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The 'Near Threatened' Bearded Screech-owl *Megascops barbarus*: diet pattern and trophic assessment using $\delta^{13}C$ and $\delta^{15}N$ stable-isotopes

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Summary

The diet patterns and trophic relationships are poorly understood for most tropical owl species. We used stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in 24 feather samples of the rare, endemic, and 'Near Threatened' Bearded Screech-owl *Megascops barbarus* to determine the trophic level of their prey and evaluate whether diet patterns vary (1) among individuals, (2) spatially along the species's range in the highlands of Chiapas, Mexico, and (3) temporally during the short- and long-term. Our results indicated that there was diet variation among individuals during the period of feather growth and there was a high positive correlation between stable isotopes in body and rectrices. The stable isotopes showed significant temporal differences in $\delta^{15}N$ signature values, but not in $\delta^{13}C$ values, with no obviously interpretable temporal pattern. Spatially, values of $\delta^{13}C$ and $\delta^{15}N$ did not vary across all nine sampled locations. The observed lower $\delta^{13}C$ values suggested that this owl lives in humid forests. More long-term studies and spatial dietary and prey analysis will be necessary to increase our understanding of how habitat conditions determine the distribution, abundance and quality of food for the Bearded Screech-owl.

Introduction

The Bearded Screech-owl *Megascops barbarus* is rare, strictly nocturnal, and endemic to the montane forests (cloud and pine-oak forest) of 1,800–2,500 m in the central highlands of Chiapas and Guatemala (del Hoyo *et al.* 1999, König and Weick 2008). Limited information about its natural history has been reported. Based on its restricted distribution and the lack of ecological information available, this species has been listed recently as 'in Peril' on the Mexican Red List (SEMARNAT 2008) and 'Near Threatened' globally (BirdLife International 2008). Montane forests in Chiapas have been reduced to less than 25% of their original area with an annual deforestation rate ≥2.7% in the last 30 yrs (Cayuela *et al.* 2006).

Diet plays a significant role in the health and viability of organisms while their trophic relationships define their ecological functions (Kupfer *et al.* 2006). Since the abundance of food types varies greatly in space and time (Recher 1990), a large number of animal species show a wide intra-specific and temporal variation in diet patterns (Dalerum and Angerbjörn 2005).

For most tropical owl species, the diet patterns and trophic relationships are poorly known (König and Weick 2008). Traditionally, diet composition for owls has been determined mostly by observations of foraging and identification of prey remains at nests, in regurgitated pellets, in faeces, and in stomachs (Rosenberg and Cooper 1990, Livezey 2007). However, identification of prey items by direct observation is difficult for nocturnal species. Analysis of stomach contents requires invasive surgery or killing of the individuals, which is not a suitable approach for rare and threatened species. Some insectivorous owls rarely produce pellets, making studying their diets difficult (see Lee and Severinghaus 2004). Fecal analysis is limited to the number of individuals that one can capture. Therefore, stable isotopes analysis could be a better tool for studying diet patterns and trophic relationships in owl species (Hobson and Sealy 1991, Hobson and Clark 1992). Stable isotope analysis will not reflect the bulk diet composition available by other methods but will allow quantification of the diet origin of assimilated nutrients in animal tissues (Kelly 2000). It is a useful tool to evaluate spatial-temporal variation in diets and to establish trophic position in birds and mammals (Hobson and Montevecchi 1991, Urton and Hobson 2005). Here, we used analysis of stable isotopes to answer whether diet patterns of the Bearded Screech-owl vary temporally in the short- and long-term, and spatially along the range in the Central highlands of Chiapas. Since remaining montane forest habitats for the owls are simplified in structure and their vegetation composition is associated with a drier and warmer forest interior (Ramírez-Marcial *et al.* 2001), we predicted that if there is variation in diet over the period when the feathers were growing there would be intra-feather and inter-feather variations in stable isotopes (Mizutani *et al.* 1990). Furthermore, if the distribution and abundance of food types varied among locations and habitat conversion has reduced the diet quality of Bearded Screech-owl, we would expect to find spatial and temporal differences in isotopic signatures of $\delta^{13}C$ and $\delta^{15}N$.

Methods

Study area

This study was conducted in the central highlands of Chiapas, Southern Mexico (17°11′N; 92°53′W), which are located from 1,500 to 2,000 m in altitude, and only < 4% is at elevations above 2,500 m. The climate is temperate sub-humid with a mean annual temperature of 13°–15°C. Mean annual precipitation is 1,150 mm (>80% occurs between May and October). The main forest types in the region consist of a wide diversity of pines *Pinus* spp. and oaks *Quercus* spp. and patches of diverse secondary communities associated with pine-oak forests (Rzedowski 1978).

Field and museum reference feathers (sample collection)

Studying stable isotopes in metabolically non-active tissues such as feathers (Duxbury and Holroyd 1997) only reflects the dietary habits during the feather-growth period (Mizutani *et al.* 1990). Nevertheless, it is possible to assess short- and long-term variation in diet patterns by comparing progressive sections of a single feather (Thompson and Furness 1995), among feathers grown at different stages of the moult cycle (Dalerum and Angerbjörn 2005), and by analysing feathers collected in different locations and periods of time within the species range (Kelly 2000).

Owls were captured using a procedure combining broadcasting of pre-recorded calls and mist-netting. Each captured owl was weighed, measured and banded with a numbered aluminium band. Prior to release, body and tail feathers were collected (two each), stored in a paper envelope, and kept at ambient temperature before analysis. The date of capture, location, and sex were recorded. Additionally, we obtained Bearded Screech-owl body feathers from bird collections (Table 1).

Stable isotope measurements

Because C_3 and C_4 plants have distinct carbon-isotope signatures (Hobson and Sealy 1991), the stable-carbon isotope analysis can distinguish C_3 plants, which are associated with humid habitats and have low $\delta^{13}C$ values, from C_4 plants and CAM (Crassulacean Acid Metabolism)

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Table 1. Feathers used from Bearded Screech-owl specimens located in museums and bird collections.

Museum*	Date	Location	Lat/Long	No. (sex)	Collector
KUNHM	3-Mar-55	13.5 Km E to San Cristóbal de las Casas, Huixtán	16°43′12″N; 92°30′30″W	35072 (♀)	R. W. Dickerman
WFVZC	14-Oct-62	Finca Patichuitz, 53 Km NE Margaritas, Ocosingo	16°24′35″N; 91°47′45″W	10253 (♂)	A. Gardner
CZRAV	6-Nov-69	Entrance to Chilil trail, San Cristóbal de las Casas	16°39′54″N; 92°34′00″W	202 (♂)	M. Álvarez del Toro
CZRAV	6-Nov-69	Entrance to Chilil trail, San Cristóbal de las Casas	16°39′54″N; 92°34′00″W	203 (♂)	M. Álvarez del Toro
CZRAV	6-Nov-69	Entrance to Chilil trail, San Cristóbal de las Casas	16°39′54″N; 92°34′00″W	204 (?)	M. Álvarez del Toro
AMNH	12-Sep-72	8 Km to WNW from San Cristóbal, Zinacantán	16°40′05″N; 93°42′32″W	6959 (♀)	J. T. Marshall
CZRAV	15-Nov-77	Close to Teopisca, San Cristóbal de las Casas	16°31′00″N; 92°28′60″W	205 (♂)	Ni**
CZRAV	11-Jul-88	Huitepec Biological Reserve, San Cristóbal	16°44′50″N; 92°41′10″W	5158 (♀)	R. Vidal
CZRAV	Ni*	Huitepec Biological Reserve, San Cristóbal	16°44′50″N; 92°41′10″W	5171 (♂)	R. Vidal
CZRAV	16-Jul-93	San José Bacomteneltè, Zinacantán	16°43′00″N; 92°42′28″W	5513 (♀)	M. A. Altamirano
CZRAV	20-Jan-99	Huitepec Biological Reserve, San Cristóbal	16°45′05″N; 92°41′00″W	6542 (♀)	J. L. Rangel
AMNH	May-1897	Baja Vera Paz, Guatemala	15°06′05″N; 90°19′07″W	71493 (?)	A. Alfaro

*KUNHM (University of Kansas-Natural History Museum), WFVZ (Western Foundation of Vertebrate Zoology), CZRAV (Colección Zoológica Regional Aves-Instituto de Historia Natural y Ecología de Chiapas), and AMNH (American Museum of Natural History). **Ni (No information).

that are associated with drier habitats and exhibit higher $\delta^{13}C$ values (Marra *et al.* 1998, Kelly 2000). There is an enrichment of $\delta^{15}N$ at each trophic level (i.e., more positive nitrogen values will be present at higher levels of the food chain than animals at lower levels; Gannes *et al.* 1997), which is detectable by stable-nitrogen isotope analysis.

We removed oil and dirt from feathers by washing them with liquid soap and then with chloroform-methanol (2:1) solution (Wassenaar and Hobson 2000). After drying at room temperature, we cut the distal end (calamus) and the upper part of each feather into small fragments and packed each part separately (0.7–1.1 mg) in clipping silver capsules for solid samples (5 x 9 mm; Costech, Valencia, CA, USA). Whenever possible, pairs of body feathers and rectrices were analysed to confirm that these feathers contained similar carbon and nitrogen isotope ratios. Stable isotope ratios of carbon and nitrogen were measured by continuous flow isotope ratio mass spectrometry (IRMS; 20–20 mass spectrometer, PDZ Europa, Northwich, UK) after sample combustion to CO^2 and N^2 at 1,000° C in an on-line elemental analyzer (PDZ Europa ANCA-GSL). Gases were separated on a Carbosieve G column (Supelco, Bellefonte, PA, USA) before introducing them to the IRMS. Sample isotope ratios were compared to those of standard gases injected directly into the IRSM before and after the sample peaks, and delta ^{13}C (PDB) and delta ^{15}N (AIR) values were calculated. Final isotope values were adjusted to the mean values of standard samples, which was a mixture of ammonium sulphate and sucrose with delta $^{13}C = -23.83$ and delta $^{15}N = 1.33$ distributed at intervals in each analytical run to the correct values of the working standards. The working standards were periodically calibrated against international isotope standards. The standard model to calculate the whole sample and report the ^{13}C and ^{15}N in parts per mil (‰) in delta (δ) notation was:

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$$\delta X = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000$$

Where X is the ^{13}C or ^{15}N, R_{sample} is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$ and $R_{standard}$ is the Pee Dee Belemnite (PDB) standard for Carbon and AIR standard for nitrogen. The standard deviation of the measurements for C samples was ±0.22‰ and for N ± 0.14‰.

Prior to statistical analysis, data residuals were checked for statistical normality with Shapiro-Wilks (W) test, and for equal variance with Bartlett's test (Gotelli and Ellison 2004). We compared means of the $\delta^{13}C$ and $\delta^{15}N$ signature concentration using ANOVA or χ^2 statistical analysis. We evaluated the variation in isotopic values within feathers, between feathers of the same individual, sex, locations, and years. All statistical analyses were performed using JMP IN-SAS 5.1 (Sall *et al.* 2005). All means are presented (±1 SD) and tests were considered significant at $\alpha = 0.05$.

Results

We obtained feathers from 24 individuals (12 individuals captured in the field and 12 museum specimens) of the Bearded Screech-owl from the highlands of Chiapas and Guatemala. The mean feather isotope signature values for $\delta^{13}C$ was −22.53 ± 1.29 (range −24.74 to −19.77‰), and that for $\delta^{15}N$ was 5.87 ± 0.71 (range 3.96–7.13‰). Figure 1 shows the distribution and correlation between stable-isotope ratios of carbon and nitrogen in body feathers (calamus) of the Bearded Screech-owl. There were no significant differences in $\delta^{13}C$ values ($\chi^2_{18} = 17.75$, $P = 0.47$) and $\delta^{15}N$ values ($\chi^2_{18} = 20.2$, $P = 0.33$) among feather samples.

Intra- and inter-feather variations in stable isotopes

Stable isotope analysis of intra-body feathers (calamus and the upper part of the feathers) showed an enriched trend in assimilation time in $\delta^{13}C$ ($F_{1, 31} = 3.68$, $P = 0.06$) but not in $\delta^{15}N$ ($F_{1, 31} = 0.27$, $P = 0.6$). Neither $\delta^{13}C$ ($F_{1, 16} = 3.88$, $P = 0.07$) nor $\delta^{15}N$ ($F_{1, 16} = 0.35$, $P = 0.56$) showed intra-rectrices variation. There was a high and positive correlation between body feathers and rectrices in $\delta^{13}C$ ($r^2 = 0.77$, $P = 0.004$) and in $\delta^{15}N$ ($r^2 = 0.67$, $P = 0.01$).

Spatial differences in stable isotope measurements

Values of $\delta^{13}C$ and $\delta^{15}N$ did not vary strongly across nine locations where Bearded Screech-owls have been recorded (Figure 2). Teopisca showed the highest values of $\delta^{13}C$ (−20.87) and $\delta^{15}N$ (6.42). Huitepec and El Callejón showed the most depleted values of $\delta^{13}C$; these two locations

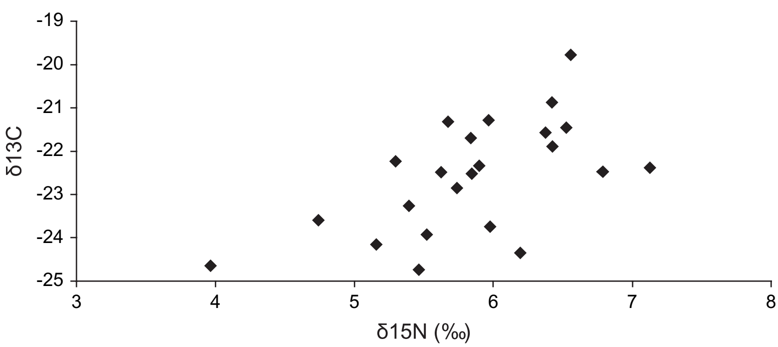

Figure 1. Distribution of the stable-nitrogen (^{15}N) and carbon (^{13}C) isotopes values from body feathers (calamus) of the Bearded Screech-owl. Each point represents an individual owl.

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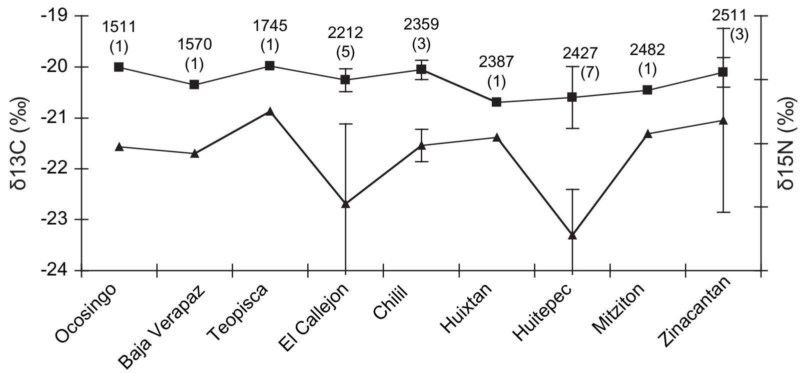

Figure 2. Isotope ratios of $\delta^{15}N$ (squares) and $\delta^{13}C$ (triangles) of body feathers from the Bearded Screech-owl in nine locations in the central highlands of Chiapas and Guatemala. Locations are in elevation gradient (metres above sea level) from minor to major (range 1,000 m), and sample size given in parenthesis. SD values given only for more than one sample.

had the highest occurrence of Bearded Screech-owls (Enríquez 2007) and these locations were highly significant than the other sample locations ($F_{1,20} = 15.68$, $P < 0.001$). No significant difference was observed for $\delta^{15}N$ values ($F_{1,20} = 2.87$, $P = 0.10$) between these same areas. Elevation was not related to $\delta^{15}N$ or $\delta^{13}C$ values ($\delta^{15}N$: $r^2 = 0.38$, $F_{9,12} = 0.83$, $P = 0.60$; $\delta^{13}C$: $r^2 = 0.58$, $F_{9,12} = 1.84$, $P = 0.16$; Figure 2).

Temporal differences in stable isotope values

There was no observable pattern or trend in the stable isotope values through the years analysed ($n = 22$; Figure 3). The stable isotopes in feathers collected over the years showed values

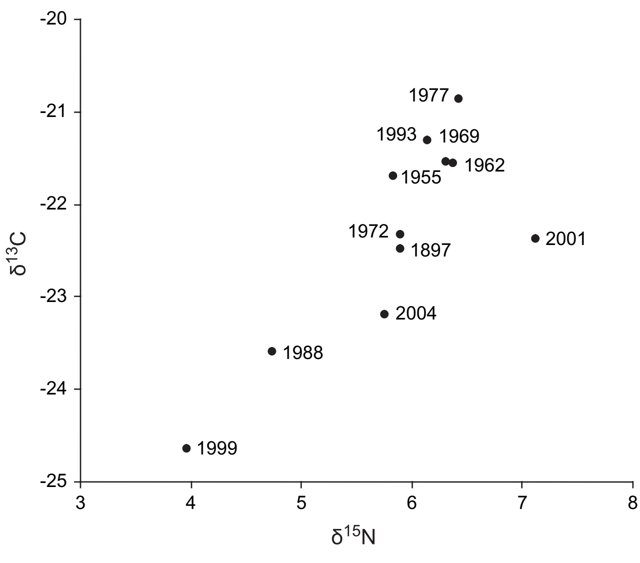

Figure 3. Annual distribution of the isotope ratios of $\delta^{13}C$ and $\delta^{15}N$ of body feathers from Bearded Screech-owl in the Central Highlands of Chiapas and Guatemala.

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remarkably constant for $\delta^{13}C$ ($F_{9,12,} = 1.10$, $P = 0.45$; Figure 4a) with the value for 1897 virtually identical to the recent measurements. However, the $\delta^{15}N$ signature values showed significant temporal differences ($F_{9,\ 12} = 4.52$, $P < 0.01$; Figure 4b).

Discussion

Feather analysis reflected that the Bearded Screech-owl inhabits a terrestrial C_3-dominated ecosystem (Kelly 2000), which matches with their preferred habitat of humid oak forests. The mean nitrogen values for our species are similar to that reported for Northern Hawk Owl *Surnia ulula* (3.77%), Barred Owl *Strix varia* (4.29%), and Great Horned Owl *Bubo virginianus* (8.89%) (Duxbury and Holroyd 1997). The diets of these species include a variety of vertebrates and invertebrates (König and Weick 2008). On the other hand, the Great Horned Owl, considered a generalist (del Hoyo *et al.* 1999), showed the greatest dietary diversity among owl species and also the largest range of isotope values (Duxbury and Holroyd 1997). The variation of isotopic values found in Bearded Screech-owl was not to the degree found in a true generalist as the Great Horned Owl. The Bearded Screech-owl is mainly insectivorous (Enríquez and Cheng 2008) and the range of nitrogen isotopes values found overlapped those reported for forest birds that are mainly insectivorous with fruit supplements (e.g. Bright-rumped Attila *Attila spadiceus*; Herrera *et al.* 2003).

The moulting period for the Bearded Screech-owl is prebasic (Pyle 1997a) and occurs during the rainy season (Enríquez and Cheng 2008). Analysis of intra- and inter-feather variation suggested no significant changes in the types of food ingested during feather growth.

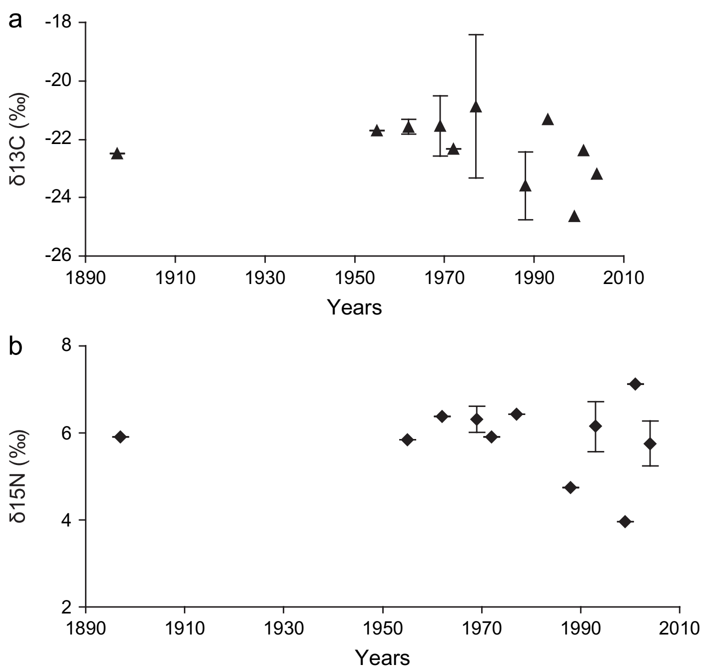

Figure 4. a) Isotope ratios of $\delta^{13}C$ (‰) and b) Isotope ratios of $\delta^{15}N$ (‰) of body feathers from Bearded Screech-owl per year (1955–2004), as well as one sample from 1897 in the Central Highlands of Chiapas and Guatemala. SD values given for years with more than one sample/yr.

Some screech-owl species exhibit both spatial and temporal variations in their diets (e.g., Western Screech-owl *M. kennicottii*; Cannings and Angell 2001). Our study species did not show significant spatial variation; although the most depleted carbon values were from owls from cloud and humid oak forests at the Huitepec Biological Reserve and El Callejón. The region is threatened by habitat fragmentation (Ochoa-Gaona and González-Espinosa 2000) and it is not known how much prime Bearded Screech-owl habitat remains.

The Huitepec Biological Reserve is one of the last remnants of mature forest protected in the highlands of Chiapas. Forest fragmentation and habitat degradation are considered the most severe threat to conservation of raptors in the tropics (Thiollay 1985). In the highlands of Chiapas, it has been estimated an annual deforestation rate ≥2.7% in the last 30 yrs (Cayuela *et al.* 2006). These habitat modifications may affect both distribution and abundance of owls and their prey. More long-term spatial dietary and prey analysis will be necessary to gain a better understanding of how habitat conditions are determining the distribution, abundance and quality of food for the 'Near Threatened' Bearded Screech-owl.

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