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Nutritional Management, Caloric Food Intake, and Body Mass of Grey Seals (*Halichoerus grypus*) Under Human Care

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Abstract

A varied and balanced diet is essential for maintenance of good health. A nutritional program must rely on a good understanding of the composition and quality of the food offered. When basic nutritional needs are not met, animals may develop changes in physiological function that may potentially compensate for stress related to an unbalanced diet. Poor nutrition could lead to decreased resistance to infectious agents and, ultimately, to disease. Understanding and application of nutritional energetics may prevent such problems from developing. The aim of this study was to describe the nutritional management of six grey seals (*Halichoerus grypus*) kept under human care between 2005 and 2015, and to report for the first time the kilo-caloric intake of grey seals over a 11-year period, thus presenting objective tools that would be useful for improving their nutritional management.

Key Words: caloric food intake, daily metabolic rate, nutritional energetics, grey seals, *Halichoerus grypus*

Introduction

The grey seal (*Halichoerus grypus*) has the widest distribution of all the phocids (Phocidae) and inhabits both the North Atlantic and the North Pacific Oceans (Bonner, 1972). Grey seals usually feed in coastal waters. Information about their prey species and the proportions in which they are eaten has become available through the examination of seal stomach contents and by fish otoliths found in seal feces (Rae, 1968; Härkönen, 1987; Payne & Selzer, 1989). Very little is known about their daily food consumption, the amount of kilo-calories (kcal) per week, or the possible variability due to seasonality. Energy requirements are determined by factors such as body size, activity level, reproductive state, thermoregulatory expense, and whether or not the animal is actively growing. The energy expenditures are collectively referred to as the daily metabolic rate (DMR) (Bartholomew, 1977). DMR can be subdivided into two energy components: (1) maintenance and (2) production. Maintenance energy includes basal (standard) metabolism (BMR = 3.4 M0.75 Kleiber's equation), thermoregulation, and locomotion. The thermo-neutral-zone (TNZ) is the range of temperature where no additional metabolic energy is necessary for stasis and metabolic rates are independent of environmental temperature (Bartholomew, 1977). If an animal is below the lower critical temperature (LCT), then the metabolic rate increases to produce heat. If the animal is above the upper critical temperature (UCT), then the metabolic rate increases to dissipate heat (Bartholomew, 1977). In young grey seals, the TNZ ranges from 1 to 10°C (water) and from 10 to 20°C (air) (Boily & Lavigne, 1987).

A varied and balanced diet in protein, fat, and carbohydrate is an essential factor in maintaining the health of this species under human care (Trumble & Castellini, 2005; Claus et al., 2010). For this reason, a diet of fatty fish is usually supplemented with leaner fishes or invertebrates such as squid (Worthy, 2001; Couquiaud, 2005).

A successful nutritional program must rely on a good understanding of the composition and quality of the food provided to the animals. When basic nutritional needs are not met, animals may develop changes in physiological function that may potentially compensate for stress related to an unbalanced diet (Worthy, 2001). Poor nutrition could lead to decreased resistance to infectious agents and, ultimately, to disease. Understanding and application of nutritional energetics may prevent such problems from developing (Worthy, 2001). The aim of this study was to describe the nutritional management of grey seals under human care between 2005 and 2015.

Methods

Animal Collection

Six grey seals, three males and three females, born and kept under human care, were evaluated in this study. All seals were housed in saltwater pools and provided with access to dry areas. The average monthly water temperature varied between 12°C in winter to 24°C in summer, while the average monthly air temperature varied between 8°C in January and 28°C in July, fluctuating with weather. The zoological park, Zoomarine Italia, is located in Rome, Italy, at 41° 53' N and 12° 30' E. General activity patterns and the behavior of each animal, including the proportion of time between hauling out and swimming, were recorded daily by trainers. We analyzed data from records of monthly animal diets over a 11-y period from 2005 to 2015.

Diet

Considering the *in situ* nutritional habits of these grey seals and the available frozen fish stocks, the diet was formulated with different species and different fish sizes (Hammill & Stenson, 2000; Gulland et al., 2001; Lundström et al., 2007, 2010). The diet of all study animals consisted of capelin (*Mallotus villossus*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*), mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), and squid (*Loligo* spp.). In accordance with all the protocols on fish analysis, storage, thawing, manipulation, and administration decided by Zoomarine Italia's Veterinary Department, the fish were frozen-stored for a maximum of 4 mo at -21°C. Multivitamins (Akwavit®; one tablet per 2.5 kg of food) were added to the fish after being defrosted in the thawing room between 4 and 6°C for 24 h. The energy intake of each seal was calculated from daily feeding records and caloric value of fish in the diet. Each animal was fed daily during six feeding sessions from 0800 to 1800 h, with a diet based on the kcal content of the fish that was customized for each individual, taking into consideration age, physiological status (e.g., reproduction, molting, etc.), behavior, environmental temperature, and other individual features (Williams et al., 2007). Diet was developed for each seal by the Veterinary Department in concert with the pinnipeds' head trainer through the evaluation of fish characteristics (e.g., chemical and organoleptic ones such as percentage of protein, fat, carbohydrate, humidity, etc.). Trumble & Castellini (2005) suggested that a mixed diet consisting of prey differing in lipid and protein amounts increases digestible energy intake in seals. In their study, measures of intake and apparent digestible dry matter in seals revealed digestive flexibility and indicated that digestion is more efficient in a mixed diet.

Standard analyses were performed on each new lot (every 4 mo), including examination of nutritional elements and caloric content, peroxides index, total volatile basic nitrogen (TVB-N), bacterial contamination, and histamine. For the study, animals in good health conditions were examined; good health is defined as assuming a normal posture, being alert with clear eyes, responding well to touch and calls, having an appetite, possessing good body and skin conditions, and having normal blood values. A scoring system to assess body condition is widely used in veterinary medicine as an effective, inexpensive method for quantifying patient condition. This technique has been useful for assessing the degree of obesity in non-domestic carnivores, but relatively few reports exist in the wildlife literature (Stringer et al., 2010). Body condition scoring is a subjective assessment of subcutaneous body fat stores, which is based on visual or tactile evaluation of muscle tone and key skeletal elements (Stringer et al., 2010). Scores are commonly based on a cardinal 5-point scale. Low scores represent animals with less body fat, and higher scores represent animals with more body fat. Standards for an appropriate body condition score vary between animal species, and scoring is subjective based on individual evaluator experience. In addition to the body condition scoring, the animals were weighed weekly via voluntary participation. The evaluated animals did not have a goal weight range; the weekly weight, body condition score, and veterinary check, in addition to the head trainer reports about animal behavior, appetite, and attitude, were considered and the diet modified accordingly.

Statistical Analysis

Kendall's (1962) coefficient of concordance test was used to examine the significance of seasonal fluctuations in food intake between different years for each grey seal. Due to differences of food intake, it was assigned a rank number from 1 to 12 to the average daily food intake for each month per year, thus allowing assessment of potential seasonal patterns (Kastelein et al., 2005). In addition, a relationship between the food consumption of six grey seals by age (in years) and by age and weight was investigated via the correlation coefficient. Moreover, a short-term variation of the diet and of each animal's weight were statistically examined. Lastly, potential relationships between average daily food consumption per seal and the seal's weight were examined via the correlation coefficient and in terms of a regression equation.

Results

The male food consumption (001M, 002M, and 003M) showed variability; however, consumption generally increased from around 20,000 kcal/wk at the age of 1 y to ~40,000 kcal/wk at the age of 5 y, with a maximum of 67,000 kcal/wk at the age of 15 y. The food consumption of both non-reproductive females (001F and 003F) was slightly different from males, ranging from ~20,000 kcal/wk at the age of 1 y to about 30,000 kcal/wk at the age of 8 y, with a maximum of 36,000 kcal/wk at the age of 5 y (001F). The reproductive female (002F) in the years before reproduction was similar to the non-reproductive females with food consumption varying from 37,000 to 40,000 kcal/wk; her consumption decreased from 41,000 to 32,000 kcal/wk in the reproductive years (at 10 to 11 y) with a peak of ~50,000 kcal/wk at the age of 12 y (Figure 1).

Male 001M reached 11 y with an average seasonal fluctuation in food intake (Figure 2A) that was also representative for the other two adult males. The seasonal fluctuation in food intake had an annual pattern (Kendall's coefficient of concordance test = 58.80; $p < 0.001$). Between the ages of 13 and 23 y, 001M generally had a decrease of food intake between March and August and a peak between October and January.

The seasonal fluctuations of food intake for the two adult non-reproductive females differed slightly from the males. Non-reproductive female 001F is presented as representative of the average seasonal fluctuations in food intake for non-reproductive females (Figure 2B). The seasonal fluctuation in food intake had an annual pattern (Kendall's coefficient of concordance test = 23.36; $p = 0.02$). Between the ages of 5 and 8 y, 001F generally had a peak of food intake in January, February, November, and December, and a drop between March and September. In particular, a strong drop was observed between July and August when molt occurred (around 56% loss in weight) in both males and females.

Analyzing seasonal fluctuations in food intake of the reproductive female 002F yielded differences with the non-reproductive adult females (Figure 2C). During mating and nursing, 002F generally had a decrease in food intake between February and April and a peak between October and December and in January.

All six animals were weighed weekly. Body mass globally increased according to weight, and fluctuation in weight was common for all individuals. In males, the maximum registered weight was approximately 250 kg, whereas females were ~160 kg at their heaviest (Figure 3). Variation of the diet and of the animal weights were evaluated (Table 1): 001M and 003F are examples of short-term variation of the diet and the weight variation in males and females, respectively. In males, a 35% dietary reduction in kcal between January and March corresponded with a reduction of 2% of body weight during the same period. While keeping the same reduction in kcal until May, the total reduction of the body weight was

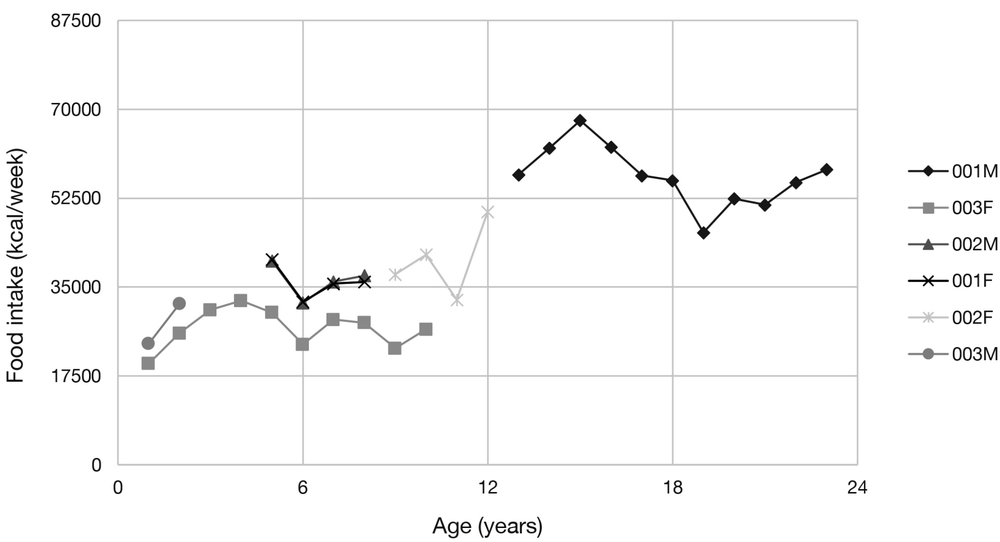

Figure 1. Food consumption of six grey seals (*Halichoerus grypus*) evaluated by age (in years); data points of the same individual are connected by lines.

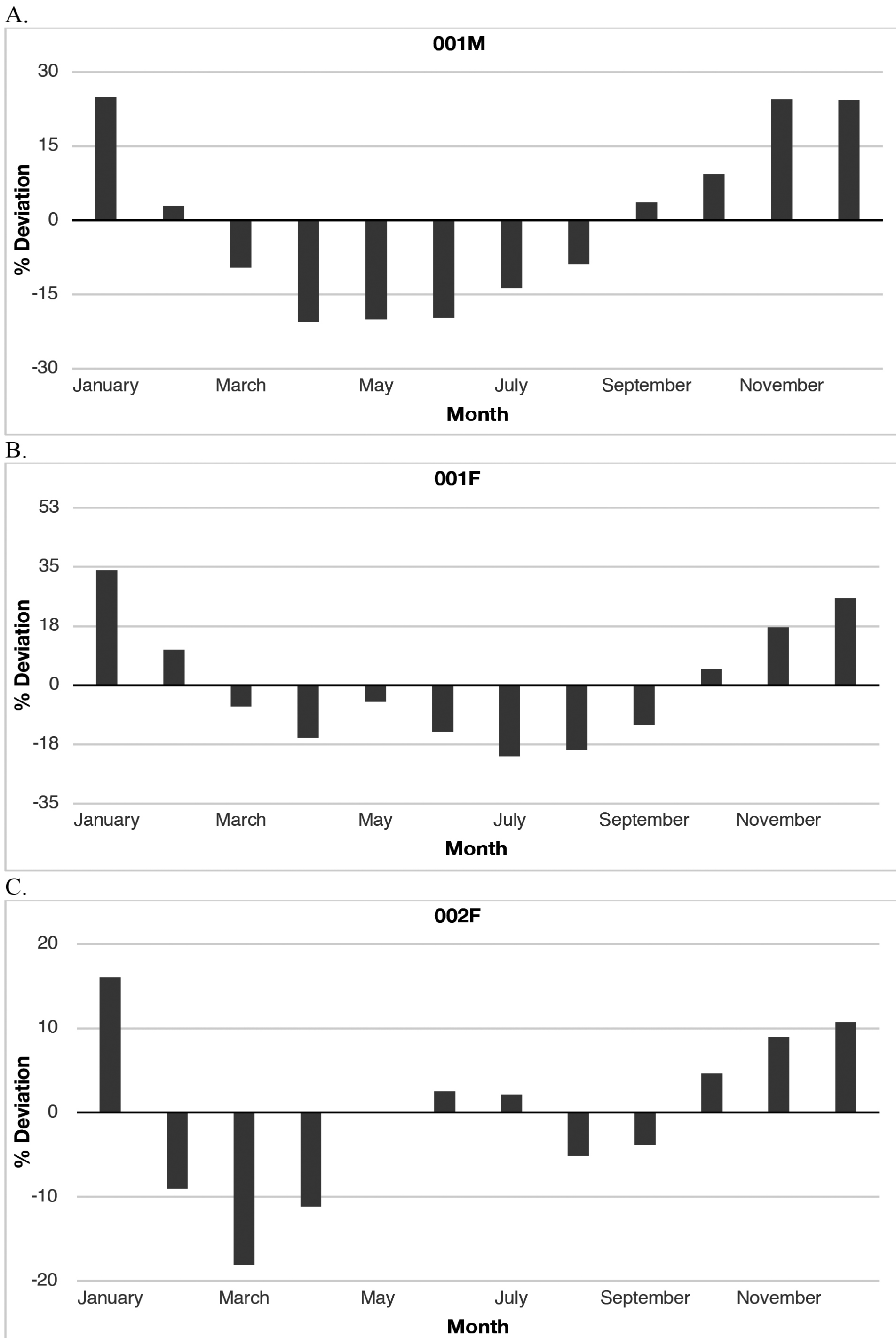

Figure 2. (A) Deviation from the overall annual average food intake in adult male 001M between the ages of 13 and 23 y (n = 11 y of study); (B) deviation from the overall annual average food intake in adult non-reproductive female 001F between the ages of 5 and 8 y (n = 4 y of study); and (C) deviation from the overall annual average food intake in adult reproductive female 002F between the ages of 9 and 12 y (n = 4 y of study) during reproduction and nursing.

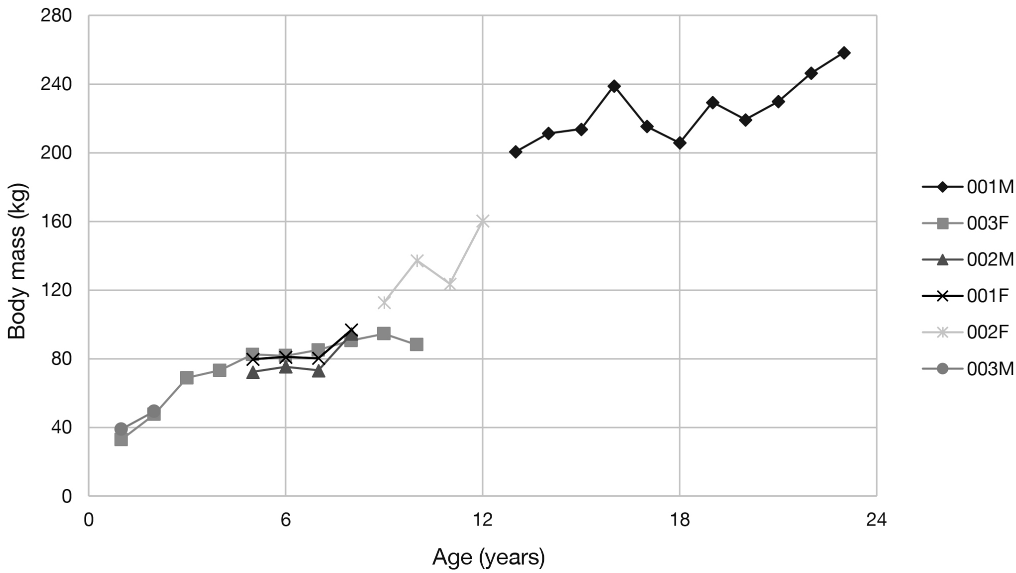

Figure 3. The relationship between age and weight of the six grey seals; data points of the same animal are connected by lines.

Table 1. Coefficient of variation (CV%) for the short-term diet (kcal) and the animal weight (kg). The minimum and the maximum value recorded during the study for each animal are shown, as well as the age (y) for each animal in the study period.

	001M	002M	003M	001F	002F	003F
Age (y)	13-23	5-8	1-2	5-8	9-12	1-10
CV% diet (kcal) min-max	9-40	23-34	28-29	22-30	21-24	7-55
CV% weight (kg) min-max	2-16	5-9	4-15	4-6	11-11	2-20

15% between January and May. In details, males showed a 13% reduction from March to May, and females showed a 15% reduction in kcal of the diet between January and March. This corresponded with a reduction of 2% of the body weight during the same period, whereas a reduction of 12% in kcal between January and May corresponded with a reduction of 18% of the body weight during the same period. There was no linear correlation in short-term variation of the diet and the body weight in males, whereas it was about 57% in females. How the variations in average daily food consumption between years have produced variations in animal weight was also investigated.

The average daily food intake was also compared to the average annual body mass for each grey seal (Figures 4 & 5). A positive correlation between body mass and average daily food consumption, both for males and females, was detected (Figure 5). Specifically, the relationship is that average daily food consumption equaled to $743.91e^{0.0041}$ (body mass in kg). Positive correlation and relationship were different between males and females (R = 0.83): average daily food consumption equaled $672.76e^{0.0047}$ (body mass in kg) for males (R = 0.39) and $984.08e^{0.0029}$ (body mass in kg) for females.

Discussion

The nutritional management of grey seals kept under human care between 2005 and 2015 was reviewed in this article; and for the first time, the kcal intake for this species was investigated and summarized over a 11-y period. Annual caloric consumption was different between males and females of a similar age and was probably related to sexual dimorphism in body weight for this species

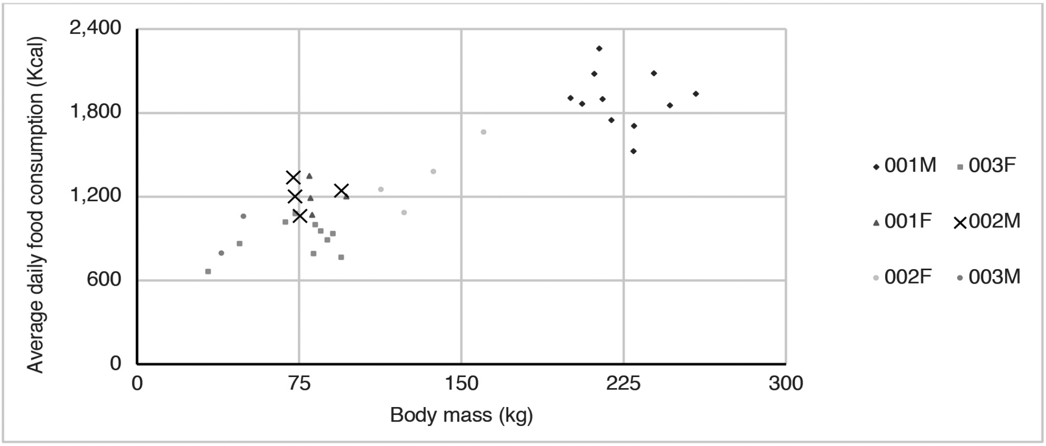

Figure 4. The relationship between the average of daily food consumption (kcal) and the animal weight (kg)

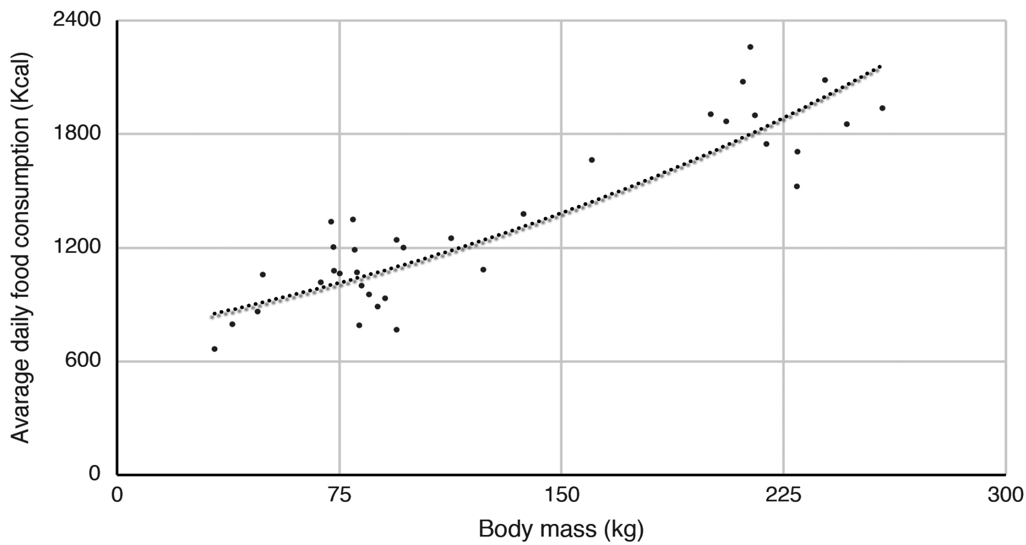

Figure 5. The relationship between body mass and average daily food consumption for six grey seals. Best fit curve (exponential): Average daily food equaled $743.91e^{0.0041(\text{body mass})}$ (R = 0.88).

(Ashwell-Erickson & Elsner, 1981). Dietary variation between sexes may be related to different energy requirements and trade-offs between feeding and other activities that vary between males and females (Beck et al., 2007). Male grey seals are on average 50% heavier than females (Beck et al., 2003). Austin et al. (2006) showed how grey seal weight ranged from being 30% heavier in the autumn and 45% heavier at the start of the breeding season. As absolute metabolic requirements increase with body size, a larger animal requires a greater energy intake and may forage differently as a result (Renouf & Noseworthy, 1988, 1990; Renouf, 1993; Rosen & Renouf, 1998; Worthy, 2001). Male grey seals require about one to three times the energy intake of females (Mohn & Bowen, 1996), suggesting that size dimorphism may be largely responsible for these findings. Seasonal patterns of energy storage may also influence the observed sex differences in feeding. Males begin to accumulate energy stores during the pre-breeding foraging period following a 6-mo period of body energy loss (Beck et al., 2003). Energy gain increases in September and continues throughout the autumn.

In contrast, females have a more consistent strategy of energy accumulation throughout the year and do not demonstrate an increase in autumnal months (Beck et al., 2003). This difference reflects the earlier reproductive costs in females and differences in the sex-specific trade-off between the benefit of stored body energy for reproduction and the cost of mass and energy storage over long periods. Given the critical role of stored energy for female reproductive success, females should reduce uncertainty in future reproductive success by accumulating body energy as soon as possible. Maternal condition has an important influence on early fetal development in grey seals, with later implantation occurring in females in poorer condition (Beck et al., 2003). Thus, females ought to recover body condition quickly following the breeding season to ensure successful implantation (Beck et al., 2007).

Lesser fluctuation in food intake during the reproductive period, which is shown by all animals included in this study compared with previous studies (Kastelein & Wiepkema, 1988, 1990; Kastelein et al., 1990, 1991, 1994, 1995), may be due to the higher average external temperature at the latitude, although only one female reproduced during the study period, and it is clear that reproduction requires extra caloric intake. The food intake of the reproductive female in the present study during the reproductive season was 25% above her average annual intake. This finding agrees with other studies (Kastelein & Wiepkema, 1988, 1990; Kastelein et al., 1990, 1991, 1994, 1995). The increase in food intake mainly occurs during lactation when food is also converted into milk for the growing pup. Female grey seals transfer large amounts of energy rapidly and efficiently to their pups (Fedak & Anderson, 1982). Over 80% of a female's energy reserves are used to feed her pups. This massive transfer of resources in a short period is thought to be an adaptation by an offshore aquatic feeder, which must return to land to give birth. Larger female grey seals come ashore to give birth earlier in the season and lose weight more rapidly than smaller females (Fedak & Anderson, 1982). Anderson & Fedak (1987) studied free-ranging animals and reported that male pups are larger at birth and gain weight more rapidly than female pups, and their mothers show a correspondingly faster rate of weight loss than mothers of female pups. In energy terms, weaning males is therefore 10% more costly than weaning females (Anderson & Fedak, 1987). During lactation, female grey seals lose about 40% of their body mass, depleting 62 to 68% of their lipid stores and 16% of their protein stores (Mellish et al., 1999; Beck et al., 2003).

Mating occurred in December and January when the body condition of the studied animals was excellent. Molting occurred in both sexes after the mating season. The molt cycle of grey seals is influenced by the photoperiod (Ling, 1972; Mo et al., 2000). The males regularly molted from May to July and visibly lost weight during the molting period (around 56%). The timing of the molt and its seasonal effect on food intake seems to reflect what occurs with grey seals in the wild (Kastelein et al., 1990), even if the animals of the present study were housed outdoors at a southern latitude similar to wild grey seals. Kastelein et al. (1990) reported that there was no significant reduction in food intake for grey seals under human care during the molting period, which could be due to the lower external temperature and to the lower number of specimens as compared with the present study or possibly to a difference in management of weight and diet (Markussen et al., 1990).

Davis et al. (1985) showed that metabolism increased curvilinearly with swimming speed. The evaluated animals were in a 3.5-m depth pool where they could swim but could not perform deep dives. Thus, grey seal food consumption was probably less than that of wild conspecifics of similar age and gender, likely because of the difference in energy requirements between swimming and diving.

Finally, the present study showed how short-term variation in diet (kcal) does not match variation in animal weight (kg), especially for heavier animals (e.g., 001M), while a variation of diet (kcal) over a long period (~1 y) matches variation in animal weight (kg). This study could be a useful tool to improve the nutritional management of grey seals under human care, especially because data from a 11-y period were examined and included animals in different physiological states (e.g., pregnancy, growth, etc.) and ages, and in a different environment (8°C < average temp. < 28°C). A good diet for animals should consider age, physiological status (e.g., reproduction, molting, etc.), environmental temperature, individual features, and activity level. The food consumption data presented herein should be used only as a conservative estimate of grey seals' caloric intake under human care as these seals require less energy for locomotion and thermoregulation than their wild counterparts do.

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