

Long Distance Transport of Arsenic by Migrating Bogong Moths from Agricultural Lowlands to Mountain Ecosystems

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Abstract

Bogong Moths *Agrotis infusa* (Lepidoptera: Noctuidae) migrate in spring from the inland plains of eastern Australia to aestivate up to 1000 km away in rock crevices in tors and periglacial block-streams in the Snowy Mountains and Victorian Alps. In spring/summer 2000/01, heavy rains washed debris from caves in the Snowy Mountains, killing adjoining grass. Arsenic was detected in soils from the caves and soil and grass from outwash areas, but not in soils and grass from adjacent unaffected areas. Faeces from mammalian predators of moths contained more arsenic than faeces from a herbivore from the same region. Arsenic levels were higher in moths from caves in the Snowy Mountains where vegetation was killed than in moths from the ACT or Victoria. The results indicate long distance transport of sublethal quantities of arsenic which are then concentrated to damaging levels by the millions of moths at aestivation sites. (*The Victorian Naturalist* 118 (4), 2001, 112-116.)

Introduction

The larvae of Bogong Moths *Agrotis infusa* (Noctuidae) are found from autumn to spring in eastern Australia from the Darling Downs in Queensland, south to the north-western plains of Victoria (Fig. 1). These areas have historically been used for grazing and cropping, and the Bogong Moth cutworm larvae are sometimes considered an agricultural pest (Common 1954). The larvae feed on annuals, but in the absence of their food plants over summer the moths migrate to the Australian Alps where they fast while aestivating gregariously in rock crevices and caves (Common 1954). Historically, Bogong Moths formed an important part of the summer diet of Aboriginal people from around the Australian Alps (Flood 1980). Today they still form an important part of the diets of many vertebrate species, including the endangered Mountain Pygmy-possum *Burrhamys parvus*, the most reliant of the native mammals on Bogong Moths (Mansergh and Broome 1994).

Heavy rains in November 2000 washed accumulated debris of dead moths out of many aestivation sites. In January 2001

complete mortality of grass *Poa fawcettiae* in the outwash zone at one site prompted an investigation of possible chemical contamination in the moths, the affected soils and vegetation.

Methods

In order to examine soil chemical properties in detail, soil samples were collected (approximately 0-10 cm depth) from up to five separate areas within each site and samples were then pooled. Samples were collected from within caves used as aestivation sites by Bogong Moths, in the area outside the cave over which water and debris from the cave had drained, and as close as possible to this but outside of the drainage line from the cave. Soil exchangeable cations were determined using an ammonium acetate extraction (Lambert 1978) and analysed on a Varian Flame Atomic Absorption Spectrophotometer. Statistical analysis of arsenic levels was undertaken using two-way ANOVA.

From preliminary findings it was established that arsenic occurred in higher concentration in affected soils, and therefore, subsequent analysis concentrated on this one element.

Bogong Moths were collected live by hand at aestivation sites or by ultra violet moth lights at Mt. Gingera (ACT), South Ramshead (Snowy Mountains NSW) and from Mt. Buller and Mt. Buffalo (Victoria) (Fig. 1). Sample size varied from 50-120 moths depending upon availability, and

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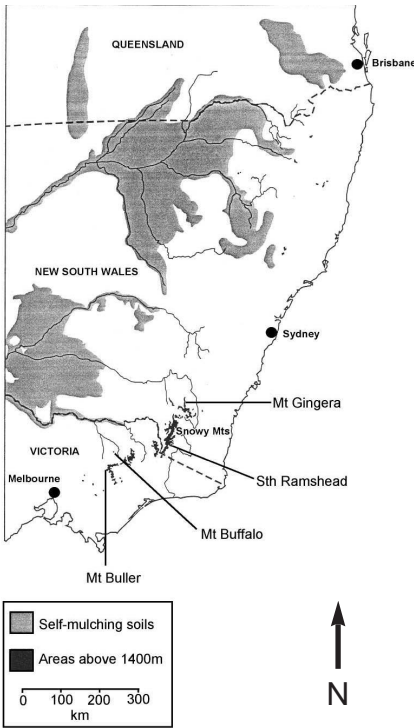


Fig. 1. Map of south eastern Australia showing areas above 1400 m altitude, including the mountain aetivastion sites sampled in the present study, and the chief areas of self-mulching soils that appear to be the most important breeding grounds of Bogong Moths (after Common 1954).

samples were pooled and frozen as soon as possible after capture. Analysis was of a subsample of approximately 50 moths (adjusted to give approximately equal mass) from each location. Analysis of arsenic levels in Bogong Moths was conducted using a nitric acid digest (modified from Rayment and Higginson 1992) with arsenic determination on a Varian Vista ICP-MS (Inductively Coupled Plasma - Mass Spectrophotometer).

Samples of grass were collected from three to four sites of approximately 400 cm² within the area outside the cave over which water from the cave drained (dead grass) and from adjacent to this, outside of the cave drainage but still close to the

Table 1. Elemental arsenic content of Bogong Moths *Agrotis infusa* compared to a known sample of 0.0000 µg.kg⁻¹ arsenic (for use with samples at low concentrations).

Location	Elemental arsenic (µg.kg ⁻¹)
Control (known sample)	0.103
Mt. Gingera (ACT)	0.101
South Ramshead (NSW)	2.296
Mt. Buffalo (Vic)	0.186
Mt. Buller (Vic)	0.333

rocks (live grass). Grass samples were pooled, sub-sampled and then prepared using a wet acid digestion method using hydrochloric acid (Lambert 1978, Rayment and Higginson 1992) and analysed on a Varian Flame Atomic Absorption Spectrophotometer.

Sub-sampling of stored faeces of Mountain Pygmy-possums was conducted following the discovery of arsenic in the mountain system. Faecal samples had been collected annually for dietary studies and stored frozen. Individual samples were sub-sampled so as to retain information on diet, and all samples for one area were then pooled. Three other mammal species were also tested. These were trapped at Smiggin Holes, 3.5 km from the nearest Bogong Moth aestivation site. These had differing diets ranging from insectivorous (*Dusky Antechinus Antechinus swainsonii*), omnivorous with the major food being fungus and insects (*Bush Rat Rattus fuscipes*) and one obligate herbivore (*Tooarana* or *Broad-toothed Rat Mastacomys fuscus*) (Green and Osborne 1994). Samples from the latter species were chosen as representative of background levels of arsenic in mountain mammals. Only *M. fuscus* is marked individually on the trapping grid, so samples could be collected from individuals over the three days of trapping. For the other two species which were not marked individually, faeces were pooled from all animals after the first night's trapping. Analysis of arsenic levels in faecal samples was undertaken using ICP-MS (Inductively Coupled Plasma - Mass Spectrometry) on a Hewlett Packard HP4500 ICP-MS using nitric acid digest (Rayment and Higginson 1992).

Table 2 Arsenic levels in soils adjacent to moth aestivation sites where live moths were sampled and for all sites combined. (Each site is pooled from up to five samples.) Mean and standard deviation.

Site	Grass state	Elemental arsenic (mg.kg ⁻¹)
South Ramshead site 2 – in cave	n/a	15.7272
South Ramshead site 2 – outwash area	Dead	3.5551
South Ramshead site 2 – undisturbed	Live	0.0000
Average of 8 sites – in cave	n/a	6.0292±8.9292
Average of 8 sites – outwash area	Dead	0.5035±1.2553
Average of 8 sites – undisturbed	Live	0.0005±0.0013
Mt. Gingera – in cave	n/a	0.1542
Mt. Gingera – outwash area	Live	0.0000
Mt. Gingera – undisturbed	Live	0.0000

Results and Discussion

The movements of arsenic from Bogong Moths to soil to grass and from moths to mammals are firmly established (Tables 1-4). There was a significant trend (F=3.593, P<0.05) of decreasing levels of arsenic in soils from caves to unaffected sites outside of drainage lines (Table 2) that mirrored the observed effect on vegetation. The analyses of unaffected soils, live grass and herbivore faeces indicated that the arsenic in the affected soil, dead grass and faeces of insectivores was not of local origin but had been introduced to the system by immigrant insects. The presence of arsenic in the most heavily preyed upon insect, the Bogong Moth (Table 1), indicates that these moths are the source of arsenic at the aestivation sites. Bogong Moths do not feed locally during aestivation (Common 1954) so it is most likely that the arsenic originated in the soils where the larvae feed (I.F.B. Common, *pers. comm.*). The distances between the larval sites inland to the aestivation sites in the mountains is up to 1000 km. This finding constitutes yet another example of long-distance transport of pollutants, but one that is unusual in that an insect is the transporting agent. Although there are few data on insects, the levels of arsenic detected in moths at the most affected site were well below levels causing mortality of moths elsewhere (Eisler 1994). Arsenic levels in moths were highest at the location where the impact of outwash from aestivation sites on vegetation was first noted at South Ramshead. Arsenic levels in caves and outwash (Table 2) reflect the differing levels found in the moths at Mount Gingera and South Ramshead (Table 1). Soils at

Table 3. Elemental arsenic content in affected and unaffected grass beside moth aestivation sites at South Ramshead. (Each site is pooled from up to four samples.)

Site	Grass state	Elemental arsenic (mg.kg ⁻¹)
Site 1		
– edge of cave	Dead	0.005
– outwash area	Dead	0.006
Site 5		
– undisturbed	Live	0.000
– outwash area	Dead	0.006
Site 6		
– outwash area	Dead	0.007

five other sites where grass was killed had similarly elevated levels of arsenic in the cave and outwash relative to undisturbed soil. Unfortunately the phenomenon was noticed too late in the season to sample moths at those sites prior to their emigration. The compound containing the arsenic has not yet been identified, due to the shortage of moths subsequent to the main migration, but all dead grass contained levels of arsenic not found in live grass (Table 3). There was obviously uptake of arsenic from the soil by the grass although the causal connection of arsenic with grass mortality is not firmly established. The arsenic levels in soils in two caves at South Ramshead, a major aestivation site south-west of Mt. Kosciuszko, were higher, at 15.7 and 23.8 ppm, than residues generally found in farmlands in America (Yan-Chu 1994) and orchards in New South Wales (EPA 1995) but within the range of residues accumulated in orchards in America (Yan-Chu 1994).

Arsenic appears to be well entrenched in the mammalian insectivore food chain,

Table 4. Elemental arsenic content (mg.kg⁻¹) of faeces of three mammal species that feed on Bogong Moths and one herbivore (*Mastacomys fuscus*) acting as a control.

Year	1994	1995	1998	2000
<i>Burramys parvus</i>				
Trap grid 1	0.1	0.4	0.1	<0.2
Trap grid 2	<0.5	1.6	<0.2	<0.2
Trap grid 3				<0.5
Trap grid 4	0.2	<0.1	0.3	0.3
Trap grid 5	<0.5	0.8*	0.1	<0.5
Trap grid 6	0.2	0.4	<0.5	0.3
Smiggin Holes:				
<i>Antechinus swainsonii</i>				0.5
<i>Rattus fuscipes</i>				0.6
<i>Mastacomys fuscus</i>				<0.1

*1994 and 1995 combined.

with only one species of small mammal tested, the herbivorous Toarana or Broad-toothed Rat, being unaffected. The impacts of arsenic within the mountain ecosystem are unknown. The small size and the rarity of dead specimens of the endangered Mountain Pygmy-possum make it difficult to collect samples to determine the levels in tissue and to speculate as to its possible effect in suppressing the population of Mountain Pygmy-possums.

Bioaccumulation of environmental pollutants and their concentration by terrestrial organisms normally occur *in situ* in, for example, plants such as willows (*Salix* spp.) (Larison *et al.* 2000). Exceptions to this are where transport of pollutants occurs through the action of wind or water prior to uptake (Sivertsen *et al.* 1995; Kalas *et al.* 2000) with levels generally decreasing with distance from the source (Kalas *et al.* 2000). What is less frequently documented is the long-distance transport of small amounts of chemicals by individual organisms and subsequent concentration to detrimental levels. The altitudinal flow of anthropogenic nutrients such as crop fertilisers has, however, been documented for phosphorus in windblown Alfalfa Moths *Loxostage cerareolis* (Halfpenny 1994).

Polluting sources such as smelters and fossil fuel power plants are major sources of arsenic in surface soils (Yan-Chu 1994). However, Bogong Moths come from upwind of the eastern seaboard of Australia where industry is concentrated. It is possible that there are natural sources of arsenic in

systems from which the larvae feed which are amplified by bioaccumulation via the Bogong Moths. However, a more likely source is agricultural. The use of arsenic in agriculture has left a legacy of broad-acre contamination of soils, mainly associated with areas of intensive agriculture and horticulture (EPA 2001). Arsenic has been used in a variety of agricultural applications: in pesticides, insecticides and in cattle and sheep dips (Azcue and Nriagu 1994). It has also been used as lead arsenate for the control of moths in fruit crops (Buchanan 1977; Yoon and Kim 1977). From the 1860s to 1940s, when DDT was introduced, arsenical compounds were the major insecticides available to agriculture (Nriagu and Azcue 1990) and remained in use in Australia until the 1950s and 1960s (EPA 2001). The major use of arsenic is still in agriculture in various forms including monosodium methylarsenate (MSMA) (Azcue and Nriagu 1994). There are five MSMA herbicide sprays currently licensed for use in agriculture in New South Wales (National Registration Authority 2001). In soils, arsenic is present as arsenate (AsO₄³⁻), and its behaviour resembles that of phosphate (Davies and Jones 1988). For example, arsenate is absorbed by ligand exchange on hydrous iron and aluminium oxides (Davies and Jones 1988). This study shows that the soils of the Snowy Mountains have naturally low levels of exchangeable arsenic. Addition to these soils of exogenous arsenic, which is readily taken up by plants, has led to major impacts on the vegetation around the aestivation areas.

The presence of arsenic in all four years for which faeces of *B. parvus* were tested (Table 4) suggests that arsenic may be transported to the mountains annually. This suggests that there may be regular absorption of arsenic by the cutworm larvae, probably from their food plants. Small amounts of arsenic are then transported at low concentrations, by individual moths but in extremely high numbers, and concentrated where they congregate in the mountains, causing visible and extensive damage. The arsenic content of moths and soils at Mt. Gingera (Tables 1 and 2), contrasting to those at South Ramshead and in Victoria, suggests that there are different sources of these moths. It has long been suspected that Bogong Moths in different aestivation sites come from different areas and this study adds credence to that speculation. This question may be resolved by genetic studies matching adults to larvae from known agricultural areas. Collection of material for this study is currently in progress with the primary aim of the genetic study being to narrow the focus of searching for the source of the arsenic.

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International Year of Mountains 2002

The United Nations has declared 2002 as the International Year of Mountains. The aim is to celebrate and focus global attention on mountain communities and environments. A number of activities associated with mountain environments in Australia are already planned including a 'biodiversity blitz' at Kosciuszko in January (under the auspices of the Australian Institute of Alpine Studies) and a conference on rehabilitation of mountain ecosystems in November (Australian Alps Liaison Committee).