

Validation of a Rapid Visual-Assessment Technique for Categorizing the Body Condition of Green Turtles (*Chelonia mydas*) in the Field

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Many important questions in ecology and conservation biology require assessment of the body condition of animals, which is often achieved using mass and length data. However, fully quantitative condition indices can be difficult to obtain in the field for large taxa like marine turtles. Therefore, rapid visual-assessment techniques for categorizing condition can be useful for field studies. Here, we test whether a visual method of categorizing body condition in the Green Turtle (*Chelonia mydas*) based on the shape of a turtle's plastron is comparable to two commonly used body condition indices derived from mass and length measurements. Condition scores for both mass-length indices varied in the expected manner with our visual condition categories, verifying that the rapid visual assessment technique accurately reflects differences in body condition. This technique should aid many field studies of turtles where body condition data are required but mass data cannot easily be obtained.

BIOLOGISTS have long been interested in reliable means of assessing an animal's body condition (Fulton, 1904; Le Cren, 1951) because condition can have a profound impact on a variety of behavioral decisions and physiological processes that directly or indirectly influence fitness. For example, body condition can influence the timing of migration and egg laying (Snow Geese, *Chen caerulescens atlantica*, Bêty et al., 2003), arrival times at breeding sites (Spadefoot Toads, *Pelobates fuscus*, Eggert and Guyétant, 2003), onset of vitellogenesis (Asp Viper, *Vivipera aspis*, Nalleau and Bonnet, 1996), and susceptibility to predation (Red Squirrels, *Tamiasciurus hudsonicus*, Wirsing et al., 2002) or cannibalism (Cardinal Fish, *Apogon doederleini*, Okuda and Yanagisawa, 1996). Body condition-dependent behavioral decisions can further influence population and community dynamics. For example, condition-dependent risk-taking can lead to populations being regulated by synergistic effects of food supply and predation risk (McNamara and Houston, 1987; Wildebeest, *Connochaetes taurinus*, Sinclair and Arcese, 1995) and can modify spatiotemporal patterns of resource exploitation (Heithaus et al., 2007).

In many cases, body condition is assessed using indices derived from mass and length measurements (birds, Chastel et al., 1995; mammals, Cattet et al., 2002; reptiles, Nalleau and Bonnet, 1996; fish, Bolger and Connolly, 1989; amphibians, Pope and Matthews, 2002; reviews in Jakob et al., 1996; Schulte-Hostedde et al., 2001). In some situations, however, mass measurements may be difficult to obtain, particularly for large animals in challenging field situations. For example, weighing large marine turtles along nesting beaches and in remote field sites is logistically difficult, which may affect mass measurements, and often involves transport to a weighing facility and holding for prolonged periods of time. Long handling times can severely limit sample sizes, reducing the scope of questions that can be addressed, and potentially have a negative impact on the animals.

A technique for rapidly assessing the body condition of marine turtles in the field that limits extensive handling is desirable. In some birds, the shape of the abdominal region has been shown to reflect energy reserves and a visual index

based on abdominal shape correlates with condition indices using mass and length measurements (Owen, 1981; Madsen and Klaasen, 2006). However, no such techniques have been validated for marine turtles. Here, we test whether a visual method of categorizing body condition for Green Turtles based on the shape of their plastron (Heithaus et al., 2005) can serve as a proxy for body condition indices (BCIs) derived from mass and length measurements.

MATERIALS AND METHODS

Between June 2006 and June 2008, adult and sub-adult Green Turtles were captured by hand from a 4.5 m boat in Shark Bay, Western Australia (see Heithaus et al., 2002, 2005 for methods). Once captured, we measured the curved carapace length (CCL; ± 0.5 cm) and applied a titanium flipper tag to the foreflipper (Eckert and Beggs, 2006). Turtles were considered male if the tail was ≥ 25.0 cm in length, as probable female if the CCL was ≥ 100.0 cm but the tail was < 25.0 cm, and 'unclassified' (including adult females and immature males) if the CCL was < 100.0 cm and the tail was < 25.0 cm (Heithaus et al., 2005).

During inspection for condition, turtles were held next to the boat or placed on a flat platform at the stern to allow for a quick and accurate visual assessment of plastron shape. The plastron was first viewed while looking at the turtle head-on. Turtles were then maneuvered as necessary (e.g., by tilting to one side or front to back) to allow a full view of the plastron. Often, a hand passed along the underside of the turtle also revealed plastron shape and provided support to the visual classification. Based on this method, turtles were assigned to one of three condition categories (modified from Heithaus et al., 2005). Turtle condition was classified as Good ($n = 13$) when the plastron was convex, Fair ($n = 34$) when it was flat, and Poor when it was concave ($n = 11$; Figs. 1, 2). Following visual classification, turtles were placed in a polyester sling that supported the turtle's body but allowed the flippers to hang freely. The sling was connected to a hanging Salter scale (± 0.5 kg), which was raised using a winch mounted on a custom-built davit arm. A mass measurement was obtained and the turtle was released.

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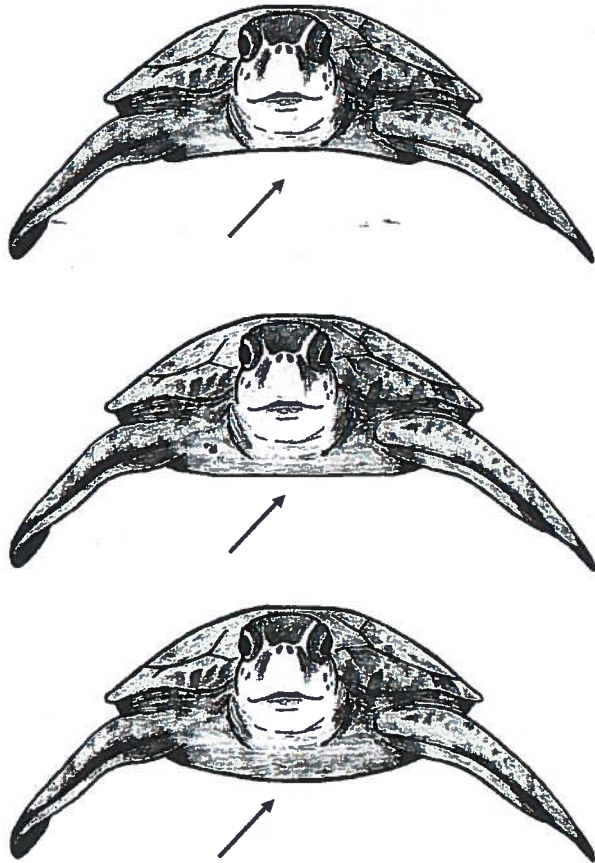


Fig. 1. Line drawings illustrating plastron shapes (concave, flat, convex; from top to bottom) used to assign turtles to one of three body condition categories (Poor, Fair, Good).

We compared visual condition classes of turtles to two BCIs (Jakob et al., 1996) that have previously been applied to Green Turtles: the "ratio index" [(mass/CCL³)*10⁴; Bjørndal et al., 2000] and the "residual index" (residual values from mass predicted by the linear regression of body mass on CCL; Jessop et al., 2002). Two quantitative indices were used to validate our visual method because both have been used for a variety of taxa, including marine turtles, but debate remains as to which is most appropriate. For example, in some cases, the "ratio index" may correlate with body size, confounding results and clouding interpretations that can be made (Reist, 1985; Jakob et al., 1996).

Data were analysed using JMP version 7.0. Ordinal logistic regression was used to assess the influence of sex class (male, probable female, or unclassified), size (CCL), and a sex by CCL interaction on plastron shape (i.e., visual condition classification). For turtles in our study site, age (juvenile, sub-adult, or adult) is categorized based on CCL alone; as a result, an age term was considered redundant and not included in the analysis. Subsequently, for both body condition indices, a standard least squares regression model was constructed that included visual condition category, CCL, sex class, and a CCL by sex class interaction term as independent variables. For both models, planned contrasts (one-tailed *t*-tests) were conducted on body condition scores in adjacent condition categories using Bonferroni correction



Fig. 2. An adult Green Turtle in (A) Fair condition (flat plastron) and (B) Poor condition (concave plastron).

for multiple contrasts ($\alpha = 0.025$). We predicted that body condition scores for both quantitative indices would vary with our visual condition categories with Good condition turtles having significantly higher scores than Fair turtles and Fair turtles having significantly higher scores than Poor turtles.

RESULTS

We categorized and weighed 58 sub-adult and adult green turtles between 61.5 and 108.5 cm CCL (mean = 88.9, SE = 1.49) and 28.0 and 159.0 kg (mean = 91.7, SE = 4.68). Log transformation of mass and CCL data was performed to stabilize variance about the regression and generate residuals for the "residual index." The relationship between $\log(\text{mass})$ and $\log(\text{CCL})$ was linear ($R^2 = 0.900$, $F_{1,56} = 505.5$, $P < 0.0001$; Fig. 3). Ordinal logistic regression revealed no effect of CCL ($\chi^2_1 = 0.032$, $P = 0.858$), sex class ($\chi^2_2 = 1.417$, $P = 0.492$), or the CCL by sex class interaction ($\chi^2_2 = 1.049$, $P = 0.592$) on visual condition classification.

Quantitative index scores satisfied assumptions for linear regression. For the "ratio index," the least squares regression model revealed no effect of CCL ($F_1 = 0.000$, $P = 1.000$), sex class ($F_2 = 0.009$, $P = 0.991$), or the CCL by sex class interaction ($F_2 = 0.025$, $P = 0.976$) but a strong effect of visual condition category ($F_2 = 18.387$, $P < 0.0001$) on index scores. Planned contrasts were significant, as predicted, between adjacent condition categories. Good condition turtles (mean = 1.364, SE = 0.048) had significantly higher

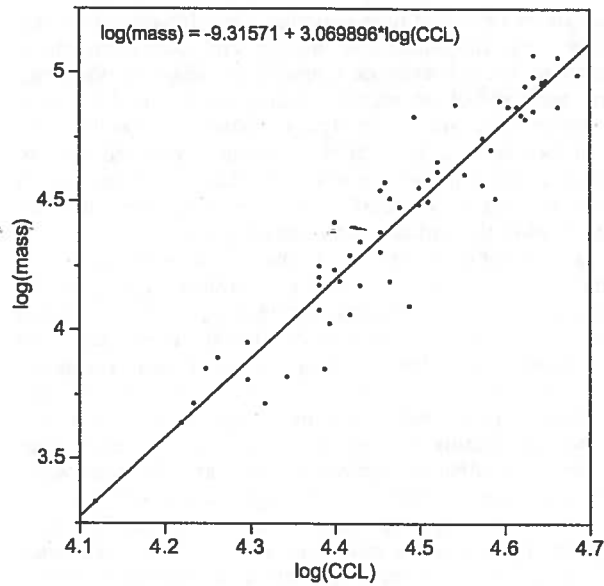


Fig. 3. Linear regression of $\log(\text{mass})$ on $\log(\text{CCL})$ ($R^2 = 0.900$, $F_{1,56} = 505.5$, $P < 0.0001$) for 58 Green Turtles captured between June 2006 and June 2008.

index scores than Fair condition turtles (mean = 1.260, SE = 0.018; $t_{2,50} = 2.220$, $P = 0.016$), and Fair condition turtles had significantly higher scores than Poor condition turtles (mean = 1.041, SE = 0.039; $t_{2,50} = 4.786$, $P < 0.0001$; Fig. 4A).

For the “residual index,” the standard least squares regression model revealed no effect of CCL ($F_1 = 0.022$, $P = 0.882$), sex class ($F_2 = 0.014$, $P = 0.986$), or the CCL by sex class interaction ($F_2 = 0.013$, $P = 0.988$) but a strong effect of visual condition category ($F_2 = 20.344$, $P < 0.0001$) on index scores. Planned contrasts were significant, as predicted, between adjacent condition categories. Good condition turtles (mean = 0.093, SE = 0.035) had significantly higher index scores than Fair condition turtles (mean = 0.021, SE = 0.015; $t_{2,50} = 2.061$, $P = 0.023$), and Fair condition turtles had significantly higher scores than Poor condition turtles (mean = -0.175, SE = 0.036; $t_{2,50} = 5.212$, $P < 0.0001$; Fig. 4B).

DISCUSSION

Body condition can influence many aspects of animal behavior including habitat selection, foraging, anti-predator behavior, migration, and reproduction. Therefore, fast, reliable, and minimally invasive means of assessing an animal's body condition in the field are useful for ecological studies. Previous work with Green Turtles in Shark Bay has revealed that plastron shape, shown here to be a reasonable proxy for condition, varies for individuals on the scale of weeks to months (Heithaus et al., 2007). Moreover, Green Turtle habitat use in Shark Bay varies with body condition and predation risk (Heithaus et al., 2007), and condition is likely to have a similar influence on other aspects of turtle behavior (e.g., migratory timing). Therefore, a minimally intrusive and efficient means of obtaining body condition data in the field should be of great interest and utility to marine turtle researchers.

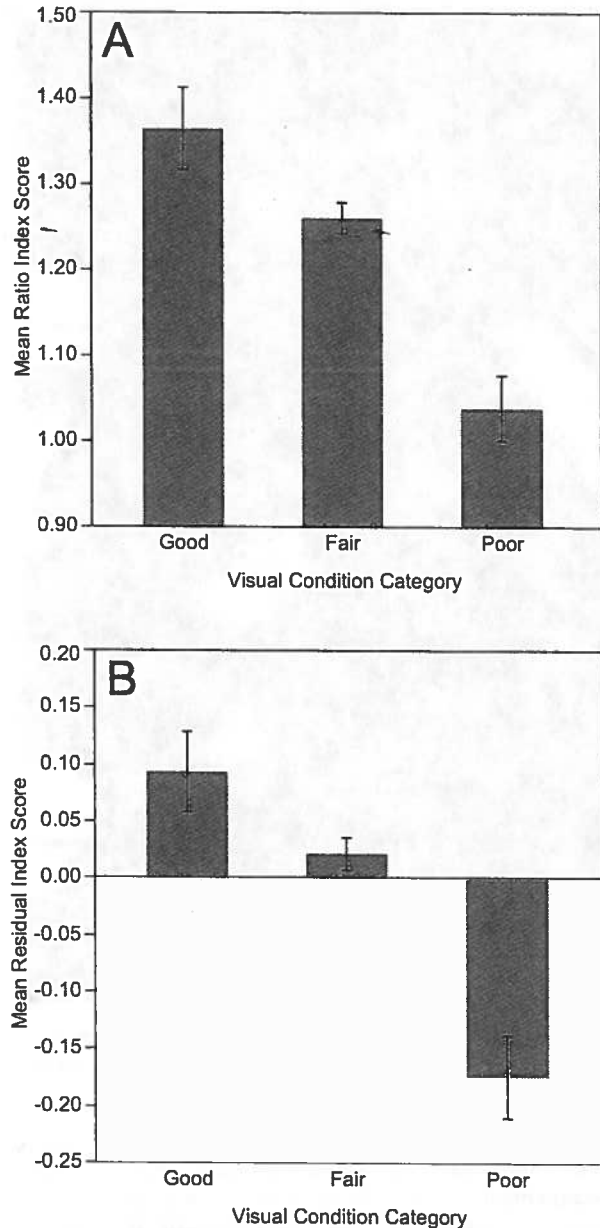


Fig. 4. Differences in means (\pm SE) between visual condition categories for (A) the “ratio index” [(mass/length³)*10⁴] and (B) the “residual index” (residuals from relationship in Fig. 3). Planned contrasts between all adjacent condition categories are significant at $\alpha = 0.025$.

Because of their subjective nature, qualitative methods such as ours should be corroborated by comparison with fully quantitative condition indices based on mass and length measurements (Owen, 1981; Madsen and Klaasen, 2006). We found that our visual classification scheme accurately reflected body condition scores for two common, fully quantitative indices, the “ratio index” and the “residual index.” Furthermore, agreement was found between both quantitative body condition indices, and neither was confounded by a correlation between body size and index score suggesting that, for Green Turtles at least, either approach is valid.

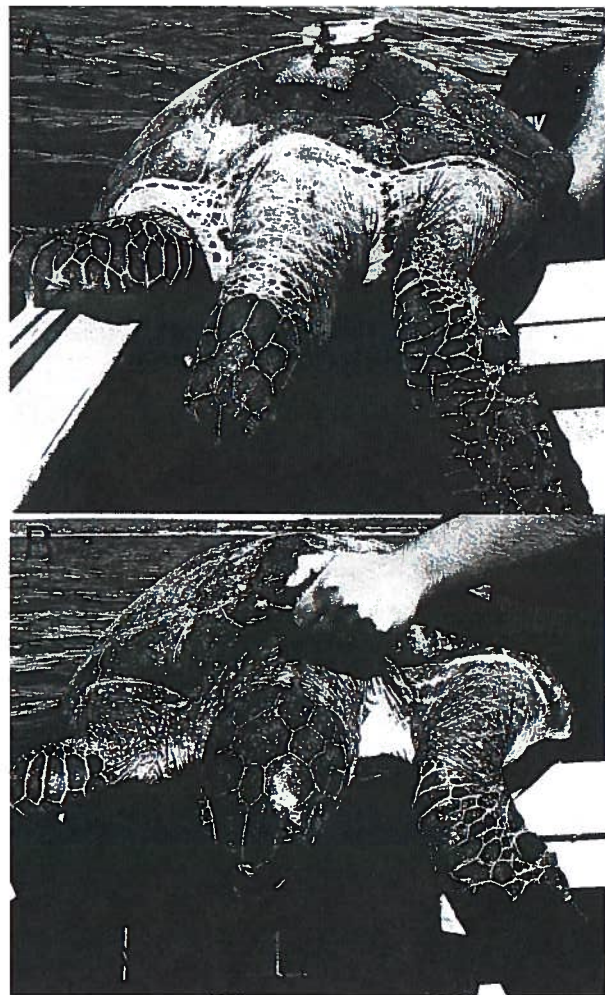


Fig. 5. An adult Green Turtle in (A) Good condition and (B) Poor condition showing the difference in tissue bulk around the neck and shoulders between these condition categories.

The primary advantage of our visual method versus conventional estimates of condition using mass and length measurements is that it is rapid and can be conducted with minimal manipulation of the animal. Particularly if research vessels are not equipped to weigh turtles, the visual method greatly reduces handling time. Visual condition assessment should also lend itself well to surveys of nesting females; following nesting, females can be easily approached and a condition assessment can be made in a matter of seconds. For in-water surveys, condition can be estimated with the turtle restrained in the water at the side of the boat or on board the research vessel. Based on our experience, capture, data collection (tagging and measuring) and visual assessment of turtle condition can be achieved in ten minutes or less, the condition assessment itself taking only a few seconds.

The primary drawback to a visual method of categorizing condition is its inherent subjectivity. However, once validated using mass and length data, and with due care in training observers to assess shape, visual methods can accurately estimate body condition. If there were substantial variation among observers in assigning turtles to condition

categories we would have expected a much weaker relationship between quantitative indices and our rapid visual method. There is also the potential for observer bias since the behavior of an animal during capture and restraint (relative resistance or lethargy) co-varies with body condition (see below). Though we have not collected data to address this, a possible way to minimize bias would be to have the person responsible for classifying condition not involved in the capture and restraint process.

Qualitative observations of other areas of the body and the behavior of turtles during data collection support the validity of our visual assessment technique. In addition to concave undersides, Green Turtles in Poor condition displayed emaciation around the neck and shoulders (Fig. 5), were much slower swimmers, far less evasive, and resisted capture less vigorously than turtles in better condition. During processing on the research vessel, Poor condition individuals appeared listless and lethargic while those in better condition often required restraint throughout the measuring procedure. Furthermore, Green Turtles in our study area select microhabitats based on their body condition in a manner consistent with theoretical predictions of predation risk-sensitive foraging (Heithaus et al., 2007), suggesting that, although coarse, our classification scheme is biologically meaningful.

Previously, we have used a four-category system of estimating condition (Heithaus et al., 2005, 2007). Unfortunately, we were unable to achieve sufficient sample size of the poorest condition class to validate this finer resolution system. Although behavioral studies suggest that there are real differences among turtles in a four-tier system (Heithaus et al., 2007), the three-tier system we describe here will be easier to apply widely since the four-tier approach requires differentiation between 'Slightly Concave' and 'Very Concave' plastrons.

It is important to note that the applicability of this method to other marine turtle species has yet to be determined. A preliminary data set for Loggerhead Turtles (*Caretta caretta*) in Shark Bay reveals the same trend in body condition scores across visual categories but much higher variability within categories, potentially resulting from sexual dimorphism in carapace shape. Therefore, we suggest that, before using our method with other marine turtle species, it be validated with quantitative indices of body condition.

We have demonstrated that a fast, logistically simple, visual method of assessing Green Turtle body condition agrees with quantitative condition indices based on mass and length measurements. By reducing handling time and stress placed on the animal, our technique should be of use in field studies in which it is difficult to obtain mass data. Such condition estimates can inform studies of individual behavior, which has important implications for community ecology and conservation of marine turtle populations.

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LITERATURE CITED

- Béty, J., G. Gauthier, and J. F. Giroux. 2003. Body condition, migration and timing of reproduction in snow geese: a test of the condition-dependent model of optimal clutch size. *American Naturalist* 162:110–121.
- Bjorndal, K. A., A. B. Bolten, and M. Y. Chaloupka. 2000. Green turtle somatic growth model: evidence for density dependence. *Ecological Applications* 10:269–282.
- Bolger, T., and P. L. Connolly. 1989. The selection of suitable indices for the measurement and analysis of fish condition. *Journal of Fish Biology* 34:171–182.
- Cattet, M. R. L., N. A. Caultkett, M. E. Obbard, and G. B. Stenhouse. 2002. A body-condition index for ursids. *Canadian Journal of Zoology* 80:1156–1161.
- Chastel, O., H. Weimerskirch, and P. Jouventin. 1995. Body condition and seabird reproductive performance: a study of three petrel species. *Ecology* 76:2240–2246.
- Eckert, K. L., and J. Beggs. 2006. Marine turtle tagging: a manual of recommended practices. WIDECAST Technical Report No. 2. Revised edition. Beaufort, North Carolina.
- Eggert, C., and R. Guyétant. 2003. Reproductive behavior of spadefoot toads (*Pelobates fuscus*): daily sex ratios and males' tactics, ages, and physical condition. *Canadian Journal of Zoology* 81:46–51.
- Fulton, T. W. 1904. The growth rate of fishes. Fisheries Board of Scotland Annual Report 22:141–241.
- Heithaus, M. R., A. Frid, and L. M. Dill. 2002. Shark-inflicted injury frequencies, escape ability, and habitat use of green and loggerhead turtles. *Marine Biology* 140:229–236.
- Heithaus, M. R., A. Frid, A. J. Wirsing, L. Bejder, and L. M. Dill. 2005. Biology of sea turtles under risk from tiger sharks at a foraging ground. *Marine Ecology Progress Series* 288:285–294.
- Heithaus, M. R., A. Frid, A. J. Wirsing, L. M. Dill, J. W. Fourqurean, D. Burkholder, J. A. Thomson, and L. Bejder. 2007. State-dependent risk-taking by green sea turtles mediates top-down effects of tiger shark intimidation in a marine ecosystem. *Journal of Animal Ecology* 76:837–844.
- Jakob, E. M., S. D. Marshall, and G. W. Uetz. 1996. Estimating fitness: a comparison of body condition indices. *Oikos* 77:61–67.
- Jessop, T. S., R. Knapp, J. M. Whittier, and C. J. Limpus. 2002. Dynamic endocrine responses to stress: evidence for energetic constraints and status dependence in breeding male green turtles. *General and Comparative Endocrinology* 126:59–67.
- Le Cren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology* 20: 201–219.
- Madsen, J., and M. Klaasen. 2006. Assessing body condition and energy budget components by scoring abdominal profiles in free-ranging pink-footed geese *Anser brachyrhynchus*. *Journal of Avian Biology* 37:283–287.
- McNamara, J. M., and A. I. Houston. 1987. Starvation and predation as factors limiting population size. *Ecology* 68:1515–1519.
- Nalleau, G., and X. Bonnet. 1996. Body condition threshold for breeding in a viviparous snake. *Oecologia* 107: 301–306.
- Okuda, N., and Y. Yanagisawa. 1996. Filial cannibalism by mouthbrooding males of the cardinal fish, *Apogon doederleini*, in relation to their physical condition. *Environmental Biology of Fishes* 45:397–404.
- Owen, M. 1981. Abdominal profile—a condition index for wild geese in the field. *Journal of Wildlife Management* 45:227–230.
- Pope, K. L., and K. R. Matthews. 2002. Influence of anuran prey on the condition and distribution of *Rana muscosa* in the Sierra Nevada. *Herpetologica* 58:354–363.
- Reist, J. D. 1985. An empirical evaluation of several univariate methods that adjust for size variation in morphometric data. *Canadian Journal of Zoology* 63: 1429–1439.
- Schulte-Hostedde, A. I., J. S. Millar, and G. J. Hickling. 2001. Evaluating body condition in small mammals. *Canadian Journal of Zoology* 79:1021–1029.
- Sinclair, A. R. E., and P. Arcese. 1995. Population consequences of predation-sensitive foraging: the Serengeti wildebeest. *Ecology* 76:882–891.
- Wirsing, A. J., T. Steury, and D. L. Murray. 2002. Relationship between body condition and vulnerability to predation in red squirrels and snowshoe hares. *Journal of Mammalogy* 83:707–715.

