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Modeling trophic positions of the alpine meadow ecosystem combining stable carbon and nitrogen isotope ratios

Xianfeng Yi [a,b,c,*], Yueqin Yang [a], Xiaoai Zhang [b]

[a] *College of Agriculture, Henan University of Science and Technology, Luoyang 471003, PR China*
[b] *Northwest Institute of Plateau Biology, Chinese Academy of Sciences (CAS), 59#, Xiguan Street, Xining 810001, Qinghai, PR China*
[c] *Institute of Zoology, Chinese Academy of Sciences, 25#, Beisihuan Xilu, Beijing 100080, PR China*

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Abstract

Stable carbon and nitrogen isotope ratios of single tissues or whole bodies were analyzed to establish trophic positions of main consumers living at the alpine meadow ecosystem in the Tibetan Plateau. The results demonstrated that δ^{13}C and δ^{15}N values of vertebrates showed great variations and ranged from −26.83 to −22.51‰ and from 2.33 to 8.44‰, respectively. Plateau pika, root vole, plateau hare, infants of rodents and hatchlings of passerine bird species had the lowest δ^{13}C and δ^{15}N values. δ^{13}C and δ^{15}N values of omnivorous and insectivorous birds and amphibians showed intermediate. Carnivorous species, steppe polecat and Upland buzzard, and omnivorous Robin accentor and White wagtail possessed extremely higher δ^{13}C and δ^{15}N values. Omnivorous birds captured in earlier year had significantly less negative δ^{13}C and greater δ^{15}N values than those captured later. Based on steady angular enrichment between trophic levels, an "alpha and vector model" combing δ^{13}C and δ^{15}N values was introduced to reveal trophic positions, the results indicated that Tibetan sheep, Tibetan yak, plateau pika, root vole, plateau hare, infants of small rodents showed the lowest trophic positions (TP 1.81–2.38). While omnivorous and insectivorous birds, their hatchlings and amphibians showed intermediate trophic positions (TP 2.06–2.89), carnivorous species steppe polecat and Upland buzzard, migrant birds possessed extremely higher trophic positions (TP 2.89–3.05). The isotopic investigation of organisms and the introduced "alpha and vector model" successfully demonstrated the same trophic positions and diet prediction of consumers as nitrogen enrichment model at the alpine meadow ecosystem. Besides of this information, the "alpha and vector model" can also be incorporated into multiple isotope signatures to infer trophic relationships. This angular enrichment model has the potential to address basic ecological questions, such as trophic structure, trophic dynamics, and energy flow in other terrestrial ecosystems if properly handled.

Keywords: Stable carbon and nitrogen isotopes; Alpha and vector model; Trophic relationships; Alpine meadow ecosystem; Tibetan Plateau

* Corresponding author. Tel.: +86 379 64282340; fax: +86 379 64282340.
E-mail addresses: yxfeng1975@126.com, yxfeng1975@sohu.com (X. Yi).

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1. Introduction

The stable isotope approach is based on the fact that naturally occurring stable isotope ratios in consumer tissues can be related to those in consumer's diets (DeNiro and Epstein, 1978, 1981). Changes in, or fractionation of stable isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) occur with trophic level and are of the order of 0–2 and 2–5‰, respectively (Hobson and Clark, 1992; Hilderbrand et al., 1996). Thus, isotope measurement of consumers' tissue can reveal information about their assimilated foods and about trophic positions in systems that are relatively simple and do not involve multiple isotopic inputs. Elevations in an animal's $^{13}C/^{12}C$ and $^{15}N/^{14}N$ relative to those of the community food base have thus been used to infer a consumer's trophic distance from that food base (Schoeninger and DeNiro, 1984). Wada et al. (1987) have used this approach studying lower animal trophic levels in the Antarctic Ross Sea. On average, the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of predators' muscles are increased by 0–2 and 2–5‰ compared with their prey (Hobson and Clark, 1992; Szepanski et al., 1999). In top predators, therefore, the concentration of ^{13}C and ^{15}N are at a maximum. Due to the stepwise ^{13}C and ^{15}N enrichment with increasing trophic level, the ^{13}C and ^{15}N content of predator can be used as time-integrated indicator of their trophic position and relationships. A trophic position-based approach to representing trophic structure incorporates omnivore and weights feeding links according to their relative energetic importance, thereby representing realized trophic structure (Kling et al., 1992). Use of trophic position is likely to improve our ability to model and understand ecosystem process and food web dynamics.

However, lots of information addressing $\delta^{13}C$ and $\delta^{15}N$ values and their trophic relationships are constrained to marine ecosystems (Rau et al., 1983; Wada et al., 1987; Hobson and Welch, 1992) and little touches on terrestrial ecosystems (Hilderbrand et al., 1996). Alpine meadow ecosystem, prevailing over Qinghai-Tibetan Plateau, "the third pole of the world", made itself the ideal place of the research of structure, function of alpine meadow ecosystem. However, there is no report on trophic relationships among the ecosystem with the application of ^{13}C and ^{15}N values measurement at the Haibei Alpine Meadow Ecosystem Research Station (HAMERS) of the Chinese Academy of Sciences (CAS). Our objective was to analyze a single tissue or whole body (i.e., hatchlings and amphibians) to better establish the relationship among animals using the combination of stable carbon and nitrogen isotopes as one indicator, i.e., "alpha and vector model".

2. Methods

2.1. Study area

The study was carried out at the Haibei Alpine Meadow Ecosystem Research Station (HAMERS) of the Chinese Academe of Sciences (CAS). It was established in 1976 in order to understand the structure and function of alpine meadow ecosystem, form and development of biodiversity, the adaptive and evolutionary strategies of species, and the impact of global changes on grassland ecosystem. The HAMERS is located in the region of the Tibetan Plateau, in a large valley oriented NW-SE surrounded on all sides by the Qilian Mountains with N latitude 37°29′–37°45′ and E longitude 101°12′–101°33′. The average altitude of mountainous area is 4000 m above sea level and 3200 m for the valley area. The climate of the HAMERS is dominated by the Southeast monsoon and the higher-pressure system of Siberia. It has a continental monsoon type climate, with severe and long winters and short cool summers. The average air temperature is −1.7 °C with extreme maximum of 27.6 °C and minimum −37.1 °C. During winter months, the average temperature drops to −15 to −20 °C in highland area; during summer, the temperature in the warmest month (July) averages 14–22 °C in the valleys and 4–10 °C in the mountains. Average annual precipitation ranges from 426 to 860 mm, 80% of which falls in the short summer growing season from May to September. The annual average sunlight is 2462.7 h with 60.1% of total available sunshine. Vegetation was characterized by alpine shrub, alpine meadow, and swamp meadow. The research site was roughly confined in alpine meadow, with *Kobresia humilis* as dominant species and *Polygonum viviparum*, *Carex atro-fusca*, *Saussurea superba*, *Elymus nutans* and *Gentiana straminea* as sub-dominant species. The HAMERS has been expanding as a field open station of CAS in 1988, one of the key stations of the Chinese Ecosystem Research Network (CERN) in 1992, the