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Honors Thesis

Gull Egg Mass as a Function of Length and Width

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Primary Advisor Signature: _____

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Abstract

The mass of a Glaucous-winged Gull (*Larus glaucescens*) egg provides a convenient estimation of parental energy allocated towards reproduction. Obtaining accurate mass measurements, however, can be hindered by logistical constraints associated with field research. In this study, I create a mathematical model to estimate egg mass from easily determined measurements of length and width. Egg measurements were collected at a gull colony on Protection Island National Wildlife Refuge, WA. These measurements facilitated the estimation and validation of model parameters. A multi-variable allometric model incorporating both length and width variables provided the best estimation of egg mass.

Introduction

Reproductive success of Glaucous-winged Gulls (*Larus glaucescens*) is affected by a variety of factors, including habitat, nest density, and egg size. The mass of gull eggs serves as one measure of success. Smaller eggs have been found to produce smaller chicks that are less likely to survive (Parsons, 1975). Converting egg mass directly into caloric content provides a measure of parental energy investment. For closely related Glaucous-winged and Western Gulls (*Larus occidentalis*), caloric content can be estimated by multiplying total egg mass by 0.92750 and 1.57 kcal/g, respectively (Carey et al., 1980; James-Veich & Booth, 1954).

Glaucous-winged Gulls typically lay a clutch of three eggs each laying season. While the first two eggs in a clutch are fairly similar in size, the third egg is typically significantly smaller and lighter (Hayward & Verbeek, 2008; Verbeek, 1986). Pierotti and Bellrose (1986) found that increased food availability can lead to larger third eggs. Therefore, the mass of the third egg may serve as an indication of parental energy availability.

During nest surveys, egg mass typically is obtained by transporting a portable scale throughout the colony. In order to receive an accurate reading, the scale must rest on a level surface, remain sheltered from the wind, and be recalibrated at every new site. Furthermore, because eggs lose moisture over time and get progressively lighter, an egg must be weighed on the same day that it is laid (Romanoff & Romanoff, 1949). Due to constraints associated with field research, it is not always possible to fulfill each of these requirements for measuring egg mass. To date, there has been no convenient method of estimating gull egg mass without complex equipment, time intensive procedures, or damaging egg integrity.

Allometric models describe proportions and changes in ratios. They often appear as power-law equations of the form $y = ax^b$. Bjarnadottir et al. (2007) and Brandeis et al. (2009),

for example, used power-law allometric models to estimate plant biomass from diameter and height. In this study, I construct three alternative allometric models that relate egg mass to egg length and width. In particular, I (1) parameterize the models with data collected from a Glaucous-winged Gull colony on Protection Island, WA, (2) select the best model using the Akaike Information Criterion (AIC), and (3) validate the selected model on an independent data set. I also compare the allometric proportions of third eggs to those of the first two eggs in the clutch.

Materials and Methods

Data were collected from all gull nests within five sample plots on Violet Point, Protection Island National Wildlife Refuge, WA, during the laying seasons of late May, June, and early July, 2009 and 2010. Protection Island provides a breeding site for over 70% of seabirds in the Puget Sound region (Hirsch, unpubl., as cited by Galusha et al., 1987). The Andrews University Seabird Ecology Team conducted a daily survey for new nests and eggs within each plot. Each new egg was measured with calipers at its widest and longest points, weighed on a portable scale, and marked with an A, B, or C to indicate its respective order within the clutch. In total, 1475 eggs were recorded with 751 eggs measured in 2009 and 724 eggs in 2010. In order to make comparisons between laying seasons, data from 2009 were randomly selected to estimate model parameters; data from 2010 were then applied to validate the selected model.

The modeling portion of this study occurred in three specific steps: parameterization, model selection, and validation. Two related allometric models were compared. Model 1 ($y = ax_1^b x_2^c$) utilizes variables x_1 and x_2 which represent length and width, respectively.

Model 2 ($y = ax^b$) is a single-variable model; both length and width variables were tested separately with Model 2a using length and Model 2b using width. Parameters for each model were estimated with egg measurements from 2009. The MATLAB function *fminsearch* minimized residuals between the data and the predicted model. For model selection, I calculated the AIC value for each model and selected Model 1 for validation over Model 2. I applied a square-root transformation to Model 1 in order to normalize the residuals and account for demographic noise. To validate Model 1, the estimated parameters were used to predict the masses of the 2010 eggs. I then compared the goodness-of-fit between the parameter estimation and model validation steps.

I also examined allometric properties of third eggs compared to the previous two eggs in the clutch. These methods involved the same processes of parameterization and model validation but utilized different data. Estimated parameters were specific to a group of eggs within the clutch. The first trial examined how much variation in C eggs could be described by A and B eggs. Model 1 was parameterized with the combined A and B egg data. This re-parameterized model was validated with the C egg data. I then compared the goodness-of-fit for each step. To provide a baseline for C egg variation, Model 1 was re-parameterized with C egg measurements from 2009 and validated with C egg measurements from 2010.

Results

Model 1 ($y = ax_1^b x_2^c$) had a lower AIC value and a higher R^2 value than Model 2 (Table 1, Figure 1) and thus is favored. The parameters estimated for Model 1 were $a = 0.0024$, $b = 0.8979$, and $c = 1.721$. The R^2 values for both the parameter estimation and model validation steps rounds to 0.89. The average error between data and model predictions is 2.2 grams.

In the laying-order comparison, the model parameterized with combined A and B egg data described 84% of the variation in the significantly smaller C eggs. The parameter estimation R^2 was 0.93 and the validation R^2 was 0.84 (Table 2). A model parameterized with C-egg measurements was associated with an estimation R^2 of 0.84 and a validation R^2 of 0.91.

Discussion

As indicated by the low AIC value, the multi-variable Model 1 ($y = ax_1^b x_2^c$) provides a more accurate estimation of egg mass than do variations of the single-variable model. An estimation of mass requires both length and width variables. A comparison of the estimation and validation R^2 values suggests that the parameterized Model 1 can describe 89% of the variability in the data. Since a model parameterized with 2009 data described the same amount of variation in 2010, the model appears to be capable of estimating egg mass over different laying seasons. As a result, this parameterized model may serve as a practical tool in field research. Egg length and width are easily obtained and remain constant over time. Estimation of egg mass is obtained by entering an egg's length and width measurements into Model 1 along with the estimated parameter values. A mathematical model relating egg dimensions to mass may reduce or eliminate the need for a portable scale during nest surveys. Such a model may also prove useful to estimate the original masses of empty shells and museum specimens.

The comparison among A, B, and C eggs was completed to determine how the significantly smaller C eggs compared to the larger eggs in the clutch. This comparison is based on the amount of variability that the model can describe. The R^2 values using C egg data tended to be lower than the estimation R^2 for A and B eggs and the R^2 for the original parameterized model. One explanation is that C-egg density may be more variable than the densities of the first

two eggs. Therefore, mass for C eggs may be less predictable. Because R^2 analysis does not incorporate a level of significance, it is not possible to make any further statistical conclusions. However, given that all R^2 values were fairly high, the original parameterized model seems capable of describing all three groups. A separately parameterized model for C eggs would be less practical because it is difficult to know laying order within a clutch without previously monitoring a given nest.

Whereas Model 1 provides a relatively accurate estimation of egg mass, it cannot describe all intraspecific variation even among eggs with similar dimensions. Model accuracy may improve by incorporating variables such as egg shape or volume. In the estimation of egg volume, Bridge et al. (2007) found that digital photograph analysis of avian eggs better accounts for variations in shape than a model utilizing only measurements of length and width. Unfortunately, egg volume and shape can be difficult to measure in the field due to equipment and time limitations. While such variables may increase model accuracy, they decrease model practicality. However, if data for egg volume and shape become easily accessible, future research could create a more detailed model by incorporating these variables and testing for overfitting using the AIC method.

A model parameterized with data from Protection Island presents implications for the study of reproductive success. The vast majority of gulls nesting at this site are hybrids between Glaucous-winged and Western Gulls, although they tend toward a Glaucous-winged phenotype (Moncrieff, 2012). Hybrid gulls at some sites are more successful than either of the pure parental species (Bell, 1997). Model parameters in this study are specific for these hybrids. Further research may be necessary to test how well these parameters describe the eggs of pure Glaucous-winged or Western Gulls.

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Tables

Table 1: AIC and R squared values of Model 1 (both length and width), Model 2a (length only), and Model 2b (width only).

	Model 1	Model 2a (length)	Model 2b (width)
R ²	0.89	0.41	0.73
AIC	1386	2663	2070

Table 2: Comparison of R² values between the estimation and validation steps for two separate trials.

	Model 1: All eggs	Model 1: AB eggs estimate, C eggs validate
Estimation R ²	0.89	0.93
Validation R ²	0.89	0.84

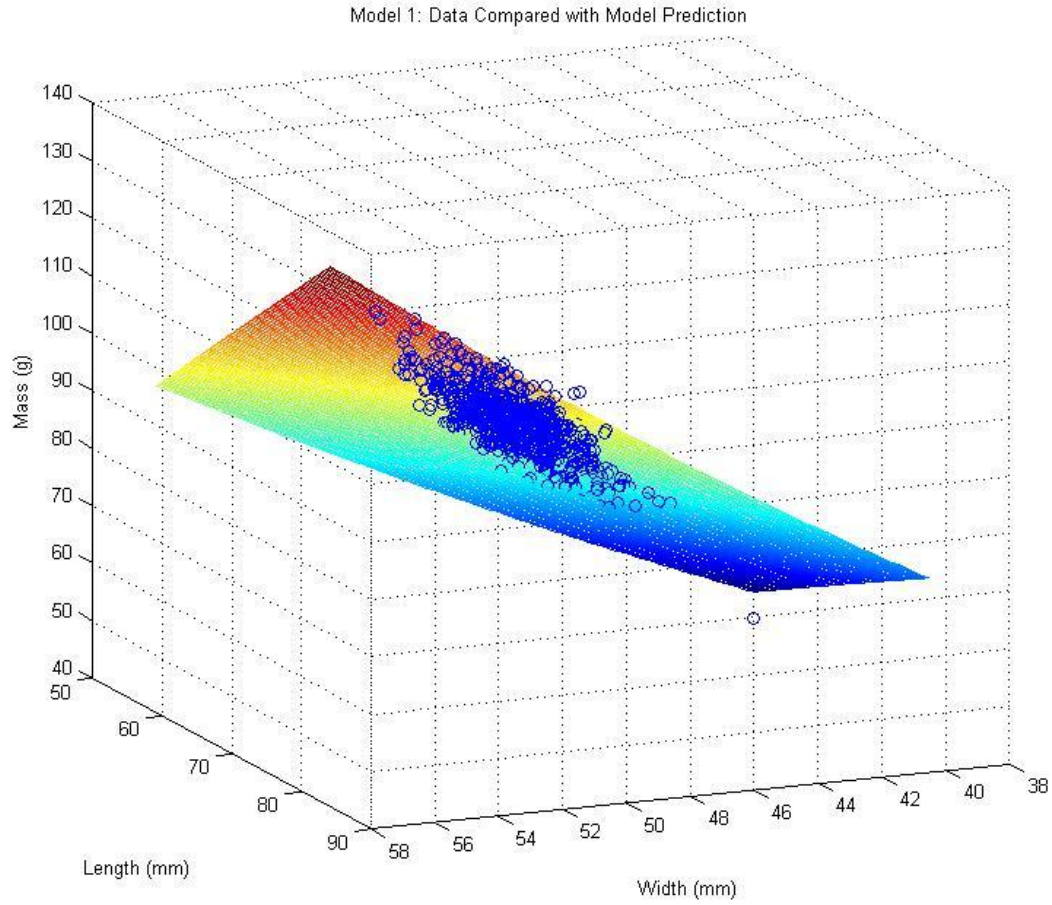
Figures

Figure 1: Three-dimensional graph of Model 1 comparing the validation data with a plane representing a portion of model predictions. The R^2 value is 0.89.