comparison of beak lengths and body weights according to gender factor was conducted using Independent Samples T Test analysis. Regression analyses were performed to

determine which independent variables best predicted live weight. The best regression equations were obtained using a stepwise procedure. The multiple regression equations were evaluated with the determination of coefficient (R^2) and the residual standard deviation (RSD). The relationship between beak lengths across years was assessed using One-way ANOVA and Tukey HSD as post hoc test significant difference (HSD) test as a post hoc analysis, as the data exhibited normal distribution based on the Kolmogorov-Smirnov test. A significance level of $P < 0.05$ was taken into account. All the data were analyzed using the SPSS statistical program (version 28.0).

RESULTS

Average upper beak length was 15.68 cm in male northern bald ibis juveniles and 15.08 cm in female juveniles, while average lower beak length was 11.34 cm in male juveniles and 10.84 cm in female juveniles (*Table 1*). The average body weight was found to be 1.11 kg in male juveniles and 1.07 kg in female juveniles (*Table 1*). Significant differences were observed between male northern bald ibis juveniles ($M=15.68$, $SD=1.34$) and female juveniles ($M=15.08$, $SD=1.17$) in terms of upper beak length. It was found that the average upper beak length of male northern bald ibis juveniles is longer than that of female juveniles ($t = 7.294$, $P < 0.01$) (*Table 1*).

There are significant differences between male northern bald ibis juveniles ($M=11.34$, $SD=1.27$) and female juveniles ($M=10.84$, $SD=1.01$) from standpoint of lower beak length. It has been observed that the average lower

beak length of male northern bald ibis juveniles is longer than that of female juveniles ($t=5.734$, $P < 0.01$) (*Table 1*). Significant differences were also found in body weight between male northern bald ibis juveniles ($M=1.11$, $SE=0.01$) and female juveniles ($M=1.07$, $SE=0.01$). It was noted that the average body weight of male northern bald ibis juveniles was higher than that of female juveniles ($t=8.245$, $P < 0.01$) (*Table 1*).

It was found that there is a significant, moderate positive relationship between upper beak length and body weight ($r=0.542$, $P < 0.001$) (*Table 2*). Similarly, a significant, moderate positive relationship was observed between lower beak length and body weight ($r=0.512$, $P < 0.001$) (*Table 2*). As the length of both the upper and lower beaks increases, the body weight also increases. The highest positive correlation was found between the length of the upper beak and the length of the lower beak ($r=0.926$, $P < 0.001$) (*Table 2*).

There is a significant difference in the length of the upper beak in male northern bald ibis juveniles across years ($F=30.363$, $P < 0.001$). In 2012, the average upper beak length differences between male juveniles were significantly longer compared to the years 2016, 2017, 2018, 2019, 2020, and 2021 (2.4 cm, 2.0 cm, 1.6 cm, 2.2 cm, 1.5 cm, 1.5 cm), respectively ($P < 0.01$). The average upper beak length of male juveniles in 2012 was not significantly different from those in 2013, 2014, 2015, and 2022 ($P > 0.05$). In 2014, the average upper beak length differences of male juveniles were significantly different compared to those in 2013, 2016, 2017, 2018, 2019, 2020,

Table 1. Upper and Lower beak length measurements and body weights measurements

Measurements	Gender	n	Mean $\pm$ SE	Standard Deviation (SD)	Min. - Max.	P-Value
Upper Beak Length (cm)	Male	197	15.68 $\pm$ 0.09	1.33	10.00-18.50	<0.01
	Female	263	15.07 $\pm$ 0.07	1.16	11.20-18.30	
	Total	460	15.33 $\pm$ 0.05	1.27	10.00-18.50	
Lower Beak Length (cm)	Male	197	11.34 $\pm$ 0.09	1.27	5.50-14.30	<0.01
	Female	263	10.84 $\pm$ 0.06	1.01	8.00-13.70	
	Total	460	11.05 $\pm$ 0.05	1.15	5.50-14.30	
Body weight (kg)	Male	197	1.11 $\pm$ 0.00	0.10	0.73-1.40	<0.01
	Female	263	1.07 $\pm$ 0.00	0.11	0.72-1.43	
	Total	460	1.09 $\pm$ 0.00	0.11	0.72-1.43	

Table 2. Correlation between lower beak length upper beak length and body weight in *Geronticus eremita*

Beak Length	Upper Beak Length (cm)	Body Weight (kg)
Lower Beak Length (cm)	.926**	.512**
Upper Beak Length (cm)		.542**
** $P < 0.01$		

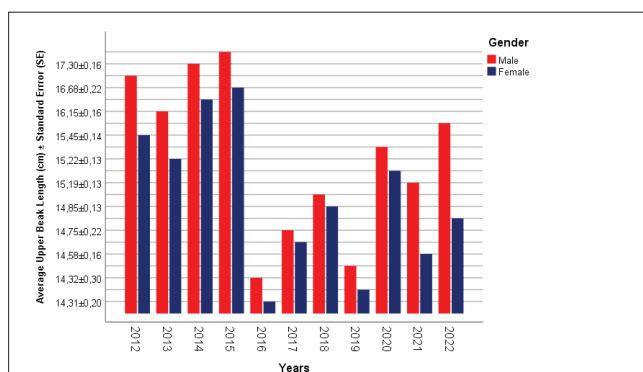


Fig 1. Average upper beak length by years

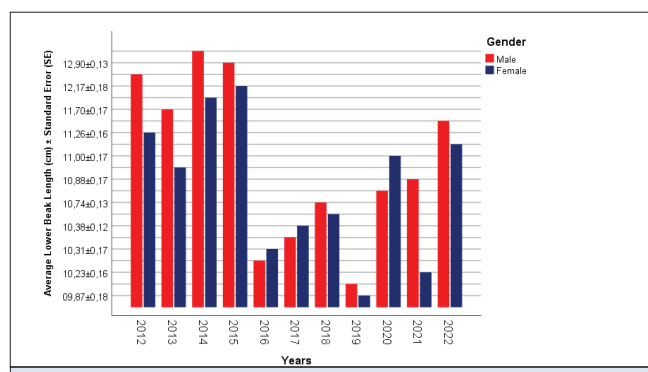


Fig 2. Average lower beak length by years

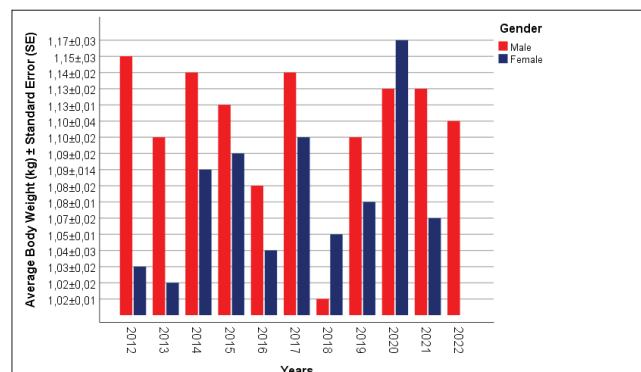


Fig 3. Average body weight by years

2021, and 2022 ($P < 0.01$), with differences of 1.15 cm, 2.9 cm, 2.5 cm, 2.1 cm, 2.7 cm, 2.0 cm, 2.1 cm, 1.8 cm, respectively.

Similarly, there is a significant difference in the upper beak length of female northern bald ibis juveniles across years ($F = 14.576$, $P < 0.001$). In 2012, the average upper beak length differences between female juveniles were significantly longer compared to the years 2016, 2019, 2021, and 2022, which were shorter than 2015 (1.4 cm, 1.3 cm, 0.9 cm, 0.9 cm, 1.2 cm), respectively ($P < 0.01$). The average upper beak length of female juveniles in 2012 was not significantly different from those in 2013, 2014, 2017, 2018, and 2020 ($P > 0.05$) (Fig. 1).

There is a significant difference in the length of the lower beak in male northern bald ibis juveniles across years ($F = 30.363$, $P < 0.001$). The mean lower beak length differences of male juveniles in 2012 were significant compared to those in 2016, 2017, 2018, 2019, 2020, and 2021, respectively (2.0 cm, 1.9 cm, 1.6 cm, 2.2 cm, 1.4 cm, 1.6 cm), ($P < 0.001$). The average lower beak length of male juveniles in 2012 was not significantly different from those in 2013, 2014, 2015, and 2022 years ($P > 0.05$).

Similarly, there is a significant difference in the lower beak length of female northern bald ibis juveniles across years ($F = 17.735$, $P < 0.001$). The mean lower beak length differences of female juveniles in 2015 were significant compared to those in 2012, 2013, 2016, 2017, 2018,

Table 3. Multiple regression equations for Upper and Lower beaks for predicting live weights of juvenile *Geronticus eremita*

Dependent Variable	Gender	Intercept	Independent variables		^a RSD	^b R ²	P-Value
			Upper Beak	Lower Beak			
Body Weight (kg)	Male	0.66	0.04	-	0.10	0.21	<0.01
		0.47	-0.003	0.04	0.10	0.24	<0.01
	Female	0.24	0.06	-	0.10	0.32	<0.01
		0.25	0.04	0.02	0.10	0.32	<0.01
	General	0.35	0.05	-	0.10	0.26	<0.01
		0.53	-	0.05	0.10	0.29	<0.01

^a RSD: Residual standard deviation, ^b R²: Determination coefficient

2019, 2020, 2021, and 2022, respectively ($P < 0.001$). The differences were as follows: 0.9 cm, 1.2 cm, 2.1 cm, 1.8 cm, 1.7 cm, 2.4 cm, 1.3 cm, 1.9 cm, 1.4 cm. The average lower beak length of female juveniles in 2015 was not significantly different from that in 2014 ($P > 0.05$) (Fig. 2).

There is no significant difference in body weight among male northern bald ibis juveniles across years ($F = 1.869$, $P > 0.05$). However, a significant difference in body weight was observed among female juveniles ($F = 4.774$, $P < 0.001$). In female juveniles, the body weight difference in 2020 was significant compared to 2013, 2016, 2018, and 2022, being heavier in these years (0.14 kg, 0.13 kg, 0.12 kg, 0.11 kg) ($P < 0.01$). Likewise, the body weight difference in 2017 was significant compared to 2016, 2018, and 2022, with a higher weight in those years (0.09 kg, 0.08 kg, 0.07 kg) ($P < 0.01$). No significant difference was found between the other years ($P > 0.05$) (Fig. 3).

Multiple regression equations using upper and lower beak measurements to predict body weight are presented in (Table 3). These equations were developed through multiple linear regression, with beak measurements as the independent variables. It was found that 21% of the variation in body weight was explained by the upper beak alone, and with the addition of the lower beak, the variation increased by 3% in male birds. However, when introducing both upper and lower beak measurements as independent variables in the multiple linear regression equations for female birds, no improvements were observed in predicting body weight. The model including beak measurements explained 32% of the variation in body weight for female birds. Overall, body weight variation could be explained by using upper beak and lower beak measurements alone by about 26% and 29%, respectively.

DISCUSSION

We found that the beak length and body weight of northern bald ibis juveniles reported for Türkiye were different from those reported for Northeast Africa and Northwest Africa. In Western individuals, the average beak length is reported as 14.1 cm in males and 13.3 cm in females. However, in Eastern individuals (in Türkiye), the beak length is shorter, averaging 12.9 cm in males and 12.4 cm in females^[10,11]. Our results show that the average upper beak length was 15.68 cm in male northern bald ibis juveniles and 15.08 cm in female juveniles, while the lower beak length was 11.34 cm in male juveniles and 10.84 cm in female juveniles.

It appears that the beak length measurements reported in past studies^[10,11] on northern bald ibises in Türkiye are lower than our results (upper beak length: male 15.68 cm, female 15.08 cm; lower beak length: male 11.34 cm, female 10.84 cm). However, since the reported beak lengths are stated as the average beak length, they do not

provide detailed results about the exact levels in adult and juvenile individuals. Considering that the beak length of adult individuals is typically longer than that of juveniles, our results suggest that the beak length of the northern bald ibis in Türkiye is not necessarily shorter than that of the northern bald ibis in Northwest Africa. Our results also show a strong positive correlation between lower and upper beak length, which is consistent with the high positive correlation reported by some researchers^[24]. Studies conducted on chickens have also reported a positive relationship between beak length and body weight, supporting our findings^[25].

When examining the upper and lower beak lengths of northern bald ibis juveniles, we observed an increase from 2012 to 2015, followed by a sharp decrease in 2016. However, from 2016 to 2022, there has been a continuous increase in beak lengths. This pattern is believed to be influenced by environmental factors, such as variations in feeding habits during rainy and drought periods, which can impact beak lengths and body weights. It's important to note that these fluctuations are not hereditary and have varied over the years.

Morphological traits, such as beak size, must be inherited to be considered adaptive^[26]. Therefore, the morphological changes observed in the beak length of juvenile northern bald ibis birds are primarily influenced by genetic inheritance from their parents rather than environmental effects.

It was found that the body weight of male northern bald ibis juveniles was higher than that of females. Previous reports revealed that northern bald ibises have an average body weight of 1.0-1.3 kg (35-46 ounces)^[11]. The earlier studies on juvenile bald ibises suggested an average body weight of 1.02 kg with no gender difference. However, our findings revealed that the average body weights of male and female juveniles differed, with males being heavier than females^[16].

Our findings (1.11 kg for males and 1.07 kg for females) indicated higher body weights compared to those reported by other researchers (1.02 kg)^[16]. Previous studies have generally reported an average body weight range of 1.0-1.3 kg (35-46 oz) for bald ibises, and our results align with these findings. However, it's worth noting that these previous studies did not differentiate between adult and juvenile birds^[11].

Interestingly, in 2018 and 2020, female bald ibis juveniles were, on average, heavier than male juveniles. This observation suggests that the females may have hatched earlier than the males, a phenomenon observed in other species like chickens, where individuals reaching sexual maturity on time often exhibit higher egg production. This could also be applicable to bald ibises^[27].

Based on the results of the multiple regression equation, it can be inferred that upper and lower beak measurements were not strong predictors of body weight in juvenile northern bald ibises, as indicated by determination coefficients ranging from 21% to 32%. These findings suggested that upper and lower beak measurements may not be precise predictors for estimating body weight in juvenile northern bald ibises. Since there is a limited research on using beak measurements to predict body weight in juvenile northern bald ibises, a direct comparison with other studies was not feasible.

We observed that there has been no significant change in the body weight of juvenile bald ibises over the years. However, there have been slight variations in body weights between male and female juveniles, which were not statistically significant. These fluctuations are believed to be influenced by factors such as nutrition and environmental conditions. Providing appropriate dietary supplements to poultry feed has been known to enhance body weight. Despite efforts to protect bald ibises across different regions, their general body weight and beak length have remained stable for an extended period.

From standpoint of nutrition and health management in juvenile birds, the addition of enzymes to their diets has been effective. This approach should be investigated for bald ibises as well [28-31]. However, it's crucial to avoid using additives that could potentially disrupt the intestinal flora [32].

In conclusion, a long beak in bald ibises provides them with a great advantage in capturing their natural food and enhancing their survival abilities. Juvenile bald ibises that are well-fed and have reached sufficient body weight for migration are released to migrate alongside the adults from the breeding station. Their migration success is monitored to ensure that the new generations learn the migration routes alongside the adults.

DECLARATIONS

Availability of Data and Materials: The data results obtained in this study are available from the corresponding author and first author upon request.

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Authors' Contributions: AU and AO designed this study. AU: Field work and data collect, AO: Statistical analyze, AU and AO: writing manuscript.

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