

Mycophagy among Primates

AMY M. HANSON¹, KATHIE T. HODGE² & LEILA M. PORTER³

¹Department of Ecology and Evolution, State University of New York at Stony Brook, Stony Brook, New York, USA.
Current address: Wildlife Conservation Society/Bronx Zoo, Mammal Department, Bronx, 2300 Southern Boulevard, NY, 10460, USA. (corresponding author). Email: ahanson@wcs.org.

²Department of Plant Pathology, Cornell University, Ithaca, NY, 14853, USA.

³Department of Anthropology, University of Washington, Seattle, W. A. 98195, USA.

The majority of the 22 primate species known to eat fungi spend less than 5% of their feeding time doing so. The Goeldi's monkey (*Callimico goeldii*), a small South American primate, devotes up to 63% of its feeding time to the consumption of *Auricularia auricula*, *A. mesenterica*, *Ascopolyporus polyporoides* and *A. polychrous*. This may be as much as 6.1 kg/animal/year of fresh weight of fungus consumed by an animal weighing half a kilogram; in comparison, the average person in the U.S.A. consumes 1.9 kg/person/year of fresh weight of mushrooms. The nutritional benefits of mycophagy appear to be relatively few, but need to be investigated further. Mycophagy by Goeldi's monkeys may be a strategy for reducing feeding competition during the dry season and likely affects the monkeys' home range size and distribution pattern.

Keywords: Primates, *Callimico*, mycophagy, *Auricularia*, *Ascopolyporus*

Terrence McKenna (1992) argued that our human ancestors first surpassed their monkey cousins when they learned to seek and use hallucinogenic fungi. Although McKenna's hypothesis finds few supporters among evolutionary biologists, it does pose an interesting question: do our nearest relatives appreciate fungi? Surprisingly, this question has been little studied by primatologists. Here we synthesize the few documented reports of mycophagy in lemurs, monkeys and apes, and relate first-hand observations of a South American primate (Goeldi's monkey) that is unusually fond of fungi (Fig 1).

Mycophagy has been documented in at least 22 primate species, including gorillas, bonobos, macaques, vervet monkeys, mangabeys, colobines, marmosets and lemurs (Quris, 1975; Terborgh, 1983; Harrison, 1984; Watts, 1984; Richard *et al.*, 1989; Bermejo *et al.*, 1994; Corrêa, 1995; Tan, 1999; Kirkpatrick *et al.*, 2001; N. Shah, pers. com.). However, the consumption generally occurs at very low rates – typically comprising less than 5% of their feeding time. Exceptions include Goeldi's monkeys (to be discussed below); buffy tufted-eared marmosets, which spend up to 12% of their feeding time consuming sporocarps (Corrêa, 1995); and the snub-nosed monkeys, which spend up to 95% of their feeding time consuming lichens (Kirkpatrick, 2001).

Most reports of mycophagy are anecdotal and the taxonomic identifications of the fungi consumed are rarely noted. Mountain gorillas were observed consuming unidentified bracket fungi (Fossey, 1983), bonobos have been documented to dig for truffles (Bermejo *et al.*, 1994) and chimpanzees have been observed consuming mushrooms scraped from the inside of termite mounds (Boesch, 1995). A possibly unique account of primate mycophagy, detailed by Corner (1992), involves macaques that were trained to collect botanical specimens in Malaysian forests. These monkeys showed individual preferences for different types of fungi. The few definitive identifications of fungi consumed by non-human primates include an *Auricularia* sp. consumed by golden bamboo lemurs (Tan, 1999), *Ganoderma australe* consumed by mountain gorillas in Uganda (K. Hodge & J. Berry, pers. obs.), a *Pleurotus* species that was likely partially consumed by a colobus monkey in Kibale National Park, Uganda (K. Hodge, pers. obs.), and *Bryoria* lichens consumed by the Yunnan snub-nosed monkey (Kirkpatrick *et al.*, 2001).

Mycophagy by Goeldi's monkeys

Goeldi's monkeys are one of 31 species of small (300–600g) New World primates of the subfamily Callitrichinae (Fleagle, 1999). They are endemic to the Amazon basin and inhabit the tropical wet forests of

Brazil, Bolivia, Peru and Columbia (Ferrari *et al.*, 1998). Travelling in groups of two to twelve individuals (Porter, 2001a), they forage for fungi, fruit, insects, small vertebrates (frogs and lizards), tree exudates, and occasionally bird eggs and soil (Porter, 2001b; Hanson, 2000). A year-long study of a wild group of Goeldi's monkeys showed that they spend 29% of their feeding time consuming fungal sporocarps (Porter, 2001b).

Goeldi's monkeys consume the sporocarps of four fungal species on a regular basis: *Auricularia auricula*, *A. mesenterica*, *Ascopolyporus polyporoides* and *A. polychrous* (Porter, 2001b; Hanson, 2000). *Auricularia* species are relatively common saprobes that subsist on dead and decaying wood (Fig 2). Their gelatinous, ear-shaped fruiting bodies are valued for human consumption in Asian countries, and may have been the first fungal species brought into cultivation (Cheng & Tu, 1978; Chang & Miles, 1989). Conversely, very little is known about *Ascopolyporus* species (an Ascomycete in the order Clavicipitales). Members of this genus occur on living bamboos and produce perithecia on the underside of hoof-shaped fruiting bodies that resemble their polypore namesakes. In northwestern Bolivia they were observed growing on the culms of *Guadua weberbaueri* (Fig 2). Aside from Møller's (1901) anecdotal report that the fruiting bodies of *Ascopolyporus* taste sweet, little is known of their edibility, and the very nature of the interaction between these fungi and their plant hosts has not yet been studied.

Challenges of mycophagy

Careful study of the growth and distribution patterns of sporocarps consumed by Goeldi's monkeys reveals several challenges that mycophagy presents to primates. Relative to other typical primate foods such as fruit and leaves, the availability of fungal sporocarps is low and sporadic. The production rate (increase in biomass) of the sporocarps consumed by Goeldi's monkeys ranges from 8 to 36g dry weight per day per hectare of forest (Hanson, 2000). Comparable estimates of food production in a number of tropical rainforests range from 84 to 4,000g/day/ha for fruit, and 16,000 to 28,000g/day/ha for leaves (Bourlière, 1979). In addition to having a low production rate, the fungal sporocarps were found to have patchy spatial and temporal distributions, a fact familiar to any avid mushroom hunter. Thus, monkeys must travel widely and search thoroughly for the sporocarps.

A second challenge posed to mycophagous primates is in obtaining nutritional resources from the sporocarps they do find. Although research on the

digestibility of fungi to primates is limited, studies conducted on non-primate mycophagous mammals reveal important insights into how primates are likely to process fungi. Digestibility trials conducted on rodents and marsupials have shown that sporocarps are difficult to digest and thus represent a relatively poor nutrient resource (Claridge *et al.*, 1999; Cork *et al.*, 1998). Most fungi are composed predominantly of structural carbohydrates that are hard to break down. Mammals without foregut fermentation digestive systems (e.g. Northern brown bandicoot, ground squirrel and red-backed vole) extract little or no protein and low amounts of energy from sporocarps. However, mammals with foregut fermentation (e.g. Northern bettong, long-nosed potoroo and rat kangaroo) do much better, digesting up to 74% of the available protein and 89% of the available energy in the sporocarps they consume (Cork *et al.*, 1998). The diet of the snub-nosed monkey is composed primarily of lichens, and the foregut fermentation capabilities of this primate are thought to contribute substantially to their ability to extract nutrients from lichens and leaves (Kirkpatrick, 2001). Nutritional analyses revealed that the sporocarps consumed by Goeldi's monkeys are, like most fungi, composed predominantly (74 ± 7.3% of dry matter) of structural carbohydrates (A. Hanson, unpubl. data). Goeldi's monkeys are not foregut fermenters, so sporocarps are almost certainly a relatively poor source of nutrients for them.

Why eat fungi?

Given the difficulties involved with relying on fungus as a major food resource, why then would Goeldi's monkeys do so? Among primates that consume sporocarps infrequently, mycophagy may provide important vitamins or minerals deficient in the rest of their diet, as is theorized for occasional geophagy (Heymann & Hartmann, 1991). The causes of the extensive and unusual reliance of Goeldi's monkeys on sporocarps warrant closer examination. Goeldi's monkeys consume sporocarps year-round, but fungi are much more prevalent in their diet during the early part of the dry season, when fruit is less available. The amount of feeding time devoted to the consumption of sporocarps during the dry season was as high as 63% (Porter, 2001b). Thus, sporocarps appear to be a fallback resource, utilized most extensively during the dry season when fruit is not available in sufficient quantity. Like fruits, sporocarps are also less common during the dry season. Despite this, Goeldi's monkeys find and consume relatively large numbers of the



Fig 1 A wild Goeldi's monkey consuming an extremely large, dried specimen of *Auricularia auricula* in northwestern Bolivia. (Photograph by Yasunori Sato, Mainichi Newspapers, Tokyo, Japan.) See also the front cover

sporocarps that are present. In fact, on a few occasions, the monkeys appeared to go 'mushroom hunting', travelling quickly and directly to places where sporocarps were likely to occur, such as bamboo patches and river-edge forest (A. Hanson, pers. obs.).

Why do Goeldi's monkeys take the time to search for uncommon sporocarps during the dry season, instead of looking for similarly hard to find but more nutritious fruits? One hypothesis is that Goeldi's monkeys consume relatively large amounts of sporocarps compared to other primates because of their tendency to travel and rest in the forest understory, below 5m (Porter, 2000). The sporocarps favoured by Goeldi's monkeys are much more abundant in the understory than in the middle and upper canopies where the other primate species in the area tend to live (A. Hanson, pers. obs.). An alternative hypothesis is that Goeldi's monkeys rely on sporocarps to reduce feeding competition with other mammals and other primates in particular (Porter, 2001b). Competition for fruit in the forest is high, especially during the dry season, and Goeldi's monkeys tend to be the losers of aggressive interactions with other species. Indeed, many of the aggressive interactions between Goeldi's monkeys and other primates occur during feeding in fruit trees, and the Goeldi's monkeys are often chased away (A. Hanson and L. Porter, pers. obs.). In contrast, Goeldi's monkeys' consumption of sporocarps is never contested. A further theory that warrants investigation is that Goeldi's monkeys consume more fungi than other primates because their digestive system has adaptations that improve their ability to process sporocarps.

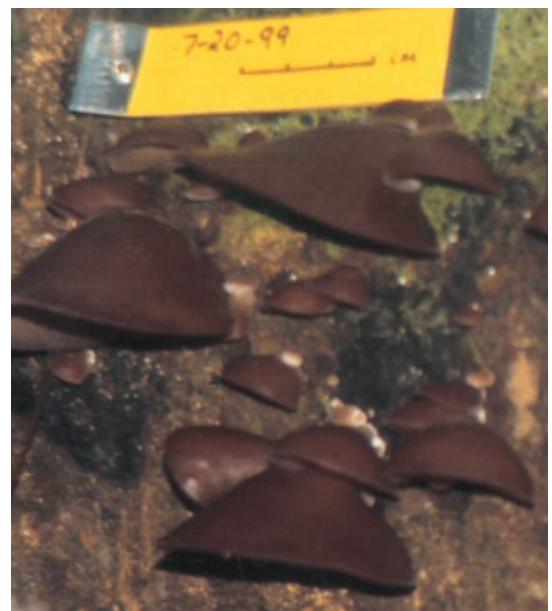


Fig 2 Sporocarps of fungi that are consumed by Goeldi's monkeys: *Auricularia auricula* (left) and *A. mesenterica* (right).

Implications of mycophagy

Assuming that fungi are as important to all Goeldi's monkeys as they are to the wild group whose feeding ecology has been studied in detail (Porter, 2000; Hanson, 2000), the reliance on fungi has a number of important implications for this unusual primate. The distribution of Goeldi's monkeys throughout their range may be affected by the availability of fungi. Goeldi's monkeys have been found predominantly in areas containing bamboo and river-edge forest, both important habitat types for the growth of the fungi these monkeys consume (Hanson, 2000). The home range sizes and population densities of Goeldi's monkeys may also be related to their reliance on fungi. Their home ranges are four to five times larger than those of similarly sized callitrichids in the same forest (Porter, 2000; Garber, 2000), and their population densities are much lower. The low productivity of fungi, the sporadic availability of sporocarps and the relatively poor nutrient resources they provide all lead to a large home range size requirement and low population density for Goeldi's monkeys (relative to other similarly sized primates that rely on more abundant, predictable, and nutritious food resources).

Conclusion

If the amount of fungus consumed by Goeldi's monkeys is any indication of their gustatory preferences, then clearly they appreciate fungi. While the average person in the U.S. consumes 1.9 kg/person/year of mushrooms (fresh weight; NASS, 2000), Goeldi's monkeys may consume as much as 6.1 kg/animal/year (fresh weight, calculation based on values from Hanson, 2000) – a startlingly large amount for an animal weighing half a kilogram. A person weighing 70 kg who consumed an equivalent amount of fungus (adjusted for body weight) would ingest close to one metric ton of fungus in a year. While fungi do not play as important a role in the lives of most primates, the numerous records of primates consuming fungi, along with anecdotal accounts by field scientists of monkeys fighting over some rarely encountered sporocarps (e.g. N. Shah, pers. comm.) provide further evidence that many of our nearest cousins appreciate fungi at least as much as we do.

Acknowledgements

We are grateful to Dr. Jean-Paul Schmidt (Field Museum, Chicago) for identifying the two *Auricularia* species, and to Dr. Lynn Clark (University of Iowa) for identifying the

bamboo hosts. The cooperation and support provided by the Herbario Nacional de Bolivia and Colección Boliviana de Fauna enabled the research on Goeldi's monkeys in Bolivia. Funding for research on Goeldi's monkeys was generously provided by the following organisations: Chicago Zoological Society; Margot Marsh Biodiversity Foundation; Primate Conservation, Inc; Explorer's Club, WJ Fullbright Scholarship, National Science Foundation #9815171, LBS Leakey Foundation and the Douroucouli Foundation.

References

- Bermejo, M., Illera, G. Sabater Pi. (1994). Animals and mushrooms consumed by Bonobos (*Pan paniscus*): New records from Lilungu (Ikela), Zaire. *International Journal of Primatology* **15**: 879-898.
- Bourlière, F. (1979). Significant parameters of environmental quality for nonhuman primates. In *Primate Ecology and Human Origins: Ecological Influences on Social Organizations*, I. S. Bernstein, E. O. Smith, (eds.), Garland STPM Press, NY.
- Boesch, C. (1995). Innovation in wild chimpanzees (*Pan troglodytes*). *International Journal of Primatology* **16**: 1-18.
- Chang, S. T., Miles, P. G. (1989). *Edible mushrooms and their cultivation*. Boca Raton, Florida: CRC Press.
- Cheng, S., Tu, C. C. (1978). *Auricularia* spp. In *The Biology and Cultivation of Edible Mushrooms*, Eds. S. T. Chang and W. A. Hayes, Academic Press, New York.
- Claridge, A. W., Trappe, J. M., Cork, S. J., Claridge, D. L. (1999). Mycophagy by small mammals in the coniferous forests of North America: nutritional value of sporocarps of *Rhizopogon vinicolor*, a common hypogeous fungus. *Journal of Comparative Physiology. B* **169**: 172-178.
- Cork, S. J., Claridge, A. W., Trappe, J. M. (1998). The comparative nutrition of mycophagy among mammals. *Proceedings of the Comparative Nutrition Society*. pp. 27-33.
- Corner, E. J. H. (1992). *Botanical monkeys*. Edinburgh: Pentland Press.
- Corrêa, K.M. (1995). Ecologia e comportamento alimentar de um grupo de Aguis-da-Serra-Escuros (*Callitrichix aurita* E. Geoffroy 1812) no Parque Estadual da Serra do Mar, Núcleo Cunha, São Paulo, Brasil. Master's thesis, Instituto de Ciências Biológicas, Departamento de Zoologia, Universidad Federal de Minas Gerais, Minas Gerais, Brasil.
- Ferrari, S. F., Iwanaga, W., Ramos, E. M., Messias, M. R., Ramos, P. C. S., da Cruz Neto, E. H. (1998) Expansion of the known distribution of Goeldi's monkeys (*Callimico goeldii*) in south-western Brazilian Amazonia. *Folia Primatologica* **70**: 112-116.
- Fleagle, J. (1999) *Primate Adaptation and Evolution*. San Diego: Academic Press.
- Fossey, D. (1983). *Gorillas in the mist*. Boston: Houghton Mifflin.
- Garber, P. A. (2000). The behavioral ecology of mixed species troops of *Callimico goeldii*, *Saguinus labiatus*, and *S. fuscicollis* in northwestern Brazil (Abstract). *American Journal of Physical Anthropology Supplement* **30**: 155.
- Hanson, A. M. (2000). Habitat use in relation to diet, with particular emphasis on mycophagy, by *Callimico goeldii* in Pando, Bolivia. Masters Thesis, State University of New York at Stony Brook.

- Harrison, M. J. S. (1984). Optimal foraging strategies in the diet of the green monkey *Cercopithecus sabaues* at Mount Assirik, Senegal. *International Journal of Primatology* **5**(5): 435-472.
- Heymann, E. W., Hartmann, G. (1991). Geophagy in moustached tamarins, *Saguinus mystax*, at the Rio Blanco, Peruvian Amazonia. *Primates* **32**: 533-537.
- Kirkpatrick, R. C., Zou, R. J., Dierenfeld, E. S., Zhou, H. W. (2001). Digestion of selected foods by Yunnan snub-nosed monkey *Rhinopithecus bieti* (Colobinae). *American Journal of Physical Anthropology* **114**: 156-162.
- McKenna, T. (1992). *Food of the Gods: the search for the original tree of knowledge*. New York: Bantam Books.
- Møller, A. (1901). Phycomyceten und Ascomyceten. *Botanischen Mittheilungen aus den Tropen* **9**: 1-319.
- NASS (National Agricultural Statistics Service, USA)(2000). *Mushrooms*. Washington, D.C.: US Department of Agriculture.
- Porter, L. M. (2000). The ecology and behavior of the Goeldi's monkey (*Callimico goeldii*) in Northern Bolivia. PhD Thesis, State University of New York at Stony Brook.
- Porter, L. M. (2001a). Social organization, reproduction and rearing strategies of *Callimico goeldii*: New clues from the wild. *Folia Primatologica* **72**: 2(69-79).
- Porter, L. M. (2001b). Dietary differences among sympatric Callitrichinae in Northern Bolivia: *Callimico goeldii*, *Saguinus fuscicollis* and *S. labiatus*. *International Journal of Primatology* **22**(6):961-992.
- Quris, R. (1975). The ecology and social organization of *Cercocebus galeritus agilis* from Northeast Gabon. *Terre Vie* **29**(3): 337-398.
- Richard, A. F., Goldstein, S. J., Dewar, R. E. (1989). Weed macaques: the evolutionary implications of macaque feeding ecology. *International Journal of Primatology* **10**: 569-591.
- Tan, C. (1999). Group composition, home range size, and diet of three sympatric bamboo lemur species (Genus *Haplemur*) in Ranomafana National Park, Madagascar. *International Journal of Primatology*. **20**: 547-566.
- Terborgh, J. (1983). *Five New World Primates*. Princeton University Press, Princeton, New Jersey.
- Watts, D. P. (1984). Composition and variability of mountain gorilla diets in the central Virungas. *American Journal of Primatology* **7**: 323-356.

MISAC Competition 2002

The Microbiology in Schools Advisory Committee (MISAC) has run a popular annual competition for schools since 1985, with cash prizes for both pupils and their schools. The competition is advertised in the national educational press and at the annual meeting of the Association for Science Education, and details are sent by mail to all secondary schools in England and Wales <www.ase.org.uk>. Pupils must research information on a particular microbiological topic and present it in a specified format, such as a poster or newspaper article. The topic changes every year but is always tied to the National Curriculum and can be used as a teaching aid or an assessment. The British Mycological Society sponsored the 2002 competition, which was entitled "I've got you under my skin: fungal infections of the human body". The challenge was to produce an eye-catching illustrated fact sheet for a teenage magazine about the diseases caused by fungi and ways of preventing infection. This gave pupils the opportunity to demonstrate their understanding of the impact of fungi on human health and also to develop and apply their key skills in information technology and communication.

The competition was well supported, with nearly 300 entries involving almost 400 pupils from 44 schools. Judging took place in April at the Institute of Biology, London. The BMS was represented by Professor Neil Gow

(President), Professor Roy Watling and Professor John Peberdy, and they were joined on the judging panel by members of MISAC. The competition was judged in two age groups: Key Stage 3 (11-14 age group) and Key Stage 4/GCSE. The winning entries were selected on the basis of their scientific accuracy and quality of presentation. (See the illustrations on page 27)

First prize for Key Stage 3 went to Joanne Box (Kirkham Grammar School), and David O'Sullivan (Brinsworth Comprehensive School, Rotherham) scooped the honours in the higher age group. Professor Tony Trinci and Dr Susan Isaac visited the schools winning first prizes to present prizes and certificates and to give a short talk on the importance of fungi. All participating students received a certificate for their record of achievement and every school entering the competition was sent a pack of microbiology teaching resources. Further details of the winners can be seen on the BMS website (www.britmycolsoc.org.uk).

The 2003 Competition will be sponsored by the Society for General Microbiology on the topic "Your Body is a Fortress: A Barrier to Microbial Invaders", with the brief to produce an eye-catching A3 annotated diagram of the human body highlighting non-specific barriers to infection by micro-organisms.

Sue Assinder