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Measuring rodent incisors from scats can increase accuracy of predator diet studies. An illustration based on island cats and rats

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Abstract

Non-invasive diet studies, which are a simple but important tool to understand trophic interactions inside ecosystems, need to be as detailed as possible. Determining the precise biomass of ingested prey is a key to obtaining not only a better understanding of the amount of food really ingested but also the predator-prey interactions. It is particularly relevant in the case of rodents, because they are often a predominant prey in carnivores' diet and can differ widely in biomass. This study demonstrates how an original and simple method for measuring rat incisors found in cat scats produces measurements which can be correlated with rat weight. This correlation, used in a field application, made it possible to: (*i*) calculate a more accurate biomass of rats in cat diets and thus obtain a better estimation of the proportion of rats compared to other prey in cat diets; (*ii*) show that cats preferentially ate smaller rats, indicating that the use of the mean weight of rodents sampled by trap-lines may induce a significant bias in the biomass calculation. Likewise, a correlation between rat lens weight and incisor measurements was found. Using this correlation, it should be possible to estimate the age of the rats eaten by cats and obtain a better understanding of the impact of predators on prey population dynamics.
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Keywords: Feral cat; Rattus rattus; Rodents; Lens weight; Teeth measurements; Diet studies; Biomass

1. Introduction

Diet studies play a key role in investigating essential aspects of ecological system functioning, such as ecological requirements like trophic niche or food preferences, and species behaviour. They are particularly valuable in revealing predator-prey interactions [1,2]. Despite the recent development of stable isotopic studies [3,4], most predator diet studies are still conducted through easy and cheap non-invasive methods, based on the identification of non-assimilated remains like hairs, bones, teeth and feathers found in scats or pellets [5,6]. These methods allow to these be identified, counted and the proportion of each species or group of species in the predator diet to be calculated, but their efficiency in revealing predator trophic ecology or predator-prey relationships largely depends on the manner and the

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precision with which their results are expressed [7,8]. Indeed, when diet studies expressed their results not only in frequency of occurrence or frequency of prey but expressed diet in ingested biomass, they lead to a better understanding of predator trophic behavior and ecology [9]. Most results expressed in biomass ingested use the mean weight of species (as given by literature or by field studies) as a surrogate for the precise weight of the individual eaten [10]. Obviously, this method is too rough to be accurately applied to prey with a large range of body mass in the field, and whose individual weight can differ greatly from the mean weight of the species. This is particularly true for rodents, especially rats, whose weight can dramatically change from young pups just leaving the nest to old mature males [11]. Moreover, because they are generally abundant, easy to catch and naturally or artificially distributed in most ecosystems, rodents are present in the diet of many small carnivores worldwide and often constitute the main food category eaten by these predators [6,12]. Consequently, when studying these carnivores' diet via the identification of remains found in scats, obtaining the biomass that has been ingested, especially biomass due to consumption of rodents, can be problematic.

Here we aimed at testing whether the measurement of certain rodent remains found in carnivore scats can be used to reconstruct the biomass of the individuals preyed upon. We chose a simple ecological system: a small Mediterranean island, where a predator (feral cat *Felis silvestris catus*) preys mainly upon an invasive and abundant rodent (ship rat *Rattus rattus*) [13]. Teeth, especially incisors, are the rat remains most frequently found in cat scats and the least damaged by carnivore ingestion and digestion [14]. In rodents, teeth are also known to grow continuously throughout the life of the individuals [15]. Therefore, we hypothesized that the measurement of rat incisors found in cat scats could be used to reconstruct the weight of rats ingested. We thus used a set of free-living rats trapped in the field and sacrificed for the purpose of this study to test for a possible correlation between some incisor morphometric measurements and body weight. Thereafter, we applied this correlation on all rat incisors found during a feral cat diet study that we conducted to the same island. This allowed us to evaluate the advantages offered by this new method over the standard practice of using simple rat weight measured in the field for: (*i*) calculating the rodent biomass ingested by the carnivore; and (*ii*) determining which weight classes of rat were most frequently eaten. Finally, since eye lens weight is commonly considered a crude estimator of mammal age, continuing to grow after birth [16,17], we searched for a potential correlation with incisor size to test whether rodent teeth found in scats could be used to determine the age of rats preyed upon by cats.

2. Materials and methods

2.1. Study site

Our study was conducted on Port-Cros Island (6.40 km^2), protected by National Park status since 1963 and located in the north-western Mediterranean Sea (43°00′N, 6°21′E). This hilly island has a maximum elevation of 196 m above sea level and is 15 km from the mainland. Climate is sub-humid, temperate Mediterranean with an average annual rainfall of 582.4 mm and an average annual temperature of 16.5 °C (Levant Island Meteorological Office, 1997–2007). The siliceous island is 80% covered by mixed forests of the sclerophyllous oaks *Quercus ilex* and *Quercus suber* and the Aleppo pine *Pinus halepensis*. Port-Cros Island is home to introduced vertebrates, especially cats and rats, and a Mediterranean endemic seabird of particular conservation interest, the Yelkouan shearwater (*Puffinus yelkouan*).

2.2. Relationship between incisor size and rat weight applied to a field study on cat diet

To test the relationship between the measurement of rat incisors and rat weight, we needed rats of known weight. 47 free-living ship rats were trapped at Port-Cros island during 4 consecutive nights on 4 lines of 30 "INRA" traps (BTT mécanique, France) placed at 10 m intervals [18]. All trapped individuals were killed, sexed, weighed, frozen and returned to the laboratory for incisor extraction. Each rat's incisors (2 upper and 2 lower incisors) were removed, washed and measured with a stereo microscope containing a micrometer slide with a measurement accuracy of 0.01 mm. We measured the antero-posterior diameter (AP) of upper and lower incisors at the tooth curve tangent (Fig. 1), the part of the tooth least likely to vary in diameter, avoiding incisor extremities which can be thinner or broken. We obtained five variables: AP_{ur} (AP for upper incisor right), AP_{ul} (AP for upper incisor left), AP_{lr} (AP for lower incisor right), AP_{ll} (AP for lower incisor left), and Rat Weight (R_{weight}). All the variables were tested and did not have a standard distribution. Spearman rank tests were therefore performed to test for a possible correlation between Rat Weight and incisor measurements [19].

These correlations between rat weight and incisor measurements were then applied to rat incisors found

Table 1
The correlation tables between rat weight and lens weight in relation to incisor measurements

	All rats				Females				Males			
	Rat weight		Lens weight		Rat weight		Lens weight		Rat weight		Lens weight	
	R	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*
AP_{ur}	0.7768	***	0.7715	***	0.7796	***	0.8606	***	0.7347	***	0.7274	***
AP_{ul}	0.7637	***	0.7635	***	0.7536	***	0.8238	***	0.7433	***	0.7184	***
AP_{lr}	0.8172	***	0.7317	***	0.7513	***	0.7454	***	0.7135	***	0.6587	***
AP_{ll}	0.8155	***	0.7279	***	0.7504	***	0.7357	***	0.6953	***	0.6723	***

AP_{ur}: Antero-Posterior diameter for upper right incisor, AP_{ul}: Antero-Posterior diameter for upper left incisor, AP_{lr}: Antero-Posterior diameter for lower right incisor, AP_{ll}: Antero-Posterior diameter for lower left incisor, *R*: Spearman correlation coefficient, *p*: statistical significance, *** $p < 0.001$.

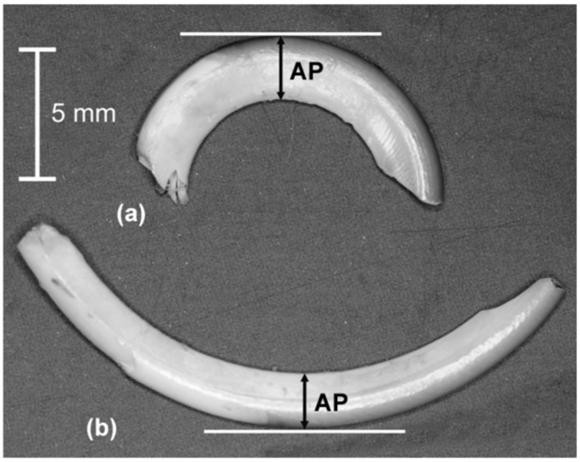

Fig. 1. Photos of a (a) upper, (b) lower rat incisor and measurements of the antero-posterior diameter (AP) of upper and lower incisor at the tooth curve tangent.

during a recent feral cat diet study based on scat analysis [13]. Feral cat scats were collected on paths on Port-Cros Island every two months and analyzed in the laboratory by washing over a 0.5-mm sieve under a stream of hot water and separating all items [13], particularly incisors, to perform measurements. During the same year as the cat diet study, rats were trapped on the study site and weighed. A Mann–Whitney test was performed to test differences between mean weight of trapped rats and eaten rats. A Chi square-test was performed to test homogeneity between the six weight classes determined (1–50 g, 51–100 g, 101–150 g, 150–200 g, 201–250 g, 251–300 g) for trapped rats and eaten rats [19]. The two first and the two last weight classes were pooled, due to the small sample size.

2.3. *Relationship between incisor size and rat lens weight*

Eyeballs were removed from the sample set of 47 killed rats used to determine the relationship between incisor size and rat weight. Both eyeballs of each rat were removed just after rat death and placed, in pairs, in a 10 percent buffered formalin solution [20,21]. After fixing in formalin for 2 months (previously determined in a sample test as the most suitable tinning time) lenses were removed, dried in an oven at 80 °C and regularly weighed to the nearest 0.01 mg [20], until weight variation ceased (after 28 hours, as determined previously by a sample test). Each lens of the pair was weighed. If each lens in a pair weighed nearly the same, the joint weight of the pair was used [17,21]. If the weights of the two lenses differed, the higher weight was used and doubled to obtain the weight of the pair (the lower weight being generally due to damage during extraction of the lens). The same Spearman rank tests as above were performed to test for possible correlation between Lens Weights (L_{weight}) and incisor measurements (AP_{ur}, AP_{ul}, AP_{lr}, AP_{ll}) [19].

3. Results

3.1. *Relationship between incisor size and rat weight applied to a field study on cat diet*

47 wild ship rats were trapped in the field: 28 females and 19 males, with weights ranging from 19 to 270 g. The correlations between rat weight and incisor measurements were all statistically significant ($p < 0.001$) whatever the type and the position of incisor we considered (Table 1). We obtained the same level of statistical significance when correlations were tested separately for males and females (Table 1). The results of this significant correlation between rat weight and incisor measurements were used to determine the weight of rats eaten by cats, based on the measurements of rat incisors found in cat scat.

The equation used was:

$$R_{weight} = a\mathrm{AP} + b,$$

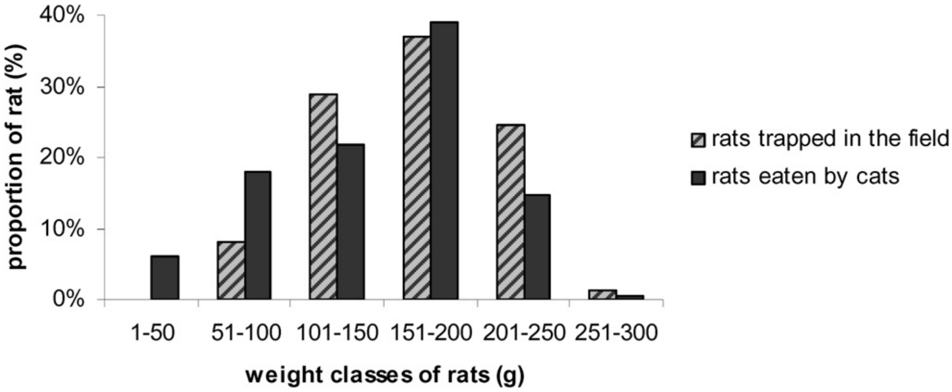

Fig. 2. The proportions, by weight class, of rats trapped and rats preyed upon by cats during one complete year.

Table 2
Mean rat weight determined from the unaltered rat incisors found in cat scats during one complete year

Sampling session	Scat number	Rat number	Number of rats available for measurement	Mean rat weight (g)
Jul–Sep	72	76	49	153.1 ± 44.1
Sep–Dec	39	41	23	177.3 ± 51.6
Dec–Feb	80	70	29	153.1 ± 50.2
Feb–Apr	49	39	22	147.0 ± 68.2
Apr–Jun	61	53	28	137.9 ± 52.8
Jun–Aug	85	87	60	129.3 ± 57.6
complete year	386	366	211	149.6 ± 16.4

with: $a = 192$, $b = -311$ for AP_{ur}; $a = 191$, $b = -308$ for AP_{ul}; $a = 193$, $b = -238$ for AP_{lr}; $a = 194$, $b = -240$ for AP_{ll} 386 cat scats were collected during one year of study (Table 2). They contained remains from 366 different rats, 211 with incisors well-enough preserved to be measured. This enabled us to estimate the weight of eaten rats by using the equations linked to these correlations. The weight of rats eaten by cats ranged from 20 to 284 g, their annual mean weight being 146.31 ± 3.79 g (SD) and seasonal variations appearing in the biomass (Table 2). During the same year, the mean weight of the trapped rats was 171.5 ± 5.43 g (SD). Thus, the mean weight of rats trapped in the field was significantly higher from that of rats eaten by cats ($U = 5902.5$, $p = 0.003$), and the weight classes of trapped rats were significantly different than those of eaten rats ($\chi^2 = 11.6$, ddl = 3, $p = 0.01$). We observed a higher proportion of small rats (< 100 g) in the feral cat diet compared with rats trapped in the field (Fig. 2). Conversely, there appeared to be a smaller proportion of large rats (> 200 g) preyed on by feral cats than in the sample trapped in the field.

3.2. Relationship between incisor size and rat lens weight

The correlations between lens weight (L_{weight}) and incisor measurements (AP_{ur}, AP_{ul}, AP_{lr}, AP_{ll}) were all statistically significant ($p < 0.001$) whatever the type and the position of incisor (Table 1). We obtained the same level of statistical significance, no matter whether correlations were tested separately for males and for females or both together (Table 1).

4. Discussion

4.1. Relationship between incisor size and rat weight applied to a field study on cat diet

This study demonstrates a strong correlation between rat weight and measurements of the antero-posterior diameter of upper and lower rat incisors. This simple measurement of rat incisors, one of the most frequently found and best-preserved rodent items in cat scats, can thus be used as an easy surrogate to obtain an accurate evaluation of biomass of each rat eaten by cats. Moreover, there can be no bias, since rodents are entirely ingested [22]. This approach offers a key to solving the problem posed by the wide range of biomass of rats [13], one of the most frequent preys for feral cats, especially on islands [23,24]. Obtaining the precise biomass for this primary and introduced prey opens the way to more precise calculation of the proportion represented by this prey in the overall biomass intake by the predator.

From the incisors found in cat scats, we can identify the predation patterns of feral cats as a large range of rats of different weights, from the smallest, just out of their shelters, to the largest adults. The fact that cat scats revealed a higher proportion of the smallest rats than was found among those trapped in the field may indicate that the predation pattern is linked more to "catchability" (the smallest, i.e. the youngest, being more naïve and easier to catch) than to availability [25]. However, a review of 66 published feral cat diet studies [26] indicates that only 10 express the feral cat diet in biomass of preys, and even then without taking into consideration the precise weight of preyed rats. Moreover, using the mean weight of rodents sampled by trap-lines for the biomass calculation is not only too rough, but may also induce a significant bias, since cats appear preferentially to eat smaller rats. Consequently, an accurate evaluation of prey biomass is essential and our study should contribute to this by providing a simple and easy-to-use tool for future diet studies.

4.2. Relationship between incisor size and rat lens weight

The strong correlation found between rat incisor measurements and rat lens weights, a crude estimator of mammal age, showed that the age of each rat could potentially be derived from simply measuring of rat incisors. Although the correlation between age and eye lens weight has been demonstrated for the *Rattus* genus [20], no abacus of lens weight in relation to rat age is, unfortunately, yet available for ship rats. To determine the age of rats eaten by feral cats, ship rats should be bred from rats originating from the study site. With this protocol, the pattern of predation by cats on each age-class of rats (juveniles, sub-adults, adults) can be determined easily, enabling the impact of cats on the population dynamics of this introduced mesopredator to be better calculated. In particular, some surprise effects, like mesopredator release after cat eradication, could be evaluated with more accuracy [27,28]. This should improve understanding of the complex longstanding interactions between the dynamics of alien and native species [29,30].

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