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SHORT COMMUNICATION

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A method to estimate the volume of gull nests

En metod för att uppskatta måsbons volym

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MEASURING NEST SIZE is an important aspect of studying the breeding biology of birds. Although some simple equations for estimating the volume of passerine nests are available, no methods to estimate nest size for gulls have been described. This paper offers an equation for calculating the volume of gull nests, based on the truncated cone. It requires only four measurements of the nest: outer diameter, inner diameter, height, and cup depth. We also present a way of estimating the volume of nest material.

Keywords: Laridae | Larinae | breeding ecology | equation | nest size | field measurements

Introduction

Avian nests are special constructions whose main function is to provide insulation and protection to developing eggs and young. There is much variation in how nests are built, constructed, and maintained, which affect characteristics like size, shape, composition, and location. To understand the variability in nest size, and the factors determining it, one must be able to quantitatively describe nest characteristics. For example, Møller (1982) and Vergara *et al.* (2010) have provided equations to calculate the nest volume of swallows and storks, but there are no methods described for estimating the volume of gull nests.

Gulls (family Laridae, subfamily Larinae) are globally distributed waterbirds and comprise 53 species (Gill *et al.* 2022). They occur in very different habitats: from tundra swamps to the world's largest cities. This means that they utilize numerous kinds of nest support: sand and gravel, cliff ledges, grass, floating mats of vegetation, reeds, trees, concrete, or building rooftops. Some aspects of reproductive ecology differ among gull species, but their nests are generally of the same shape. Here, we present a method to calculate the volume of gulls nests, and the nest components, based on a few simple mathematical equations.

Methods

Gull nests are congruent with a geometric figure: the truncated cone. We thus assume that: (1) the nest is vertically symmetrical, (2) it has an outer form of a truncated cone, and (3) the nest cup has the form of a semi-ellipsoid. For the calculation of nest volume, we only need to record four measurements—outer diameter (OD), inner diameter (ID), height (h), and cup depth (CD; Figure 1)—using, for example, a steel ruler with an adjustable (running) right angle (up to 50 cm is sufficient).

First, we use an equation for the volume of the truncated cone,

$$(1)\quad V = \frac{\pi}{3h}\left(R^2 + Rr + r^2\right)$$

where h is the height of the figure, R the radius of the lower base and r the radius of the upper base.

Second, to calculate nest cup volume (Figure 2c) we use an equation for the volume of a semi-ellipsoid,

$$(2)\quad V = \frac{2}{3}(\pi abc)$$

where a, b, and c are radii of the semi-ellipsoid (Figure 2).

For cases in which the nest cup protrudes deeper than the base of the built nest (Figure 2b), we use the equation for a volume of an ellipsoidal cup to calculate the part of nest cup, when the nest is in the hole,

$$(3)\quad V = \frac{\pi ab}{3c^2} H^2(3c - H)$$

where a, b and c are radii of the semi-ellipsoid and H the height of the ellipsoidal cup (Figure 2).

These are all standard mathematical equations, thus requiring radii rather than diameters, which is more easily measured in the field. We will therefore convert the equations so that field measurements can be inserted directly.

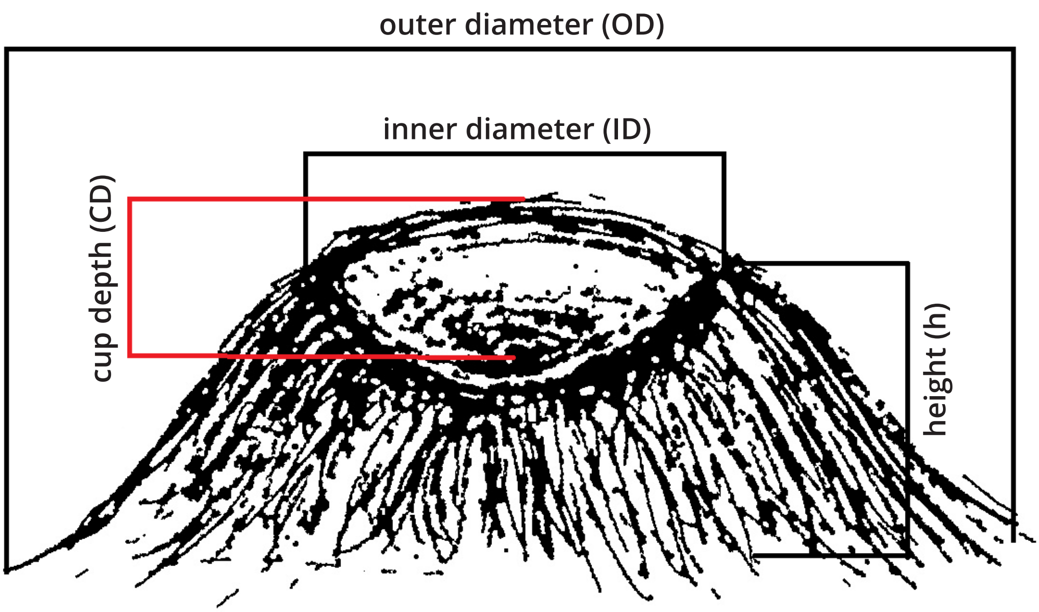

FIGURE 1. Gull nest dimensions to measure for the calculation of nest volume.
— Mått som krävs för att beräkna volymen för ett måsbo (boets basala ytterdiameter, boskålens innerdiameter, boskålens djup och boets höjd).

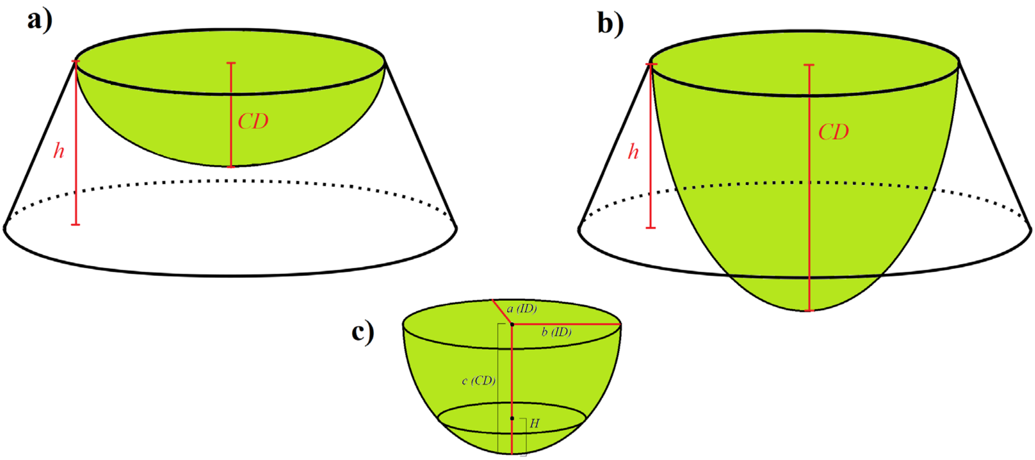

FIGURE 2. Schematic representations of nests where (**a**) the whole cup is above ground and (**b**) a part of the cup is below the ground. The sketch between them (**c**) specifies the dimensions of the nest cup.
— *Schematisk representation av bon där (**a**) hela boskålen är ovan mark eller (**b**) en del av boskålen går under markytan. Skissen mellan dessa (**c**) specificerar boskålens relevanta dimensioner.*

Results

After some shortening, the transformed equation for the nest volume is

$$(4) \quad V_n = \frac{\pi h}{12}\,(OD^2 + OD\,ID + ID^2)$$

where V_n is the volume of the nest, h is the height of the nest, OD is the outer diameter and ID is the inner diameter of the nest (Figure 1).

The converted equation for the nest cup volume is

$$(5) \quad V_{nc} = \frac{\pi}{6}\,ID^2\,CD$$

where V_{nc} is the volume of the nest cup and CD is the cup depth (Figure 2).

For nests situated in small holes in the ground, the nest cup depth is larger than the nest height (Figure 2b). In such cases, the part of the nest cup that is 'under the nest' (in a hole in the ground) must be added because it is also a piece of the nest construction. The equation for the volume of this part of nest cup is

$$(6) \quad V_{pnc} = \frac{\pi\,ID^2}{12\,CD^2}\,(CD^2 - h)^2\,(2CD + h)$$

where V_{pnc} is the volume of protruding lower part of the nest cup (Figure 2b). This is added to the equation of the nest volume to produce the full equation for the volume of such nests,

$$(7) \quad V_{nh} = \frac{\pi h}{12}\,(OD^2 + OD\,ID + ID^2) + \frac{\pi\,ID^2}{12\,CD^2}\,(CD^2 - h)^2\,(2CD + h)$$

where V_{nh} is the full volume of a nest situated in a hole. We are also able to calculate only the volume of nest material brought by birds to build the nest. This requires removing the volume of the nest cup and results in the following two equations: (a) for nests where the whole cup is above the ground (Figure 2a),

$$(8) \quad V_{nma} = \frac{\pi h}{12}\,(OD^2 + OD\,ID + ID^2) - \frac{\pi}{6}\,ID^2\,CD$$

and (b) for nests where part of the nest cup is below the ground (Figure 2b),

$$(9) \quad V_{nmb} = \left[\frac{\pi h}{12}\,(OD^2 + OD\,ID + ID^2) + \frac{\pi\,ID^2}{12\,CD^2}\,(CD^2 - h)^2\,(2CD + h)\right] - \left(\frac{\pi}{6}\,ID^2\,CD\right)$$

where V_{nma} is the nest material volume when whole nest cup is above ground, and V_{nmb} is the nest material volume when a part of the nest cup is below the ground (in a hole).

Discussion

Calculating nest volume from nest dimensions is often used in studies of avian breeding biology (e.g. Møller *et al.* 2014a). The lack of tested equations for estimating nest volume for gulls has posed an obstacle, but the equations presented here are not only to gulls, but to any species whose nests are shaped as a truncated cone. In addition, the equation for nest cup volume may also be used for species with differently shaped open nests.

When studying the intraspecific variation in nest construction among the ground-nesting gulls, we generally observe two types of nest cup: set above the ground (Figure 2a) or located partly under the ground in a small hole (Figure 2b). The nest mass and quantity of nest material are almost equal between the two, while the nest volume may vary significantly.

A nest's main functions are to support the eggs, nestlings, and incubating adult birds, to provide an optimal microenvironment that protects the eggs and nestlings against bacteria and parasites, and to offer protection from predators (Collias & Collias 1984, Møller *et al.* 2014a). Nest size and shape can be under both natural and sexual selection (Collias & Collias 1984, Møller *et al.* 2014a) and the nest characteristics most frequently studied are the quantity of nest material, the nest mass, and the nest cup volume (i.e. the nest wall thickness; McCracken *et al.* 1997, Palomino *et al.* 1997, Powell & Rangen 2000, Crossman *et al.* 2011). The majority of studies have been conducted on passerines, especially tree cavity-nesters (Álvarez & Barba 2008, Mainwaring 2012, Møller *et al.* 2014b), but it is still unknown which are the most important environmental factors affecting nest construction. Deeming (2013) suggested that different factors determine the nest size and the cup size, which might be true for gulls. With the methods we present here one can easily calculate both, taking into consideration the difference between nests entirely above ground and partly underground, and collate a general dataset of nest measurements for gull species.

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Svensk sammanfattning

Fågelbon varierar storligen i utförande, men utgör en central del av häckningsbiologin för många arter, då konstruktionen ger skydd och isolering för ägg och ungar. Därför är det viktigt att kunna karakterisera bon, vad gäller material, placering, storlek och form. Tidigare studier (t.ex. Møller 1982, Vergara m.fl. 2010) har beskrivit matematiska formler som kan tillämpas för att beräkna bostorlek för exempelvis svalor och storkar.

Måsar och trutar (familj Laridae, underfamilj Larinae) omfattar 53 arter (Gill m.fl. 2022). De har en global utbredning och förekommer i många olika habitat, vilket innebär att de använder vitt skilda typer av bomaterial. Vissa aspekter av deras häckningsekologi skiljer sig mellan arterna, men typiskt sett har boet samma form, vilken kan liknas vid en stympad kon. I denna rapport presenterar vi metoder för att beräkna måsbons volym, baserade på mått som enkelt tas i fält samt några lättanvända matematiska formler.

Vi antar att boets yttre form är vertikalt symmetrisk och motsvarar en stympad kon, samt att boskålen är formad som en halv ellipsoid. För att kunna beräkna bovolymen behöver endast fyra mått tas i fält: den yttre diametern vid boets bas (OD), den inre diametern vid boskålens kant (ID), boets höjd (h) och boskålens djup (CD; se figur 1). Detta kan exempelvis göras med en halvmeterlång stållinjal med löpande rät vinkel.

För ett typiskt bo, vars boskål inte är nedsänkt under markytan (figur 2a), är formeln för bovolymen V_n

$$(4) \quad V_n = \frac{\pi h}{12}\left(OD^2 + OD\,ID + ID^2\right)$$

För ett bo där botten av boskålen är nedsänkt under den omliggande markytan är formeln för bovolymen V_{nh}

$$(7) \quad V_{nh} = \frac{\pi h}{12}\left(OD^2 + OD\,ID + ID^2\right) + \frac{\pi\,ID^2}{12\,CD^2}\left(CD^2 - h\right)^2\left(2CD + h\right)$$

För att beräkna bomaterialets volym V_{nma}, det vill säga bovolymen utan boskålen, används följande formel för typiska bon (figur 2a)

$$(8) \quad V_{nma} = \frac{\pi h}{12}\left(OD^2 + OD\,ID + ID^2\right) - \frac{\pi}{6}\,ID^2\,CD$$

För nedsänkta bons materialvolym V_{nmb} (figur 2b) är motsvarande formel i stället

$$(9) \quad V_{nmb} = \frac{\pi h}{12}\left(OD^2 + OD\,ID + ID^2\right) + \frac{\pi\,ID^2}{12\,CD^2}\left(CD^2 - h\right)^2\left(2CD + h\right) - \left(\frac{\pi}{6}\,ID^2\,CD\right)$$

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