Ecological Indicators 63 (2016) 332–336

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short Communication

Stable isotope evidence for Turkey Vulture reliance on food subsidies from the sea

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ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form
11 December 2015
Accepted 13 December 2015

Keywords:
Baja California
Cathartes aura
Isotopic niche
Marine subsidies
Stranded carcasses

ABSTRACT

Turkey Vulture (*Cathartes aura*) reliance on marine subsidies in coastal Baja California peninsula was quantitatively assessed by analyzing carbon and nitrogen stable isotope ratios in its feathers. Feathers were collected in two separate roosts in a small farm, a small fishing village and an uninhabited beach. We compared among them the isotopic niches of the four populations and also with those of Yellow-footed Seagull (*Larus livens*), Brown Pelican (*Pelecanus occidentalis*) and Orange-throated Whiptail lizard (*Aspidoscelis hyperythra*), used as reference for sympatric marine and terrestrial species. The importance of nutrients of marine origin varied among local close subpopulations, suggesting some spatial segregation. Dominant individuals would be established near predictable sources of food (human settlements), having a mixed terrestrial–marine diet influenced by local human activities (isotopic signature of feathers also indicated the role of human-fed cattle as vulture food). Subordinate individuals would be relegated to wandering along the beaches searching for washed up food, having a diet almost exclusively marine.

1. Introduction

Contiguous ecosystems exchange nutrients, energy and organisms, usually referred to as resource subsidies. These subsidies can substantially influence population dynamics, interactions, trophic pathways and other aspects of the recipient food webs (Polis et al., 1997). Often it is assumed that the roles of ecosystem crossing resources vary in function of their productivity, more productive systems being mainly donors and poorer ones being recipients. The Gulf of California with its islands and surrounding lands makes a good example of this resources asymmetry, as very low terrestrial productivity contrasts with the highly productive sea (Maulf, 1983). Probably because of this, the area has been scenario of several pioneering studies showing the effects of marine subsidies on terrestrial consumers at species (e.g. Coyote, *Canis latrans*; Rose and Polis, 1998), guild (e.g. spiders; Polis and Hurd, 1995) and community levels (e.g. algae, arthropods and lizards; Barrett et al., 2005). To the best of our knowledge, the use of marine subsidies by terrestrial bird species has been scarcely assessed anywhere in the world, with some exceptions (e.g. Hobson and Sealy, 1991).

The Turkey Vulture (*Cathartes aura*) is the most widespread of all Neotropical vultures, ranging from south Canada to Tierra del Fuego in Chile and Argentina. Its diet includes dung and refuse, some fruits, small animals actively hunted and mainly carrion, which it can locate through olfaction (Houston, 1994). We suspect marine food is important in the diet of Turkey Vultures living by the coast in subtropical Baja California peninsula, as individuals eating from discarded remains near fishermen's camps or from stranded carcasses at the beach are frequently detected (Fig. S1.B and C). However, this prediction has not been evaluated until now. We will prove that stable isotope ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in Turkey Vulture feathers can indicate the quantitative importance for the species of marine resources at four sites of Baja California (Mexico).

Supplementary Fig. S1 can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.12.015.

The isotopic composition of body tissues reflects the materials used to build them. Classical pioneering studies proved that marine

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http://dx.doi.org/10.1016/j.ecolind.2015.12.015
1470-160X/

resources are enriched in heavier nitrogen and in heavier carbon (when terrestrial C_3 biomass is dominant), which allows using carbon and nitrogen stable isotopes for dietary analyses focusing on the relative importance of terrestrial and marine food sources (Schoeninger and De Niro, 1984). Also, differences in the role of some kinds of terrestrial resources, including human-fed livestock, could be detected, because plants using different photosynthetic metabolic ways (C_3, C_4 and Crassulacean Acid Metabolism, CAM) generate distinct δ^{13}C signatures (Bender, 1971).

As feathers are metabolically inert tissue, their isotopic values indicate what the bird consumed at the time the feather was growing (Inger and Bearhop, 2008). Turkey Vulture feathers grown while its owner was consuming marine food should be enriched in heavier nitrogen and (in C_3 based food-webs) heavier carbon, having rather similar isotopic signatures to feathers of sympatric marine birds. On the other hand, feathers grown when the bird was consuming mainly terrestrial foods should be depleted in heavier nitrogen and (in a lesser degree) carbon, their isotopic signatures resembling those of tissues of sympatric high-level trophic terrestrial consumers.

We expect a mixed terrestrial-marine diet for coastal Turkey Vulture residents in Baja California. To test this prediction we compared the isotopic niche of Turkey Vulture with those of two typically marine birds, the Yellow-footed Seagull (*Larus livens*) and the Brown Pelican (*Pelecanus occidentalis*), and a terrestrial high-level trophic consumer, the arthropodivorous Orange-throated Whiptail (*Aspidoscelis hyperythra*). Additionally, we also predict a reduced intrapopulation variation in the Turkey Vulture isotopic niche, as it is a mobile bird and our sampling sites were nearby.

2. Materials and methods

2.1. Study area

Baja California peninsula is a volcanic fringe of land at the Western side of North America, running from north-west to south-east 1300 km long and, on average, about 100 km wide. Our study area at the Gulf of California coast, characterized by soft hills, dry sandy pebbly riverbeds, and scattered oasis with palm trees, is arid and hot, with uncertain precipitations from August to October, and practically without rain in other months of the year.

The Turkey Vulture is the most abundant raptor species in southern Baja California, especially near villages, in agricultural areas and by the coast. Feathers were collected on October 2011, before the arrival to the area of potential wintering individuals, at three localities (and four sites) on the Gulf coast of southern Baja California. From north to south, these were:

(A) Los Dolores (25°4′34″ N, 110°51′32″ W): A palm oasis, with a traditional cattle farm (about 400 cows and goats), owned by one family. Some feathers (n = 11) were taken under a vulture roost on high palms (*Washingtonia robusta*, *Phoenix dactylifera*) by the beach (site Dolores 1). More feathers (n = 33) were taken under another roost on giant cacti (Cardon, *Pachycereus pringlei*), about 1 km inland, by an open-air abattoir (site Dolores 2) (see Fig. S1.E).

(B) San Evaristo (24°54′25″ N, 110°42′14″ W): A small fishermen's village (about 80 inhabitants), 27 km south of Los Dolores. Feathers (n = 14) were collected under a metal lighthouse where vultures roost at night.

(C) Punta Arenas (24°53′17″ N, 110°41′28″ W): An uninhabited beach with sand dunes, 5 km south of San Evaristo. Feathers (n = 12) were collected around a marine turtle carcass that was being eaten by several Turkey Vultures.

Seagull and pelican feathers (n = 17 and 23, respectively) were also collected on October 2011 at distinct communal roosting places in San Evaristo and Nopoló (24°59′49″ N, 110°45′32″ W). For comparison, we used isotopic data of tail tissue of whiptail lizards (n = 13) live-captured in 2009 at Presa de Ihuazil (24°56′49″ N, 111°24′25″ W; for details, see Delibes et al., 2015). This location is at the same latitude as A, B and C but 52 km inland.

2.2. Sample collection and analyses

We collected equally downy, small and large contour feathers. From large feathers, we cut a transversal fringe of about 1 cm of the tail tip, in order to select a fraction grown in a few days, removing potential within-feather variation (Grecian et al., 2015). Before analysis, feathers were cleaned of surface contaminants using warm water (50 °C) in an ultrasonic cleaner for 5 min and dried at room temperature for 24 h. Isotope measurements were carried out at the Stable Isotope Laboratory of the Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR, Granada, Spain), using a Carlo Elba NC1500 (Milan, Italy) elemental analyzer on line with a Delta Plus XL (ThermoQuest, Bremen, Germany) mass spectrometer (EA-IRMS). Isotopic ratios of carbon and nitrogen are presented as δ values, where $\delta = (R_{sample}/R_{standard} - 1) \times 1000$, being $R = {}^{13}C/{}^{12}C$ for δ^{13}C values, and $R = {}^{15}N/{}^{14}N$ for δ^{15}N values. Commercial CO_2 and N_2 were used as internal standards for C and N isotopic analyses. For C, two internal standards of −30.63‰ and −11.65‰ (Vienna Pee Dee Belemnite; VPDB) were analyzed every 10 samples. For N, two internal standards of −1.02‰ and +16.01‰ (AIR) were used. Precision calculated, after correction of the mass spectrometer daily drift from standards systematically interspersed in analytical batches, was better than ±0.1‰ for both δ^{13}C and δ^{15}N.

Most results are presented through isotopic niche quantitative metrics developed by Layman et al. (2007), adapted to population level by including the δ^{13}C and δ^{15}N values of all samples in each population. We first analyzed all Turkey Vulture together in order to obtain an estimation of the overall isotopic niche of the species in the area and compare it with those of the other species. We then analyzed separately the Turkey Vulture niches at each site. Calculations were made in R using the SIAR package (Jackson et al., 2011). For each species or population we calculated:

(1) Mean and low and upper 95% confidence limits of δ^{13}C and δ^{15}N. In this case, differences among means of species and populations were also analyzed through GLM-Anova tests.

(2) Carbon range (CR) and nitrogen range (NR), corresponding to the distance between the two feathers (for whiptails, the two individuals) with the lowest and the highest δ^{13}C and δ^{15}N values within each population; they estimate the total carbon and nitrogen range exploited by each population and its relative position in the δ^{13}C–δ^{15}N space.

(3) Total area (TA) of the convex hull encompassing all points, as a measure of population niche width. This estimator is very dependent on sample size. Because of this we also calculated:

(4) Bayesian Standard Ellipse Area (SEAb), bootstrapping data (n = 10,000). Standard ellipse (SEA) contains about 40% of the points and estimates the mean core population niche, being to bivariate data as standard deviation is to univariate data (Jackson et al., 2012). SEAb allows comparisons among populations differing in sample size. Mean areas and the low and upper 95% credible limits are shown.

(5) Mean distance to centroid (CD), calculated as the mean Euclidean distance of each sample of a population to the δ^{13}C–δ^{15}N centroid for that population, as an estimator of the population isotopic diversity.