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Pål Prestrud & Caroline M. Pond

We determined the validity of water content, rump fat thickness, a subjective fat index, a kidney fat index, and an index based on total body weight (TBW) and the hind foot length (HFL) in order to predict lipid content of arctic foxes *Alopex lagopus*. The total fat content was either determined by extracting lipid from minced carcasses (N = 75) or by dissecting all visible adipose tissue (N = 35). Water content and rump fat thickness proved to be the best predictors of fat content in arctic foxes. The ratio TBW/HFL was also a reliable index and should be a convenient and practicable way of estimating the condition of live foxes. A subjective fat index could be applied when divided into three categories, whereas the kidney fat index was not a reliable predictor of lipid content of arctic foxes.

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Fecundity in and survival of wild animals are strongly related to their fat content, which reflects availability and quality of food. In many temperate and arctic homeotherms, fat deposition in summer and autumn is crucial for their winter survival. Hence, techniques of estimating fat content of animals have been widely used in management of and research on wildlife populations.

To obtain absolute figures of fat content by chemical extraction of lipid from a homogenate of the animal or by dissecting all visible adipose tissue is time consuming and expensive, and often not practicable. Indexing of fat content has therefore been widely used. On live specimens, the estimation of water content by dilution methods (e.g. Torbit, Carpenter, Alldredge & Swift 1985) which assumes a linear relationship with lipid content, and indices made by using body weight and one or more linear measurements (e.g. Cattet 1990, Ryg, Lydersen, Markussen, Smith & Øritsland 1990) are the most

common. In dead specimens, subjective fat indices, subcutaneous adipose tissue thickness and the kidney fat index are commonly used (e.g. Kirkpatrick 1980).

In some cervids (Torbit et al. 1985, Adamczewski, Gates & Hudson 1987), seals (Ryg et al. 1990), polar bear *Ursus maritimus* (Cattet 1990) and harbour porpoises *Phocoena phocoena* (Read 1990), the validity of such indices has been tested against the absolute values of fat content. Fat indices have also been used to assess the condition of canids (Hammill 1983, Lindström 1983, Todd & Keith 1983, Hall 1989, Windberg, Engeman & Bromaghin 1991, Poulle, Crête & Huot 1995), but only in red foxes *Vulpes vulpes* and arctic foxes *Alopex lagopus* have these estimates been compared with absolute measurements of lipid content (Prestrud & Nilssen 1992, Winstanley, Saunders & Buttemer 1998, Lefebvre, Crête, Huot & Patenaude 1999).

Arctic foxes live in an environment where the avail-

ability of food fluctuates greatly both seasonally and multi-annually, which may cause large fluctuations in population density. In Svalbard, where no native small rodents are present, caching appears to be crucial to winter survival. The significance of the seasonal pattern of fat deposition for survival is largely unknown (Prestrud 1991, Prestrud & Nilssen 1992). Angerbjörn, Arvidson, Norén & Strömgren (1991) suggested that the winter fat content of arctic foxes in Sweden determines ovulation rate and foetal mortality. Reports from studies of arctic foxes in Canada on the relationship between litter size at birth and lipid content or density of small mammals are ambiguous (Macpherson 1969, Hammill 1983, Hall 1989).

To understand the mechanisms behind the large fluctuations in population density and how arctic foxes survive the arctic winter, it is necessary to have reliable quantitative methods for estimating lipid content. In order to improve the methods by which the condition of arctic foxes is estimated (Prestrud & Nilssen 1992), we evaluated how well 1) water content, 2) kidney fat index, 3) rump fat thickness, 4) a subjective fat index and 5) an index made from body weight and linear measurements predicted the fat content in arctic foxes.

Material and methods

During 1977-1987 (Data set I) and 1991-1992 (Data set II), we purchased skinned carcasses of arctic foxes caught during the trapping season (1 November - 15 March) by trappers in Svalbard (77°30'N - 79°50'N, 10°-18°E). Data set I is described by Prestrud & Nilssen (1992). All foxes were aged by counting incremental lines in a sectioned canine tooth (Grue & Jensen 1976).

We determined the relationship between water content and fat content from the analysis of whole body composition of 75 fox carcasses (Data set I), including abdominal viscera, but excluding the skin and fur (see Prestrud & Nilssen 1992). In addition, a kidney fat index (KFI = mass of dissectible kidney fat/mass of kidney x 100) was estimated for 42 of these 75 foxes. All 75 carcasses were minced in an industrial meat grinder. Total lipid in all the homogenates was determined using chloroform-methane in a Soxhlet apparatus (Christie 1987), and total water was determined by either oven-drying at 103-105°C or at 60°C in a vacuum furnace, until a constant mass was reached.

Before being skinned, the total body mass (TBM) of foxes (N = 35) collected for Data set II was measured by the trappers to the nearest 50 g, and the trappers also measured the hind foot length (HFL) to the nearest mm from the bases of the claws to the rear side of calcaneum. We measured the total length (TL) on skinned carcasses from the tip of the tail to the tip of the nose. The rump fat thickness (RFT; to the nearest mm) of subcutaneous fat was measured 1-2 cm anterior to and 0-2 cm laterally to the tip of the ilium of the pelvic girdle. A vertical cut was made through the fat to the *musculus erector spinae*, and the greatest fat depth was measured. A subjective fat index was made in order to evaluate the visible amount of subcutaneous and abdominal fat on the carcasses, and it included the categories: 1) none (no visible fat); 2) low (barely measurable or visible fat); 3) moderate (visible fat over the rump and in the abdomen); 4) considerable (subcutaneous fat over the rump, belly and flanks, and fat in the abdomen conspicuous); and 5) extensive (subcutaneous fat covering most of the body, and the intra-abdominal fat depots thick and extensive). Adipose tissue was dissected from nine superficial, four intra-abdominal and three intermuscular depots (TDF = Total Dissectible Fat) as described by Pond, Mattacks & Prestrud (1995). Each depot was weighed to the nearest 0.1 g using an electronic balance.

We developed a fat index for live foxes using the TBM and HFL. These parameters were chosen because they are easy to obtain under field conditions. It is not practicable to measure total body length or girth length on non-drugged foxes, and moreover, these linear measurements are inaccurate due to the thick fur of arctic foxes.

We applied a step-wise regression procedure to achieve the best prediction of TDF from TBM and HFL. The Residual Sum of Squares (RSS) was used as criteria for the best fit. We calculated the relationships between chemical extractable fat and water content, KFI and chemical extractable fat content and RFT and the TDF by simple linear regression. Differences in the mean TDF among the different categories of the subjective fat index were tested using a 1-way ANOVA and a Tukey's test.

Results

The mean TBM (± SD) and the mean lean body mass (TBM-TDF; ± SD) of foxes collected from data set II were 3,197 ± 661 g (N = 35; range: 2,100 - 4,750 g) and 2,700 ± 435 g (N = 35; range: 1,976 - 3,719 g), respectively. The mean TDF (± SD) was 498 ± 324 g (N = 35; range: 24 - 1,320 g). Of the 35 foxes collected, 19 were males and 16 were females; 14 were juveniles between 6 and 10 months of age, and 21 were more than one year old. The oldest fox in the sample was between 13 and 15 years old.
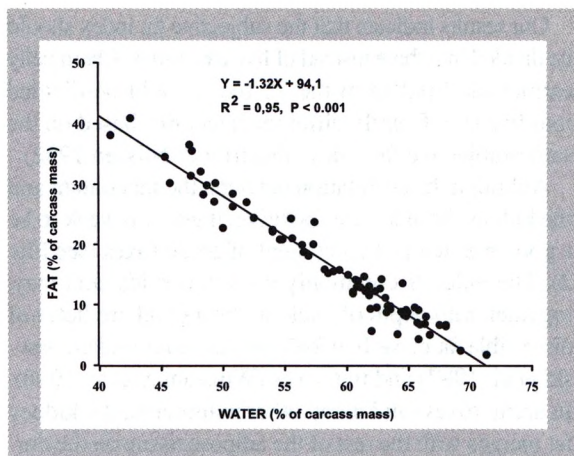
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Figure 1. Linear relationship between water content and ether extractable lipid content (in % of skinned carcass mass) of arctic foxes (N = 75) collected in Svalbard, Norway, between 1977 and 1987.

Figure 3. Linear relationship between rump fat thickness (in mm) and total dissectible adipose tissue (mass of all dissectible adipose tissue as % of total body mass) of arctic foxes (N = 35) collected in Svalbard, Norway, during the winter of 1991/92.

The percent lipid content of minced carcasses decreased linearly with the water content (Fig. 1). The relationship between in lipid in minced carcasses and the kidney fat index was not significant (Fig. 2). The TDF increased linearly with the RFT (Fig. 3). The mean weight of TDF (± SE) in the five different categories of the subjective fat index differed: none = 1.4 ± 0.4% (N = 2); low = 8.9 ± 1.0% (N = 11); moderate = 16.2 ± 1.4% (N = 10); considerable = 18.0 ± 1.4% (N = 9); extensive = 28.4 ± 1.9% (N = 3). The categories 'none' and 'low' differed from the categories 'moderate' and 'considerable', and the category 'extensive' differed
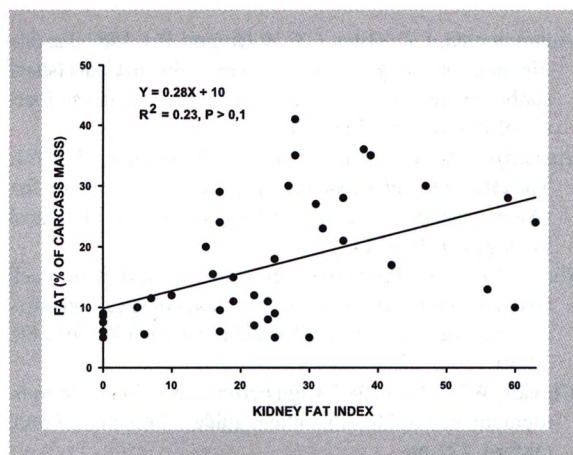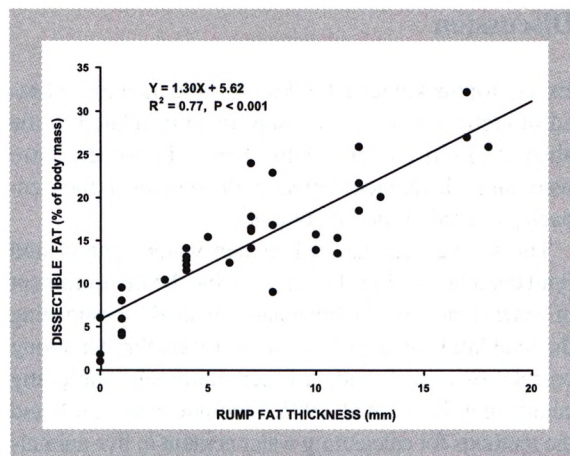
from the four other categories (Tukey's test: F = 23.1, df = 4, P < 0.001).

The correlations between HFL and TL and between HFL and the fat-free body mass (TBM- TDF) were positive (r = 0.80, P < 0.001 for both correlations). Consequently, HFL reflected body size of arctic foxes as the linear dimension of the skeleton. The best index predicting TDF based on TBW and HFL was the simple ratio TBM/HFL (Fig. 4). Squaring or cubing the denominator did not improve the RSS. The relationship between TBM/TL (X) and the TDF (Y) was $Y = 371.77 - 36.50X + 0.97 X^2$ ($R^2 = 0.79$).

Figure 2. Non-significant relationships between kidney fat index (mass of dissectible kidney fat divided by mass of the kidneys x 100) and ether extractable lipid content (in % of skinned carcass mass) of arctic foxes (N = 42) collected in Svalbard, Norway, between 1984 and 1987.
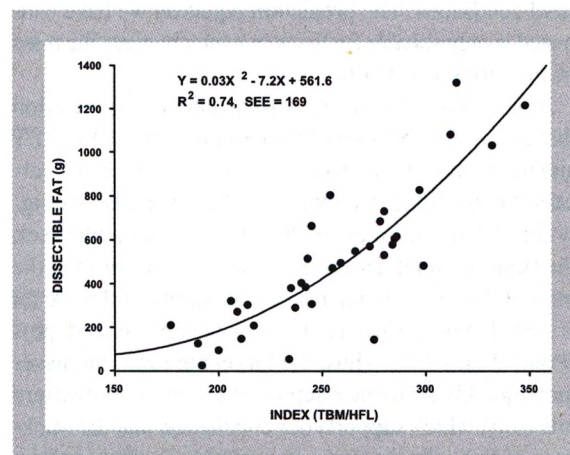

Figure 4. Curvelinear relationship between a fat index (total body mass (TBM) in g), divided by hind food length (HFL; in cm) and total dissectible fat of arctic foxes (N = 35) collected in Svalbard, Norway, during the winter of 1991/92.

Discussion

Except for the kidney fat index, the lipid indices we tested in arctic foxes were all significantly related to the absolute lipid content of the foxes. However, there were large differences between the indices in their capacity to predict the fat content.

The strong correlation between water content and lipid content (see Fig. 1) suggests that the measurement of water content is a highly reliable method for estimating the total lipid content of live arctic foxes. Similar strong correlations are found in other mammals, including canids (e.g. Torbit et al. 1985, Lefebvre et al. 1999) and the methods for calculating water content in live animals are commonly used to estimate body composition.

Lipid content of live foxes may also be accurately predicted by using the TBM/HFL index, but the correlation was less strong than for water content (see Fig. 4). Indices derived from body mass and linear measurements have been shown to be strongly related to fat content in other mammals (e.g. Cattet 1990, Ryg et al. 1990, Lefebvre et al. 1999). Winstanley et al. (1998), however, reported that external morphological measurements were poor predictors of total body fat in red foxes. The weak correlation we found in our study is probably caused by errors in the measurements of HFL which were taken by three different non-scientific persons. The HFL is short compared to the body length, and small errors in the measurement of HFL therefore have relatively large effects on the prediction of body fat compared to the small errors in the measurement of a larger linear dimension. However, errors in measuring body length of live foxes are great, and HFL is the most practicable linear dimension that can be measured under field conditions. The prediction equation we have estimated is only suitable for foxes in winter because the mass of fur varies seasonally.

In accordance with the strong positive correlation that Prestrud & Nilssen (1992) found between the RFT and the chemically extractable lipid of 75 arctic fox carcasses in Svalbard, we found that RFT was also strongly correlated to the mass of dissectible fat. In adult foxes, the superficial fat depots increase much faster than the intra-abdominal and intermuscular depots, and more fat is stored in posterior than in anterior superficial depots (Pond et al. 1995). Thus, the fat on the rump increases more quickly than other depots and is easier to measure precisely, which supports our conclusion that the thickness of this adipose depot is a reliable predictor of the lipid content of arctic foxes, even though wild animal adipose tissue is never more than about 70% lipid (Pond 1998, Pond et al. 1995).

Our results indicate that the subjective fat index should be divided into three instead of five categories. Chemically extractable lipid from the 75 foxes could be divided into five significantly different categories based on the same subjective fat index (Prestrud & Nilssen 1992).

Although the correlation between the fat content and the kidney fat index was positive, it was too weak to be a good predictor of fat content of arctic foxes (see Fig. 2). The index is commonly used in cervids, and may, together with depth of back fat, be a good predictor of dissectible fat in caribou *Rangifer tarandus* (Adamczewski et al. 1987) and red foxes (Winstanley et al. 1998). In arctic foxes (and many other mammals), the kidney fat merges with the rest of the adipose tissue on the dorsal wall of the abdomen (Pond et al. 1995). Thus, it is difficult to determine which should be considered kidney fat. Furthermore, the depots are often too small to be dissected.

In conclusion, determination of water content, total body mass divided by the hind foot length and the rump fat thickness are reliable indices of lipid content in arctic foxes. The subjective fat index is also a good predictor when it is divided into three categories, whereas the kidney fat index is a poor predictor of the lipid content of arctic foxes.

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