Mycophagy in the larger bodied skinks of the genera *Tiliqua* and *Egernia*: are there implications for ecosystem health?

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ABSTRACT

The larger bodied skink of the genera *Tikiqua* (blue -tounged and shingle-back lizards) and *Egernia* may be contributing to the maintainance of ecosystem health by dispersing fungle spores that form symbiotic relationships with most terrestrial plant species.

We observed an Eastern Blue-tongued Lizard *Tiliqua scincoides* digging for fungi in a garden bed, which prompted us to examine the literature on the consumption of fungi by skinks. Our observation, together with a previous record of *Tiliqua nigrolutea* having consumed the fruiting bodies of truffle-like fungi (Webb and Simpson 1985), indicates that blue-tongued lizards can detect the presence of subterranean fungi and will readily eat them.

Key words: mycophagy, Scincidae, Reptilia, ecosystem health, truffle, fungi, spore dispersal

The larger bodied skinks of the genera *Tiliqua* (blue-tongued and shingle-back lizards) and *Egernia* have a more omnivorous diet than their smaller relatives in the family Scincidae that are predominantly generalist predators of insects and other arthropods (Greer 1989). Among the larger lizards, including skinks, the degree of herbivory generally increases with increased body size (Pough 1973; Brown 1991), including a change in diet from insectivory to herbivory from juvenile to adult in some species (Greer 1989). For example Brown (1991) analysed the diet of 15 species of skink, including several large *Tiliqua* and *Egernia* species, and concluded that the degree of herbivory was directly related to body size, with these large skinks preferring easily-accessible non-animal material such as flowers, soft vegetative parts and fungi. This dietary shift is believed to be a function of the larger species being unable to meet calorific demands from a diet of insects alone (Pough 1973).

Dietary studies and casual observations made of these large skinks indicate that fungi may also be an important part of their diet. Mycophagy has been recorded for five *Tiliqua* and two *Egernia* species with descriptions of the fungi consumed varying from simply 'fungi' to identification of genera (Table 1). Webb and Simpson (1985) found that the stomach contents of a road killed *T. nigrolutea* consisted entirely of bolete mushrooms; another contained four different species of fungi, some of which were truffle-like fungi that fruit in shallow soil or under leaf litter. The volume and variety of fungi consumed, in conjunction with observations of these skinks actively digging for fungi (Schulz and Eyre 1997; our observation) suggests that fungi may be a desirable food source for these animals and is actively sought when encountered.

In early December 2006, we observed a large adult Eastern Blue-tongued Lizard *Tiliqua scincoides* on the University of New England campus (Armidale, New South Wales: 30°29'07"S 151°38'28"E) move towards the base of a mature Coastal Rosemary shrub *Westringia fruticosa* and commence digging. We realised that the lizard was digging for fungi when it retrieved and quickly consumed a white, ball-shaped mass that had not been visible from the surface. At this point we disturbed the animal (which retreated a short distance) and recovered three more ball-shaped fungi which resembled the 'eggs' of immature stinkhorn or anemone fungi from the Family Phallaceae (Figure 1a). One of these was offered to the lizard which immediately consumed it (Figures 1b, 1c), and another was allowed to mature in our laboratory on water-soaked paper towel, inside a glass beaker that was covered in opaque plastic. On maturity this specimen was identified as the Anemone or Flower Fungus *Aseroe rubra* (Figure 1d). *A. rubra* is a saprophytic fungus, but the immature 'eggs' have an external appearance not unlike the sporocarps of truffle forming mycorrhizal fungi, and they develop beneath the soil, as do truffles.

Mammals are generally considered to be the primary consumers and dispersers of subterranean (hypogeous) fungi, including those species that form truffle-like structures that require excavation and consumption as a means of spore dispersal via faeces (Maser *et al.* 1978). As the blue-tongued lizard we observed clearly had an appetite for the fungi that it was able to detect developing beneath the ground, and Webb and Simpson (1985) found truffle-like fungi in the stomach of a *T. nigrolutea*, we speculate that it may be common for blue-tongued lizards to dig up and consume aromatic hypogeous fungi as part of their normal diet. This suggestion is further supported by research by Noble and Kumpf (1936) that demonstrated that some lizards can detect hidden food sources by olfaction alone, and work by Cooper (2000) that found that herbivorous lizards can identify the scent of plant food chemicals.

Table 1. Observations of the consumption of fungi by herbivorous skinks in the genera *Egernia* and *Tiliqua*. More extensive records can be found in Shea (1989), and Webb and Simpson (1985).

Species	Description of Fungi Consumed	Reference
Egernia major Land Mullet	Fruiting bodies of several different woody fungi and gilled mushrooms[1]; caps of soft bolete-type mushrooms; portions of other fungi[1]	Shea 1999
	Unidentified fungi[1], including fungi dug up from under Bitou Bush	Schulz & Eyre 1997
Egernia saxatilis Black Rock Skink	Unidentified fungi[1]	Brown 1991
Tiliqua multifasciata Centralian Blue-tongued Lizard	Gilled mushroom (cap 4 cm in diameter)[1]	Shea 2006
Tiliqua nigrolutea Blotched Blue-tongued Lizard	Agarics *Clitocybe* sp.[2] and *Pholita* sp.[2]; gasteroid fungi *Setchelliogaster* sp[3]. and *Zelleromyces* sp.[3]; macerated fruiting body of an unidentified bolete[2]	Webb & Simpson 1985
Tiliqua occipitalis Western Blue-tongued Lizard	Approx. 6 small, macerated, gilled mushrooms (caps 1 cm in diameter)[1]	Shea 2006
	Unidentified fungi[1]	Dell and Chapman 1979
Tiliqua rugosa Shingle-back	Unidentified fungi[1]	Brown 1991
	Dried boletus-type fungus[4]	Serventy 1970
	Toadstools[4]	Waite 1925
Tiliqua rugosa konowi Rottnest Island Bobtail	Small mushrooms[1]	Shea 1989
Tiliqua scincoides Eastern Blue-tongued Lizard	Subterranean 'eggs' of immature flower fungi *Aseroe rubra*[2]	This study
	Unidentified fungi[1]	Koenig *et al.* 2001

[1]Nutritional mode of fungi unknown; [2]Saprotrophic (wood decaying) fungi; [3]Hypogeous (including truffle-forming) mycorrhizal fungi; [4]Epigeous mycorrhizal fungi

Herbivorous skinks are therefore well equipped to detect the aroma of 'ripe' fruiting bodies of truffle-like fungi, and because many of these fungi develop and mature either just beneath the soil surface, or at the soil surface beneath a layer of leaf litter (Claridge and May 1994), they would be easily accessible to foraging lizards. These fruiting bodies, commonly called 'truffles', give off increasingly stronger odours as they mature that attract mycophagous animal species (Fogel and Trappe 1978; Johnson 1996; Maser *et al.* 2008) which are the principal agents for their spore dispersal (Maser *et al.* 1978; Bougher and Lebel 2001). Spores that have been through the digestive tract of a mammal have been found to be viable (Trappe and Maser 1976; Reddell *et al.* 1997). It has even been suggested that spore viability may be increased by passage through the digestive tract of an animal (Lamont *et al.* 1985; Claridge *et al.* 1992; Caldwell *et al.* 2005). The fungus benefits from this relationship by acquiring a means of dispersal, and the animal receives a source of food (Fogel and Trappe 1978; Bougher and Lebel 2001; Maser *et al.* 2008).

As most terrestrial plant species form a symbiotic relationship with mycorrhizal fungi (such as the truffle-like fungi) to facilitate the uptake of nutrients (Smith and Read 1997; Maser *et al.* 2008), the dispersal of these fungal spores has implications for ecosystem health (Maser *et al.* 1978; Johnson 1996; Maser *et al.* 2008). The presence of mycorrhizal fungi can enhance seedling growth (Janos 1980; Malajczuk *et al.* 1987) and affect plant productivity generally, as well as influence plant biodiversity and community structure (van der Heijden 1998; Hartnett and Wilson 1999; Kiers *et al.* 2000; Klironomos *et al.* 2000). The exclusion of mycophagous vertebrate species from areas of rainforest was shown to reduce abundance and diversity of mycorrhizal fungi, as well as decrease colonisation of plant roots by fungal associates (Gehring *et al.* 2002). By default, the loss of vertebrate fungal spore dispersers may have serious consequences for community and ecosystem productivity, structure and function.

Animal dispersers of fungal spores are a vital link in the maintenance of ecosystem health (Maser *et al.* 2008). Mammals are considered to be the primary vertebrate agents of fungal spore dispersal, but it is possible that the mycophagous skinks also play an important role. The combined distribution of all species of skink known to ingest fungi extends across the Australian mainland and northern Tasmania (Cogger 2000). The consumption and dispersal of fungal spores by herbivorous skinks may therefore be particularly important in areas where there are few mycophagous mammal species. A suitable place to test our hypothesis that reptiles are important dispersers of hypogeous fungi would be the islands of New Caledonia and New Zealand; these islands have native truffle-forming fungi and a depauperate mammal fauna, but have a preponderance of large-bodied reptiles.

Figure 1. (a) *Aseroe rubra* 'egg' dug from the feeding site; (b-c) the Eastern Blue-tongued Lizard *Tiliqua scincoides* consuming an *A. rubra* 'egg'; and (d) the mature *A. rubra* 'hatched' in our laboratory.

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