A survey of frog odorous secretions, their possible functions and phylogenetic significance

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Abstract. This study provides a survey of frog odour (with particular reference to Australian species) and discusses the human perception and classification of frog volatile secretions. Professional and amateur herpetologists were solicited for information on the frogs they perceived as odorous. In addition, volunteers were asked to smell stressed frogs and describe the odour that they perceived. A total of 131 species, representing 30 genera (14 Australian and 16 other) and 11 families were assessed for odour. Odours ranged from pleasant floral aromas (e.g. \textit{Notaden} spp. and \textit{Neobatrachus} spp.) through to acrid, repulsive odours (e.g. \textit{Litoria alboguttata}). The systematic relationships of these odours and their potential biological roles are discussed.

Key words: Frog; functional significance; odorous secretions; phylogenetic relationships; skin secretions; volatile secretions.

Introduction

The integumentary glands of frogs produce a diverse range of chemicals. Compounds isolated from frog secretions include bioactive peptides and proteins, guanidine derivatives, biogenic amines (e.g. dopamine and serotonin), steroids and alkaloids (for detailed reviews see Habermehl, 1981; Daly et al., 1987; Bevins and Zasloff, 1990; Daly et al., 1993; Erspermer, 1994; Toledo and Jared, 1995; Daly, 1995, 1998a,b). In addition to these non-volatile components many frog species emit volatile compounds (Smith, 2001) and a large proportion of these volatiles are odorous (Brodie and Formanowicz, 1981; Tyler, 1976; Williams et al., 2000; Smith, 2001; Smith et al., 2003). For example, Noble (1931) noted that the secretions of \textit{Rana septentrionalis} (the aptly named “Mink Frog”) and \textit{Gastrotheca monticola}...
(the Marsupial Frog) both smell like mink (*Mustela vison*, a small, semi-aquatic weasel-like carnivore), and the European toad, *Bufo vulgaris* smells like vanilla. Boulenger (1911) reports that some pelobatids smell like onions, Martin and Littlejohn (1966) state that *Litoria jervisiensis* (Jervis Bay Tree-frog) smells like curry, Tyler (1968, 1976) described the odour of *L. infraprenata* (Giant Tree-frog) from New Britain and *L. aurea* (Green and Golden Bell Frog) from New South Wales as similar to that of dried thyme, Myers et al. (1991) commented on the defensively malodorous, mercaptan-like odour of *Aromobates nocturnes* and Waye and Shewchuk (1995) noted that the skin secretion of *Scaphiopus intermontanus* (Great Basin Spadefoot) smells like peanuts.

Despite interest in the chemistry of frog skin secretions, along with the fact that numerous researchers and amateur naturalists have commented on the distinct smell of many species of frogs and toads, there are few published records on the analysis of anuran volatile chemicals or odorous secretions. The purpose of this paper is to provide a comprehensive review of frog odours (as perceived by humans) and hopefully stimulate research into the role and chemical identity of volatile secretions. Particular reference is given to Australian species with data drawn from literature searches, surveys, field observations and human sensory studies.

In addition to the review, the question of whether the grouping of frogs by ‘odour similarity’ provides information about the phylogenetic relationship or life history traits of the animals under study is considered. There is a need for greater understanding of the compositions and properties of odours generally, quite apart from their likely behavioural, pharmacological or ecological significance. Comparative studies of frog odour may provide information about whether any odours are common to all frogs, and whether any are species specific.

Amphibians are amongst the oldest terrestrial vertebrate animals on earth. They originated from aquatic Devonian animals some 300 million years ago. Thus, the taxonomic distribution of many of the compounds isolated from frog granular glands corresponds to the classification based on other criteria (e.g. morphological characteristics) (Cei and Erspamer, 1966; Roseghini et al., 1976; Erspamer et al., 1984). Some groups of anurans (e.g. phyllomedusine and pelodryadine hylids) contain large amounts of unique polypeptides, and each species has its own characteristic polypeptide spectrum (Cei, 1963; Steinborner et al., 1996). The dendrobatids are well known for their strong toxins; *Phyllobates* secrete mainly batrachotoxins, which are highly toxic steroidal alkaloids, whereas *Dendrobates* secretes a wide variety of less toxic and chemically simpler piperidine alkaloids (Myers et al., 1978; Daly et al., 1987). Thus the biochemical differences in the genera of dendrobatid frogs seem to have phylogenetic significance. Analyses of biogenic amines (Cei et al., 1967, 1968, 1972) and secretions of the parotoid glands (Low, 1972) of *Bufo* from throughout the world showed that trends in these biochemical traits correspond to morphological groups of toads presumably representing different evolutionary lineages. As odours are a result of the volatile