Published by Associazione Teriologica Italiana
Hystrix, the Italian Journal of Mammalogy
Volume 27 (2): 123–128, 2016
OPEN ACCESS
Available online at:
http://www.italian-journal-of-mammalogy.it
doi:10.4404/hystrix-11895

Research Article

# Seasonal feeding habits of coypu (*Myocastor coypus*) in South Korea

Sungwon Hong[1], Phil Cowan[2], Yuno Do[1], Jeong-Soo Gim[1], Gea-Jae Joo[1,*]

[1] *Department of Biological Sciences, Pusan National University, Busan 609-735, Republic of Korea*
[2] *Landcare Research, Lincoln 7640, New Zealand*

*Keywords:*
*Myocastor coypus*
invasive species
diet analysis
stable isotope
trapping period

*Article history:*
Received: 22 May 2016
Accepted: 18 August 2016

*Acknowledgements*
We appreciated the help of veterinarians with the processing of coypus in Nakdong River Estuary Eco-center. In addition, we thank Seung-Ki Kim for carrying out the isotope analyses, and Maurice Lineman for editing the manuscript. This work was supported by a National Research Foundation of Korea, grant from the Korean Government (NRF-2015-Fostering Core Leaders of the Future Basic Science Program/Global Ph.D. Fellowship Program).

**Abstract**

Since their introduction in 1985, coypus (*Myocastor coypus*) have spread widely throughout South Korea and are now considered an invasive species, with negative impacts on both agriculture and native biodiversity. Management of the species began in 2005, and related research has focused on factors influencing population control. Cold weather may cause significant population declines but the basis of that susceptibility has yet to be identified. Therefore, based on the analysis of 28 coypus trapped on Eulsuk Island in the Nakdong River over a 12-month period, we sought to: (1) investigate coypu diet and body condition using the relationships between the $\delta^{13}$C and $\delta^{15}$N stable isotope values of coypu liver and hind-leg muscle tissues, mean temperature, and body condition index (log weight/log body length); (2) clarify the relative use of aquatic and terrestrial food plants, and (3) determine seasonal variations in coypu diet. Carbon and Nitrogen isotope values both differed seasonally and, in winter, between adults and juveniles. Carbon, but not Nitrogen, isotope values were influenced by temperature in the weeks before sampling. The $\delta^{15}$N values of liver tissues were influenced by sex and life stage at low temperatures; otherwise, with regard to diet, isotope ratios suggested that coypu primarily fed on aquatic vegetation. Coypus appear to make more use of the heavier nitrogen isotope in hind-leg muscle during winter, presumably associated with muscle tissue metabolism contributing to weight loss. During winter, these higher metabolic requirements together with the decreased availability of aquatic vegetation suggest that baiting near waterways in winter could be an effective method to control invasive coypu populations.

## Introduction

Coypus (*Myocastor coypus*) are native to tropical regions of South America but have been introduced to a variety of other climactic zones and ecosystems across North America, Europe, Asia, and Africa, primarily for exploitation of their fur and meat (Carter and Leonard, 2002). The escape and subsequent establishment and spread of farmed coypus into the wild has resulted in significant impacts, particularly the disturbance of native ecosystems, damage to crops, and flooding that results from their burrowing activities (Carter et al., 1999; Lowe et al., 2000; Baroch and Hafner, 2002; Panzacchi et al., 2007; Angelici et al., 2012). However, owing to the tropical origins of coypu, their mortality is often high during winter months in the colder parts of their invaded range (Gosling, 1981a,b; Battisti et al., 2015). Therefore, we investigated coypu diet, feeding, and body condition, particularly focusing on seasonal changes and how those might be exploited to improve coypu management.

In South Korea, coypus have spread widely throughout the Nakdong River basin since the late 1990's; however, we previously found that coypu cannot survive in areas subject to prolonged periods of temperatures below $-4\,^{\circ}$C (Hong et al., 2014; Battisti et al., 2015). Although coypu feeding habits have been well studied in their native habitat and in other countries where they have been introduced, little is known about the feeding habits of coypus in South Korea, especially regarding their relative use of aquatic and terrestrial plants (Abbas, 1991; Borgnia et al., 2000; Guichón et al., 2003; Prigioni et al., 2005; Corriale et al., 2006; Panzacchi et al., 2007). In the present study, we used $\delta^{13}$C and $\delta^{15}$N values to investigate coypus feeding habits, since stable isotopes can be used to evaluate the relative use of aquatic and terrestrial plants (Kielland, 2001). In this methodology, higher isotope ratios indicate a higher assimilation on animal tissues and, hence, greater food intake (Fry, 2006). In addition, different tissues of animals have different isotope turnover rates, with liver tissues having the fastest rate (DeNiro and Epstein, 1981). We hypothesized that seasonal changes in temperature would be correlated with the $\delta^{15}$N values of liver and hind-leg muscle tissues, since coypu feeding activity is reduced by cold temperatures (Gosling, 1981a), and we expected that a coypu body condition index (log weight/log body length) would be correlated with the $\delta^{15}$N values of hind-leg muscle tissue. The turnover rate of liver tissue is relatively higher than that of hind-leg muscle (DeNiro and Epstein, 1981).

Specifically, we sought to: (1) investigate coypu diet and body condition using the relationships between the $\delta^{13}$C and $\delta^{15}$N stable isotope values of coypu liver and hind-leg muscle tissues, mean temperature, and body condition index (log weight/log body length); (2) clarify the relative use of aquatic and terrestrial food plants, and (3) determine seasonal variations in coypu diet.

## Materials and methods

### Study area

The area (35°6′25.30″ N, 128°57′10.94″ S) used for trapping coypus was located around a small pond (6.94 ha) with three key trap locations (Fig. 1). The area was located on Eulsuk Island in the Nakdong River estuary, and is part of a nationally-designated refuge for migratory birds (Lee et al., 2010). The island covers ≈336 ha and has several wetlands and ponds that have been colonized by coypus. There was a sewage treatment facility on the island from 1975 to 1993, and the island was used as a landfill from 1993 to 1997. In 2005, the island was designated

*Corresponding author
*Email address:* gjjoo@pusan.ac.kr (Gea-Jae Joo)

as a migratory bird park (Williams et al. 2006; http://wetland.busan.go.kr).

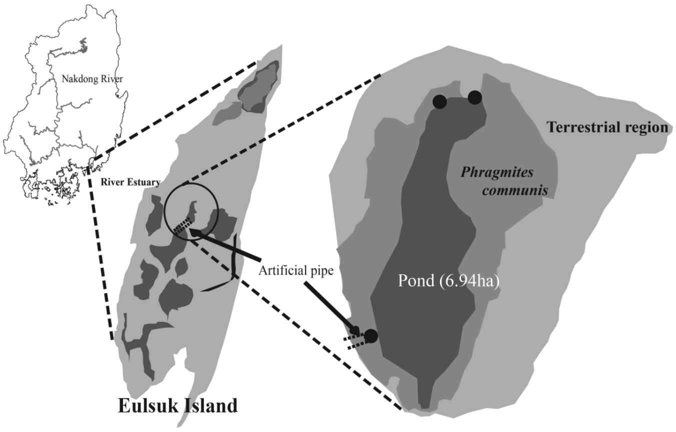


**Figure 1** – Study area on Eulsuk Island (≈336 ha) in the southern Nakdong River estuary of South Korea. Coypu trapping was conducted in the area surrounding the pond (6.94 ha). The filled circles are the key sites for trapping.

### Tissue collection

Coypus were captured from January 2013 to January 2014 using unbaited live animal traps (28×30×90 cm, self-made) to avoid influencing isotope ratios by bait. The traps were set continuously and checked twice a week, and trapped animals were euthanized. Since the coypu is classified as an invasive species in South Korea, no approval was required to trap the animals. For each trapped coypu, recorded data included sex (female, male), body length (cm), and weight (kg), with animals weighing <1.25 kg considered juveniles (Brown, 1975). In addition, tissue samples (liver and hind-leg muscle) were taken from each coypu killed and samples were stored at −20 °C until analysed (4–6 weeks). For analysis, the tissues were dried at 60 °C to constant weight and then soaked in a solution of methanol, chloroform, and water (2:1:0.8, volume) for 24 h to remove lipids. After three washes with distilled water, the tissue samples were re-dried at 60 °C for 2 d and ground to a fine powder, using a porcelain mortar and pestle (Choi et al., 2014).

### Stable isotope analysis

To obtain $\delta^{13}$C and $\delta^{15}$N values, 0.4–0.6 mg dried tissue samples were individually placed in tin capsules (4×6 mm) and analysed by continuous-flow isotope ratio mass spectrometry (CF-IRMS; Micromass IsoPrime, Centre for Research Facilities, Pusan National University). The isotope ratios were then determined from the following relationship:

$$\delta\, X(‰) = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000\ ‰$$

where $X$ is $\delta^{15}$N or $\delta^{13}$C and $R$ is the corresponding $\delta^{15}$N/$\delta^{16}$N or $\delta^{13}$C/$\delta^{12}$C value. Pee Dee Belemnite (from the Peedee Formation, South Carolina, USA) and $N_2$ gas were used as standards for $\delta^{13}$C and $\delta^{15}$N analysis, respectively. The ratios are reported as means ± standard error (SE) (Fry, 2006).

### Estimating the effects of low temperatures on the $\delta^{15}$N values of coypu tissues

To investigate the relationship between temperature and body condition, we used mean temperatures over time periods that corresponded to the isotope turnover rates for each tissue (liver tissue, 3 weeks before capture; hind-leg muscle tissue, 3 months before capture; Major et al., 2007). In order to assess the relative importance of low temperatures, we analysed the relationship between the $\delta^{15}$N values of the liver and hind-leg muscle tissues, body condition index, and mean temperature, using multiple regression analysis (as implemented in SPSS 18, IBM Inc., Chicago, IL, USA) for coypu groups and life stages. We log-transformed the $\delta^{15}$N values of the liver tissues and all values were normalized to remove bias (Zar, 1999).

### Food plant analysis

We defined plants that did not occur in the pond as terrestrial plants and the others as aquatic plants. The sampling area was restricted to within 100 m of the water's edge, since coypu feeding is limited to that area (Abbas, 1991). Because isotopic values of soils are likely to have influenced the plant isotopic values, plants from around the pond were chosen randomly, with a distance of at least 30 m between specimens from the same species (Corriale et al., 2006), and the plants were identified using the taxonomic keys in Lee (2006). In order to assess any preference of coypu for particular plant parts, the plants were separated into above- and below-ground parts. Vegetation sampling was limited during winter months since the aboveground plant parts were dead. Plant parts were dried at 60 °C for 2 d and ground separately, except for floating plants which were dried and ground in their entirety since coypu eat them whole (Gosling, 1981a; Abbas, 1991; Wilsey et al., 1991; Marini et al., 2013). The vegetation components were then soaked in 1 mol/L HCl for 24 h to remove organic carbon, after which they were re-dried at 60 °C for 2 d (Choi et al., 2014).

### Statistical analysis

An index of body condition was calculated using log weight per log body length (Anderson and Neumann, 1983), and for data analysis, winter was defined as the period from December to February, spring from March to May, summer as from June to August, and autumn as from September to November (Abbas, 1991; Hong et al., 2014; Battisti et al., 2015).

If the elapsed time between coypu captures exceeded 3 months, we assumed that the coypu population had been depleted and that a new group had colonized. Therefore, we compared the body condition indices and isotope ratios of the coypu groups (all or adults only), as well as the body condition indices and isotope ratios of adult and juvenile coypus, using the independent t-test for normally distributed data or the Mann-Whitney test for variables that did not exhibit normal type error distributions. In addition, we also compared the sex ratio between the groups, using chi-square tests (contingency table analysis), and the relationship between sex and body condition, using independent t-tests. In order to assess the influence of season, sex, and life stage on the isotopic ratios and the occurrence of interactive effects, we conducted two-way multivariate analysis of variance (MANOVA; Johnson and Wichern, 1988) as implemented in SPSS 18 (IBM Inc., Chicago, IL, USA).

Subsequently, the isotope ratios of the aquatic and terrestrial plants and coypus were separately analysed, using SigmaPlot 10.0 (Systat Software, San Jose, CA, USA). We used t-tests for normally distributed variables and the Mann-Whitney test for variables that did not exhibit normal type error distributions. Seasonally divided isotope ratios of plants and coypus were plotted against the C/N ratio in multiple scatter plots and were compared using t-tests.

## Results

### Sample data

During the 12-month trapping period, we captured a total of 28 coypus, with one group (n=13) trapped during winter to spring and a second group (n=15) trapped during autumn to winter (Fig. 2). Juveniles (n=4) were only trapped in the winter of 2013 (Tab. 2). The sex ratio of the two groups was similar ($\chi^2$=3.49, df=1, $p$>0.05), and, excluding juveniles, the mean body condition index of the two groups was also similar ($t$=-1.132, df=22; Fig. 2, $p$>0.05).

We found 6 aquatic, 10 terrestrial, and 4 unknown plant species in the study area (Tab. 3). As the mean temperature increased, the occurrence of floating and submerged vegetation also increased.

Excluding juveniles from the analysis, the $\delta^{13}$C values of the two groups differed significantly, for both liver and hind-leg muscle tissue (liver: $t$=-2.83, df=16, $p$<0.05; hind-leg muscle: $t$=-4.183, df=21,

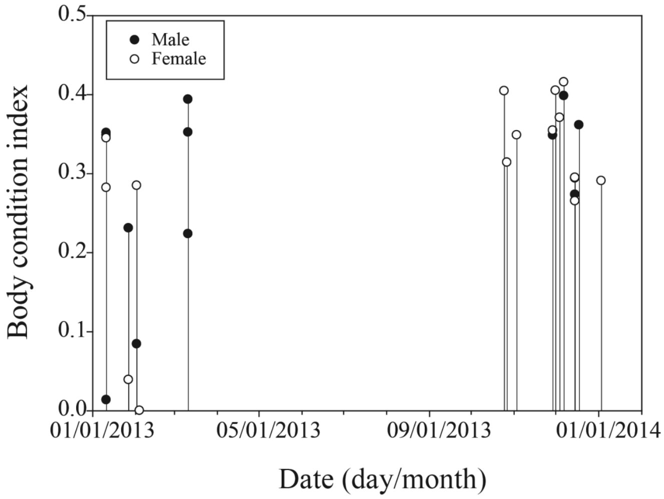


**Figure 2** – Body condition indices of coypus (n=28) captured on Eulsuk Island, South Korea during a 12-month period (11 Jan 2013 to 3 Jan 2014). Filled circles represent male coypus, and empty circles represent female coypus.

$p$<0.01; Fig. 3), with lower values observed in the winter/spring group than in the autumn/winter group.

With juveniles excluded, the $\delta^{15}$N values of the two groups also differed significantly for both liver and hind-leg muscle tissue, with lower values of hind-leg muscle tissues observed in the winter/spring group than in the autumn/winter group, and higher values of hind-leg muscle tissues observed in the winter/spring group than in the autumn/winter group (liver tissues: $p$<0.05, $t$=-2.96, df=12, hind-leg muscle: $p$<0.01, $t$=-3.23, df=17). In addition, the $\delta^{15}$N values of the hind-leg muscle tissue of juveniles in the winter/spring group differed significantly from those of the adults. ($t$=3.34, df=11, $p$<0.01).

The $\delta^{15}$N levels in liver tissue were not dependent on the mean temperature of the 3 weeks prior to capture ($p$>0.05), although the levels of $\delta^{13}$C were influenced significantly by temperature ($p$<0.05). Similarly, the $\delta^{15}$N level of hind-leg muscle was not associated with the mean temperature of the 3 months before capture ($p$>0.05) whereas the $\delta^{13}$C level was ($p$<0.05). The model of sex based on life stage was significant ($p$<0.05 for $\delta^{15}$N of liver tissues, MANOVA).

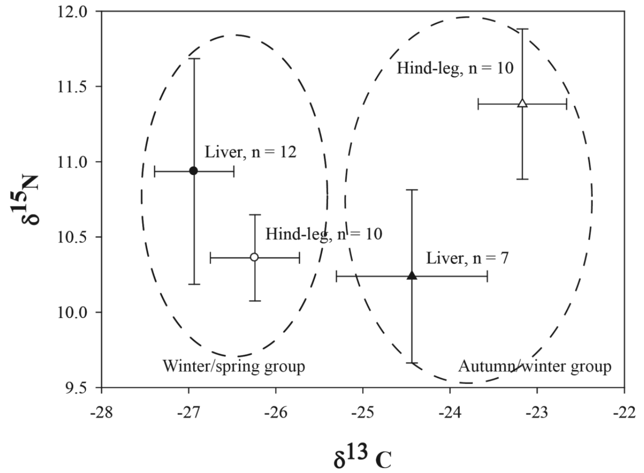


**Figure 3** – Isotope ratio plots (means with 95% error bars) of liver and hind-leg muscle tissue from two groups of coypus captured on Eulsuk Island, South Korea during a 12-month period (11 Jan 2013 to 3 Jan 2014). Filled symbols represent liver tissue, empty symbols represent hind-leg muscle tissue, circles represent the group captured during the winter and spring of 2013, and triangles represent group captured during the autumn and winter of 2013/2014.

## Relationship between the $\delta^{15}$N values of coypu tissues and other factors

The $\delta^{15}$N values of hind-leg muscle were more highly correlated with body condition ($\beta$=0.42, $p$<0.05) than with mean temperature of the 3 months before capture ($\beta$=0.24, $p$>0.05; $r^2$=0.47, $p$<0.01). For adults (n=24), the $\delta^{15}$N values of hind-leg muscle were more highly correlated with body condition index ($\beta$=0.35, $p$>0.05) than mean temperature ($\beta$=0.19, $p$>0.05; $r^2$=0.33, $p$<0.05). Whereas for the juveniles (n=4), the $\delta^{15}$N values of hind-leg muscle were more highly correlated with mean temperature ($\beta$=0.98, $p$<0.05) than body condition index ($\beta$=0.16, $p$>0.05; $r^2$=1.00, $p$<0.05).

## Isotope ratios of food plants

The isotope ratios of terrestrial and aquatic plants differed significantly for both above- and below-ground tissues ($\delta^{13}$C: $z$=-3.30, $p$<0.01; $\delta^{15}$N: $z$=-6.09, $p$<0.01). No differences were observed in the isotopes of above- and below-ground parts for either aquatic plants ($\delta^{13}$C: $z$=-1.25, $p$>0.05; $\delta^{15}$N: $t$=-0.21, df=33, $p$>0.05) or terrestrial plants ($\delta^{13}$C: $t$=-0.31, df=37, $p$>0.05; $\delta^{15}$N: t = 0.31, df=37, $p$>0.05). However, the isotope ratios of aquatic plants clustered closer to those of coypus than to those of terrestrial plants (Fig. 4).

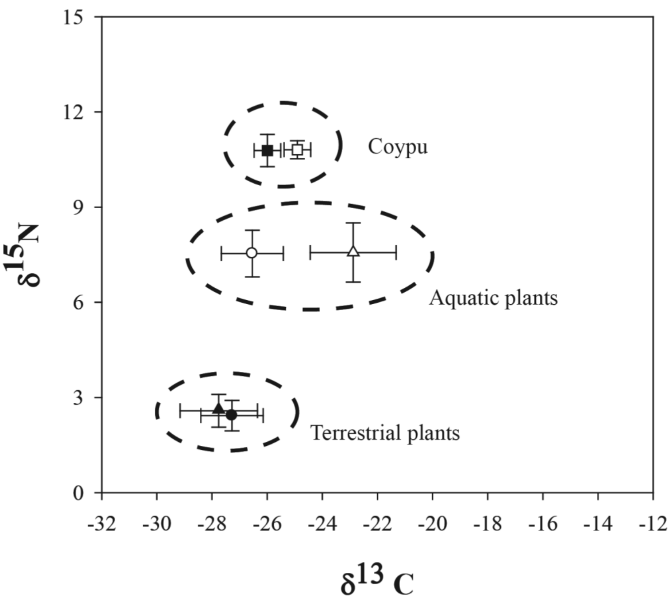


**Figure 4** – Isotope ratio plots (means with 95% error bars) of plants and coypus collected from Eulsuk Island, South Korea during a 12-month period (11 Jan 2013 to 3 Jan 2014). For the plant data, empty symbols represent aquatic plants, filled symbols represent terrestrial plants, triangles represent aboveground plant parts, and circles represent belowground plant parts. For the coypu data, empty quadrangle represents hind-leg muscles, and filled quadrangle represents liver tissues.

The $\delta^{15}$N values of aquatic plants differed significantly from those of terrestrial plants, except during the first winter sampling period, when analysis was limited by low sample sizes (winter: $p$>0.05, $z$=-1.464; spring: $p$<0.01, $t$=5.33, df=12.68; autumn: $p$<0.01, $t$=5.07, df=9, winter: $p$<0.01, t=3.00, df=19). In addition, the $\delta^{15}$N values of roots and stems from aquatic plants differed significantly ($\delta^{15}$N: $t$=-2.85, df=7, $p$<0.05). In general, the isotope ratios of the coypu were more similar to those of the aquatic plants than the terrestrial plants. During the first winter, coypu diets included little, if any, aquatic plants. During spring, the $\delta^{15}$N values of aquatic plants were closer to those of the coypu tissues. By autumn, the floating plants had emerged. The nitrogen isotope ratios of the underground parts of aquatic plants and coypu tissues were related. The aboveground portions of the aquatic plants yielded comparatively higher nitrogen isotope ratios than the coypu tissues. During early winter, the overall $\delta^{15}$N values of any aquatic plants and coypus decreased, and the values of livers and hind-leg muscles also decreased. Similarly, the values of aquatic plants were closely related to the values of coypus (Fig. 4).

**Table 1** – Summary of adult coypu captured from Eulsuk Island, South Korea during a 12-month period (11 Jan 2013 to 3 Jan 2014). (The number of isotopic ratios determined is shown in parentheses if those differ from the number of captured individuals due to sample contamination).

| Season | Winter 2013 | | Spring 2013 | Autumn 2013 | | Winter 2014 | |
|---|---|---|---|---|---|---|---|
| Sex | Female | Male | Male | Female | Male | Female | Male |
| Number | 3 | 3 | 3 | 5 | 1 | 6 | 3 |
| log Weight/log Body length | 0.30±0.02 | 0.31±0.04 | 0.32±0.05 | 0.37±0.02 | 0.35 | 0.32±0.02 | 0.34±0.04 |
| $\delta^{13}$C of liver | -27.75±0.41 | -27.43±0.21 (2) | -25.95±0.53 | - | - | -25.10±0.73 (5) | -22.54±1.09 (2) |
| $\delta^{15}$N of liver | 10.22±1.89 | 9.55±0.36 (2) | 10.35±0.89 | - | - | 10.53±0.79 (5) | 10.48±0.51 (2) |
| $\delta^{13}$C of hind-leg | -27.04±0.83 | -27.10±0.89 | -23.67±0.83 | -23.53±36 (3) | - | -23.32±0.58 (4) | -22.62±1.68 |
| $\delta^{15}$N of hind-leg | 10.85±0.24 | 11.12±0.12 | 10.51±0.71 | 13.20±0.38 (3) | - | 10.32±0.67 (4) | 10.98±0.47 |

# Discussion

## Food plant analysis

Most investigations of isotope ratios in animals have been restricted to carnivorous or omnivorous mammals, owing to the lack of $\delta^{13}$C signatures for soil or plants (Kielland, 2001; Urton and Hobson, 2005; Ben-David and Flaherty, 2012). Recently, however, the application of a mixing model has enabled the analysis of herbivore food sources (Severud et al., 2013). Isotope ratios of soils normally cannot be used to identify vegetation, since plants use the same soil as a nutrient source. However, when the same plant species are growing in different soils, it may be possible to use isotope ratios to determine feeding sites (Kielland, 2001). Our study area was transformed from a landfill into a protected area in 2005, which involved creating new waterways and wetlands using soils from other regions (Lee et al., 2011). Therefore, the aquatic and terrestrial soils of the island possessed different isotope ratios. In addition, the water level of the pond is managed so that terrestrial areas are not flooded (Williams et al., 2013). Thus, local soil composition may have contributed to the different $\delta^{15}$N values of aquatic and terrestrial plants.

## Relationship between the $\delta^{15}$N values of coypu tissues and other factors

The strongest relationship among mean temperatures, body condition index, and the $\delta^{15}$N values of liver and hind-leg muscle tissues, was that between isotope assimilation by hind-leg muscle tissue and mean temperature. Coypus would be expected to exhibit higher rates of metabolism at lower temperatures than at higher temperatures (Dixon et al., 1979; Fry, 2006). The $\delta^{15}$N values of the hind-leg muscle tissues were correlated with the relatively long-term mean temperature (i.e., 3-month average), since the turnover rate of the hind-leg muscle tissue was relatively slow, owing to the lower metabolic rate of muscle tissue at lower temperatures. However, the isotope ratios in hind-leg muscle tissues exhibited a stronger relationship to the body condition index than to mean temperature, and the body condition indices of trapped coypus decreased after winter (Tab. 1). Therefore, coypus appear to make more use of the heavier nitrogen isotope in hind-leg muscle during winter, presumably associated with muscle tissue metabolism contributing to weight loss. In addition, this pattern was even more evident in juveniles, perhaps a reflection of their lower fat reserves and higher surface area to volume ratios than adults. This may explain the higher rate of mortality in juveniles than in adults (Aliev, 1973; Doncaster and Micol, 1990).

**Table 2** – Characteristics of juvenile coypu captured from Eulsuk Island, South Korea during winter only.

| Season | Winter 2013 | |
|---|---|---|
| Sex | Female | Male |
| Number | 2 | 2 |
| log Weight/log Body length | 0.02±0.02 | 0.05±0.04 |
| $\delta^{13}$C of liver | -27.67±2.66 | -25.98±1.01 |
| $\delta^{15}$N of liver | 15.12±0.98 | 10.10±1.22 |
| $\delta^{13}$C of hind-leg | -26.49±0.23 | -27.34±0.80 |
| $\delta^{15}$N of hind-leg | 8.85±0.31 | 9.77±0.81 |

Seasonal variation in isotope ratios enables has been used to identify changes in the relative importance of vegetation types in animal diets (Owen-Smith, 1994; Kielland, 2001). During the winter, the $\delta^{15}$N values of aquatic plants decreased at the study site, but the C/N ratios of the coypu tissues did not follow the changes in vegetation isotope ratios, likely because the coypus fed on the live submerged parts of some aquatic plants, thus, maintaining similar $\delta^{15}$N values. In addition, as mentioned previously, the isotopic values could be maintained by the metabolism such as use of the heavier nitrogen isotope in hind-leg muscle. Therefore, the $\delta^{15}$N liver values could be higher than hind-leg muscle values. During spring, floating plants were not included in the analysis since they had not emerged yet, so the aquatic plants are fully featured in the diet, and coypus appeared to eat both above- and below-ground plant parts (Tab. 2). As floating plants emerged, the $\delta^{15}$N hind-leg values increased, and reflected with those of coypu tissues. At our study site, there were few floating plants, so we were unable to determine food preferences within aquatic plants, although coypus are known to prefer floating plants (*Lemna* spp.) and plants in the Pontederiaceae (Wilsey et al., 1991; Guichón et al., 2003). Although we could not determine preferences for specific plants, it was

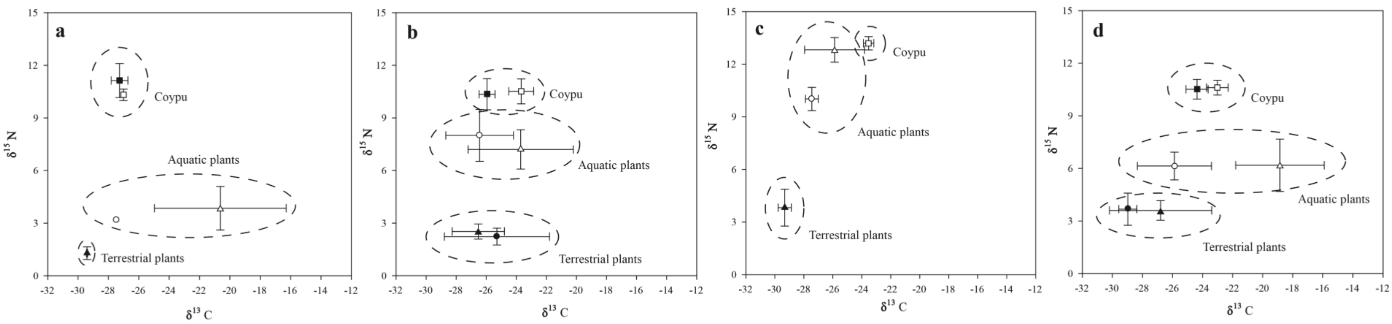


**Figure 5** – Seasonal $\delta^{13}$C and $\delta^{15}$N values (means with 95% error bars) of plants and coypus collected from Eulsuk Island, South Korea during a 12-month period (11 Jan 2013 to 3 Jan 2014). For the plant data, empty symbols represent aquatic plants, filled symbols represent terrestrial plants, triangles represent aboveground plant parts, and circles represent belowground plant parts. For the coypu data, empty quadrangle represents hind-leg muscles, and filled quadrangle represents liver tissues. a) winter 2013; b) spring 2013; c) autumn 2013; and d) winter 2013/2014.

**Table 3** – Plants collected from Eulsuk Island, South Korea and their carbon and Nitrogen isotope levels in different seasons (n = sample size).

| | | | n | Winter | | n | Spring | | n | Autumn | | | Winter | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $\delta^{13}$C | $\delta^{15}$N | | $\delta^{13}$C | $\delta^{15}$N | | $\delta^{13}$C | $\delta^{15}$N | | $\delta^{13}$C | $\delta^{15}$N |
| **Aquatic plants** | **Emergent** | **Poaceae** | | | | | | | | | | | | |
| | | *Paspalum distichum* | 2 | -13.13±0.29 | 5.00±0.15 | 2 | -15.16±0.33 | 6.44±0.39 | - | - | - | 2 | -15.16±0.79 | 6.33±2.71 |
| | | *Phragmites communis* | 2 | -28.71±0.62 | 6.46±0.24 | 2 | -27.71±1.02 | 5.54±0.86 | 5 | -27.48±0.63 | 10.79±1.04 | 3 | -26.51±0.18 | 4.10±0.28 |
| | | *Phragmites communis* | 2 | -28.71±0.62 | 6.46±0.24 | 2 | -27.71±1.02 | 5.54±0.86 | 5 | -27.48±0.63 | 10.79±1.04 | 3 | -26.51±0.18 | 4.10±0.28 |
| | | *Pseudoraphis ukishiba* | - | - | - | 2 | -29.24±1.29 | 6.60±0.43 | - | - | - | 1 | -29.14 | 5.8 |
| | | **Cyperaceae** | | | | | | | | | | | | |
| | | *Scirpus tabernaemontani* | 1 | -28.32 | 0.13 | 5 | -29.35±0.80 | 9.18±4.27 | 1 | -28.42 | 8.82 | 2 | -29.59±1.80 | 6.63±1.28 |
| | **Floating** | **Salviniaceae** | | | | | | | | | | | | |
| | | *Salvinia natans* | - | - | - | - | - | - | 1 | -29.91 | 14.2 | - | - | - |
| | **Submerged** | **Haloragaceae** | | | | | | | | | | | | |
| | | *Myriophyllum spicatum* | - | - | - | - | - | - | 2 | -21.73±3.59 | 13.61±0.70 | 2 | -18.02±0.34 | 8.76±0.27 |
| **Terrestrial plants** | | **Poaceae** | | | | | | | | | | | | |
| | | *Setaria viridis* | - | - | - | 3 | -12.56±0.07 | 1.57±0.59 | - | - | - | 1 | -12.42 | 3.55 |
| | | **Chenopodiaceae** | | | | | | | | | | | | |
| | | *Chenopodium album* | - | - | - | - | - | - | 1 | -28.87 | 4.86 | - | - | - |
| | | **Asteraceae** | | | | | | | | | | | | |
| | | *Artemisia princeps* | 1 | -30.56 | 1.37 | 2 | -29.93±0.83 | 3.71±1.27 | - | - | - | 4 | -29.47±0.61 | 3.82±0.85 |
| | | *Conyza bonariensis* | - | - | - | 2 | -28.79±1.39 | 1.89±0.14 | - | - | - | 1 | -28.5 | 0.43 |
| | | *Bidens frondosa* | 2 | -29.01 | 0.83±0.10 | 3 | -28.90±0.16 | 1.85±0.80 | 1 | -29.76 | 2.77 | - | - | - |
| | | *Taraxacum platycarpum* | - | - | - | - | - | - | - | - | - | 2 | -28.19±0.64 | 3.98±0.38 |
| | | **Onagraceae** | | | | | | | | | | | | |
| | | *Oenothera biennis* | - | - | - | 2 | -29.39±0.81 | 1.30±0.68 | - | - | - | - | - | - |
| | | **Amaranthaceae** | | | | | | | | | | | | |
| | | *Spinacia oleracea* | - | - | - | 2 | -31.00±0.47 | 4.49±0.98 | - | - | - | 3 | -30.87±0.53 | 3.95±1.40 |
| | | **Cannabaceae** | | | | | | | | | | | | |
| | | *Humulus japonicus* | 1 | -29.05 | 2.17 | 1 | -28.97 | 4.61 | - | - | - | - | - | - |
| | | **Lamiaceae** | | | | | | | | | | | | |
| | | *Salvia plebeia* | - | - | - | 3 | -26.60±2.64 | 2.08±0.75 | - | - | - | - | - | - |
| | | **Unknown species** | 4 | -30.06±0.96 | -0.76±3.0 | | | | | | | | | |

clear that the diet of coypus was largely derived from the aquatic system, as has been reported previously (Borgnia et al., 2000; Guichón et al., 2003; Corriale et al., 2006; Battisti et al., 2015).

The low temperatures of winter influence thermoregulation, so that more energy is required for maintenance and activity (Moinard et al., 1992), and both food availability and coypu feeding activity are reduced during winter months (Gosling, 1979). Therefore, coypus appear to survive winter by sacrificing body mass and use various strategies to maintain their body temperature, including the avoidance of heat loss, controlling the rate at which food passes through the pyloric sphincter (Gosling, 1979), burrowing in dens, and huddling in groups (Gosling et al., 1980; Moinard et al., 1992). Furthermore, although not observed in the present study, coypus may also invade crops and farm buildings (Panzacchi et al., 2007; Battisti et al., 2015). Thus, the winter food shortage can be exploited, by baiting for coypu during that period. The coypu population in the lower Nakdong River has previously been affected by cold weather (Hong et al., 2014), but the high productivity of the survivors has enabled rapid population recovery (Ehrlich, 1966; Doncaster and Micol, 1989). Therefore, annual control during winter may be the best approach for sustained coypu population reduction (Hong et al., 2014).

## References


Abbas A., 1991. Feeding strategy of coypu (*Myocastor coypus*) in central Western France. J. Zool. 224(3): 385–401.

Aliev F., 1973. Cases of mass mortality of nutria in the wetlands of Azerbaidzhan in winter 1971–1972. Mammalia 36: 539–540.

Anderson R.O., Neumann R.M., 1983. Length, weight, and associated structural indices. In: Nielsen L.A., Johnson D.L. (Eds.) Fisheries techniques. American Fisheries Society. Bethesda, Maryland, USA. pp. 447–482.

Angelici C., Marini F., Battisti C., Bertolino S., Capizzi D., Monaco A., 2012. Cumulative impact of rats and coypu on nesting waterbirds: first evidences from a small Mediterranean wetland (central Italy). Vie et Milieu 62(3): 137–141.

Baroch J., Hafner M., 2002. Biology and natural history of the nutria, with special reference to nutria in Louisiana. In: Baroch J., Hafner M., Brown T.L., Mach J.J., Poché R.M. (Eds.) Nutria (*Myocastor coypus*) in Louisiana. Louisiana Department of Wildlife and Fisheries pp. 3–22.

Battisti C., Marini F., Vignoli L., 2015. A five-year cycle of coypu abundance in a remnant wetland: a case of sink population collapse? Hystrix 26(1): 37–40. doi:10.4404/hystrix-26.1-10981

Ben-David M., Flaherty E.A., 2012. Stable isotopes in mammalian research: a beginner's guide. J. Mammal. 93(2): 312–328.

Borgnia M., Galante M.L., Cassini M.H., 2000. Diet of the coypu (Nutria, *Myocastor coypus*) in agro-systems of Argentinean Pampas. J. Wildl. Manage. 64: 354–361.

Brown L.N., 1975. Ecological relationships and breeding biology of the nutria (*Myocastor coypus*) in the Tampa, Florida, area. J. Mammal. 56: 928–930.

Carter J., Foote A.L., Johnson-Randall A., 1999. Modelling the effects of nutria (*Myocastor coypus*) on wetland loss. Wetlands 19(1): 209–219.

Carter J., Leonard B.P., 2002. A review of the literature on the worldwide distribution, spread of, and efforts to eradicate the coypu (*Myocastor coypus*). Wildl. Soc. Bull. 30: 162–175.

Choi J.Y., Kim S.K., Chang K.H., Kim M.C., La G.H., Joo G.J., Jeong K.S., 2014. Population growth of the cladoceran, *Daphnia magna*: a quantitative analysis of the effects of different algal food. PLOS One 9(4): e95591.

Corriale M.J., Arias S.M., Bó R.F., Porini G., 2006. Habitat-use patterns of the coypu (*Myocastor coypus*) in an urban wetland of its original distribution. Acta Theriol. 51(3): 295–302.

DeNiro M.J., Epstein S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochim. Cosmochim. Acta 45(3): 341–351.

Dixon K.R., Willner G.R., Chapman J.A., Lane W.C., Pursley D., 1979. Effects of trapping and weather on body weights of feral nutria in Maryland. J. Appl. Ecol. 16: 69–76.

Doncaster C.P., Micol T., 1989. Annual cycle of a coypu (*Myocastor coypus*) population: male and female strategies. J. Zool. 217(2): 227–240.

Doncaster C.P., Micol T., 1990. Response by coypus to catastrophic events of cold and flooding. Ecography 13(2): 98–104.

Ehrlich S., 1966. Ecological aspects of reproduction in nutria (*Myocastor coypus* Mol.). Mammalia 30(1): 142–152.

Fry B., 2006. Stable isotope ecology. Springer. New York.

Gosling L.M., 1979. The twenty-four hour activity cycle of captive coypus (*Myocastor coypus*). J. Zool. 187(3): 341–367.

Gosling L.M., 1980. The duration of lactation in feral coypus (*Myocastor coypus*). J. Zool. 191(4): 461–474.

Gosling L.M., Guyon G., Wright K., 1980. Diurnal activity of feral coypus (*Myocastor coypus*) during the cold winter of 1978-9. J. Zool. 192(2): 143–146.

Gosling L.M., 1981a. Climatic determinants of spring littering by feral coypus, *Myocastor coypus*. J. Zool. 195(3): 281–288.

Gosling L.M. 1981b. The effect of cold weather on success in trapping feral coypus (*Myocastor coypus*). J. Appl. Ecol. 18(2): 467–470.

Guichón M., Benitez V., Abba A., Borgnia M., Cassini M., 2003. Foraging behaviour of coypus *Myocastor coypus*: why do coypus consume aquatic plants? Acta Oecol. 24(5): 241–246.

Hong S., Do Y., Kim J.Y., Kim D.K., Joo. G.J., 2014. Distribution, spread and habitat preferences of nutria (*Myocastor coypus*) invading the lower Nakdong River, South Korea. Biol. Invasions. 17(5): 1485–1496.

Johnson R.A., Wichern D.W., 1988. Applied multivariate statistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey.

Kielland K., 2001. Stable isotope signatures of moose in relation to seasonal forage composition: a hypothesis. Alces 37(2): 329–337.

Lee C.W., Jang J.D., Jeong K.S., Kim D.K., Joo G.J., 2010. Patterning habitat preference of avifaunal assemblage on the Nakdong River estuary (South Korea) using self-organizing map. Ecol. Inform. 5(2): 89–96.

Lee J.O., Song Y.J., Kim Y.S. Park H.J., 2011. Analysis of Quantitative Topographical Change in Eulsuk-Island Using Aerial Images. Korean J. Geomat. 29(5): 527–534.

Lee T.B., 2006. Coloured flora of Korea. Hyang Mun Sa. Seoul. Korea. [In Korean]

Lowe S., Browne M., Boudjelas S., De Poorter M., 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Invasive Species Specialist Group Species Survival Commission. World Conservation Union (IUCN). Auckland. New Zealand.

Major H.L., Jones I.L., Charette M.R., Diamond A.W., 2007. Variations in the diet of introduced Norway rats (*Rattus norvegicus*) inferred using stable isotope analysis. J. Zool. 271(4): 463–468.

Marini F., Gabrielli E., Montaudo L., Vecchi M., Santoro R., Battisti C., Carpaneto G.M., 2013. Diet of coypu (*Myocastor coypus*) in a Mediterranean coastal wetland: a possible impact on threatened rushbeds? Vie et Milieu 63(2): 97–103.

Moinard C., Doncaster C.P., Barré H., 1992. Indirect calorimetry measurements of behavioral thermoregulation in a semiaquatic social redent, Myocastor coypus. Can. J. Zool. 70(5): 907–911.

Owen-Smith N., 1994. Foraging responses of kudus to seasonal changes in food resources: elasticity in constraints. Ecology 75(4): 1050–1062.

Panzacchi M., Bertolino S., Cocchi R., Genovesi P., 2007. Population control of coypu *Myocastor coypus* in Italy compared to eradication in UK: a cost-benefit analysis. Wild. Biol. 13(2): 159–171.

Prigioni C., Balestrieri A., Remonti L., 2005. Food habits of the coypu, *Myocastor coypus*, and its impact on aquatic vegetation in a freshwater habitat of NW Italy. Folia Zool. 54(3): 269.

Severud W.J., Belant J.L., Windels S.K., Bruggink J.G., 2013. Seasonal variation in assimilated diets of American beavers. Am. Midl. Nat. 169(1): 30–42.

Urton E.J., Hobson K.A., 2005. Intrapopulation variation in gray wolf isotope ($\delta^{15}$N and $\delta^{13}$C) profiles: implications of the ecology of individuals. Oecologia 145(2): 316–325.

Williams J.R., Dellapenna T.M. Lee G.H., 2013. Shifts in depositional environments as a natural response to anthropogenic alterations: Nakdong Estuary, South Korea. Mar. Geol. 343: 47–61.

Wilsey B.J., Chabreck R.H., Linscombe R.G., 1991. Variation in nutria diets in selected freshwater forested wetlands of Louisiana. Wetlands. 11(2): 263–278.

Zar J.H. 1999. Biostatistical analysis. Pearson Education. India.


*Associate Editor:* G. Amori