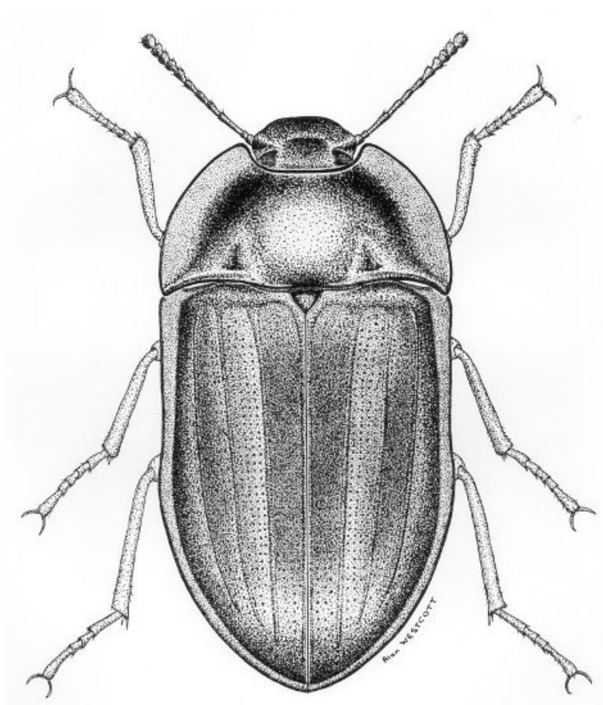
GENERAL

and

APPLIED ENTOMOLOGY

The Journal of the Entomological Society of New South Wales Inc.



Volume 52
Gen. appl. Ent

Published 24 December 2024

THE ENTOMOLOGICAL SOCIETY OF NEW SOUTH WALES INC.
c/- Entomology Department, Australian Museum, 1 William Street, Sydney, NSW 2010

PRICE OF JOURNAL

Australian subscriptions ordered directly from the Society, $45.00 per issue or if via agents; $50.00 per issue both including postage and handling.

Overseas subscriptions ordered directly from the Society or via agents $60.00 per issue including airmail postage and handling.

Past volumes of the Journal if available may be purchased at the prices indicated plus postage and handling costs. Volumes 1-27 (1964-1996) at $10.00 each, Volume 28 onwards (1997 to volumes over 5 years old) at $15.00 each. Articles appearing in issues from Volume 23 & from volume 27 onwards (except the most recent volume) may be downloaded free from the Society webpage http://www.entsocnsw.org.au

Claims for replacements of journals not delivered will only be considered within six months of date of invoice.

Hard copy orders and remittances should be sent to The Business Manager, Entomological Society of New South Wales, c/- Entomology Department, Australian Museum, 1 William Street, Sydney, NSW 2010. Electronic orders, remittance advice and communications should be emailed to the Business Manager at <buisinessmanager@entsocnsw.org.au>.

SOCIETY MEMBERSHIP

Ordinary Membership $50
Student Membership $25
Corporate Members $150
Company Associate Membership $60

Cover image: *Pterohelaeus darlingensis* Carter Tenebrionidea (COL.) Artist Alan Westcott.

This journal is abstracted by Clarivate Analytics

Printed by Arrowprint

COMPANY ASSOCIATE MEMBERS

In 1963 the Society offered Company Associate Membership to firms whose activities are substantially concerned with entomology or allied subjects. The following companies are current members:

Australian Entomological Supplies Pty Ltd, Unit 3/173 Lundberg Dr, South Murwillumbah, NSW 2484

ISSN 0158 0760

OBITUARY

ROBERT FRANCIS RYAN MSc, ASTC; FRSN; FRACI, C.Chem; FAIFST; FAMI CPM (1942 - 2024)

Bob Ryan was president of the Entomological Society of NSW from 2012 until his recent unexpected death. He had been a member of the Society since 1977, and had served as a Councillor and Vice President. He stepped up in 2012 when the Society was without a president, and continued to guide it with skill and good humour for the ensuing twelve years. He will be sadly missed by all members.

Bob himself admitted that he was an unlikely president of an entomological society. His training was as an industrial chemist and in his early career he had been a pest controller and had taught the pest control course at TAFE following Phil Hadlington's retirement from that role. His work in R&D was mainly in the field of development and delivery of fumigant chemicals for use in various environments, all research done at BOC at various locations. Some of his publications are listed below. We sometimes joked about his having more letters after his name than any other member. These letters indicate the wide range of professional bodies of which Bob was an esteemed member or Fellow. He was later Principal and Senior Consultant of his company Vaporfaze.

More information on Bob's highly significant research at a national and global level is given in his profile published in the EntSocNSW newsletter *Tarsus*, **612:** 6-7.

Bob's quiet and friendly presence hid the persistent and intelligent application that gave the Society's Council drive and substance during a period of reduced participation and purpose. He proposed and supported the application of new approaches and updated systems of management through communication and support of other members of Council.

Critically from 2017 onward Bob was out there as a sounding board, reviewer and provider of direction; particularly important considering the reduced in-person meetings. As a result of Bob's influence, membership improved and council processes were brought up to date and became more efficient. Thanks to his leadership, the Society survived COVID and was beginning to move forwards again.

The destruction of insect pests was not Bob's only interest. Apart from his role in EntSocNSW, he was a willing volunteer in other bodies, such as Marine Rescue NSW, where he was qualified both as crew and as radio officer, and had served for many years. He was involved in the movement Sailors with disAbilities, which teaches sailing skills to children and adults with physical impairment or other difficulty, the emphasis being on freedom, joy and achievement. He worked with the Sydney Heritage Fleet, volunteering at the Rozelle shipyards restoring ferries and other craft. He volunteered as crew on the heritage yacht *Boomerang* when it was hired by visitors, and also volunteered in the Heritage Fleet Library.

His association with the North Ramsgate swimming club started when his daughters were learning to swim in the 1980s, and continued until a few years ago. Truly a remarkable record of service to his community.

We will miss Bob's calm management of our society, and send our thoughts and condolences to his wife Adele, and their children and grandchildren. We thank Adele for providing extra information about Bob's activities.

PARTIAL LIST OF PUBLICATIONS AND PATENTS

Bob's Patents include innovative liquefied gases/gas mixtures for the application of fumigants, insecticides, natural biocides and deodorant chemicals. Commercial products developed by Bob include Gaseous PH_3; Gaseous PH_3/CO_2; Ethyl Formate/CO_2; Natural pyrethrum/CO_2; DDVP/CO_2; Natural Tea Tree Oil/CO_2; Odour Absorbent/CO_2 and equipment/processes to dispense gaseous/vapour mixtures.

Gallagher, M.J., Hook, J., Jeong, H.K., Ryan, R.F., Reibelt, G., and Diep, B. (1991). Pyrophoric contamination in commercial phosphine. In: *Proceedings of the 11th RACI Analytical Chemistry* Conference Hobart Tasmania, 5-7 July.

Ryan, R.F. (1988). Pesticide Boosts Export Opportunity. *Process & Control Engineering* **41:** 8.

Karunaratne, C., Moore, G.A, Jones, R., and Ryan, R. (1997a). Vase life of some cut flowers following fumigation with phosphine. *HortScience* **32:** 900-902.

Karunaratne, C., Moore, G.A, Jones, R., and Ryan, R. (1997b). Phosphine and its effect on some common insects in cut flowers. *Postharvest Biology and Technology* **10:** 255–262.

Ryan, R.F. (1990). PHOSFUME®- A gaseous phosphine grain protectant. *Chemistry in Australia, Proceedings of the Royal Australian Chemical Institute* **57:** 184.

Ryan , R.F. (1992). Attaining insect-free and residue-free status in foods. *Food Australia* **44:** 556.

Ryan, R.F. (1997). Gaseous phosphine - a revitalised fumigant. In*: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Stored Products* (Edited by Donahaye, E.J., Navarro, S. and Varnava, A.), 21-26 April 1996, Printco Ltd, Nicosia, Cyprus, pp. 305- 310.

Ryan R.F. and De Lima, C. P. F. (2013). Phosphine – an overview of a unique 80 year fumigant. *General and Applied Entomology*, **42:** 31-42

Ryan, R.F. and Latif, S. (1989). Fumigant System. US Patent 4,889,708, 26 December 1989.

Ryan, R.F. and Shore, W.P. (2005). Process and Apparatus for Supplying a Gaseous Mixture, U.S. Patent 6,840,256 B1.

Ryan, R.F. and Shore, W.P., (2010). Pre-mix and on-site mixing of fumigants. *10th International Working Conference on Stored Product Protection.* Julius-Kühn-Archiv, **425:** 419-422.

Ryan, R.F. and Shore W.P. (2012). The use of gaseous phosphine by onsite mixing. *Proceedings of the 9th International Conference on Controlled Atmosphere and Fumigation in Stored Products. Antalya Turkey.* 15-18 October 2012, pp 358-362.

Schonstein D, Shore W., Ryan, R. and Waddell, S. (1994). Controlled release of phosphine – an update. In: Highley, E.; Wright, E.J.; Banks, H.J.; Champ, B.R. (Eds.), *Stored Product Protection, Proceedings of the 6th International Working Conference on Stored-Product Protection*, 17-23 April 1994, Canberra, Australia. CAB International, Wallingford, United Kingdom, pp. 188-191.

Winks, R.G. and Ryan, R.F. (1990). Recent developments in the fumigation of grain with phosphine. In: Fleurat-Lessard, F. and Ducom, P., eds), *Proceedings of 5th International Working Conference on Stored-Product Protection, Bordeaux, France*, 9-14 September 1990, pp. 935-943.

Winks, R.G., Whittle, C.P. and Ryan, R.F. (1995). Improved methods of application for fumigating grain with phosphine and the associated benefits. In: *Proceedings of the 45th RACI Cereal Chemistry Conference, Adelaide Australia,* 10-14 September 1995, pp 526-529.

Dinah Hales and **Robin Parsons**

RISE AND DEMISE OF CHEMICALS USED FOR AUSTRALIAN GRAIN PROTECTION WITH A FOCUS ON NEW SOUTH WALES

Robert Ryan[1] and Bernard C. Dominiak[2]

[1] Principal Consultant, VAPORFAZE, PO Box 4 Sans Souci, NSW 2219, Australia
[2] NSW Department of Primary industries, The Ian Armstrong Building, 105 Prince Street, Orange, NSW 2800, Australia

Summary

Malathion is a key insecticide for the treatment of stored grain pests but its continued use patterns are under review by regulatory authorities. In this literature review, we reflect on grain storage protection issues in Australia but with a focus on New South Wales. Any grain stored for extended times is likely to become infested with storage insect pests. We review storage and export issues in early Australia and observe the challenges and changes created by two world wars, the depression and boom production years. Modern grain protection started with the use of malathion, however the detection of malathion resistance necessitated the introduction of other insecticide options. Fumigants were developed but these also suffered from the onset of resistance. The efficacy of insecticides and fumigants could be improved through combination with other gases or insecticides with different modes of action. Finally, we review the pesticides registered for grain insect pest control and speculate on prospects for grain protection.

Keywords: malathion, phosphine, ethyl formate, insecticides, fumigants, resistance,

INTRODUCTION

Export grain from Australia is a significant contributor to the country's economy; grain production in 2021/22 exceeded 60 million tonnes and AU $14 billion, with ~80% exported (ABS-ACA 2021/22). Currently, Australia enjoys a reputation for exporting "insect-free" grain, but this was not always the case. Waterhouse (1973) reported that insects infested stored grain that arrived with the First Fleet and no doubt that the early settlers tasted the added flavour of insect fragments and pheromone in their daily bread. It was simply accepted that if grain was stored for any length of time, then it became infested. Joseph Banks wrote on the Endeavour in 1769 on his way to Australia: *"Our bread indeed is but indifferent, occasioned by the quantity of vermin that are in it, I have often seen hundreds nay thousands shaken out of a single bisket"* (Waterhouse 1973). Many believed insects germinated spontaneously inside the grain. Winterbottom (1922) noted that "there were numbers of men who have been connected with the wheat trade all their lives who were adamant that every grain of wheat carries a weevil germ". This belief continued into the 1960s (Winterbottom 1922).

In New South Wales (NSW), the main grain pests were *Oryzaephilus surinamensis* (L.) sawtoothed grain beetle, *Tribolium castaneum* (Herbst) rust-red flour beetle, *Rhyzopertha dominica* (F.) lesser grain borer, *T. confusum* (Jacquelin du Val) flour beetle, *Sitophilus oryzae* (L.) rice weevil, and *Cryptolestes ferrugineus* (Stephens) rusty grain beetle (Greening 1969; Herron 1990; Wallbank 1996). Malathion became a cornerstone insecticide to treat these pests. However, currently malathion use patterns are under review by regulatory authorities and some existing use patterns may be withdrawn. Other insecticides such as bioresmethrin have entered the industry but been withdrawn (Daglish and Wallbank 2003). Therefore, it is timely to review stored grain treatments and the place that malathion has in that role. If malathion use patterns are restricted or withdrawn, our review with provide background information to develop a revised stored grain strategy into the future.

The research into the protection of grain has a long history in NSW and Australia. The Journal *General and Applied Entomology* (G&AE), published by The Entomological Society of New South Wales (NSW), has been an important contributor to applied entomology in Australia for 60 years (Volume 1 was published 1 July, 1964) (Greening 1969; Herron 1990; Wallbank 1996). In the intervening decades, GA&E papers covering applied entomology supporting Australian industry (eg Walters and Dominiak 1984; Holtkamp and Horwood 1991; Wallbank and Farrell 2002; Duric et al. 2022). G&AE became centred and managed by entomologists at the *Biological and Chemical Research Institute*, based at Rydalmere in western Sydney. Many of those entomologists, such as Barry Wallbank, Fred Attia, Howard Greening, Grant Herron, and their support staff contributed to grain treatment research. Similarly, many NSW scientists published papers in *The Agricultural Gazette of New South Wales.*

Additionally, during this period, the grain industry benefited from the CSIRO Division of Entomology's Research and Development. The Australian Grain Industry-CSIRO specialist laboratory, Stored Grain Research Laboratory (SGRL) (some 60 scientific and support staff), focussed on protection of grain from stored grain insect infestations (Wright and Morton 1995; Banks and Sharpe 1997; Wright 2003; Waterford et al. 2004). Currently, ongoing support continues with input from Grain Research and Development Corporation (GRDC), Queensland Department of Primary Industries (QDPI), New South Wales Department of Primary industries (NSW DPI), Murdoch University, chemical manufacturers, and grain industry specialists. Research has resulted in the use of many chemicals that played a part in the economic growth in the export and domestic grain markets. Here, we review some of the chemicals used in grain protection technology adopted by the Australia grain industry, with a focus on NSW.

HISTORY

Prior to 1914, most of Australia's two million tonnes of locally produced grain were consumed locally, and any for export was shipped soon after harvest, mostly to Britain. When the First World War broke out, shipping became difficult and Australia was forced to store grain in bags for years (Graver and Winks 1995). Previously, all marketable grain was exported as rapidly as possible and there was no provision for long term storage (Wilson 1953; Graver and Winks 1994). Winterbottom (1922) reported in the Wallaroo, South Australia yard alone, up to 1 tonne of weevils per day were gathered up and destroyed and he estimated a tonne contained over 1 billion insects. The second period of long-term storage of surplus grain was in the 1930's as a result of the depression (Anon 1958). The third period was during World War Two (WW2) when shipping services were diminished (Anon 1958). The peak occurred in 1942 when the carry-over stocks in Canada, USA, Australia and Argentina was equal to several years of export requirements (Druce 1950). The 1949-50 wheat crop was the second largest in NSW history resulting in longer term storage (Graham 1950). Another period occurred in 1957 when the carry-over stocks in USA, Canada and Australia was equivalent to the world export requirements for two years (Anon 1958). In essence, we see patterns where grain needs to be stored for long periods (years), and this raises challenges for protecting grain from storage insects.

As port storage facilities became full, farm storage became increasingly used. However, farm storages were of a lower quality compared to port facilities. Due to poor farm hygiene and poorer storage facilities, grain on-farm became infested and was responsible for subsequent infestations in central and port grain storages (Champ 1962). Regarding farm storage, producers used gravity feed units or spray equipment to apply insecticides to grain on conveyor belts or augers. The gravity feed systems were less costly (Minett *et al*. 1981). In an effort to combat resistant pests in farm storages, azamethiphos and mixtures of fenitrothion and carbaryl were effective treatments of concrete silo walls, and effective for six weeks (Wallbank 1982). Usually, infestations in bagged grain were distributed through most of the mass whereas infestations in bulk grain often was localised in the top layers (Champ 1963).

A wheat committee was established to consider the options which would combat weevils and other insects. These included heat treatment, poison gases, mechanical cleaning, treatment with carbon dioxide in gas-tight containers, lime treatment, sand treatment and underground storage. These are similar to some treatments that are considered today, but the ability to implement them was limited in the past. Nevertheless, in one year alone, approximately 1.7 million tonnes of grain was cleaned and sterilised. It was acknowledged then that the wheat could not be shipped "if infected with weevil" (Winterbottom 1922). Early experiments with poison gases including hydrogen cyanide and carbon disulphide failed, not surprising considering the difficulty of rendering a bag stack gastight. Additionally, the Wheat Committee sponsored experiments with controlled atmospheres. In 1918, the first silo was erected in Australia at Peak Hill, in the central west of NSW (Graver and Winks 1994). Despite grain being traded as bagged wheat into the 1960s (Winks and Ryan 1994), constructions of bulk silos proceeded at a rapid rate from 1918, only disrupted by the onset of the war years (Graver and Winks 1994).

Regarding long term storage of grain, turning of grain could lower the high temperatures caused by insect infestations, but did little to control the insects and, at worse, served to spread insects through a storage facility (Winks and Ryan 1994). Consequently, until the early 1960s, insects were an accepted component of stored grain. The only issue was whether or not their numbers reached levels that were "visible" or at which significant losses or heating/mould development occurred. Chemical treatments used during WW2 were not well documented. DDT and BHC were developed at the time (Champ 1963), and there is some evidence to suggest that after the war these insecticides were added in small quantities to mineral dust for mixing with grain (Winks and Ryan 1994). During WW2, carbon disulphide and hydrogen cyanide were used effectively to disinfect grain (Winks and Ryan 1994). Also, mixtures of ethylene dichloride and carbon tetrachloride were used (Winks and Ryan 1994). There was clearly an improvement in the methods employed to render structures gastight however it is unlikely whether they were of a standard that we now understand as gastight.

The 1949-50 wheat crop was the second largest in NSW history and seaboard storages and terminal elevators in Sydney and Newcastle became full (Graham 1950). Additionally, Britain was slow to import wheat, adding to storage woes and subsequently, the use of farm storage increased. In the 1950s, methyl bromide began to be used to disinfest both in central storage facilities and on-farms storages (Wilson 1953; Winks and Ryan 1994). Considerable and significant research into grain storage problems was undertaken during the war years (Graver and Winks 1994). There was additional funding for 19 new wheat silo storages in NSW to improve longer term storage and grain treatments (Graham 1950b).

In 1948, the Wheat Stabilisation Act created the Australian Wheat Board (AWB) as the only licenced marketer of wheat, leading to a centralisation and coordination of the industry. The AWB provided the vehicle for a centralised decision process to address the choice of pesticides; rate of application; and compliance with health and safety issues. Up until the late 1950s, Australia's principal market was Britain. It was not uncommon to receive reports of infested Australian grain. The importers did not penalise Australia and therefore, there was no specific incentive to improve. In 1958, Australia entered into a contract to sell wheat to mainland China (Graver and Winks 1994). The Chinese Authorities insisted that all shipments be accompanied by certificate stating that the grain should be inspected and that it should be "free on shipment from evidence of injurious diseases and from live insects / pests". In 1963, the federal Department of Primary Industries promulgated the Exports (Grain) Regulations which prohibited the export of grain from Australia unless it was found to be free from insect pests. (Winks and Ryan 1994).

Grain Protectants: and the *"golden age of Malathion"*.

Malathion was an insecticide which was developed after WW2 and was adopted in Australia in 1960/61 to protect wheat for export and domestic use (Watt 1962; Herron 1990; Wallbank 1996). Spraying the grain with liquid insecticides or grain protectant using malathion was trialled during the 1960/61 season (Hodgson 1961). By 1963/64, some 80% of grain shipped from Australia was treated with malathion. Most malathion was applied as grain was received into export terminals, and although the insecticide killed adults, immature stages continued to emerge during the 14-day voyage to China and other long-haul markets. Based on the life cycle of various species, a period of up to six weeks from application to shipment was needed to ensure that all insects present at the time of treatment had emerged and were killed. Clearly, the logical point of the spray application was as the grain was received into country storage. The industry very rapidly relocated their application to country receival points and so commenced the "golden age of malathion". Within the next year, complaints about insect infestations diminished to no more than several per year (Winks and Ryan 1994).

However, malathion resistance was detected in New South Wales (NSW) in 1968 (Greening 1970). The resistance could be managed with addition of the synergist triphenyl phosphate, which achieved complete mortality of malathion-resistant insects (Greening 1970). Resistance to malathion was due to its degradation by carboxyesterase, that can be inhibited by the addition of triphenyl phosphate (Dyte and Rowlands 1968). Dichlorvos was introduced in 1970 as the effectiveness of malathion declined but ultimately dichlorvos was recognised as a short-term solution to resistance (Graver and Winks 1994). Fenitrothion and bioresmethrin mixtures became available in the 1976-77 harvest and served the industry well for about 15 years (Bengston *et al*. 1977; Graver and Winks 1994). Wallbank (1982) found that azamethiphos controlled insects for six weeks and also was effective in completely treated silo cells for over 26 weeks.

Cognisant of the development of insect resistance, the AWB set up a committee to investigate Australia's ongoing technical requirements of the industry. In 1973, the Stored Grain Research Laboratory (SGRL) (located within CSIRO Division of Entomology, Canberra) was established. Using levies, the grain industry funded the SGRL and met annually to consider pest control issues and to plan pest control strategies for the coming season. From the outset of the malathion era, the question of residues was an important consideration and efforts were made to ensure the grain exported from Australia complied with the 8 ppm (malathion; mol. Wt. = 330g/mol) or 0.1g/m^3 maximum residue-level (MRL). Soon, it was found that it was not always an easy task to meet this MRL or the nil residue standard. To cope with the multiple treatments from the farm onwards, handling authorities needed to supplement their application technology with residue analysis. The ability to control export grain residue levels using analytical laboratories was demonstrated by the WA (Western Australia) Co-operative Bulk Handling Ltd, which led to the National Residue Survey (NRS). NRS operates within the Australian Government Department of Agriculture, Water and the Environment (DAWE), and since 1992 has been funded by industries through levies and direct contracts. NRS residue monitoring programs monitor the levels of, and associated risks from, pesticides and veterinary medicine residues and contaminants in Australian food products.

Malathion protected grain for up to nine months (Anon. 1969) and it was often necessary to disinfect infested grain with other chemicals such as methyl bromide, phosphine, and with hydrogen cyanide in WA (Winks and Bailey 1965). Other chemicals were used to treat surfaces of storage facilities where typically infestations were localised (Champ 1963). Prior to malathion, the most prevalent species in Australian wheat were *T. castaneum* and *S. oryzae*. In 1968, resistance was detected in *T. castaneum* in peanuts, then subsequently in *S. oryzae* from wheat. In 1972, *R. dominica* was by far the most tolerant species to malathion and doses were set to control this species. This *R. dominica* domination was presumeably due to its tolerance to malathion. Grain protectants continue to be needed (exception is WA where a large proportion of grain is delivered directly to port facilities) and are a part of the implementation plan in most states (Winks and Ryan 1994). Protectants are an alternative use especially where gastight storage is not available and where there is an outbreak of insects resistant to alternative chemistry.

WA was able to meet the increasing demand for low or residue-free grain during the late 1980s using fumigants. Up to 1994, no grain protectants were used by WA Cooperative Bulk Handling Ltd (Winks and Ryan 1994). Other states were not so fortunate because few of their storages were sealed and the move to reduce the use of grain protectants during the late 1980s posed significant problems. Progressively over the years, it became necessary to introduce other grain protectants and mixtures of new/existing protectants. For example, a bioresmethrin plus fenitrothion mixture served the industry well over 15 years (Winks and Ryan 1994). Mixtures of fenitrothion and carbaryl controlled *R. dominica* on localised areas for six weeks but provided variable effectiveness against other species (Wallbank 1982). Other chemicals used included malathion, dichlorvos, bioresmethrin, carbaryl, diazinon, pyrethrins (+ piperonyl butoxide – a synergist often used with pyrethroids) (Winks and Ryan 1994). Bioresmethrin was withdrawn from the market in the early 2000's after years of use in Australia (Daglish and Wallbank 2003). Bifenthrin was seen as part of a combined treatment and was effective against a range of grain insects except against pyrethroid-resistant insects (Daglish and Wallbank 2003). Bifenthrin, combined with piperonyl butoxide and chlorpyrifos-methyl, was effective against most grain pests for about seven months. This combination was not effective against species resistant to organophosphates and bioresmethrin (Daglish *et al.* 2003). Magnesite (magnesium carbonate) could protect stockfeed oats for up to two years when applied to oats at >10% moisture (Wallbank *et al.* 2001).

Because of widespread insect resistance, mixtures of current grain protectants were recommended together with rotations over time. The current recommended best practice for protectants is to use mixtures (*below*) and rotate every one or two years, e.g.:

*Spinosad + S-methoprene + **EITHER** chlorpyriphos-methyl **OR** fenitrothion **OR** pirimiphos-methyl*

OR

*Deltamethrin (+Piperonyl Butoxide) + **EITHER** chlorpyriphos-methyl **OR** fenitrothion **OR** pirimiphos-methyl*

OR

*Deltamethrin (+Piperonyl Butoxide.) + S-methoprene + **EITHER** chlorpyriphos-methyl **OR** fenitrothion **OR** pirimiphos-methyl*

Fumigants

Concerns about grain protectant residues and insect resistance issues led to the widespread use of fumigants. Candidate chemicals for fumigant selection need to be either gases or volatile liquids to meet the requirements of uniform distribution in the storage unit to be treated and achieve subsequent effective aeration to ensure efficacy and residue-free status. Effective fumigation depends upon the availability of sealed storage which can reach the required C x t (Concentration x exposure time). In the early 1970's, the SGRL developed the specification for sealing storages to a standard suitable for the effective fumigation (Winks and Ryan 1994); a silo is only deemed truly sealed if it passes a five-minute half-life pressure test according to the Australian Standard: AS 2628 (2010) "Sealed grain storage silos – Sealing requirements for insect control". In the early 1980s, WA commenced sealing their many sheds for effective and cheap fumigation with phosphine gas (Winks and Ryan 1994). WA was able to meet the increasing demand for residue-free grain since the late 1980s because of the decision of WA Cooperative Bulk Handling Ltd to forego grain protectants for fumigants.

Fumigants - Methyl Bromide

Pre-2005, methyl bromide (MBr) (CH_3Br) was the universal fumigant used extensively in agriculture, horticulture, soil, cut timber, logs etc. However, MBr became recognised as an ozone depleting gas and its use should be minimised. The Vienna Convention was adopted in 1985 with the intention to reduce the adverse effects of MBr in the ozone layer. Subsequently, the Montreal Protocol was signed as an international agreement in 1987 (DEP 2023). The Montreal protocol on substances that deplete the ozone layer required a phase out of MBr for applications other than quarantine and pre-shipment purposes (QPS) by January 2005. There were issues with QPS especially the amount used which is a high percentage of the former global methyl bromide consumption. Also, there were WHS concerns for local communities especially with fumigations conducted in urban areas. In keeping with the reduction of MBr use, Williams (1985) found that MBr application could be halved in an atmosphere containing >20% carbon dioxide. MBr toxicity was not reduced in the absence of oxygen although oxygen concentration influenced other fumigants such as hydrogen cyanide and ethylene dibromide (Bond *et al.* 1967). Eventually, the Montreal protocol was successful as it resulted in the replacement of a large number of chemicals that deplete the ozone layer. Specifically for MBr, its large use in soil fumigation was discontinued (DEP 2023).

Fumigants - Phosphine

The fumigants of choice were phosphine (PH_3) and MBr. PH_3 is a naturally occurring gas and is the fumigant of choice for stored products pests. PH_3 is short lived because it reacts with the atmosphere forming phosphoric acid (Fluck 1973) which is an acid used extensively as a food additive. The "solid" metallic phosphide tablets, formulated to release phosphine by reacting with moisture in atmospheric air, was patented in 1935. Phosphine has many of the properties desirable for a fumigant (e.g. high penetrant ability, low sorption on foodstuffs, very low residues, short lived). However, phosphine has a major disadvantage: it is highly flammable and explosive in mixtures with air.

The first gaseous PH_3 formulation in industrial gas cylinders was patented as a non-flammable mixture of 2wt% PH_3 in carbon dioxide (CO_2) which allowed the safe rapid dispensing of the PH_3 into the grain storage being fumigated (Ryan and Latif 1989). Early applications of high-pressure industrial gas cylinders containing a non-flammable gaseous PH_3/CO_2 mixture were successfully completed in gastight horizontal bulk grain storages up to 30,000t in WA using 0.3g PH_3 per tonne (Ryan 1988). Treatments, using gaseous PH_3 with CO_2 plus heat in USA (Mueller 1994), achieved successful fumigations in large silos and flour mills. Noting that effective fumigation depends upon concentration x exposure time (C x t) facilitated by a sealed storage environment, CO_2 aids the movement of PH_3 through commodities and the addition of heat lowers the effective dose of PH_3 required for a lethal C x t product (Zettler 1997). Recirculation of PH_3 improved by Cook (1984) included the closed-loop system (Noyes and Kenkel 1994). These technologies reduced the dosage of PH_3 required to produce a lethal C x t product in grain pests and thus improved the efficiency of conventional types of PH_3 fumigations (Zettler 1997). The CSIRO patented flow-through fumigation (SIROFLO – see below) provided a method for fumigating grain in leaky storage, resulting in many old silos being used for storage without reliance on grain protectants (Winks 1993; Graver and Winks 1994).

An additional patent for on-site mixing of pure phosphine (99% PH_3) with air had advantages of lower costs and reduction in the number of gas cylinders required (Ryan and Shore 2005). Both high pressure gaseous PH_3 cylinder products (2% premix and 99% on-site mixed) compete with the "solid products" because of their shorter exposure time (quick mixing), no spent/unreacted residues requiring disposal and the ability to simply "top-up" PH_3 to maintain the concentration. The concept of on-site mixing of PH_3 with ambient air was adopted by the grain industry

(Ryan and Shore 2005). The mixer is available in a range of sizes covering the treatment of small low flow (SIROFLO®) to large "bunker / pad" bulk storages and currently these units are being globally adopted (Shore, private communication).

Gaseous PH_3 has a long history as a dopant in electronic silicon chip technology manufacture, but initially, it was investigated as a fumigant for the control of fruit fly in mid 1970s (Ryan 1990). The fumigation grade PH_3 (99%) is of lower purity than electronic grade PH_3, however there are critical specifications for impurities such as di-phosphine (P_2H_4) and white phosphorus (P_4) which are pyrophoric (Gallagher *et al.* 1991). On-site mixing of PH_3 (99%) with air to less than 16,000 ppm (2.2g/m^3) (Ryan and Shore 2005) or premix with inert gases overcame flammability issues. Gaseous PH_3 mixtures have benefits over the solid metal phosphide formulations since they eliminate the PH_3 flammability hazard, allow accurate control of PH_3 concentration, deliver PH_3 gas more rapidly, achieve better distribution in the grain mass without disturbing grain, allow controlled flow and dosage maintenance for long periods. Gaseous PH_3 eliminates handling and disposal of the "spent" metallic phosphide tablets but it reacts with oxygen to produce a polymer. This reaction and polymers were issues in dispensing equipment and required pre- & post-purging of gaseous PH_3 dispensing systems with an inert gas. The polymer dust and associated oily phosphoric acid effects gas flow-control equipment (Schonstein *et al.* 1994.).

Flow-Through Fumigation (120 ppm (0.17g/m^3) PH_3)

Many grain storages fail to meet the specified standards of gas tightness for PH_3 application (Winks 1987). However, with appropriate modifications to the silo, flow-through technologies such as SIROFLO® (Winks 1993) or other systems using gaseous PH_3 can be used (Bell *et al.* 1993). In flow-through fumigation, a continuous airflow containing a low PH_3 concentration (~120ppm) (0.17g/m^3) is dispensed for an extended time of 3-4 weeks (Ryan 1997). The technique is effective because insect eggs and pupae, which are naturally tolerant to PH_3, continue to develop to larvae and adults while the bulk is still under fumigation (Winks and Ryan 1990). This flow through technique provides a method for fumigating grain in leaky storage and has resulted in many old silos being used for storage again and has enabled grain handlers to decrease their reliance on protectants in eastern Australia (Collins 2010).

Variables (PH_3; O_2; CO_2)

A unique characteristic of PH_3 is that it is not absorbed in the absence of oxygen, and in anaerobic environments is not toxic to insects (Bond *et al.* 1967). Kashi and Bond (1975) found that, in the presence of 4% CO_2, there was a 20% increase in the uptake of oxygen and a 3-fold increase in the toxicity of PH_3 to insects. The action of PH_3 is potentiated by carbon dioxide and the concentration and exposure time can be reduced when both CO_2 and O_2 are present. The optimum CO_2 concentration is in the range of 5-35%. At 5% CO_2, the PH_3 dose for LC_{90} efficacy can be reduced by ~50% (Kashi and Bond 1975).

Insect Resistance (PH_3)

Attia and Greening (1981) found low levels of PH_3 resistance in three grain pests in NSW in 1968-80. By 2003, PH_3 was used to disinfest about 80% of Australian grain compared to grain protectants (about 20%) (Emery et al. 2003). PH_3 was attractive to the Australian grain industry because it was easy to apply, versatile, inexpensive and well accepted internationally (Emery *et al.* 2023). However, fumigation in leaky structures results in a serious reduction in exposure time, with an increased likelihood of the development of resistance (Tyler *et al.* 1983). Since the early 1990's, the major focus in the grains industry was the monitoring of PH_3 resistance development. Research has established three levels of resistance to PH_3 ('weak', 'strong' and 'very strong'). It was suggested that once the frequency of 'weak' resistance reaches about 80% in a population, then there is a strong possibility of developing strong resistance in that species (Collins and Emery 2002). Weak resistance was considered controllable if phosphine was correctly applied (Emery *et al.* 2003). The incidence of weak resistance has grown since 1982 and strong resistance since 1997 (Emery *et al.* 2003). Where insects with strong resistance were detected, they could be eradicated if corrective measures were applied immediately before the infested bulk was moved to further sites or placed onto the market (Emery *et al.* 2003). Newman *et al.* (2004) found that many Australian farm storages did not retain PH_3 levels for the required time to be effective. They highlighted the need to maintain rubber seals in good condition to maintain the gas-tightness of fumigated storage vessels. These measures included moving the infested grain to another silo and treating with an effective grain protectant (Emery *et al.* 2003).

Furthermore, empty bins should be treated with a residual pesticide such as azamethifos (Wallbank and Farrell 2002; Emery *et al.* 2003). Collins (2010) considered that the evolution of strong resistance in *C. ferrugineus* was the greatest challenge facing the Australian grain industry since this resistance is several times greater than in any other species.

Sulfuryl fluoride (SF)
Sulfuryl fluoride (SF) is a broad-spectrum fumigant and has been a fumigant gas for over 60 years. Initially, SF was marketed as Vikane® (Dow Chemical Company) as an effective methyl bromide (MBr) alternative for structural fumigations. It was used to fumigate houses to halt damage to properties by drywood termites, wood-destroying and structure-infesting pests, including bed bugs and rodents. Frequently, MBr was used to control drywood termites but came with the disadvantage that it could react with wool, leather, foam rubber or other sulphur-containing materials to produce lingering malodorous compounds.

In 2004 with additional stored grain product claims, a food-grade SF was registered as a pesticide in the USA and is now marketed globally, including in Australia, as ProFume®. In the interim, there were additional registered SF products available. SF is used in the management of strongly PH_3 resistant *C. ferrugineus* populations in bulk grain. The SF has proven to be successful as a 'resistance breaker' where phosphine resistance is prevalent. Approved label dose for stored product pest fumigations is a maximum of 1500 g.h/m^3 CTP – not to exceed a maximum concentration of 128 g/m^3.

Ethyl Formate (EF)
EF is an historical fumigant (Ryan and De Lima 2012) now making a comeback. EF was used as fumigant to disinfest dry fruits and has a history of safe use as a food additive. EF is an effective bulk grain fumigant with sorption issues being accommodated by rapid dispensing. The lower toxicity EF usually requires relatively high dosage (70g/m^3) than other fumigants however its predominant attribute, similar to MBr, is short exposure times i.e. hours not days. EF can be used at a much lower temperatures compared to most other fumigants. EF controlled 78 insect species, albeit at different rates or exposure times, or in combination with other gases (Ryan and Dominiak 2021). These insects included five weevils, six aphids, six thrips, seven moths, 18 scale and mealy bugs, and ten beetles. Additionally, the brown marmorated stink bug (*Halyomorpha halys* (Stal)), Khapra beetle *Trogoderma granarium* (Everts), tomato potato psyllid (*Bactericera cockerelli* (Sulc), tramp ants and other biosecurity threats are good candidates for EF fumigation (Ryan and Dominiak 2021).

Therefore, EF application needs to be applied to current fumigation hot spots within grain storages. Currently, there is continuing pressures on fumigants due to registration requirements, atmospheric emissions controls, concerns surrounding operator safety and human health, and the incidence of resistance. These changes are occurring as the world expects increasingly high standards of pest control in international trade (Bell 1993). The in-transit fumigation of shipping containers conducted using a non-flammable mixture of 90g/m^3 EF in nitrogen, allows travel from Perth to Barrow Island (>2000 km) while fumigating full container loads of food and equipment. The EF in transit fumigation, Fume8 Technology, uses an onsite nitrogen generator or nitrogen bottles with liquid EF to produce a safe, cost effective, fast acting and environmentally friendly gas fumigant (Coetzee 2020).

EF was approved for the quarantine fumigation of containers in New Zealand (NZ) against brown marmorated stink bug *H. halys* (NZ Ministry for Primary Industries, 2023). NZ Biosecurity specify the treatment must achieve the C x t product (>142g.h/m^3), minimum concentrations endpoints (EF = 19.5g/m^3 & CO_2 = 3%), and temperature (>10ºC). Additionally, this approval includes Yellow Spotted Stink Bug (*Erthesina fullo* (Thunberg)), ants and spiders. (Approved Biosecurity Treatments, MPI-ABTRT, 8 June 2023).

We propose that the registrations of EF have not kept pace with recent research due to the existing preference for other fumigants. However, there is an increasing number of plant biosecurity incursions (Anderson *et al.* 2017) and there is a need to ensure registered uses are current to optimise biosecurity needs in Australia.

Resistance continues to develop
Resistance to insecticides and fumigants is a long-standing issue for grain storage. Ideally, grain should be removed from all equipment immediately after harvest has been completed (Greening 1969). For optimal storage, grain should be fully matured and not contain excessive moisture which favours insect infestation (Anon. 1969). Unfortunately, in a survey of 15 farms, Greening (1969) found insect pests in 14

farms reflecting inadequate cleaning and a lack of attention to detail in the clean-down of machinery. Attia (1981) reported insecticide resistance (to malathion, DDT and dieldrin) in moths of grain and stored products. Shortly afterwards, Attia and Frecker (1984) reported low levels of resistance (<10-fold) to DDT, dichlorvos, chlorpyifos-methyl, bioresmethrin and pyrethrins and moderate resistance (<40-fold) to lindane, malathion and pirimiphos methyl. They found synergistic resistance between several insecticides including malathion, fenitrothion and fenitrooxon. There were high levels of resistance (>160-fold) to fenitrothion (Attia and Frecker 1984).

Herron (1990) tested for resistance in bioresmethrin, carbaryl, chlorpyrifos-methyl, fenitrothion, malathion, phosphine and pirimiphos-methyl; resistance levels with as high as 70% to pirimiphos-methyl in one species. Low level phosphine resistance and malathion resistance was detected in all species. Carbaryl and bioresmethrin were used to control multi-organophosphate resistant insects and no resistance was detected. Chlorpyrifos-methyl was used successfully in NSW to control fenitrothion resistant insects despite some levels of resistance to chlorpyrifos methyl (Herron 1990). Resistance to fenitrophion was detected in 50% of tested populations with resistance up to 68-fold. Additionally, Herron (1990) detected resistance to chlorpyrifos-methyl and pirimiphos-methy in 39% and 70% of tested populations with a maximum resistance factor of 8.4 and 44.2 respectively. In subsequent testing, Wallbank (1996) found resistance to fenitrothion was detected in 95% of populations tested with resistance up to 85-fold. Wallbank (1996) detected resistance to pirimiphos-methyl in 95% of tested samples with up to 55-fold resistance. There was resistance to chlorpyrifos-methyl in 67% of tested populations with resistance up to 32-fold (Wallbank 1996). Additionally, 75% of tested populations were resistant to all three insecticides. Combination treatments with different pesticide groups, and different modes of action, was considered to slow the development of resistance to any single insecticide (Daglish *et al.* 2003).

Poor farm practices were a contributor to resistance development (Wallbank 1996). Additionally, the storage of grain beyond the recommended maximum storage period for a given pesticide is conducive to resistance development (Wallbank 1996). Storage units need to be gas tight to minimise the development of resistance to fumigants (Winks and Ryan 1994), and this was not always achieved or possible.

Residues

In the 1980's, pesticide residues gained prominence and became part of quality demands by importers (Graver and Winks 1994). Additionally, Australian flour millers set lower residue limits to ensure compliance with maximum residue limits (MRL) (Graver and Winks 1994). Incorrect use of protectants was one cause of MRL breaches. This was exacerbated in structures that were not gastight (Graver and Winks 1994). The use of SIROFLO® applications enabled industry to meet the increasing demand for low-residue grain (Winks 1993; Graver and Winks 1994). Despite the effectiveness of SIROFLO® technology, grain protectants continue to be used by industry and are expected to be used for some time to come, even with looming insect resistance/tolerance and pesticide residue issues.

Current registrations and pesticide reviews

Currently, amorphous silica, betacyfluthrin, carboxin, chloropicrin, chlorpyrifos-methyl, diatomaceous earth, diazinon, dichlorvos, EF, fenitrothion, malathion, MBr, PH_3 (mostly from aluminium phosphide), pirimiphos-methyl, SF, and methoprene are all registered for stored grain use (APVMA 2023). However, the volumes used vary depending on local preferences.

Most pesticides are reviewed periodically for occupational exposure, efficacy, environmental fate and other reasons. Currently, malathion is under review by the APVMA (Australian Pesticides and Veterinary Medicines Authority), however the review focuses on field crop applications (APVMA 2023). Fenitrothion active constituents, chemical products and labels were nominated for review in response to an invitation to the public made by the APVMA (then the NRA) on 1 November 1994. Eighty of the nominated chemicals, including fenitrothion, were included in the priority candidate review list published in the Gazette on 2 May 1995. In March 2004, the APVMA released the fenitrothion draft review report and publication of the proposed regulatory decision is expected in April 2024 (APVMA 2023).

DISCUSSION

Grain protectants are still used by the industry and will continue to be used for some time to come. To achieve totally pesticide-free storage systems, disinfestation must be conducted by fumigation in certified sealed storages to maintain adequate concentration of fumigant for the desired exposure time prior to ventilation. That is, there should be investment into sealed storages similar to the investment initiated by WA Cooperative Bulk Handling, 40 years ago (Barry 1984).

We speculate that phosphine is likely to continue to dominate grain fumigants over the foreseeable future. However, there are several other alternative fumigants available and utilised by industry. Alternative fumigants include: hydrogen cyanide, EF, cyanogen (EDN) and carbonyl sulphide. However, a great deal of work remains to be done on potential new pesticides before candidate products seek registration for commercial use.

Phosphine satisfies residue considerations and in this regard is not considered a major human health threat when used correctly. However in the context of efficacy, resistance has been recorded since the mid-1960s. Recently, very high levels of resistance were identified and a “resistance break” strategy using a program of alternative fumigants was employed to combat resistant populations.

In addition to alternative fumigants, other options include controlled atmosphere storage using either carbon dioxide or low oxygen atmospheres, currently utilised by niche fumigation of organic grain and food products. The CSIRO division of entomology showed that aeration has a place in the storage of grain in Australia at least in the southern States where suitable ambient conditions were available. Grain aeration can reduce grain temperature to less than 15ºC which ensures that any insects are moribund i.e. no population increase until temperature is elevated which ensures static population growth albeit for the cold months (GRDC 2021).

All levels of the grain storage industry need to be aware of storage pests and to use existing pesticides optimally to minimise and combat the development of resistance. The results of the APVMA review of the malathion use patterns will determine if malathion can continue to be used in much the same way as it currently is. If malathion use patterns are restricted, the grain protection industry will be obligated to re-configure the available pesticides used or develop other management techniques. Any reduction in malathion use patterns is likely to increase the resistance pressure on the remaining pesticides.

ACKNOWLEDGEMENTS

Jenene Kidston provided information from the APVMA and reviewed a pre-submission version of the manuscript. Aphrika Gregson and Trevor Klein reviewed a pre-submission version of the manuscript.

REFERENCES

ABS-ACA (2021/22). Agricultural Commodities, Australia https://www.abs.gov.au/statistics/industry/agriculture/agricultural-commodities-australia/latest-release.

Anderson, C., Low-Choy, S., Whittle, P., Taylor, S., Gambley, C., Smith, L., Gillespie, P., Locker, H., Davis, R. and Dominiak, B. (2017). Australian plant biosecurity surveillance systems. *Crop Protection* **100**: 8-20.

Annis, P.C. (2001). Phosphine dosage regimes required for high mortality: A data-base approach. Donahaye, E.J., Navarro, S. and Leesch J.G. [Eds.] (2001) Proceedings of. International Conference on Controlled Atmosphere and Fumigation in Stored Products, Fresno, CA. 29 Oct. - 3 Nov. 2000, Executive Printing Services, Clovis, CA, U.S.A. pp. 45-55.

Anonymous (1958). Australia’s position in the growing world trade in wheat. *Agricultural Gazette of New South Wales.* **69**: 620-622.

Anonymous (1969). Insect pests of stored grain. *Agricultural Gazette of New South Wales.* **80**: 601.

APVMA (2023). (Australian Pesticides and Veterinary Medicines Authority) http://apvma.gov.au (various nodes) accessed 17 October 2023.

Australian Standard 2628. (AS 2628) (2010). The Australian Standard “Sealed grain storage silos - Sealing requirements for insect control” 11th Mar. 9 pages.

Attia, F.I. (1981). Insecticide resistance in pyralid moths of grain and stored products. *General and Applied Entomology* **13**: 3-8.

Attia, F.I. and Greening, H.G. (1981). Survey of resistance to phosphine in coleopterous pests of grain and stored products in New South Wales. *General and Applied Entomology* **13**: 93-97.

Attia, F.I. and Frecker, T. (1984). Cross-resistance spectrum and synergism studies in organophosphorus-resistant strains of *Oryzaephilus surinamensis* (L.) (Coleoptera: Cucugidae) in Australia. *Journal of Economic Entomology* **77**: 1367-1370.

Banks, H.J. and Sharp, A.K. (1979). Insect control with CO_2 in a small stack of bagged grain in a plastic film enclosure. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**: 102-107.

Barry, C. (1984). Western Australia Studies of Sealing Horizontal Storages in 1980-82. *Developments in Agricultural Engineering* **5**: 269-280.

Bond, E.J., Monro, H.A.U. and Buckland, C.T. (1967). The influence of oxygen on the toxicity of fumigants to *Sitophilus granaries* (L). *Journal of Stored Products Research* **3**: 289-294.

Bell, C.H., Chakrabarti, B. and Mills, K.A. (1993). Use of a cylinder-based formulation of phosphine as a control strategy for floor-stored grain. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Grain Storages (Edited by Navarro, S. and Donahaye, E.), Winnipeg, Canada, 11-13 June 1992, Caspit Press Ltd., Jerusalem, 379-388.

Bengston, M., Cooper, L.M. and Grant-Taylor, F.J. (1975). A comparison of bioresmethrin, chlorpyrifos-methyl and pirimiphos-methyl as grain protectants against malathion resistant insects in wheat. *Queensland Journal of Agricultural and Animal Sciences* **32**: 51-78.

Champ, B.R. (1963). Control of stored grain pests in Queensland. *Entomological Society of Queensland* **2**: 1-3.

Carmi, Y., Golani, Y. and Frandji, H. (1990). Fumigation of a silo bin with a mixture of magnesium phosphide and carbon dioxide by surface application. In: Proceedings of 5th International Working Conference on Stored-Product Protection (Edited by Fleurat-Lessard, F. and Ducom, P.), Bordeaux, France, 9-14 September 1990, 767-773.

Coetzee, E.M. (2020). Exploration of ethyl formate + nitrogen as a fumigant for shipping containers and their in-transit fumigation. https://researchportal.murdoch.edu.au/esploro/outputs/doctoral/Exploration-of-ethyl-formate--nitrogen/991005542552207891#file-0

Collins, P.J. (2010). Research on stored product protection in Australia: a review of past, present and future directions, In: Carvalho, M.O. et al (Eds) Proc. 10th Int. Working. Conference on Stored Product Protection, 27 June - 2 July 2010, Estoril, Portugal. Julius Kuhn-Archive 425, Berlin, pp3-13.

Cook, J.S. (1984). The use of controlled air to increase the effectiveness of fumigation of stationary grain storages. In: Developments in Agricultural Engineering V: Controlled Atmosphere and Fumigation in Grain Storages (Edited by Ripp, B.E.), Elsevier Science Publishers, New York, 419-424.

Daglish, G.J. and Wallbank, B.E. (2003). An update on development of bifenthrin as a grain protectant. In Proceedings of the Australian Post harvest Technical Conference, Canberra 25-27 June 2003. 71-74.

Daglish, G.J., Wallbank, B.E. and Nayak, M.K. (2003). Synergized bifenthrin plus chlorpyrofis-methly for control of beetles and psocids in sorghum in Australia. *Journal of Economic Entomology* **96**: 525-532.

DEP (2023). Department of Environmental Protection. https://www.dcceew.gov.au/environment/protection/ozone/montreal-protocol. Accessed 12 October 2023.

Druce, P.C. (1950). The outlook for wheat. *Agricultural Gazette of New South Wales* **61**: 177-180.

Duric, Z., George, J. and van Leur, J. (2022). *Megoura crassicauda* Mordvilko (Hemiptera: Aphididae), a potential threat to Faba bean industry in New South Wales. *General and Applied Entomology* **50**: 11-17.

Dyte, C.E. and Rowlands, D.G. (1968). The metabolism and synergism of malathion in resistant and susceptible strains of *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). *Journal of Stored Product Research* **4**: 157-173.

Emery, R.N., Collins, P.J. and Wallbank, B.E. (2003). Monitoring and managing phosphine resistance in Australia. In: Proceedings of the Australian Postharvest Technical Conference, Canberra. 25-27 June 2003. 142-151.

Fluck, E. (1973). The Chemistry of Phosphine. In: *Topics in Current Chemistry*. Vol 35 (Springer Vertag N.Y 1973) p. 22.

Gallagher, M.J., Hook, J., Jeong, H.K., Ryan, R.F., Reibelt, G. and Diep, B. (1991). Pyrophoric contamination in commercial phosphine. In: Proc. 11th RACI Analytical Chemistry Conference Hobart, Tasmania, 5-7 July.

Graver, J.S. and Winks, R.G. (1994). A brief history of the entomological problems of wheat storage in Australia. In: Stored Product Protection. Proceedings of the 6th International Working Conference on Stored Product Protection (Vol. 2, pp. 1250-1258). Canberra, Australia: CAB International.

GRDC (2021). The-importance-and-process-of-optimising-grain-aeration-systems
https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/03/the-importance-and-process-of-optimising-grain-aeration-systems. 3 March Update Paper.

Graham, E.H. (1950a). Terminal elevators full: wheat shipments held up. *Agricultural Gazette of New South Wales.* **61**: 224.

Graham, E.H. (1950b). Big programme of silo additions. *Agricultural Gazette of New South Wales.* **61**: 176.

Greening, H.G. (1969). Grain insects in farm machinery and storages. *Agricultural Gazette of New South Wales* **80**: 554-557.

Greening, H.G. (1970). Malathion resistance in the rust-red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in New South Wales. *Journal of the Australian Entomological Society* **9**; 160-162.

Herron, G.A. (1990). Resistance to grain protectants and phosphine in Colopterous pests of grain stored on farms in New South Wales. *Journal of the Australian Entomological Society* **29**: 183-189.

Hodgson, S.C. (1961). Australian history in the making. *Pybuthrin Digest* **1**(3): 5-7.

Holtkamp, R.H. and Horwood, M.A. (1991). Residual activity and persistence in insecticides toxic to *Bruchophagus roddi* Gussakovski (Hymenoptera: Eurytomidae). *General and applied Entomology* **23**: 9-13.

Kashi, K.P. and Bond, E.J. (1975). The toxic action of phosphine: Role of carbon dioxide on the toxicity of phosphine to *Sitophilus granarius* (L.) and *Tribolium confusum* DuVal. *Journal of Stored Products Research* **11**: 9-15.

Minett, W., Williams, P. and Amos, T.G. (1981). Gravity feed application of insecticide concentrate to wheat in a commercial silo. *General and Applied Entomology* **13**: 59-64.

Mueller, D.K. (1994). A new method of using low levels of phosphine in combination with heat and carbon dioxide. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Stored-Product (Edited by Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R.), Canberra, Australia, 17-23 April, 1994, CAB International, Wallingford, Oxon, UK, 1, pp. 123-125.

Newman, C.R., Daglish, G.J., Wallbank, B.E. and Burrill, P.R. (2004). Investigation into control of phosphine-resistant *Rhyzopertha dominica* in sealed farm silos fumigated with phosphine. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Stored-Product (Edited by Donahaye, E.J., Bell, S., Jayas, D., Noyes, R., Phillips, T.W.), Gold Coast, Australia. 8-13th August 2004.

Noyes, R.T. and Kenkel, P. (1994). Closed loop fumigation systems in the south-western United States. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Stored-Product (Edited by Highley, E., Wright, E.J. Banks, H.J. and Champ, B.R.), Canberra, Australia, 17-23 April, 1994, CAB International, Wallingford, Oxon, UK, pp. 335-341.

New Zealand Ministry for Primary Industries (NZ MPI) (2023). Approved Biosecurity Treatments, MPI-ABTRT, 8 June 2023.

Ryan, R.F. (1988). Pesticide Boosts Export Opportunity. *Process & Control Engineering* (PACE) **41**: 8.

Ryan, R.F. (1990). PHOSFUME® - A Gaseous Phosphine Grain Protectant. Chemistry in Australia, *Proceedings of the Royal Australian Chemical Institute* **57**: 184.

Ryan, R.F (1997). Gaseous Phosphine - A Revitalised Fumigant. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Store d Products (Edited by Donahaye, E.J., Navarro, S. and Varnava, A.), 21-26 April 1996, Printco Ltd, Nicosia, Cyprus, pp. 305- 310.

Ryan, R.F. and De Lima, C.P.F. (2012). Overview of ethyl formate – 85 years as a fumigant. *General and Applied Entomology* **41**: 49-54.

Ryan, R.F. and Dominiak, B.C. (2020). Review of ethyl formate use in Australia and possible future uses for emerging biosecurity risks. *General and Applied Entomology* **48**: 82-90.

Ryan, R.F. and Latif, S. (1989). Fumigant System. US Patent 4,889,708, 26 Dec. 1989.

Ryan, R.F. and Shore, W.P. (2005). Process and Apparatus for Supplying a Gaseous Mixture, U.S. Patent 6,840,256 B1.

Schonstein, D., Shore, W., Ryan, R. and Waddell, S. (1994). Controlled release of phosphine – an update. In: Highley, E.; Wright, E.J.; Banks, H.J.; Champ, B.R. (Eds.), Stored Product Protection, Proceedings of the 6th International Working Conference on Stored-Product Protection, 17-23 April 1994, Canberra, Australia. CAB International, Wallingford, United Kingdom, 1994, pp. 188-191.

Tyler, P.S., Taylor, R.W. and Rees, D.P. (1983). Insecticide resistance to phosphine fumigation in food warehouses in Bangladesh. *International Pest Control* **25**: 10-21.

Wallbank, B.E. (1982). Effectiveness of structural treatments against grain insects in a concrete silo. *General and Applied Entomology* **14**: 7-12.

Wallbank, B.E. (1996). Resistance to organophosphorus grain protectants in *Oeyzaephilius surinamensis* (L.) (Coleoptera: Silvanidae) from off-farm grain storages in New South Wales. *Australian Journal of Entomology* **35**: 193-195.

Wallbank, B.E., Nicholls, A.W. and Saleh, F. (2001). Effectiveness of magnesite as a protectant of farm stored oats. *General and Applied Entomology* **30**: 49-54.

Wallbank, B.E. and Farrell, J.F. (2002). Development of phosphine resistance in *Rhyzopertha dominica* in southern New South Wales, and strategies for containment. In: Wright, E.J., Banks, H.J. and Highley, E. ed. Stored grain in Australia 2000. Canberra, CSIRO Stored Grain research Laboratory, 105-108.

Waterford, C. J., Ren, Y., Lee, B. H., Mahon, D. and Ryan, R. F. (2004). Carbonyl sulphide and ethyl formate update. In: Proceedings of the 2004 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions **31**: 60-61.

Waterhouse, D.F. (1973). Insects and wheat in Australia. Farrer memorial oration. *Journal of the Australian Institute of Agricultural Science* **39** (4), 215-226.

Walters, P.J. and Dominiak, B.C. (1984). The establishment in New South Wales of *Trioxys complanatus* Quilis (Hymenoptera:Aphidiidae), an imported parasite of *Therioaphis trifolii* (Monell) *f. maculata*, spotted alfalfa aphid. *General and Applied Entomology* **16**: 65-67.

Watt, M.J. (1962). Grain protection with malathion. *Agricultural Gazette of New South Wales* **73**: 529-534.

Williams, P. (1985). Toxicity of methyl bromide in carbon dioxide-enriched atmospheres to beetles attacking stored grain. *General and Applied Entomology* **17**: 17-24.

Wilson, F. (1953). Some wartime problems of insect infestation in Australian stored wheat. Paper presented at the 7th Pacific Science congress, Auckland and Christchurch, 1949. **4**: 206-210.

Winks, R.G. (1987). Strategies for effective use of phosphine as a grain fumigant and the implications of resistance. In: Donahaye, E., Navarro, S. (Eds.), Proceedings of the 4th International Working Conference on Stored Product Protection, Tel Aviv, Israel, 1986, pp. 335-344.

Winks, R.G. (1993). The Development of SIROFLO in Australia. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Grain Storages (Eds.) Navarro, S. and Donahaye, E., Winnipeg, Canada, 111-13 June 1992, Caspit Press Ltd., Jerusalem, pp. 399-410.

Winks, R.G. and Bailey, S.W. (1965). Treatment and storage of export wheat in Australia. *Tropical Stored Products Information* **11**: 431.

Winks, R.G. and Ryan, R.F. (1990). Recent Developments in the Fumigation of Grain with Phosphine. In: Proceedings of 5th International Working Conference on Stored-Product Protection (Edited by Fleurat-Lessard, F. and Ducom, P.), Bordeaux, France, 9-14 September 1990, pp. 935-943.

Winks, R.G. and Ryan, R.F. (1994). The History of Chemical Grain Protection in Australia, Chemistry in Australia, September 1994, pp.515-517

Winks, R.G., Whittle, C.P. and Ryan, R.F. (1995). Improved methods of application for fumigating grain with phosphine and the associated benefits. In: Proceedings of the 45th RACI Cereal Chemistry Conference, Adelaide, Australia, 10-14 September, 1995, pp. 526-529.

Winterbottom, D.C. (1922). Weevil in wheat and storage of grain in bags: A record of Australian experience during the War period (1915 to 1918). Government Printer, Adelaide, 1922, p122.

Wright, E.J. and Morton, R. (1995). Daily flight activity of *Trogoderma variabile* (Coleoptera: Dermestidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae). *Journal of Stored Products Research* **31**: 177-184.

Wright, E.J. (2003). Carbonyl sulfide (COS) as a fumigant for stored products: progress in research and commercialisation. In: Proceedings of the Australian Postharvest Technnical Conference, Canberra, Australia.25-27 June 2003, 224-229.

Zettler, J.L. (1997). Influence of resistance on future fumigation technology. In: Proceedings of International Conference on Controlled Atmosphere and Fumigation in Stored Products (Eds.) Donahaye, E.J., Navarro, S. and Varnava, A., 21-26 April 1996, Nicosia, Cyprus, pp. 445-454.

Submitted 21/12/2023 Revised 28 /2/2024 Accepted 14/3/2024

This page is left blank intentionally.

SCIENTIFIC NOTE

EDUCATION IS THE KEY TO SUCCESS: THE LEARNING JOURNEY OF PARASITOID WASPS

Elise Oakman

School of Life and Environmental Science, the University of Sydney, Science Road, Camperdown NSW 2050
Email: elise.oakman@sydney.edu.au

Summary

The learning journey for parasitoid wasps to find their host is unique to species. All parasitoid wasps need exposure to the correct plant volatile compound, so that they can learn how to find their hosts as adults. Depending on the wasp species, they may require multiple exposure events throughout their life cycle. *Aphidius ervi*, for example, is a species that requires two exposure events, whereas *Hyssopus pallidus* only requires one. Due to species differences, these learning opportunities must be tailored to species. It's important to understand this, because in artificial rearing conditions, incorrect or absent learning opportunities results in subpar integrative pest management.

Keywords: plant volatiles, exposure, host, chemical compounds

INTRODUCTION

The interaction between parasitoid wasp and host can be so fast, you might blink and miss it. What we see is the result of a lifelong learning journey. What we don't see is how the wasps, even from their larval stage, learn to respond to plant volatile compounds to achieve their goal (Gandolfi *et al.* 2003a,b; Tokemoto *et al.* 2012). Plant volatile compounds are produced by plants when they are damaged through herbivory (Unsicker *et al.* 2009). Parasitoid wasps can learn to respond to the compounds presence to find their host insect (Gandolfi *et al.* 2003a,b; Tokemoto *et al.* 2012). Parasitoid wasps are utilised as an important aspect of integrated pest management in agriculture (Wang *et al.* 2019). They act as a line of defence against the threat of insect pest species such as aphids (Wang *et al.* 2019; Tokemoto *et al.* 2012). It's important to understand the learning needs of wasps that are reared for this purpose. Wasps that do not know how to find their host using plant volatile compounds are a poor line of defence.

THE LEARNING PROCESS: A CASE STUDY FOR *APHIDIUS ERVI*

Parasitoid wasps begin learning from the larval stage (Takemoto *et al.* 2012; Gandolfi *et al.* 2003b). However, some wasps require multiple learning exposures (Takemoto *et al.* 2012). The wasp *Aphidius ervi* needs exposure in their larval stage, but also as an adult (Takemoto *et al.* 2012). They need multiple exposures to be able to learn and retain the information (Takemoto *et al.* 2012). Conversely, other species don't need multiple exposures throughout their life (Gandolfi *et al.* 2003b). There is no hard rule for the learning requirements the wasps need, as the learning process varies between species. Species can vary in the plant volatile compound they need present to learn, and the level of exposure required (Takemoto *et al.* 2012; Gandolfi *et al.* 2003b). It's important to understand the variety of learning requirements between species. Failing to tailor learning experiences to specific species can result in wasps that find it harder to find their host insects as an adult.

Aphidius ervi demonstrated their requirement for learning opportunities at both the larval and adult stage (Tokemoto *et al.* 2012). This double exposure provided *A. ervi* with a learned preference for the right plant volatile compound for their hosts plant (Tokemoto *et al.* 2012). Alternatively, other *A. ervi* that had been exposed to clean air with no volatiles at either of these stages, indicated no preference for different plant volatile compounds (Tokemoto *et al.* 2012). This research demonstrated that this wasp species needed two exposure events, and that one exposure event was not enough.

For *A. ervi*, failure to be exposed to the plant volatile cues that indicated that the aphids (their host insect) were present, resulted in preferences for plant volatile compounds that did not benefit the wasps (Takemoto *et al.* 2012). The wasps in their natural environment would respond to the volatile compounds of *Vicia faba*

(Takemoto *et al.* 2012). If they are not exposed to these specific compounds as a larva, they might respond to plants that are not associated with their host in the wild (Takemoto *et al.* 2012). Exposure to different combinations of plant volatiles (clean air and plants not associated with their host) at larval and adult stages, created different non-beneficial preferences (Tokemoto *et al.* 2012). Ultimately, absence of exposure to specific plant volatiles impacted their ability as an adult.

THE LEARNING PROCESS: A CASE STUDY FOR HYSSOPUS PALLIDUS

The wasp species, *Hyssopus pallidus*, is also impacted by the absence of learning opportunities as a larva (Gandolfi *et al.* 2003b). These wasps use the plant volatile compounds of the host plant (an apple tree in this case), but also the chemical cues provided by the frass of the caterpillar host (Gandolfi *et al.* 2003b). It's important to recognise the difference between *H. pallidus* and *A. ervi*. While both wasps are responding to and learn from plant volatiles, it is occurring only from specific plants. Exposure to the plant volatile compounds provided by the apple trees as a larva, meant as adults they had a stronger response to the chemical cues provided by the caterpillar frass (Gandolfi *et al.* 2003b).

Similarly, Gandolfi *et al.* (2003a), found that when these wasps were exposed to caterpillars impacting a non-host plant, it once again resulted in a situation where the wasps didn't learn to prefer the right plant. The host insects were provided with a wheat germ diet instead of an apple tree diet (Gandolfi *et al.* 2003a). This diet resulted in exposure to different plant volatiles (Gandolfi *et al.* 2003a). The wasps showed no preference between apple tree produced frass and wheat germ frass (Gandolfi *et al.* 2003a). This would impact them as adults, since their caterpillar host in natural environments utilises apple trees, not wheat (Gandolfi *et al.* 2003a).

In this situation, a second exposure of the chemical cues as an adult were not required (Gandolfi *et al.* 2003b). The information was retained from their larval stage, as a clear example of pre-imaginal learning (Gandolfi *et al.* 2003b). Previously, Gandolfi *et al.* (2003a) found that this association with the apple tree volatile compounds could only be learned as a larva. Failure to ever be exposed to the plants chemical cues as a larva could not be corrected in their adult stage (Gandolfi *et al.* 2003a). The absence of this learning opportunity affected them for the rest of their lives.

CLOSING COMMENTS

It's important to realise that the learning process is not a "one size fits all" situation. It is essential for crop managers to receive optimum biological control, and therefore, learning methods must be tailored to the species. Parasitoid wasps can be reared and released to protect crops from pests, but their success at this is impacted by the presence of species tailored learning opportunities (Gandolfi *et al.* 2003a,b; Tokemoto *et al.* 2012). The failure to learn what plant volatile compounds are the right ones to respond to, can result in subpar biological control in crops (Gandolfi *et al.* 2003b). How biological control agents respond to plant volatile cues is incredibly important (Gandolfi *et al.* 2003a). Therefore, testing their response can decide whether they will be effective in integrated pest management (Gandolfi *et al.* 2003a). In artificial rearing conditions, it is up to program managers to ensure wasps are exposed to these learning opportunities to achieve the best result in biological control. Continuing to expand our understanding of parasitoid wasp learning needs, will be critical in their use in biological control schemes going into the future.

ACKNOWLEDGEMENTS

Bernie Dominiak reviewed a pre-submission version of this manuscript.

REFERENCES

Gandolfi, M., Mattiacci, L. and Dorn, S. (2003a). Mechanisms of Behavioral Alterations of Parasitoids Reared in Artificial Systems. *Journal of Chemical Ecology* **29**: 1871 – 1887.

Gandolfi, M., Mattiacci, L. and Dorn S. (2003b). Preimaginal Learning Determines Adult Response to Chemical Stimuli in a Parasitic Wasp. *Proceedings of the Royal Society of London. Series B: Biological Sciences* **270**: 2623 – 2629.

Takemoto, H., Powell, W., Pickett, J., Kainoh, Y. and Takabayashi J. (2012). Two-Step Learning Involved in Acquiring Olfactory Preferences for Plant Volatiles by Parasitic Wasps. *Animal Behaviour* **83**: 1491 – 1496.

Unsicker, S., Kunert, G., and Gershenzon J. (2009). Protective Perfumes: The Role of Vegetative Volatiles in Plant Defense against Herbivores. *Current Opinion in Plant Biology* **12**: 479 - 485.

Wang, Z., Liu, Y., Shi, M., Huang, J., and Chen X. (2019). Parasitoid Wasps as Effective Biological Control Agents. *Journal of Integrative Agriculture* **18**: 705

Submitted 26/2/2024. Accepted 2/4/2024

NECTAR-ROBBING BEHAVIOUR BY HONEY BEES ON *ALSTROEMERIA PSITTACINA*

Dinah Hales
Independent Researcher

Summary
Nectar-robbing behaviour by honey bees, *Apis mellifera* L., was observed on parrot lilies, *Alstroemeria psittacina* Lehm., in a garden in Beecroft NSW in December 2022. Bees approaching the base of the flower alighted briefly and inserted their mouthparts between the petals and sepals, but no biting behaviour was observed. In a survey of flowers, about half were found to have sections bitten out of the base of petals, the most likely agents being small black ants. Despite the extensive nectar-robbing, pollination of the flowers was successful in nearly all cases, indicating that nectar-robbing had no detrimental effect. The structure and development of the flowers were studied and it was notable that the stamens retained their pollen caps until they hung below the opening of the corolla, making unaided self-pollination unlikely. Individual bees approached the mouth or the base of the flowers. Experiments set up in November 2023 did not clarify whether the bees were robbers, thieves or both, because of the scarcity of bees following *Varroa* mite introduction. Pollination rates were lower than in the previous season. I concluded that both bees and ants were nectar robbers. Their behaviour did not affect pollination in 2022, but pollination was reduced in late 2023 when bee numbers were low.
Key words: pollination, ants, nectar thieves, *Varroa* mite

INTRODUCTION

Nectar-robbing is a process in which bees or other pollinators obtain nectar without contacting female parts of the flower and therefore do not provide pollination services. There is a large body of recent literature on the topic. Irwin *et al*. (2010) reviewed evolutionary aspects of the relationship between plants and nectar robbers. Lichtenberg *et al*. (2020) observed that individual bumblebees showed either nectar-robbing or "legitimate" behaviour, but not usually both. Andalo *et al*. (2019) showed experimentally that nectar robbing did not affect seed production in *Antirrhinum*. Rojas-Nossa *et al*. (2021) studied the effects of nectar robbers on reproductive success of honeysuckle plants, concluding that the effects of nectar-robbers could be neutral. In contrast, Kohl and Steffan-Dewenter (2022) found that in some circumstances, related to elevation, nectar-robbers significantly reduced seed production. Some authors distinguish between nectar-robbers and nectar-thieves, the latter making use of holes made by other insects, but the term is not used consistently. For example, Peach and Gries (2016) refer to mosquitoes as potential nectar thieves although their feeding is direct, rather than facilitated by a robber as defined above. Relationships among nectar robbers, nectar thieves, "legitimate" feeders and pollination can be complex and require experimental analysis (Zhang *et al*. 2014). The presence of nectar thieves or robbers can have unexpected effects on other pollinators. Bees, especially bumblebees, generally gain entry to the bases of flowers via holes made with their mandibles, or holes made by other robbers, often unidentified, but including carpenter bees (Dedej and Delaplane, 2004).

Leonard *et al*. (2013) discussed the role of honey guides on flowers in modifying the behaviour of potential nectar robbers, and used a cultivar of *Alstroemeria* as a model flower. The possibility that flower damage by robbers might affect the visual or physiological attractiveness of flowers to legitimate pollinators was experimentally discounted by de Souza *et al*. (2019). There are many other observational and experimental studies on interactions among plants, robbers, thieves and legitimate pollinators.

Alstroemeria psittacina Lehm. is a weed pest of pastures in eastern NSW and is toxic to livestock. It can self-pollinate but still produces large amounts of nectar, attractive to bees and ants. Self-pollination is possible in *Alstroemeria* (Bridgen, 2018) and asexual reproduction occurs by budding from tubers or rhizomes. In late 2022, honey bees, *Apis mellifera* L. were seen apparently nectar-robbing flowers of *A. psittacina* in a garden in Beecroft NSW. Observations were made until most flowers had gone to seed. Bees landing at the base of flowers rapidly probed between adjacent petals and sepals (Figure 1). Field observation suggested that they depended on gaps arising naturally between the plant elements rather than chewing to create spaces. This hypothesis may not be correct: small black ants identified by the author as *Ochetellus glaber* (Mayr) were frequent visitors to the flowers (Figure 2) and may have been assisting access by the bees by deleting small sections of the margins of flower elements. If so, bees using these spaces could be regarded as robbers, thieves or both. The ant identification was based on the description by Shattuck (1992) supported by high-resolution online photographs as in PIAkey and antweb I report observations on bee behaviour and flower phenology over two flowering periods in December 2022 and December 2022.

Figure 1. Bee (*A. mellifera*) robbing nectar at the base of *A. psittacina* flower

Figure 2. Ants at base of *A. psittacina* flower

METHODS

Four patches of *A. psittacina* were selected for observation. Patch 1 was the largest, approximately 3.m x 1 m, partially in the sun most of the day. Patch 2 was along a fence, about 2.5 m x 0.5 m, and was exposed to sun all afternoon. Patch 3 was about 2.5 m x 1 m part was exposed to sun and part remained in shade. The density of flowers was lower than in the preceding two patches. Patch 4 was along the southern wall of a house and 2-3 m long and about 0.5 m deep. It had a low density of flowers.

Bees were observed for 10 min for each patch, once a day, as in Table 1. I counted bees landing in the mouth of flowers, or apparently feeding at the base of the flowers. Bees landing at the mouth of the flowers and attempting to enter the flower were noted. Observations were discontinued after 28 December, as few new flowers were being produced and few bees were attracted to the patches. The possible role of ants was examined by dissecting mature flowers to check for damage. A sample of 25 flowers was dissected on 14 January, and the number of deletions at the bases of flower elements was recorded.

The development of individual flowers was examined by tagging one flower head with well-developed buds at each site, and recording it photographically each day. Pollination rates were assessed by the number of seed capsules present after the end of flowering.

A follow-up experiment was started in the second week of November 2023, attempting to determine whether the bees were robbers or thieves. At this time only one flower head on *Alstroemeria* in Patch 1 had any opened buds. Some plants from this area, with small, uncoloured buds were excavated and potted. Ants were excluded from some plants using a water barrier. Bees were excluded from some flower heads by enclosing them in fine white plastic tree mesh, giving four treatments with four plants in each, -A-B, +A-B, -A+B, and +A+B, where A is ants and B is bees. The plants were placed in plastic trays in the same locality where they had originally grown, i.e. Patch 1. Four other plants growing undisturbed nearby served as additional +A+B controls. It was confirmed that ants could access the plants in the trays. Prior observations of bees on netted citrus trees indicated that they did not pass through the mesh, but accessed flowers via the open base of the netting. The trial was observed twice daily. Successful pollination was assessed by counting the number of seed capsules per flower head on undisturbed plants. Flower heads generally carried 8-9 flowers (Table 2).

RESULTS AND DISCUSSION

Table 1(p.18) shows observations of bee visits to flowers in 10 min observation periods in the summer of 2022-3. Patch 1 had many more visits than the other patches, probably because of its size, though other factors such as aspect could also have influenced the results. Visits to the bases of flowers always outnumbered visits to the mouth. The three smaller patches, except Patch 2 on two occasions, showed the reverse pattern, with visits to the mouth of the flower more frequent than to the base. Sometimes only one or two bees were present at a patch during an observation period. In these cases it was possible to follow the behaviour of individuals: each bee was to a large degree consistent in probing the base or alighting at the mouth of the flower, as observed also by Nagano and Yokoi (2022) who found that more experienced foragers went to the flower base. Some bees landed briefly at the mouth of the flower and were observed to lick or nibble at the pollen caps on immature stamens, but others attempted to work their way further down the corolla tube. This was generally unsuccessful, as the basal part of the *A. psittacina* flower is narrow and blocked by the bundle of stamen filaments and the pistil. Bees could possibly reach nectar by this route in times of high nectar flow. Bees were not collecting pollen and any pollen transferred by them was incidental. Most flowers were successfully pollinated, as shown by the development of seed capsules. Though native bees (*Tetragonula*, *Amegilla*) are present in the garden, they were not seen to visit the flowers.

Dissection of a sample of flowers taken on 14 January 2023 showed that nearly half had small sections bitten out of the margins of one or two petals/sepals. These flowers ranged from young (still with pollen caps) (n=1), to mature (n=5), to flowers that were beginning to wither (n= 6) or actually withered (n=13). The flower in the "young" category had no deletions, but for the other categories, about half were bitten, with one or two areas damaged. I concluded that the ants had caused the damage by biting away small areas of the petal margin Even the "young" flower in this sample showed gaps between the petals and sepals at the base, and direct robbing by bees remains the most likely mode of nectar collection. The experiment to distinguish between ant and bee activity was not successful for three major reasons. The potted *Alstroemeria* plants did poorly, and the bee-excluding covers distorted flower growth. The main problem, however, was the almost complete absence of bees following introduction of the *Varroa* mite (*Varroa destructor* Anderson and Trueman) to the Sydney area in 2023. Bees in the preceding summer may have come largely from feral colonies in nearby bushland. Feral colonies do not usually survive *Varroa* infestation. I observed two bee visits to the bases of flowers and immediately inspected the basal ends of petals and sepals for damage. The structures were intact, supporting the nectar robbing scenario. In this system bees rob nectar without damaging flowers to gain access. In the absence of bees, pollination was inefficient. Table 2 shows that the majority of flower heads assessed had fewer than half the potential number of seed capsules, i.e. over half the flowers were not successfully pollinated.

Although self-pollination is possible in *Alstroemeria*, the structure and development of the flowers makes it unlikely. *A. aurea* is protandrous (Aizen and Raffaele 1996), with pollen produced before pistil maturity. Observations in the present study lead to the same conclusion. Newly-opened flowers contain stamens with pollen caps covering the anthers. As the stamens lengthen, the anthers (still with pollen caps) hang below the petals and the stigma does not reach the mouth of the flower. The timeline for flower life from bud opening is as follows. Day 1-3: buds begins to open. Four or five buds on a flower head open approximately at the same time. Day 4: stamens with capped and uncapped anthers present, do not extend beyond petals. Day 6: uncapped anthers hang down, extending beyond petals and pistil extends to end of petals. Day 9: stamens withering, and second group of buds opening. Day 10: petals and sepals withering. Day 14: all petals fallen from the first group of flowers and seed capsules are present. Hence the lifespan of individual flowers is about two weeks from bud opening to loss of petals and sepals, and the flowering season occupies about seven weeks from mid-November to the beginning of January, although occasional flowers were seen as late as March.

From these observations, I conclude that honeybees are the main pollinators of *Alstroemeria*, but they double as nectar robbers, probing between the bases of floral elements. They may be assisted in this by deletions in petals/sepals made by ants, though if this occurs, it is probably by accident rather than directed behaviour. Deletions are not necessary for nectar robbing by honeybees. Pollination is inefficient in the absence of bees, suggesting that self-pollination is not a general occurrence. *Alstroemeria* may have a low level of self-pollination, and other minor pollinators may contribute, including native bees, flies, moths, but these have not been observed in the present studies.

Table 1 Number of bee visits in 10 minutes to the base or mouth of flowers of *Alstroemeria psittacina*

Date	Patch	Time	Weather	Bees at base of flower	Bees at mouth of flower	Bees enter flower	Notes
17.12.2022	1	1455	cool, overcast	40	22	2	
	2		in sun	9	40	15	
	3		in shade	2	3 *		
	4			8	29	3	
18.12.22	1	1200	overcast	41	1**		
	2			8	23	15	
	3		rain	No bees			
	4		rain	No bees			
19.12.22	1	1450	sunny, windy	40	11		
	2			22	8	2	
	3			0	11	5	
	4			9	16	5	
20.12.22	1	1520		44	12	3	
	2			28	37	18	
	3			0	11	5	
	4			9	16	5	
21.12.22	1	1625	warm, breeze	40	11	4	
	2			12	21	10	
	3			0	20	6	one bee
	4			30	0		
22.12.22	1	1700	light rain	38	13		
	2			No bees			
	3			No bees			
	4			0	9		one bee
23.12.22	No obs						
24.12.22	1	1215	hot	34	18	1	
	2			21	6	2	2 bees
	3			0	0		
	4			2	25	15	1 bee
25-26.12.22	no obs						
27.12.22	1	1730	sun	33	15	7	
	2			5	5	2	
	3			No bees			Abt 12 flower heads
	4			No bees			Abt 12 flower heads
28.12.22	1	1020	sun	28	13	4	
	2,4			No bees			
	3			0	19	14	

Table 2. Numbers of fertilised flowers per flower head in undisturbed plants in January 2024, assessed by development of seedpods. *Top line shows possible number of seedpods per flower head, and the remainder of the table shows how many flower heads from each patch had that number of fertilised flowers. For example, at Patch 1, 14 flower heads had 4 fertilised flowers.*

	No. fertilised flowers per flower head	0	1	2	3	4	5	6	7	8	9	Total
Frequency of flower heads with given number of fertilised flowers	Patch 1	1	1	6	5	14	7	2	0	2	3	41
	Patch 2	0	1	8	4	6	2	5	2	0	0	28
	Patch 3		1		1	2						4
	Patch 4			1			1					2

REFERENCES

Aizen, M. and Raffaele, E. (1996). Nectar production and pollination in *Alstroemeria aurea*: responses to level and pattern of flowering shoot defoliation. *Oikos* **76:** 312-322. doi:10.2307/3546203

Andalo, C., Burrus, M., Paute, S., Lauzeral, C. & Field, D. L. (2019). Prevalence of legitimate pollinators and nectar robbers and the consequences for fruit set in an *Antirrhinum majus* hybrid zone. *Botany Letters*, **166:** 80-92. https://doi.org/10.1080/23818107.2018.1545142

Antweb: www.antweb.org. Accessed 6 March 2024.

Bridgen, M.P. (2018). *Alstroemeria*. In: *Ornamental Crops* (pp.231-236). Ed. Johan van Huylenbroeck**,** Springer Cham. doi:10.1007/978-3-319-90698-0_10

Dedej, S. and Delaplane, K.S. (2004). Nectar-robbing carpenter bees reduce seed-setting capability of honey bees (Hymenoptera: Apidae) in rabbiteye blueberry, *Vaccinium ashei*, `Climax'. *Environmental Entomology* **33:** 100-106. https://doi.org/10.1603/0046-225X-33.1.100

Irwin, R.E., Bronstein, J.L., Manson, J.S. and Richardson, L. (2010). Nectar robbing: ecological and evolutionary perspectives. *Annual Review of Ecology, Evolution and Systematics* **41:** 271-292. https://doi.org/10.1111/oik.07556

Leonard, A.S. and Papaj, D.R. (2011). 'X' marks the spot: the possible benefits of nectar guides to bees and plants. *Functional Ecology* **25:** 1293-1301. https://doi.org/10.1111/j.1365-2435.2011.01885.x

Lichtenberg, E.M, Irwin, R.E. and Bronstein, J.L. (2020). Bumble bees are constant to nectar-robbing behaviour despite low switching costs. *Animal Behaviour* **170:**177-188. doi/10.1016/janbehav.09.008

Nagano, Y. and Yokoi, T. (2022). Honeybees with extensive foraging experience rob nectar more frequently. *The Science of Nature* **109:** 11. https://doi.org/10.1007/s00114-021-01781-7.

Peach, D. and Gries, G. (2016). Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes. *Arthropod-Plant Interactions* **10:** 497-506. DOI:10.1007/s11829-016-9445-9

PIAkey: https://idtools.org/id?ants/pia/PIAkeyv2.html. (Accessed 6 March 2024)

Rojas-Nossa, S.V., Sánchez, J.M. and Navarro, L. (2021). Nectar robbing and plant reproduction: an interplay of positive and negative effects. *Oikos* **130**: 601-608. https://doi.org/10.1111/oik.07556

Shattuck, S.O. (1992). Generic revision of the ant sub-family Dolichoderinae (Hymenoptera Formicidae). *Sociobiology* **21:** 1-181. (No doi found)

de Souza C.V., Salvador M.V, Tunes, P., Di Stasi, L.C. and Guimarães, E. (2019). I've been robbed! – Can changes in floral traits discourage bee pollination? PLoS ONE **14:** e0225252. https://doi.org/10.1371/journal.pone

Zhang, Y-W., Zhao J-M. and Inouye, D.W. (2014). Nectar thieves influence reproductive fitness by altering behaviour of nectar robbers and legitimate pollinators in *Corydalis ambigua* (Fumariaceae). *Journal of Ecology* **102**: 229–237. doi: 10.1111/1365-2745.12166

Submitted 5/3//2024 Accepted 29/3/2024

This page is left blank intentionally.

OXYGEN CONSUMPTION OF MASS-REARED QUEENSLAND FRUIT FLY *BACTROCERA TRYONI* (FROGGATT) PUPAE IN SEALED PLASTIC BAGS

Jennifer Ekman[1], Benjamin G Fanson[2] & Bernard C Dominiak[3*]

[1] NSW Department of Primary Industries, Research Road, Narara, New South Wales, 2250, Australia, now Applied Horticultural Research, 1 Central Avenue, Australian Technology Park, Eveleigh, New South Wales, 2015.
[2] Department of Environment, Land, Water and Planning, Arthur Rylah Institute for Environmental Research, 123 Brown Street, Heidelberg Victoria, 3084 Australia
[3] NSW Department of Primary Industries, The Ian Armstrong Building, 105 Prince Street, Orange, New South Wales, 2800, Australia
*Correspondence: E-mail: bernie.dominiak@dpi.nsw.gov.au

Summary

The sterile insect technique (SIT) has been used for more than 50 years to manage a range of insects around the world. SIT is becoming a major component of many area-wide fruit fly management programs. Irradiation of immature life stages induces sterility in adults, and after a pre-release holding period, the emerged adults are distributed over large areas to mate with wild flies, resulting in no viable offspring. However, irradiation in normal air (about 21% oxygen (O_2)) results in declining adult quality. To optimise the quality of sterile adult flies, pupae are sealed in plastic bags for a pre-determined period before irradiation. It was assumed that this improved tolerance to irradiation due to depletion of O_2 inside the bags, thereby reducing metabolic activity of the pupae. In our trials, we measured the respiration rates for up to 84 minutes of Queensland fruit fly (Qfly), *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) pupae inside sealed containers at 17ºC and 27ºC and before and after irradiation (four treatments). Respiration was minimised (<1ml.kg^{-1}.h^{-1}) at approximately 3% and 5.6% O_2 at 27ºC and 17ºC respectively. The model indicated that a standard barrier film bag containing 800g bag of Qfly pupae and 100ml headspace would fall to 6% O_2 within approximately 3h at 17ºC but only 30 minutes at 27ºC. Irradiation both suppressed and increased variability of O_2 consumption, with the greatest effects at 60-65 and 70-75 Gy in atmospheres close to air. This is consistent with previous observations that irradiation disrupts metabolic activity, reducing development rates and increasing variability of eclosion. Suppression of metabolic activity at relatively high O_2 partial pressures likely reflects a key role for CO_2 in suppressing pupal respiration. Our results are discussed in terms of optimising pupal fitness by reducing metabolic activity during irradiation, while avoiding negative impacts due to extended periods of O_2 deprivation.

Key words: insect mass production, insect quality parameters, sterile insect technique, survival, hypoxia, Diptera, Tephritidae

INTRODUCTION

The Sterile Insect Technique (SIT) is a biological control method for insects and originally postulated by Knipling (1955). SIT has been used in broad-scale management of some of the world's most economically and medically damaging pests (e.g., screwworm, fruit flies, tsetse fly, codling moth, and pink bollworm) (Krafsur 1998). SIT is ecologically attractive because it is highly targeted at a single species and is pesticide free (Hendrichs *et al*. 1983; Fisher *et al*. 1985; Fisher 1996; Suckling *et al*. 2014). Therefore, SIT has become a major component of many area-wide fruit fly management programs and systems approaches focussed on trade (Krafsur 1998; Dominiak 2019; Reynolds *et al*. 2012, 2022). In SIT programs, large numbers of sterile insects are released, overflooding the wild population. The wild population declines because the mating of wild and sterile flies produces no viable offspring (Meats 1996; Shelley and McInnis 2016; Mastrangelo *et al*. 2018). The continued introduction of sterile flies causes the eventual demise of the wild population.

All SIT programs rely on mass rearing facilities to produce large quantities of sterile insects. Standard procedures ensure that the insects produced are consistently high quality (Boller *et al*. 1981; Caceres *et al.* 2007; FAO/IAEA/USDA 1999, 2003). For fruit flies, pupae are the most commonly produced final stage and it is this lifestage that is irradiated and transported to field release centres. Queensland fruit fly (Qfly), *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) is the most economically important pest of fruit crops in eastern Australia (Dominiak and Mapson 2017). In 1996, a mass rearing facility was built at the Elizabeth Macarthur Agricultural Institute (EMAI), Camden in southern Sydney, to support SIT (Fanson *et al*. 2014). Procedures included using the bag method to create low O_2 atmospheres around pupae during irradiation.

Irradiation of immature life stages induces sterility in adults. However, the process needs to be managed carefully to limit insect stress. Irradiation in reduced O_2, or 100% nitrogen atmospheres can reduce formation of toxic free radicals and peroxides, improving insect quality (Ashraf *et al*. 1975; Ohinata *et al.* 1977). For example, Nestel *et al.* (2007a) evaluated the effect of irradiation on *Ceratitis capitata* (Wiedemann) (Medfly) under different levels of O_2. They found that mating competitiveness greatly decreased when pupae were irradiated in open packaging with full access to normal air. In sealed bags, O_2 concentrations of 2% and 10% at the beginning of irradiation did not affect the mating competitiveness of males compared to males irradiated under maximum hypoxia. Irradiation in low O_2 atmospheres is an accepted method in most mass-rearing and sterilisation facilities (FAO/IAEA/USDA 2003). However, the mechanism still is not fully understood, despite considerable research (Nestel *et al.* 2007a).

Methods of reducing oxygen levels in pupal tissue have been studied in several species. For Medfly, nitrogen flushing and similar techniques were used only where rearing and irradiation occur at the same location (Ohinata *et al.* 1977; Nestel *et al.* 2007a). This equipment is not permitted inside the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, in Sydney, which is about two hour's drive from the mass rearing at EMAI. Therefore at EMAI, sealing pupae in plastic bags offered a simpler method to decrease the level of O_2 in pupal tissue (bag method) (Nestel *et al.* 2007a). Oxygen consumption of Medfly pupae in plastic bags approached zero after 80 min, with the time to reach maximum hypoxia influenced by pupal age and temperature (Nestel *et al.* 2007a).

Dominiak *et al.* (2011) reported on eclosion changes for Qfly pupae held in plastic bags for up to 192h. However, the oxygen levels inside the bags were not tested. For normal operations at EMAI, pupae were simply sealed in plastic bags for 24h and it was assumed that O_2 levels were reduced to hypoxic levels before irradiation. Here, we report on tests conducted to evaluate O_2 consumption of Qfly at two different temperatures and at four irradiation treatments.

MATERIALS AND METHODS

Trial establishment and management

Tests were conducted on pupae from production batches between 16 November to 21 December 2011 (for production details, see Dominiak *et al.* 2008; Fanson *et al.* 2014). In each experiment, 800 g of 8-day-old pupae (at the 2-day pre-eclosion stage) were placed into 2L low density polyethylene plastic bags (approximately 150μm thick) and stored at 17°C. The tops of the bags were folded over several times and taped shut, making an airtight seal. About 18h after sealing, the samples were loaded into insulated white styrene foam boxes and transported (about 2 h one-way) in an air-conditioned passenger vehicle to ANSTO, Lucas Heights in Sydney. Previous observations indicated that the temperature inside the insulated boxes did not change significantly during this journey. The bagged pupae were irradiated by a Co_{60} GATRI in-ground gamma irradiator at a nominal dosage of 50-55, 60-65 or 70-75 Gy and then returned to EMAI. Additional sealed 'control' bags were not irradiated or transported to ANSTO, but otherwise stored under similar conditions within the laboratory (approximately 20ºC) during assessments.

Table 1. Schedule of experiments, the treatments, the number of replications, treatment temperature and time of evaluation.

Date	Treatment	Number of replications	Treatment temperature	Time of evaluation (minutes)
16 Nov 2011	Unirradiated	4	27	32
	60-65	6	27	38
	70-75	6	27	38
	Unirradiated	6	17	84
23-24 Nov 2011	Unirradiated	6	27	38
	60-65	6	27	38
	70-75	6	27	38
21 Dec 2011	Unirradiated	6	27	38
	50-55	6	27	38
	70-75	6	27	38

Oxygen consumption

Oxygen assessments (unless stated otherwise) were conducted in the EMAI quality control laboratory which was maintained at 27 ± 1 °C and 65 ± 5% RH with artificial lighting (L12:D10, with 1 h ramping up and down to simulate dawn and dusk (Fanson *et al*. 2014)). Initial calibration of equipment occurred on 10 November 2011. Two experiments were conducted. Experiment 1 (16 Nov 2011) assessed the oxygen consumption and respiration rates of unirradiated pupae at 17°C (6 reps) and 27°C (4 reps). Experiment 2 was conducted at 27°C over 3 days (Table 1), and assessed the oxygen consumption and respiration rates of unirradiated pupae (16 reps) compared to irradiated pupae: 50-55 Gy (6 reps), 60-65 Gy (12 reps) or 70-75 Gy (18 reps) (Table 1).

For each assessment, all bags (irradiated and unirradiated) were opened at the same time and placed in open trays for at least ten minutes to allow pupae recover from the altered atmospheres inside the bags and reach room temperature. Pupae have a high surface area relative to their volume, so it seemed probable that internal gas concentrations would approximate those in air within a minute or two of opening the bags. Nestel *et al*. (2007a) considered O_2 and CO_2 levels to have stabilised after 10 minutes when testing anoxia in Medfly pupae. It was assumed that 10 minutes was also sufficient for pupal respiration to recover once the atmosphere returned to normal, but this was not assessed.

Two subsamples of 250 g (from each 800 g irradiated sample) of pupae were placed inside 600 mL tubs. The head space of the closed container was estimated to be 432.5 ml (pupal volume = weight x 1.83). The KE-25 O_2 sensors (GS Japan Battery Co. Ltd, Osaka) were sealed into the tub lids using silicone sealant. These sensors have a mV output proportional to the partial pressure of O_2, reading approximately 12-14mV in air (21% O_2). Sensors reading 10mV or less in air were not used as this indicated the electrochemical sensor had aged. KE-25 sensors have a fast response time, making them ideal for measuring respiration. However, they must be calibrated daily to adjust for changes in atmospheric pressure. Sensor readings were taken using a digital voltmeter. Readings were taken every two minutes for up to 84 minutes. At the end of each run, the tubs were opened and pupae discarded.

Data analysis

All analyses were conducted using Rv3.6 (R Core Team (2017)). For each model, assumptions were assessed using graphical assessment of the model residuals, checking for homoscedasticity, normality, outliers and remaining relationship between predictors and residuals. Initial readings were discarded to allow time for the internal atmosphere to settle. We calculated respiration rates (RR) $(\mathrm{ml}^{-1}.\mathrm{kg}^{-1}.\mathrm{h}^{-1})$ as follows:

$$\text{respiration rate} = \frac{\text{change in oxygen (\%)} \times \text{container head space (ml)}}{100 \times \text{weight (kg)} \times \text{reading interval (h)}}$$

Data was approximately linearised through taking the natural log of O_2 consumption rate.

First, the relationship between respiration rates and oxygen (%) in the containers at two different temperatures (17°C and 27°C) was modelled. We ran a linear mixed model (LMM). Respiration rate was the response variable. Oxygen (log-transformed), temperature and the interaction were included in the model. We included a random slope and intercept for each container to account for the correlation within each container. This model was compared to the null model (no temperature included) using AIC (Akaike Information Criteria) to assess if temperature affected RR.

Next, we asked if irradiation affected pupal metabolism indicating a decline in pupal quality. We performed a similar LMM to the temperature model, except temperature was replaced with irradiation dose. Also, date and date-by-oxygen interaction was included as experiments were replicated over three separate temporal periods. To better assess whether irradiation dose affected, we compared the following models by comparing AIC: (1) model with four doses (unirradiated, 50-55Gy, 60-65Gy, 70-75Gy); (2) three doses (unirradiated, 50-55Gy, 60-65Gy/70-75Gy); (3) two doses (unirradiated vs. irradiated); and (4) no dose (null model).

RESULTS

Temperature effects

Not surprisingly, temperature affected respiration rates ($\Delta AIC = 51.4$; Table 2). Oxygen levels decreased more slowly at 17°C, reaching 9.0% (SD: 0.93) after 84min. In contrast, at 27°C oxygen reached the 5% threshold at the 34min mark in all containers. Respiration rates (O_2) were more than four times higher at 27ºC than at 17ºC, regardless of partial pressure of O_2. At 27ºC, respiration was rapidly inhibited as O_2 levels declined.

The relationship of respiration rate to O_2 partial pressure was accurately described by the equation

$RR(O_2) = [28.38 \times \ln(\%O_2)] - 30.081$; $R^2 = 0.9709$. The relationship between partial pressure and respiration rate (RR) could be approximated by the equation $RR = [9.6708 \times \ln(\%O_2)] - 15.702$, but R^2 was only 0.5409. Nevertheless, this modelling indicated that O_2 consumption approached zero ($<1 ml.kg^{-1}.h^{-1}$) at 3% and 5.6% O_2 at 27°C and 17°C respectively.

Table 2: ANOVA results for the statistical models. Temperature model had two temperatures: 17°C and 27°C. Irradiation dose was the fourdose model: Unirradiated, 50-55, 60-65, and 70-75Gy.

Type	Variable	F value	df	p-value
Temperature	oxygen	64.7	1, 39.4	<0.001
	temperature	528.1	1, 15	<0.001
	oxygen:temperature	128.4	1, 25.4	<0.001
Irradiation	oxygen	488.7	1, 42.8	<0.001
	irradiation	55.5	3, 24.2	<0.001
	group	6.8	1, 24.1	0.016
	oxygen:irradiation	74.9	3, 34.2	<0.001
	oxygen:group	11.6	1, 44	0.0014

Irradiation effects

Similarly, irradiation dose affected the rate of change in O_2 over time ($\Delta AIC = 60.0$ compared to no dose model, see Table 2). Respiration rates of irradiated pupae were significantly lower than those of the unirradiated pupae (Figure 1). The magnitude of the irradiation dose (50-55 vs 60-65 vs 70-75Gy) did not affect respiration rates, as indicted by two dose model (unirradiated vs. irradiated) having the lowest AIC ($\Delta AIC = 5.5$ compared to four dose model). The difference between O_2 consumption rates of irradiated and unirradiated pupae was greatest as O_2 partial pressures approached those of normal air. As O_2 decreased close to 5%, rates of O_2 consumption by irradiated pupae approached those of the unirradiated pupae.

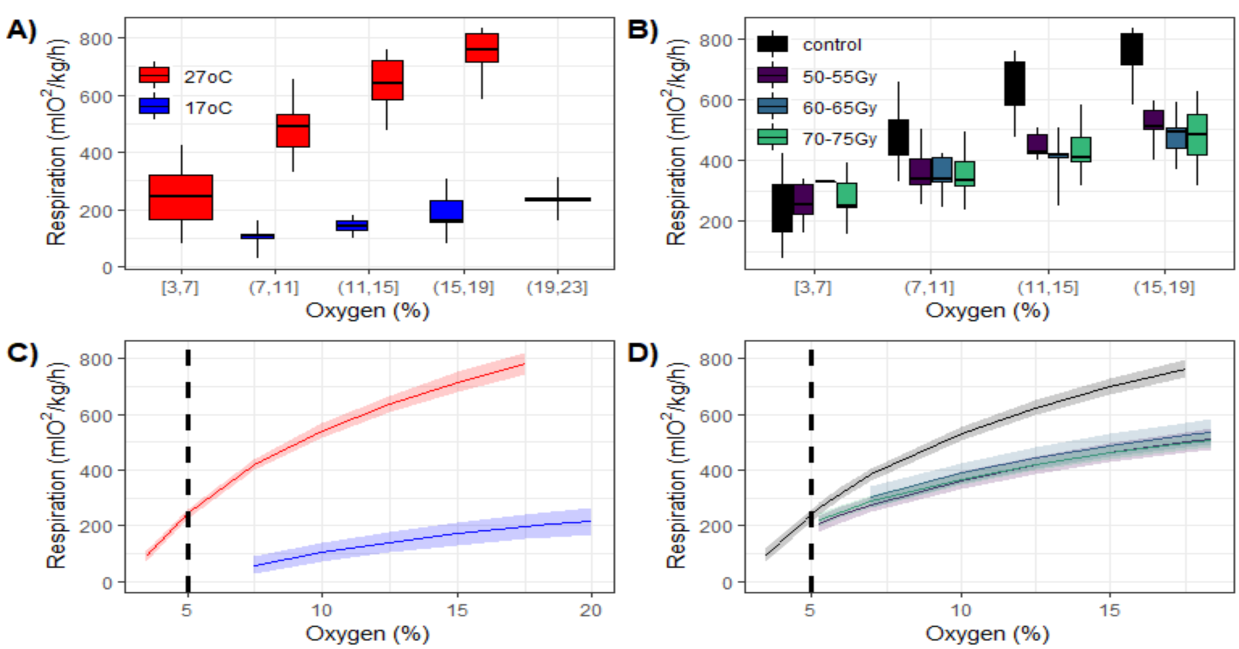


Figure 1: Relationship between respiration rates and oxygen (%) levels. Panels A and B show boxplot of raw respiration rates (binned by oxygen) for temperature and irradiation experiments, respectively. Panels C and D show the modelled relationships. Error bars are 95% confidence intervals. Vertical dashed line shows 5% threshold.

DISCUSSION

Mammals and birds can survive only a few minutes without oxygen, but many insects are adapted to withstand damage from severe O_2 deprivation (Visser *et al.* 2018). In the case of fruit flies, late instar larvae feed by tunnelling into environments with little or no available O_2 (Callier *et al.* 2015). Also, fruit flies pupate in the soil, where wet conditions can lead to extended periods of hypoxia. Therefore, fruit flies have a relatively high tolerance to O_2 stress. For example, larvae of Oriental fruit flies (*Bactrocera dorsalis* Hendel) can survive up to 24h of anoxia without significant reductions in survival. However only 4% survived after 60h and there was 100% mortality at 84h (Deng *et al.* 2018). Similar results were reported for *Anastrepha ludens* (Loew), with 72h anoxia achieving 100% mortality (Lara-Perez *et al.* 2019). In contrast, nearly 83% of Qfly pupae survived 72h of low O_2 conditions (Dominiak *et al*. 2011).

Dominiak *et al*. (2011) speculated that Qfly were relatively tolerant of anoxic conditions due to their origin in the wet tropics, where soils are frequently saturated. However, this does not explain why Qfly appears to be better adapted to anoxic conditions than Oriental fruit fly, even though the latter is a lowland pest found in high rainfall areas (Ekesi *et al.* 2006). Comparing the two species directly, using the same experimental conditions, could answer whether this observation is an experimental anomaly or a true difference between species.

Brief exposure to hyoxia can provide cross tolerance to other stresses, including the extreme oxidative stress incurred during irradiation. Fruit fly pupae irradiated in low O_2 or no O_2 environments perform better than flies irradiated in normal air (Zumreoglu *et al.* 1979; Lopez-Martinez *et al.* 2016). For example, only 1h of exposure to full anoxia increased emergence and flight ability of irradiated Caribbean fruit flies (*Anastrepha suspensa* Loew), and this result was attributed to stimulation of antioxidant enzyme activity (Lopez-Martinez and Hahn 2012). There was significantly improved tolerance by *B. dorsalis* to irradiation in 0% or 2% O_2, but above 4% O_2 there was no difference from ambient air (Zhan *et al.* 2020).

Since 1996 at EMAI, Qfly pupae were held at 17°C to compress seven days of production into one day's irradiation treatment. Pupae were placed in plastic bags for about 18h and stored overnight at 17°C because the time taken to reach hypoxia at 17°C was not known. Our results indicate that 800g pupae, sealed inside a bag made of barrier film and with 100ml headspace, would deplete the atmosphere to close to 5% O_2 within approximately 3h at 17°C but only 30 minutes at 27°C. However, at 17°C, respiration was almost completely inhibited once O_2 concentration fell to 6-7%, and that level that would be reached in approximately 2h in the model above. Frequently, headspaces inside the bags used were less than 100ml, which would further reduce the time required to minimise respiration and, therefore metabolic activity.

Because of the extreme inhibition of respiration that occurs at a relatively high O_2 partial pressure, we suspect that CO_2 may be more important than O_2 in suppressing metabolic activity by Qfly pupae. In our trial, CO_2 accumulation was not measured. However, assuming a respiratory quotient close to 1, a decrease in O_2 to 7% should be associated with an increase in CO_2 to approximately 14%. Although fruit flies were highly tolerant of a 100% nitrogen atmosphere, an atmosphere containing 1% O_2 and 15% CO_2, when combined with high temperature, was an effective disinfestation treatment against western cherry fruit fly (*Rhagoletis indifferans* Curran) (Neven and Rehfield-Ray 2006). Similarly, a short exposure to 95% CO_2 reduced the time needed to achieve 100% mortality of Qfly (Golding *et al.* 2012), whereas a similar exposure to 1% O_2 had no effect.

Similar to O_2 consumption, CO_2 emission is a function of respiration rate, so CO_2 emission increases at high temperatures and is reduced at atmospheres that deviate significantly from air. In addition, Nestel *et al.* (2007b) found that CO_2 emission followed a quadratic function with high metabolic activity in the first hours of metamorphosis, a lower level in the mid-pupal period and increasing up to adult emergence. The role of CO_2 in irradiation tolerance requires further research.

Many facilities use procedures to decrease O_2 or to increase CO_2 to minimise the adverse effects of irradiation. Based on our results, sealing pupae inside bags 18h prior to irradiation is likely to result in hypoxic conditions for 48h or even longer, this being the interval between initial bagging and receival at release centres. Sealing pupae inside bags on the day of irradiation, rather than the day before will still result in depletion of O_2 to 5-6% or less prior to irradiation. This could reduce the total time pupae remain hypoxic by about 16 hours. Benelli *et al.* (2021) recommended avoiding prolonged periods of hypoxia for Qfly pupae due to effects on adult fly vigour.

Further research should examine whether punching an air-hole in bags post-irradiation, further reducing the time pupae remain hypoxic, can improve pupal development. Already, there is evidence that increasing the time inside sealed bags reduces fitness; Dominiak *et al.* (2011) reported eclosion rates of 86.3% after 32h and 83.8% after 48h in pupae stored at 17ºC in sealed plastic bags. Also, additional research is required to verify the CO_2 and O_2 levels that accumulate inside the bags prior to and post irradiation as it is unclear whether the bags used are full barrier films or somewhat permeable to gas exchange.

Additionally, our results demonstrate that irradiation both suppresses and increases variability of pupal respiration. We suspect that irradiation damages a range of metabolic functions, even when pupae are irradiated at the recommended maturity (2 days pre eclosion). This is unsurprising considering the purpose of irradiation is to irreversibly damage reproductive function. Respiration is a measure of metabolic activity, and we suggest that irradiation reduces the rate of pupal maturation, and likely contributes to variable eclosion rates. Lower doses of irradiation, that still result in 100% sterility, may optimise fitness. Some research has been conducted (Collins *et al.* 2009; Dominiak *et al.* 2014; Bloomfield *et al.* 2017) but did not result in lower irradiation rates used operationally at the EMAI facility before its closure in 2018. We predict that the combination of shorter anoxic periods and lower irradiation doses could improve field competitiveness. Our results should be adopted where feasible and further explored in ongoing research to improve SIT programs in Australia.

Funding

All experiments were conducted within the operational budgets of the EMAI mass rearing facility; there was no specific funding contract or project.

ACKNOWLEDGEMENTS

All activities at the Camden facility are jointly funded by the State Departments of Primary Industries in Victoria, South Australia, and New South Wales. Selliah Sundaralingam and Laura Jiang conducted most of the laboratory work. Earlier versions of this manuscript were improved by comments from Sue McConnachie and Andrew Eliot. One journal reviewer further improved the manuscript.

REFERENCES

Ashraf, M., Chata, N., Ohinata, K. and Harris, E.J. (1975). Melon flies: dosage-response and sexual competitiveness after treatment with gamma irradiation in a nitrogen atmosphere. *Journal of Economic Entomology* **68**: 838-840.

Benelli, M., Mainali, B., Taylor, P.W. and Rempoulakis, P. (2021). Reduced quality of sterile Queensland fruit fly following post-production stress from hypoxia, irradiation and vibration. *Journal of Pest Science* **94**: 473-485.

Bloomfield, C.I.A., Fanson, B.G., Mirrington, R., Gillespie, P.S. and Dominiak, B.C. (2017). Optimising irradiation dose in mass-produced Queensland fruit fly, *Bactrocera tryoni*, for sterile insect release: the incorporation of residual effects on F_1 progeny. *Entomologia Experimentalis et Applicata* **162**: 168-177.

Boller, E.F., Katsoyannos, B.I., Remund, U. and Chambers, D.L. (1981). Measuring, monitoring and improving the quality of massreared Mediterranean fruit flies, *Ceratitis capitata* Wied., The RAPID quality control system for early warning. *Zeitschrift für Angewandte Entomologie* **92**: 67-83.

Caceres, C., McInnes, D., Shelly, T., Jang, E., Robinson, A. and Hendrichs, J. (2007). Quality management systems for fruit fly (Diptera: Tephritidae) sterile insect technique. *Florida Entomologist* **90**: 1-9.

Callier, V., Hand, S.C., Campbell, J.B., Biddulph, T. and Harrison, J.F. (2015). Developmental changes in hypoxic exposure and responses to anoxia in Drosophila melanogaster. *Journal of Experimental Botany* **218**: 2927-2934.

Collins, S.R., Weldon, C.W., Banos, C. and Taylor, P.W. (2009). Optimising irradiation dose for sterility induction and quality of *Bactrocera tryoni*. *Journal of Economic Entomology* **102**: 1791-1800.

Deng, Y., Hu, F., Ren, L., Gao, X. and Wang, Y. (2018). Effects of anoxia on survival and gene expression in *Bactrocera dorsalis. Journal of Insect Physiology* **107**: 186-196.

Dominiak, B.C., Sundaralingham, S., Jiang, L., Jessup, A.J. and Barchia, I.M. (2008). Production levels and life history traits of mass reared Queensland fruit fly *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) during 1999/2002 in Australia. *Plant Protection Quarterly* **23**: 131-135.

Dominiak, B.C., Sundaralingham, S., Jiang, L., Jessup, A.J. and Barchia, I.M. (2011). Effect of conditions in sealed plastic bags on eclosion of mass-reared Queensland fruit fly *Bactrocera tryoni,* (Diptera: Tephritidae). *Entomologia Experimentalis et Applicata* **141**: 123-128.

Dominiak, B.C., Sundaralingam, S., Jiang, L., Fanson, B.G., Collins, S.R., Banos, C., Davies, J.B. and Taylor, P.W. (2014). Evaluating irradiation dose for sterility induction and quality control for mass-produced fruit fly *Bactrocera tryoni* (Diptera: Tephritidae). *Journal of Economic Entomology* **107**: 1172-1178.

Dominiak, B.C. and Mapson, R. (2017). Revised distribution of *Bactrocera tryoni* in Eastern Australia and effect on possible incursions of Mediterranean fruit fly: Development of Australia's Eastern Trading Block. *Journal of Economic Entomology* **110**: 2459-2465.

Dominiak, B.C. (2019). Components of a systems approach for the management of Queensland fruit fly *Bactrocera tryoni* (Froggatt) in a post dimethoate fenthion era. *Crop Protection* **116**: 56-67.

Ekesi, S., Nderitu, P. and Rwomushana, I. (2006). Field infestation, life history and demographic parameters of the fruit fly *Bactrocera invadens* (Diptera: Tephritidae) in Africa. *Bulletin of Entomological Research* **96**: 379-386.

Fanson, B.G., Sundaralingam, S., Jiang, L., Dominiak, B.C. and D'Arcy, G. (2014). A review of 16 years of quality control parameters at a mass-rearing facility producing Queensland fruit fly, *Bactrocera tryoni*. *Entomologia Experimentalis et Applicata* **151**: 152-159.

FAO/IAEA/USDA (1999). Product quality control, irradiation and shipping procedures for mass-reared Tephritid fruit flies for sterile insect release programmes. International Atomic Energy Agency, Vienna, Austria.

FAO/IAEA/USDA (2003). Manual for product quality control and shipping procedures for sterile mass-reared Tephritid fruit flies, Version 5. International Atomic Energy Agency, Vienna, Austria.

Fisher, K.T., Hill, A.R. and Sproul, A.N. (1985). Eradication of *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in Carnarvon, Western Australia. *Journal of the Australian Entomological Society* **24**: 207-208.

Fisher, K. (1996). Queensland fruit fly (*Bactrocera tryoni*): eradication from Western Australia, pp. 535–541. *In* McPheron and Steck (eds.), Fruit fly pests. A world assessment of their biology and management. St Lucas Press, FL.

Golding, J.B., Jessup, A., Spohr, L., Daniels, D., Satyan, S., Pristijono, P., McGlasson, W.B. and Jacas, J. (2012). Efficacy of a combination quarantine treatment at 3ºC as a potential disinfestation treatment for Queensland fruit fly (*Bactrocera tryoni* (Froggatt)) in cherry fruit. *Acta Horticulturae* **934**: 343-346.

Hendrichs, L., Oritiz, G., Liedo, P. and Schwartz, A. (1983). Six years of successful medfly program in Mexico and Guatemala. *In* R Cavalloro [ed.], Fruit flies of Economic Importance. A.A. Balkema, Rotterdam, The Netherlands. 353-365.

Knipling, E.S. (1955). Possibilities of insect control or eradication through use of sexually sterile males. *Journal of Economic Entomology* **48**: 459-469.

Krafsur, E.S. (1998). Sterile insect technique for suppressing and eradicating insect populations: 55 years and counting. *Journal of Agricultural Entomology* **15**: 303-317.

Lara-Perez, L.A., Arredondo, J., Tejeda, M.T. and Diaz-Fleischer, F. (2019). Behavioural responses and pupa development patterns after hypoxia or anoxia in a desiccation-resistant *Anastrepha ludens* strain. *Neotropical Entomology* **48**: 739-747.

Lopez-Martinez, G. and Hahn, D. (2012). Short-term anoxic conditioning hormesis boosts antioxidant defences, lowers oxidative damage following irradiation and enhances male sexual performance in the Caribbean fruit fly *Anastrpha suspensa*. *Journal of Experimental Botany* **215**: 2150 2161.

Lopez-Martinez, G., Carpenter, J.E., Hight, S.D. and Hahn, D.A. (2016). Anoxia-conditioning hormesis alters the relationship between irradiation doses for survival and sterility in the cactus moth *Cactoblastis cactorum* (Lepidopters: Pyralidae). *Florida Entomologist* **99**: 95-104.

Mastrangelo, T., Kovaleski, A., Botteon, V., Scopel, W. and Costa, M.L.Z. (2018). Optimization of the sterilizing doses and overflooding ratios for the South American fruit fly. *PLOS One* **13**: e0201026.

Meats, A (1996). Demographic analysis of sterile insect trials with the Queensland fruit fly "Bactrocera tryoni" (Froggatt) (Diptera: Tephritidae). *General and Applied Entomology.* **27**: 2-12.

Nestel, D., Nemny-Lavy, E., Islam, A., Wornoay-Porn, V. and Caceres, C. (2007a). Effects of pre-irradiation conditioning of medfly (Diptera: Tephritidae): Hypoxia and quality of sterile males. *Florida Entomologist* **90**: 80-87.

Nestel, D., Nemny-Lavy, E., and Alchanatis, V. (2007b). Gas-exchange patterns of Mediterranean fruit fly pupae (Diptera: Tephritidae): A tool to forecast developmental stage. *Florida Entomologist* **90**: 71-79.

Neven, L.G. and Rehfield-Ray, L. (2006). Combined heat and controlled atmosphere quarantine treatments for control of western cherry fruit fly in sweet cherries. *Journal of Economic Entomology* **99**: 658-663.

Ohinata, K., Ashraf, M. and Harris, E.J. (1977). Mediterranean fruit flies: sterility and sexual competitiveness in the laboratory after treatment with gamma irradiation in air, carbon dioxide, helium, nitrogen or partial vacuum. *Journal of Economic Entomology* **70**: 165-168.

R Core Team. (2017). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Reynolds, O., Jessup, A., Dominiak, B., Smallridge, C., Cockington, V., Penrose, L., Taylor, P. and Collins, S. (2012). Enhancing Emergence and Release Methods of the Sterile Insect Technique (SIT) to Improve Market Access. Horticulture Australia Ltd. Project MT06049. Sydney, Australia, 2012; pp. 116–129.

Reynolds, O.L., Collins, D., Dominiak, B.C. and Osborne, T. (2022). No sting in the tail for sterile bisex Queensland fruit fly (*Bactrocera tryoni* Froggatt) release programs. *Insects* **13**: 269.

Shelley, T. and McInnis, D. (2016). Sterile insect technique and control of Tephritid fruit flies: do species with complex courtship require higher overflooding ratios? *Annals of the Entomological Society of America,* **109**: 1-11.

Suckling, D.M., Kean, J.M., Stringer, L.D., Caceres-Barrios, C., Hendrichs, J., Reyes-Flores, J. and Dominiak, B.C. (2016). Eradication of Tephritid Fruit Fly Populations: Outcomes and prospects. *Pest Management Science* **72**: 456-465.

Visser, B., Williams, C.M., Hahn, D.A., Short, C.A. and Lopez-Martinez, G. (2018). Hormetic benefits of prior anoxia exposure in buffering anoxia stress in a soil-pupating insect. *Journal of Experimental Botany*. **221**: jeb167825. doi:10.1242/jeb.167825

Zhan, G., Zhao, J., Ma, F., Liu, B., Zhong, Y., Song, Z., Zhao, Q., Chen, N. and Ma, C. (2020). Radioprotective effects on late third-instar *Bactrocera dorsalis* (Diptera: Tephritidae) larvae in low-oxygen atmospheres. *Insects* **11**: 526.

Zumreoglu, A., Ohinataz, K., Fujimoto, M., Higa, H. and Harris, E.J. (1979). Gamma-irradiation of the Mediterranean fruit fly (Diptera, Tephritidae): Effect of treatment of immature pupae in nitrogen on emergence, longevity, sterility, sexual competitiveness, mating ability and pheromone production of males. *Journal of Economic Entomology* **72**: 173–176.

Submitted 9/1/2024, Revised 28/3/2024, Accepted 5//4/2024

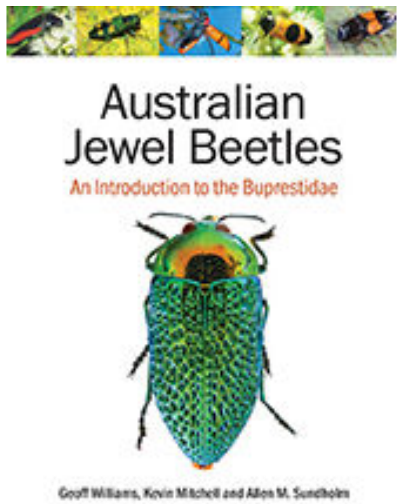
This page is left blank intentionally.

BOOK REVIEW

Australian Jewel Beetles: An Introduction to the Buprestidae

Geoff Williams, Keith Williams, Allen M. Sundholm

CSIRO Publishing. Hardback 224pp, AU $195, ISBN 9781486317400



This is a marvellous book it presents a full summary of Australian buprestid fauna accompanied by gorgeous photography. It has taxonomic, ecological and biogeographic data for all Australian genera and shows how they fit in with the global Buprestidae. The book also looks at the evolution of plant associations and the important subject of threats to the Buprestidae. There are over 570 colour images, many are rare species.

Chapter 1. Covers a range of fascinating subjects: fossil history, Gondwanna and terrestrial associations, warning and mimicry colouration for defence, life histories, plant associations and role as pollinators.

In Chapter 2 ecology, taxonomy and distribution are discussed. Also includes notes on how to best collect Buprestids and where. There are specular images of specimens.

Chapter 3 talks about regional Buprestid fauna. This is important given all the clearing, urbanisation and fragmentation that has happened. The literature is extensively discussed. Areas covered are: north Queensland and wet tropics, central Queensland, Brigalow belt, central and western NSW, Sydney and Blue Mountains, Barrington Tops, New England mountains and tablelands, littoral rainforests of northern NSW, north western Victoria, South Australia, south west Western Australian and Tasmania.

Chapter 4 deals with threats to the Buprestidae. Threats include broad scale clearing in NSW, Queensland and the wheat belt of WA, loss of coastal rainforests, fragmentation of native forests. The effects of a warming climate, fire, alien flower visitors ie honeybees and exotic plants. Collecting and trade in specimens is also a threat.

Appendices cover: List of Buprestid genera recorded from Australia; summary of larval and adult plant relationships; pollen loads; Fascinating information on early taxonomists and collectors; divisions of geological time. There is a glossary of tricky terms and comprehensive bibliography and index.

The authors have amalgamated a wealth of experience of the Australian Buprestid fauna into *Australian Jewel Beetles*. This book is a valuable reference and is recommended to entomologists and fellow Buprestid enthusiasts.

Dr Robin Gunning

This page is left blank intentionally.

SCIENTIFIC NOTE

FIRST DETECTION AND INITIAL DISTRIBUTION OF *VARROA DESTRUCTOR* IN NEW SOUTH WALES, AUSTRALIA – THE FIRST 100 DAYS TOWARDS ERADICATION.

Rod Bourke[1], Mark Page[1], Elizabeth A. Frost[1,2], Bernard Millyn[3], Chris Anderson[3] and Bernard Charles Dominiak[3*]

[1] New South Wales Department of Primary Industries, Tocal College, 815 Tocal Road, Paterson, 2421, Australia.
[2]Animal Genetics Breeding Unit, a joint venture of NSW Department of Primary Industries and the University of New England, Armidale, NSW 2351, Australia

[3]New South Wales Department of Primary Industries, the Ian Armstrong Building, 105 Prince Street, Orange, 2800, Australia.
[*] submitting author: bernie.dominiak@dpi.nsw.gov.au

Summary

The Australian honeybee industry faces many issues such as endemic pests and diseases, bushfires, floods, cost-price squeeze, climate change and exotic pest introductions. The pest *Varroa destructor* was previously absent from Australia, but was detected on 22 June 2022 in New South Wales. Here, we describe the first 100 days of detections, activities and responses. The response was initially funded by a national eradication fund of $65 million. If achieved, this would have been the first successful eradication of varroa mite in the world.

Key words
Honeybee, hive, euthanasia, destruction, sentinel, funding, plan.

INTRODUCTION

Australia exports many agricultural commodities, valued at more than A$25 billion in 2019/2020 (Plant Health Australia 2021). European bees (*Apis mellifera* L.) pollinate many of these crops, which were valued at A$14.2 billion in 2017 (Frost 2022; APAL 2022). Honey and beeswax production was valued at A$162 million (Plant Health Australia 2021). These industries are supported by approximately 25,000 registered beekeepers in Australia operating about 672,200 hives (Plant Health Australia 2021).

The honeybee industry must manage many endemic health disorders. These include American foulbrood (*Paenibacillus larvae*), Braula fly (*Braula coeca* Nitzsch), chalkbrood (*Ascosphaera apis*), European foulbrood (*Melissococcus plutonius*), nosema (*Nosema apis*), and wax moth (*Galleria mellonella* L.) (Oldroyd *et al.* 1989; Bourke 2020a,b, 2021; BeeAware 2023). Additionally, adverse effects of pesticides are a frequent problem (Frost 2020a).

Further, the Australian honeybee industry is threatened by the possible incursion of exotic pests. Australia is an island nation and is free from many pests that affect their trading partners (Anderson *et al.* 2017; Plant Health Australia 2021). However, the threat of incursion from exotic invertebrate pests and diseases is increasing annually: many incursions occur near major ports of entry because of the volume of freight (100 million tonnes arriving by sea) and the movement of humans in aircraft (9.3 million passengers) (Plant Health Australia 2021). Several exotic pests have established in Australia and adversely impacted honeybee activities including European wasp (*Vespula germanica* F.), small hive beetle *Aethina tumida* (Murray) and giant willow aphid, *Tuberolachnus salignus* (Gmelin) ((Brown 1979; Gillespie *et al.* 2003; Dominiak and Worsley 2018).

Until recently, Australia was the only major honey producing country free from varroa mites. The establishment of varroa mites in Australia was predicted to cost more than A$70 million annually (Saunders 2022a). Exotic bees and mites were detected in Australia in the past, including three detections of *Varroa jacobsoni* (Oudemans) (2016, 2019, 2020) (Plant Health Australia 2021). Most recently in February 2024, a single *V. jacobsoni* was detected in a sentinel beehive at the Port of Brisbane (Queensland Government 2024).

Early detection is key to the minimisation of any eradication cost (Anderson *et al.* 2017). Therefore, sentinel surveillance for many pests was established near major ports (Dominiak *et al.* 2013; Charlton *et al.* 2022). The National Bee Pest Surveillance program is an early warning system to detect new incursions of exotic bee pests, diseases and pest bees (BeeAware 2023). Sentinel hives and catch-boxes were established in at-risk ports and are inspected regularly (BeeAware 2023).

Varroa destructor (Anderson and Trueman 2000) is a major concern for Australia. If *V. destructor* became established in Australia, the European honeybee and the pollination services were predicted to initially decline by 90-100% (APAL 2022). Varroa mites feed on larvae, pupae and adult honeybees causing malformation and weakening the adults, and can transmit many viruses affecting honeybees. Heavy varroa mite infestations can develop in 3-4 years and cause many maladies, potentially resulting in colony breakdown and death of the hive (Plant Health Australia 2016). Rosenkranz *et al.* (2010) provided a detailed review of the biology and control of *V. destructor* and will not be covered in our paper.

New Zealand and Australia were amongst the last two beekeeping countries free from *V. destructor* until April 2000 when the parasitic mite was detected in hives at Auckland in the north island of New Zealand (Iwasaki *et al.* 2015). The mite was likely to have been present undetected for 3-5 years. This late detection allowed local dispersal and disadvantaged New Zealand authorities. Surveillance found that *V. destructor* was spread throughout both main islands and therefore it was decided in July 2000 that eradication was unlikely to succeed (Iwasaki *et al.* 2015). Biosecurity New Zealand conducted a series of workshops to educate beekeepers on varroa mite detection and control. In Australia, *V. destructor* was found on dead bees in a ship's cargo hold at Melbourne in June 2018; a live honeybee colony was found in a wooden crate and killed. The ship originated in Texas (Phillips 2020).

On 22 June 2022, *V. destructor* was detected during routine surveillance in two of six sentinel hives at Tomago near port of Newcastle, New South Wales (NSW) (Bourke 2022: Kirkwood 2022; Saunders 2022a). Mites were found on sticky mats placed in sentinel hives to trap external parasites. Here, we report on the first and subsequent detections and initial activities between 22 June and 30 September 2022 (100 days) in an attempt to eradicate *V. destructor* from NSW. Unfortunately, the program was unsuccessful (Moriarty 2023) but the initial steps towards eradication recorded here should inform other arthropod incursion responses.

THE FIRST WEEK OF THE RESPONSE

The initial actions followed Australia's normal emergency response. NSW reported the detection of *V. destructor* to the Consultative Committee on Emergency Plant Pests (CCEPP) (Anderson *et al.* 2017; Charlton *et al.* 2022). Originating in 2005, the Emergency Plant Pest Response Deed (EPPRD) (known as "the Deed") is a long-standing agreement signed by many industries including honey-related and pollination-reliant industries (GPA 2022). The Deed is managed by Plant Health Australia (PHA) and is updated as different industries sign or if pests are re-categorised. Varroa mite was a Category 3 Emergency Plant Pest in schedule 13 of the Deed (GPA 2022). The CCEPP agreed that eradication should be attempted.

After the detection on 22 June, all six sentinel hives at the three Newcastle Port sites were euthanised that evening by NSW DPI Bee Biosecurity Officers (who also manage the hives under the protocols of the National Bee Pest Surveillance Program (NBPSP)). Under the current funding agreement, the NBPSP funds one site (Port Botany) but NSW DPI still managed the other two ports (Newcastle and Port Kembla) that were considered higher risk and had assigned sentinel hives under the previous agreement that ran until end 2021. If those sentinel hives had not been operational in 2022, it likely would have been many months before *V. destructor* was discovered. Without detection, it is likely that infested hives would already have been moved to major pollination events and spread mites further afield. Pollination services to almonds and blueberries collectively require over 215,000 hives and these are distributed to south-western and north-eastern NSW orchards (Frost 2020b). Such wide dispersion of hives would have made arresting the spread of *V. destructor* highly unlikely.

The day after detection (23 June), all bees and sections of comb containing brood were removed from suspect hives and sent to the NATA-accredited EMAI NSW Department of Primary Industries diagnostic laboratory for further analysis. Two Nanopore DNA sequencing methods, PCR amplicon sequencing and Cas9-targeted sequencing, confirmed *V. destructor* was present in some samples (McFarlane *et al.* 2024).

An eradication plan was launched on 24 June (two Days After the First Detection (2 DAFD)) lead by NSW Department of Primary Industries, working with other agencies and industry organisations (Saunders 2022b). On 26 June (4 DAFD), a State-wide emergency order was issued under the Biosecurity Act 2015 (Saunders 2022c). This order required a standstill of all bees and beehives (Kirkwood 2022): under the legislation, any intentional movement of hives from a biosecurity emergency zone risked a A$2.2 million fine and potentially jail time (Parliament of Australia 2022).

There were four tiers of emergency zones (Saunders 2022c). A 10 km emergency zone (called the "red zone") was proclaimed around each infected site and all bees (commercial, recreational and feral) were to be eradicated within this zone. Additionally, all hives within the red zone were scheduled for destruction (Frost 2022). A second tier, 25 km around each of the infested sites ("purple zone"), was subjected to official monitoring and inspection of hives, including feral hives where known. In the third tier ("yellow zone"), all beekeepers were required to notify NSW DPI of the number and locations of hives within 50 km of any infested site (Saunders 2022c). It was illegal to move bees and hives within red, yellow and purple zones (Frost 2022). The fourth tier was the rest of NSW ("blue zone") that was not covered by any of the other three zones.

By 27 June (5 DAFD), bee euthanasia began within the red zone (Kirkwood 2022). By 12 July, more than 15 million honeybees had been euthanised (Saunders 2022d). Traceback procedures to identify connections between infected hives and trace forward procedures to detect yet unknown infestations began immediately (Kirkwood 2022). However by then, some hives had been moved from Newcastle to Trangie, about 450 km from the red zone (Kirkwood 2022). No varroa mites were detected in these Trangie hives but the bees were euthanised as part of the eradication plan protocols. Tracing activities detected additional infested premises in the Newcastle suburbs of Anna Bay, Heatherbrae, Williamtown, Mayfield, Tomago and Lambton (Anderson 2022). Varroa mite was found in premises at Nana Glen near Coffs Harbour on 25 July and initiated a new set of biosecurity zones (NSW DPI 2022) (see Figure 1 for locations). Additionally, the national exotic pest hotline (1800 084 881) was used as the free, central contact phone number for the public, commercial and amateur beekeepers to supply and receive the latest information (Plant Health Australia 2016; Kirkwood 2022).

COST AND NUMBER OF INFECTED PREMISES IN THE INITIAL RESPONSE

After the initial detection, the response followed the plant biosecurity surveillance cycle of delimiting survey and assessment of feasibility to eradicate (Anderson *et al.* 2017). By 9 July (17 DAFD), the National Management Group (NMG) endorsed the National Response Plan to eradicate *V. destructor* from NSW (Saunders 2022e). The overall budget for the first 100-days of the proposed eradication plan was A$65 million (Parliament of Australia 2022). Briefly, the five main activities in the first 100 days were to (1) delimit the infestation by surveillance, (2) eradicate all bees within 10 km of an infested premise, (3) eradicate known feral colonies from 10-25 km of an infested premise, (4) conduct surveillance of managed colonies within 10-25 km of an infected premise, and (5) facilitate a total standstill of all hives within NSW. Subsequently, the August standstill was lifted for some low-risk areas and the movement of hives was permitted following procedures such as alcohol washing to detect mites, verification that hives were not sourced from eradication or surveillance zones, the completion of online training, and application and approval to move (Saunders 2022f). Additionally, hives arriving for the almond pollination were monitored using sticky mats (Saunders 2022f). Hives were moved to service the almond pollination season in Victoria and no mites were detected in Victoria (AHBIC 2022). As part of the Deed, it was agreed to compensate beekeepers for the destruction of hive boxes and bees, which was projected to cost A$18 million (Saunders 2022e).

As the program developed, the number of identified infested premises increased because of tracing activities and increased surveillance. Originally, there were two infested premises on 22 June 2022, nine infested premises (6 DAFD), 38 by 12 July (20 DAFD), 43 by 25 July (33 DAFD) and 59 (40 DAFD) (APAL 2022; Parliament of Australia 2022). At the 100 DAFD, there were 100 infested premises (AHBIC 2022). By the first 100 days, over 115,000 hives had been sampled for the mite (Saunders 2022f). Additionally, 11,500 hives had been euthanised with the hive destruction program finished in the Nana Glen, Narrabri, Denman, Jerrys Plains and Wards River zones (AHBIC 2022). At 100 DAFD, the NSW Government remained confident that the State could become the first jurisdiction in the world to eradicate Varroa mite (Saunders 2022g). Unfortunately after spending A$101 million, eradication was deemed unfeasible and the program transitioned to management in September 2023 (Moriarty 2023). Details of the program's components will be published in future papers.

DISCUSSION

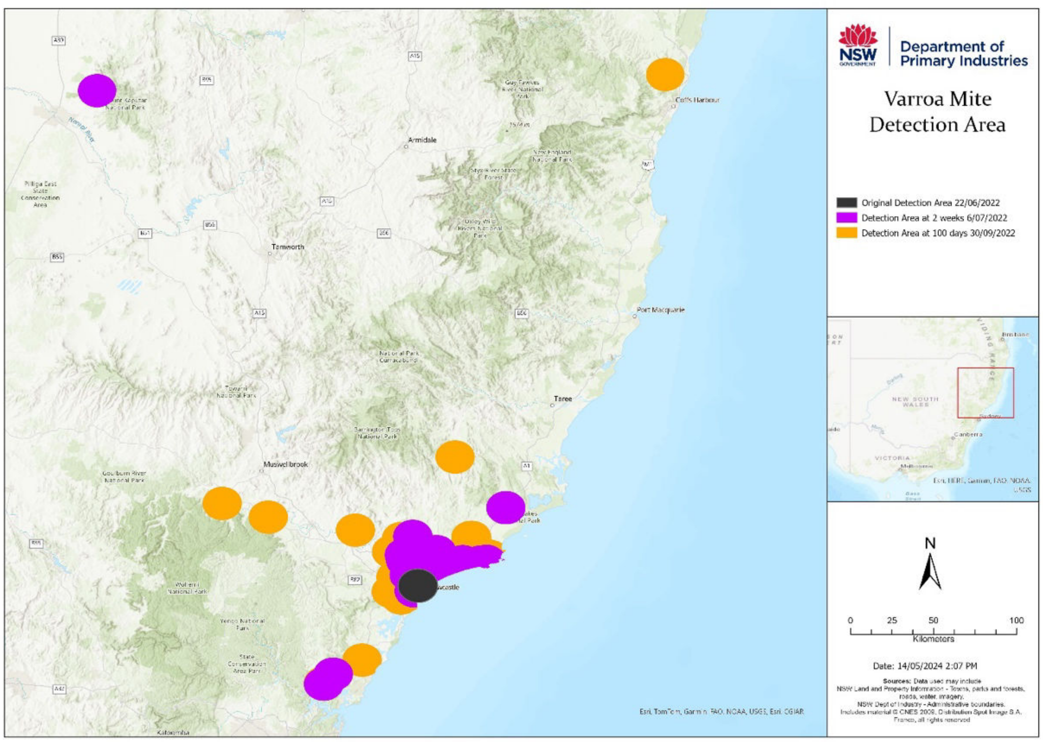
Australia is an island nation and has a good history of dealing with detection of exotic insect pests and often their eradication when deemed feasible, as it was for *V. destructor*. Additionally, Australia has a well-developed mechanism for responding to exotic detections via the CCEPP (Anderson *et al.* 2017) and the signed funding Deed. The Deed lists incursion threats at a national level, and funding of eradication arrangements and categorises are predetermined. For each incursion, an NMG is formed (containing

Australian and international experts) to provide the best technical guidance for any response, including eradication (Charlton *et al.* 2022), transition to management (Dominiak *et al.* 2009) or noting of an incursion where no action is to be taken (Hales *et al.* 2017).

The decision to attempt eradication was contingent on essential criteria including that *V. destructor* can be managed using existing techniques (see Bomford and O'Brien 1995 for essential and desirable criteria for eradication feasibility). *Varroa destructor* eradication has not been successful in other parts of the world but the Australia program benefited from more recent techniques not used in other programs. There were direct benefits to the apiary and pollination dependent industries of eradicating varroa mites from Australia. Also, the eradication of *V. destructor* would preclude the threat of many viruses entering into the Australian honeybee industry as several viruses in honeybees have spread around the world with varroa mite infestations. These maladies might explain colony collapse disorder in some countries (Iwasaki *et al.* 2015).

Here, we reported on the first 100 days of activity when the program was hopeful of achieving eradication. Unfortunately in September 2023, the NMG decided that eradication was no longer feasible and the response transitioned to management (Moriarty 2023). If varroa eradication had been successful, Australia would have been the first country to eradicate a varroa incursion. Australia would have remained the last source for varroa-free bee breeding stock and queens, an export industry that was worth M$2 annually (Clarke and Le Feuvre 2021). Despite the eradication being unsuccessful, the Australian mechanisms could inform other countries responding in exotic arthropod incursions.

Figure 1. Varroa mite detections in New South Wales between 22 June and 30 September 2022.



ACKNOWLEDGEMENTS

Nick Geoghegan and Peter Fleming reviewed a pre-submission version of the manuscript. Catherine Phillips identified the suspect samples. Several anonymous journal reviewers further improved the submitted manuscript. NSW Department of Primary Industries funded the formulation of the manuscript but there was no specific grant.

REFERENCES

AHBIC (Australian Honey Bee Industry Council). (2022). 100 day milestone of the response. https://honeybee.org.au/100-day-milestone-of-the-response/. Accessed 19 June 2024.

Anderson, C., Low-Choy, S., Whittle, P., Taylor, S., Gambley, C., Smith, L., Gillespie, P., Locker, H., Davis, R. and Dominiak, B. (2017). Australian plant biosecurity surveillance systems. *Crop Protection* **100**: 8-20.

Anderson, C. (2022). NSW Varroa net widens. *Australian Tree Crop* June/July: 4.

APAL (Apple and Pear Australia Limited). (2022). Varroa mite detections in NSW – update. https://apal.org.au/varroa-mite-detections-in-nsw-update/. Accessed 12 January 2022

BeeAware. (2023). National Bee Pest surveillance Program. https://beeaware.org.au/wp-content/uploads/2018/03/National-Bee-Pest-Surveillance-Program.pdf. Accessed 12 January 2023.

Bomford, M. and O'Brien, P. (1995). Eradication or control for vertebrate pests? *Wildlife Society Bulletin* **23**: 249-249.

Bourke, R. (2020a). National Bee Biosecurity Program. *Australian Honeybee News* **13**: 42-45.

Bourke, R. (2020b). Barrier systems: the key to containing AFB. *Amateur Beekeeper* **6**: 14.

Bourke, R. (2021). Managing hives to minimise damage from small hive beetles. *Australian Honeybee News* **14**: 33-35.

Bourke, R. (2022). Looking at Varroa mites. *Australian Honeybee News* **15**: 43-45.

Brown, G.R. (1979). The European wasp is a potentially dangerous import. *Agricultural Gazette* **90**: 38-39.

Charlton, S., Henderson, R., Sergeant, E.S.G., Worsley, P. and Dominiak, B.C. (2022). Declaring Sydney free from red imported fire ants *Solenopsis invicta* Buren – a view from the branches of the scenario tree. *International Journal of Tropical Insect Science* **42**: 1205-1214.

Clarke, M. and Le Feuvre, D. (2021). Size and scope of the Australian honey bee and pollination industry – a snapshot. AgriFutures Australia No 20-136: Project No PRJ-012405. 47pp.

Dominiak, B.C., Links, I.J., Fletcher, M.J., Worsley, P. and McDougall, S. (2009). Detection and spread of currant-lettuce aphid *Nasonovia ribisnigri* (Mosley) (Hemiptera: Aphididae) in New South Wales. *General and Applied Entomology* **38**: 27-30.

Dominiak, B.C., Gillespie, P.S. and Subasinghe, R. (2013). Surveillance for Asian Gypsy Moth (*Lymantria dispar asiatica* L.) between 2005 and 2012 in New South Wales, Australia. *Australian Plant Protection Quarterly* **28**: 12-14.

Dominiak, B.C. and Worsley, P. (2018). First detection of giant willow aphid *Tuberolachnus salignus* (Gmelin, 1790) (Hemiptera: Aphididae: Lachninae) in New South Wales, Australia. *General and Applied Entomology* **46**: 25-30.

Frost, E.A. (2020a). Fungicides and their effects on honeybees. *Australian Honeybee News* **13**: 2729.

Frost, E.A. (2020b). 24 million acres: Reports from Australia's massive fire scar. *Million Blossoms* **2**:18-22.

Frost, E.A. (2022). Help eradicate varroa mite. *Australian Honeybee News* **15**: 25-26.

GPA (Grain Producers Australia). (2022). Update – varroa mite detection in NSW. https://www.grainproducers.com.au/post/update-varroa-mite-detection-in-nsw. Accessed 12 January 2022.

Gillespie, P., Staples, J., King, C., Fletcher, M.J. and Dominiak, B.C. (2003). Small hive beetle, *Aethina tumida* (Murray) (Coleoptera: Nitidulidae) in New South Wales. *General and Applied Entomology* **32**: 5-7.

Hales, D.F., Gillespie, P.S., Wade, S. and Dominiak, B.C. (2017). First detection of *Megoura crassicauda* Mordvilko, (Hemiptera: Aphididae) in Australia and a review of its biology. *General and Applied Entomology* **45**: 77-81

Iwasaki, J.M., Barrant, B.I.P., Lord, J.M., Mercer, A.R. and Dickinson, J.M. (2015). The New Zealand experience of varroa invasion highlights research opportunities for Australia. *Ambio* **44**: 694-704.

Kirkwood, I. (2022). Bee destruction starts and NSW-wide freeze on bee movement from tonight as Varroa threat from Newcastle detection grows. https://www.portstephensexaminer.com.au/story/7795935/bee-industry-on-edge-of-crisis-as-varroa-mite-newcastle-scare-deepens/ Accessed 12 January 2022.

McFarlane, G.R., Robinson, K.L., Whitaker, K., Webster, J., Drysdale, L., Brancalion, L., Webster, A., O'Rourke, B. and Bogema, D.R. (2024). Amplicon and Cas9-targeted nanopore sequencing of *Varroa destructor* at the onset of an outbreak in Australia. *Frontiers in Bee Science* **2**: 1334543.

Moriarty, T. (2023). National industries and governments decide to transition the Varroa mite program. Press release. https://www.nsw.gov.au/media-releases/national-industries-and-governments-decide-to-transition-varroa-mite-program. Accessed 23 September 2024.

NSW DPI. (2022). New South Wales Department of Primary Industries. https://www.dpi.nsw.gov.au/emergencies/biosecurity/current-situation/varroa-mite-emergency-response/previous-updates. Accessed 13 January 2023.

Oldroyd, B.P., Goodman, R.D., Hornitzky, M.A.Z. and Chandler, D. (1989). The effect on American Foulbrood of standard oxytetracycline hydrochloride treatments for the control of European Foulbrood of honeybees (*Apis mellifera*). *Australian Journal of Agricultural Research* **40**: 691-707.

Parliament of Australia. (2022). Current threats and incursions: foot-and-mouth, lumpy skin disease and Varroa mite. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/FMDBiosecurity/Report. Accessed 13 January 2023.

Phillips, C. (2020). The force of *Varroa*: anticipatory experiences in beekeeping biosecurity. *Journal of Rural Studies* **76**: 58-66.

Plant Health Australia. (2016). Fact Sheet. Varroa mites. https://www.planthealthaustralia.com.au/wp-content/uploads/2016/02/Varroa-mites-FS. Accessed 12 January 2023.

Plant Health Australia. (2021). The National Plant Biosecurity Status Report 2020. Pp 277.

Queensland Government. (2024). Varroa mite detection at the Port of Brisbane. www.business.qld.gov.au. Accessed 24 September 2024.

Rosenkranz, P., Aumeier, P. and Ziegelmann, B. (2010). Biology and control of *Varroa destructor*. *Journal of Invertebrate Pathology* **103**: s596-s119.

Saunders, D. (2022a). Varroa mite incursion detected in NSW. Press Release. https://www.nswnationals.org.au/varroa-mite-incursion-detected-in-nsw/ Accessed 12 January 2022.

Saunders, D. (2022b). Varroa mite incursion detected in NSW. Media Release. https://www.dpi.nsw.gov.au/about-us/media-centre/releases/2022/ministerial/varroa-mite-incursion-detected-in-nsw#: Accessed 12 January 2022.
Saunders, D. (2022c). Statewide emergency order issued for varroa in NSW. Press Release. https://forms.dpi.nsw.gov.au/varroa. Accessed 12 January 2022.
Saunders, D. (2022d). More than 15m bees destroyed in NSW to contain deadly mite parasite. https://www.theguardian.com/environment/2022/jul/07/more-than-15m-bees-destroyed-in-nsw-to-contain-deadly-varroa-mite-parasite. Accessed 12 January 2022.
Saunders, D. (2022e). Varroa mite compensation for beekeepers. Joint Press Release. https://www.dpi.nsw.gov.au/about-us/media-centre/releases/2022/ministerial/varroa-mite-compensation-for-beekeepers. Accessed 13 January 2023.
Saunders, D. (2022f). NSW DPI allows restricted movement of hives out of almond farms. Press Release. https://www.dpi.nsw.gov.au/about-us/media-centre/releases/2023/general2/nsw-dpi-allows-restricted-movement-of-hives-out-of-almond-farms. Accessed 24 September 2024.
Saunders, D. (2022g). 100 days fighting Varroa mite. Press release. https://dugaldsaunders.com.au/100-days-fighting-varroa-mite/. Accessed 18 June 2024.

Submitted 11/3/2024 Accepted 30/9/2024

SCIENTIFIC NOTE

FRUIT FLY-SPECIFIC VIRUSES IN BIOLOGICAL CONTROL: DISCOVERY AND POTENTIAL APPLICATIONS IN FRUIT FLY MANAGEMENT

Sanjay Kumar Pradhan, Jennifer L. Morrow, Markus Riegler

Hawkesbury Institute for the Environment, Western Sydney University, Locked Bag 1797, Penrith, NSW, 2751
Email: S.Pradhan2@westernsydney.edu.au

Summary

Many insects carry insect-specific viruses (ISVs) that are detrimental to host fitness and health. While some ISVs result in acute infections with clear signs of pathology, others occur as persistent covert infections without any obvious visible symptoms. Widespread uptake of next generation sequencing to study transcriptomes of diverse insect species has uncovered many hidden single and double-stranded RNA viruses that so far had been difficult to identify by conventional virus discovery protocols. Recent research has shown that tephritid fruit flies, including Australia's most significant fruit fly pests, have diverse fruit fly-specific RNA viruses that occur at very high prevalence in laboratory populations, yet at moderate to low prevalence in the field. This highlights the issue that fruit fly traits assessed in laboratory populations may be influenced by virus infections, and may not be fully representative of traits in field flies that do not have these viruses. Studies have shown that the mode of transmission of the fruit-fly specific viruses is either vertical from infected parents to offspring via the embryo, or horizontal by sharing of food and other resources that have been contaminated by infected flies. Some of these ISVs show significant host fitness effects such as reduced lifespan and irreversible paralysis when flies are exposed to high concentrations of CO_2. Therefore, these viruses have the potential to affect management strategies that involve mass-reared flies such as the sterile insect technique (SIT), or have the potential to be used as biological control agent in fruit fly control.

Keywords: Biological control, sterile insect technique, host effects, insect-specific viruses, RNA viruses, virus transmission.

Several fruit fly species (Diptera: Tephritidae) are highly invasive pests of economic significance that affect the production and global trade of many fruits and fruiting vegetables. Among these, the Queensland fruit fly, *Bactrocera tryoni*, is the most significant pest affecting horticultural crops in Australia. This species can infest nearly all cultivated fruits and many vegetable crops across eastern Australia (Sharpe et al. 2021; Morrow et al. 2023). The control of fruit fly pests includes an array of different management strategies such as surveillance, orchard hygiene, cover sprays, attract-and-kill strategies involving lures and protein baits, the sterile insect technique (SIT) and biological control. Concerns about non-target effects, including on human and environmental health, have led to the restriction and ban of many chemical insecticides, and increased the interest in alternative control measures, and in particular, biological control options such as the use of parasitoid wasps, entomopathogenic fungi and entomopathogenic nematodes. Besides these natural enemies of fruit fly that can be biological control agents, viruses may also play a role, yet the potential of viruses in biological control of fruit fly pests has not yet been widely investigated (Sharpe et al. 2021; Morrow et al. 2023).

Virus infections pose a potential threat to many insect species, and can result in a significant decline in insect populations. Understanding the viruses associated with insects and their host effects is crucially important for several reasons: a) it helps in safeguarding beneficial insects like honey bee (*Apis mellifera*) and silk moth (*Bombyx mori*) from viral infections; b) it enables the utilization of insect-specific viruses (ISVs) for the management of insect pests, including invasive species either by application of viruses as biological control agents or using the viruses to express particular proteins or affect host gene expression; c) it aids in the identification of microbial interactions that may affect vectorial capacity of insect species that transmit pathogens to humans, animals and plants, and d) apart from their role as pathogens, viruses can also establish symbiotic relationships that are beneficial to their hosts, e.g. symbiotic viruses associated with parasitoid wasps can help parasitoids overcome host defence.

Many ISVs are double or single-stranded, negative or positive sense RNA viruses. Some ISVs can be highly pathogenic, exhibiting noticeable infections with acute symptoms. Other ISVs induce infections without visible symptoms and, hence, remain covert; yet they can persistently occur and affect host fitness (Hernández-Pelegrín et al. 2022). ISVs have a strict preference for specific insect tissues and are adapted to specifically infect host species. Yet for many newly discovered ISVs there is a lack of comprehensive epidemiological information about their distribution, prevalence, transmission mode and pathology in field populations.

Recent advancements in next-generation sequencing (NGS) technologies, and their application in transcriptome research, have unveiled a large diversity of RNA viruses in insects, including in tephritid fruit flies (Sharpe et al. 2021). Comprehensive analysis of nine transcriptome libraries of tephritid species from Australia (six species of *Bactrocera* and *Zeugodacus cucumis*), *Bactrocera dorsalis* from Asia and *Ceratitis capitata* from Europe revealed a large diversity of RNA viruses belonging to eight families (Sharpe et al. 2021). Although the detected viruses do not show obvious visible symptoms in flies, and very little information is known about their biology, the outcome of their infections may still influence fly fitness and thereby bring potential risk in mass-rearing and SIT applications. Furthermore, given that viruses were found highly prevalent in laboratory populations, and less prevalent in field-collected individuals, any biological traits of flies measured in infected laboratory populations may not be representative of these traits in field populations.

ISVs can be transmitted either vertically or horizontally, or a mixture of both (Bézier et al. 2009). Vertical transmission of the ISVs in fruit flies occurs either maternally from infected females to their offspring through their eggs, or paternally via sperm (Morrow et al. 2023). Horizontal transmission of ISVs in fruit flies can occur when flies share resources that had been contaminated by infected flies (Morrow et al. 2023). Field and laboratory populations of *B. tryoni* are commonly associated with three single-stranded RNA viruses only found in *B. tryoni* and closely related tephritid fruit fly species: cripavirus (*Dicistroviridae*) and iflavirus (*Iflaviridae*), both of the Picornavirales, and sigmavirus (*Rhabdoviridae*) of the Mononegavirales (Sharpe et al. 2021). In *B. tryoni* cripavirus has very efficient horizontal transmission, whereas iflavirus has very high levels of maternal transmission, together with very low levels of horizontal transmission (Morrow et al. 2023). Based on research on other fruit fly species it is known that sigmavirus is biparentally transmitted, with more effective maternal than paternal transmission (Longdon et al. 2017).

Vertically transmitted pathogens require their hosts to survive and reproduce in order to be transmitted to the offspring; therefore it has been hypothesised that this may lead to lower virulence, yet this means such viruses can still have substantial fitness effects. Only a few ISVs have been observed to have lethal or sublethal effects in their hosts. For instance, *Drosophila* flies infected with sigmavirus consistently exhibit reduced fitness. Furthermore, exposure of such infected flies to very high concentrations of carbon dioxide (CO_2) trigger irreversible paralysis that results in death (Longdon et al. 2017). Ceratitis capitata nora virus (CcaNV) is associated with a potential physiological cost for its host, the Mediterranean fruit fly (*Ceratitis capitata*); a higher viral load of this virus was found linked to a shorter adult lifespan, while no correlation was found between viral abundance and adult flight ability or mating behaviour (Llopis-Giménez et al. 2017). In fruit fly mass-rearing facilities, covert viral infections can directly impact fly physiology, potentially leading to negative effects on mass production and/or altering the competitiveness of males released into the field for SIT applications. Changes in insect rearing conditions could also cause covert infections to negatively affect insect colonies. Since SIT requires the mass-rearing of healthy insects, this can be jeopardised by ISVs. Conversely, due to their potential impact on fly fitness, ISVs hold significant potential for use as biological control agents when transmitted to naïve flies. Furthermore, ISVs of fruit flies have been demonstrated to affect the outcome of parasitisation with parasitoid wasps (Hernández-Pelegrín et al. 2022).

The utilization of NGS for virus discovery has enriched our understanding of the diversity of RNA viruses in fruit flies (Sharpe et al. 2021). While this development provided valuable insights to study the diversity of virus interactions of fruit flies, as well as uncovered some mechanisms by which these viruses interact with the host's immune system (Hernández-Pelegrín et al. 2022), further research is required to better understand the epidemiology of these viruses, in particular their transmission ecology and effects on the host. This additional knowledge will contribute significantly to our understanding of their potential to be used as a biological control agent in insect pest management.

ACKNOWLEDGEMENTS

SKP is supported by an Indian Council of Agricultural Research – Senior Research Fellowship and a Western Sydney University PhD scholarship award. Research in the team of MR is supported by The Fresh and Secure Trade Alliance funded through the Hort Frontiers International Markets Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from the Queensland Department of Agriculture and Fisheries (Queensland), Department of Primary Industries and Regional Development (South Australia), Department of Energy, Environment and Climate Action (Victoria), Department of Tourism, Industry and Trade, Department of Primary Industries and Regions (Northern Territory), Department of Natural Resources and Environment (NSW), Queensland University of Technology, James Cook University, Western Sydney University, Australian Blueberry Growers' Association, GreenSkin Avocados, and contributions from the Australian Government and the strawberry and avocado R&D levy.

REFERENCES

Hernández-Pelegrín, L., Llopis-Giménez, Á., Crava, C. M., Ortego, F., Hernández-Crespo, P., Ros, V. I. and Herrero, S. (2022). Expanding the medfly virome: viral diversity, prevalence, and sRNA profiling in mass-reared and field-derived medflies. *Viruses*, **14**(3): 623.

Llopis-Giménez, A., González, R.M., Millán-Leiva, A., Catalá, M., Llacer, E., Urbaneja, A. and Herrero, S. (2017). Novel RNA viruses producing simultaneous covert infections in *Ceratitis capitata*. Correlations between viral titers and host fitness, and implications for SIT programs. *Journal of Invertebrate Pathology*, **143**, 50–60.

Longdon, B., Day, J. P., Schulz, N., Leftwich, P. T., Jong, M. A. D., Breuker, C. J., Gibbs, M., Obbard, D. J., Wilfert, L., Smith, S. C. L., McGonigle, J. E., Houslay, T. M., Wright, L. I., Livraghi, L., Evans, L. C., Friend, L. A., Chapman, T., Vontas, J., Kambouraki, N. and Jiggins, F. M. (2017). Vertically transmitted rhabdoviruses are found across three insect families and have dynamic interactions with their hosts. *Proceedings of the Royal Society B: Biological Sciences*, **284**: 1847.

Morrow, J. L., Sharpe, S. R., Tilden, G., Wyatt, P., Oczkowicz, S. and Riegler, M., (2023). Transmission modes and efficiency of iflavirus and cripavirus in Queensland fruit fly, *Bactrocera tryoni*. *Journal of Invertebrate Pathology*, **197**: 107874.

Sharpe, S. R., Morrow, J. L., Brettell, L. E., Shearman, D. C., Gilchrist, A. S., Cook, J. M. and Riegler, M. (2021). Tephritid fruit flies have a large diversity of co-occurring RNA viruses. *Journal of Invertebrate Pathology*, **186**: 107569.

Submitted 27/8/2024, Accepted 27/8/2024

This paper following is an essay on the history of the society celebrating its 70th birthday in 2023. The authors have the editor's permission to stray from the usual instructions to authors.

HISTORY OF THE ENTOMOLOGICAL SOCIETIES OF NEW SOUTH WALES

Dinah Hales and Robin Parsons

INTRODUCTION

The history of entomological societies in NSW from the mid-20th century is fraught with conspiracy, take-over and scission. The relationship with entomological societies in other states has been one of suspicion and competition. The attitude of the NSW society to formation of a national body was one of paranoia and non-cooperation, since their own model seemed unlikely to be chosen, and the demon Entomological Society of Queensland was going to get its own wicked way. Since the late 1940s, there have been at least five groupings of entomologists based in Sydney. Some of them have changed their names, without changing their membership. Some of them have published circulars and journals under multiple names. Some have split off from existing societies, with varying degrees of goodwill. The history of our current Entomological Society of New South Wales (EntSocNSW3) cannot be separated from those of other societies dealing with insects, and this paper, celebrating the 70th anniversary of EntSocNSW3, will include brief histories of those others. The first Entomological Society of NSW (EntSocNSW1), founded by William Macleay in 1861, was active until 1873 (Marks and Mackerras 1971). Its history is not part of this paper. Below is a timeline which lists the societies, their dates, their name changes, and their publications.

The history has been based mainly on the circulars and other communications of the various societies, so has the benefit of being "in their own words". We thank Dr Max Moulds for making available his comprehensive collection of printed circulars, some of them obtained from Barry Salkilld. Without them, this work would not have been possible.

Minute books are available for some of the societies, some of the time, but have not been consulted during this study. The work is deliberately not written in the formal style of a scientific paper or of a history paper, but it attempts to recapture the feeling of the times, the dynamics of the societies and personalities of some of the people involved. Of course, it has not been possible to acknowledge every individual who has contributed to the Society's activities, or every one of the hundreds of speakers. The Society bears a debt of gratitude to all of them.

TIMELINE

This section provides the dates, names and name changes of the entomological societies active in NSW to the present, and the abbreviations of their names used in the rest of the paper.

1861 Entomological Society of New South Wales (EntSocNSW1). Founded by William Macleay.
1873 EntSocNSW1 closed. Succeeded by Linnean Society of NSW, also founded by Macleay.
1921 Royal Zoological Society of NSW Entomological Section (RZSNSWES1) founded by G.A. Waterhouse.
1930 RZSNSWES1 closed.
1947 Australian branch of the British Amateur Entomologists' Society (AES AB) founded by K.D. Fairey. Published irregular bulletins.
1949 AES AB commenced publication of *The Australasian Entomologist.*
1952 AES AB changed its name to the Entomological Society of New South Wales (EntSocNSW2). Published *The Australian Entomologist*.
1952 C.E. Chadwick proposed a separate society.
1953 The Society of Entomologists, Sydney (SES) established. It was biased towards professional entomologists but invited all.
1955 EntSocNSW2 closed.
1957 RZSNSWES re-emerged (RZSNSWES2). Some members of EntSocNSW2 moved to RZSNSWES2.
1963 SES changed its name to the Entomological Society of Australia (N.S.W.) (ESANSW).
1964 ESANSW commenced publication of the *Journal of the Entomological Society of Australia (NSW).*
1965 Australian Entomological Society (AES) established.
1979 Chadwick and supporters left ESANSW and joined RZSNSWES2.
1980 The name of ESANSW changed to the Entomological Society of NSW (EntSocNSW3).
1989 Chadwick and supporters left RZSNSWES2, which closed, and formed the Society for Insect Studies (SFIS).

2024 AES, Linnean Society of NSW, SFIS and EntSocNSW3 continuing.

THE AMATEUR ENTOMOLOGISTS' SOCIETY

In 1947, young moth enthusiast K.D. (Ken) Fairey was a member of the British Amateur Entomologists' Society (confusingly known as AES) and requested help from the society to set up an Australian branch. The AES promised support, and gave approval for re-using material published in its own bulletins. They also encouraged British members to send the names of Australians interested in insects to Fairey.[1] Fairey was just out of his teens. He had completed the Leaving Certificate at Goulburn High School in 1945 (commuting by train from Yass? boarding in Goulburn?) but his results did not qualify him for matriculation. He was disadvantaged by the peripatetic career of his father, a Presbyterian minister, taking the family to three states and seven towns during Ken's school years, and by the poor health that pursued him throughout his life. An obvious preference for moths over maths might have been another problem.

How did Ken Fairey build up membership in the new Amateur Entomologists' Society, Australian Branch (AES AB)? In 1947 his family had moved to Charlestown, a southern suburb of Newcastle. Hence Ken had to build up a new contact group with shared interests. He does not seem to have advertised in newspapers, and the other NSW members of the (British) AES were A. F. O'Farrell in Armidale, later to become professor of Zoology at the University of New England, and C.H.L. Kennard in Sydney, then aged only about 12. Colin Kennard later became a professor in the University of Queensland with a very lengthy list of publications on crystallography. His work included crystal structures of insecticides and occasional structures of plant secretions.

The wide geographic separation of these three did not facilitate the formation of a society, and even the established British society with 1000 members was having trouble finding members willing to take on practical roles. A small number of new members probably came from suggestions from the British AES members, but they were mainly interstate. The society's life depended on Ken Fairey, who, as "editor and organizer", prepared and circulated irregular bulletins to the membership (AES AB Vol. 1 No. 1 July 1947 - No. 23 Jan.-Feb 1951). In the first issue, he announced that the society was a reality, with "mostly a few friends" as members, and that its aim was largely to help young collectors. He apologised for the delay in communicating caused by prolonged illness. The early bulletins were mainly about collecting and killing methods, not infrequently with material reproduced from the British society's publications.

Ironically, a further relocation for his father brought the family to Sydney, initially in Mascot and later in Merrylands. In Sydney there were more opportunities for Ken to access jobs in entomological settings and to meet other entomologists, and he was appointed as a laboratory assistant with the Research Division of the Forestry Commission. Despite his difficult start, Ken was able to build a career related to his passion via later qualifications from Sydney Technical College, a BSc from the University of NSW, and in the early 1980s, an MSc from Macquarie University. He became a research entomologist, and later, the curator of the invertebrate collection of the NSW Forestry Commission.[2] While the family was living in Merrylands, Ken planted the back yard as an impressive forest.[3]

By October 1947, membership had risen to 10. Bulletin No. 6 was held up by shortage of paper, one of many things in short supply in the post-war years, but KDF announced his ambition to have "every entomologist in the Commonwealth" as members. He complained that existing members were not helping him increase membership by encouraging their friends to join. The society's main activity was providing practical advice to young collectors. In Bulletin No. 7, Jan.-Feb 1948, the beginnings of a structure emerged: Miss Chugg (in Melbourne) was appointed as secretary and Colin Kennard as Honorary Address Indexer. In the next, Colin Kennard added Youth Secretary to his portfolio, and M. Scott Upton became Honorary Insect Migration Secretary. Upton went on to a career at CSIRO Division of Entomology. In April, a piece with the macabre title "Is it dead yet?" was republished from a 1939 issue of the British society's bulletin. We now know that it's dead when the brilliance goes out of its eyes, it being a moth.

[1] Cooper, B.A. (1948). *Bulletin of the Amateur Entomologists' Society*, **89** (1):138
[2] Eulogy by Len Willan (pers. comm.)
[3] Don Sands (pers. comm.)

By May they had 14 subscribing members. Other natural history groups and publications spread word of AES AB but geographic scattering of the membership made inclusive meetings and field trips impossible. In August 1948 an Advisory Panel was introduced to help with identifications. The September-October bulletin announced the appointment of Mr D.N. Kennard as Honorary Treasurer. He would have been about 16 at the time and was the older brother of Colin Kennard. Desmond Kennard was to have a significant career in management of institutions such as the Powerhouse Museum, Sydney Heritage Fleet, Australian Maritime Museum, Sovereign Hill Museum and the Australian Bicentennial Exhibition. He received an Order of Australia Medal (OAM) in 2015.

It seems the Society already had a wider reach than expected. Leslie Mosse-Robinson, a former paymaster in both the Royal Navy and Royal Australian Navy,[4] Narara citrus-grower and keen butterfly collector, joined in June 1948 and was elected soon after as secretary. In 1950 he became president. His presence would have given the infant group mature leadership and potentially wider membership, but sadly, he was not with them for long enough. Following his death in 1954 his 50000-strong butterfly collection went to the Australian National Insect Collection.

1949 saw a change in the society's publications, with a "journal" supplementing the irregular Bulletins. *The Australasian Entomologist* had 8 pages in each edition and a cardboard wrap around cover. This replaced the bulletins for the time being, with the first issue dated January 1949. The contents of its eight pages were two notes and Part 1 of a longer article by Upton about insect migration. Volume 1 (ii) was dated April 1949, pages 9-18, with a continuation of Upton's article. There were also two notes, one on a light trap design and the other on mould prevention on specimens. The third and last (Volume 1, (iii), pages 21-36) was dated December 1951 and contained the final part of Upton's article. In the meantime, the Bulletins had returned. In Bulletin No. 15 (Jan.-Feb. 1950), a list of names and addresses of the members was published as "A Directory of Australasian Entomologists". Was permission asked, or was privacy less valued back then? There were 27 names on the list and only eight people were based in or near Sydney, with others as far afield as Western Australia (Barbara York, then a student, later to be an expert arachnologist), Queensland and even England. One name stood out: Chadwick, C.E., C/o Entomology Section, Dept of Agriculture, Farrar Place, Sydney. He seems not to have contributed anything to the Society in terms of written contributions or management roles, but his name will recur frequently in this history.

Don Sands (pers. comm.) noted another pathway into membership of the society. His aunt, Lucy Singleton, took him to meetings of the Naturalists' Society of NSW when he was young. She was a botanist and she and Don's mother got to know Nancy B. Adams, general assistant in Entomology at the Australian Museum. Through her, Don and other young collectors gained access to the entomologists on the Museum staff and KC McKeown was especially helpful in identifying their specimens from about 1947. Emil Zeck, renowned biological illustrator, was president of the Naturalists' Society for many years and he gave great encouragement to the young collectors and suggested that they join Ken Fairey's group.

Len Willan told of his introduction to the Museum people by Bruno Lüddemann, a butterfly and beetle collector, and through them learned of Ken Fairey's group. Len remembers his first meeting with Ken Fairey, in 1950. Len was then a young boy of 14, and KDF arranged to meet him on Hornsby Station for a field trip to Cowan. The clue to recognition: "I will be wearing a brown tie". The butterfly net was an even better clue. Gone are the days of ties on field trips. The paperwork was easier then. No permits required. No Child Safety clearance required either.

Bulletin 16 (March-April, 1950) foreshadowed the commencement of a new journal, to be known as *The Australian Entomologist*, and proposed the publication of the first two parts in the same year, an ambitious objective. At a Special General Meeting in April 1950, the Society elected a full council, with Mosse-Robinson as president, J.C. Keast as secretary, D.N. Kennard as treasurer, B.W. Salkilld as publicity officer and five other councillors. Only four council members lived in the Sydney area. Keast at the time was Principal Veterinary Research Officer at Glenfield, but a keen moth collector in his spare time: his collection is now in ANIC. Salkilld was a social worker and beetle collector. In later life he was a dealer in second-hand scientific equipment.[5]

[4] According to an obituary (*The Scone Advocate*, 3 Sep 1954 p.1) Mosse-Robinson was born in Surrey, England, and entered the Royal Navy, rising to Paymaster Lieutenant Commander. He transferred to the RAN before WW I with a similar position and later was at the RAN College at Jervis Bay till retirement in 1923.

[5] MS Moulds, pers. comm.

In mid-1950 the Society commenced monthly meetings and field trips in Sydney. The first meeting was held at the YMCA in July with eight members present. Discouragingly, only four were present at the next meeting, held at held at Science House, but the experiment was deemed successful enough to book a meeting room for monthly meetings for the next year.

The meetings continued to be held on the first Wednesday of each month. In the last Bulletin issued (Vol 1, 23, Jan-Feb 1951), KDF announced that there would be no journal or bulletin in 1952 as he would not be able to do it, but he would be pleased if someone else stepped forward. A single sheet News and Notes Sheet would be issued instead.

A few words are due on Ken Fairey's personality. Although quietly spoken, he had a mischievous sense of humour, and his enthusiasm for entomological topics was infectious to all who worked with him. He had a deep love of music, especially jazz, and was involved in the Bush Music Club. A sound system that he had designed and built is in the Powerhouse Museum Collection.[6] One of his other passions was ceramics, and we remember him speaking of his enthusiasm for Japanese pottery.

For the young members, field trips were the highlights of the society's calendar, although they did also attend evening meetings in the city. Don Sands recounted two examples of field trips. Ken Fairey had bought a Model A Ford. It would go anywhere, up bush tracks, through mud and even on the road. One midnight collecting effort with a light sheet on the Berowra hilltop was disrupted by the arrival of three police cars with lights and sirens. They were sure that the only people who would be doing anything at midnight in a remote location must be up to no good - stripping cars for example. On another occasion, Sands and Willan caught a train leaving Central at midnight. They got off at Bell in the dark and proceeded to walk to the top of Mt Wilson where they camped for a few days collecting moths. Sands was recently awarded a DSc for his entomological publications, covering a wide range of applied problems, especially in biocontrol. Willan, a master watchmaker, still references Australian moths in his email address and is one of the primary drivers of the CSIRO website Australian Moths Online. He is an Honorary Life Member of the society Moths and Butterflies of Australasia (MABA), founded in 2021.

In 1952 the society changed its name to the Entomological Society of New South Wales (EntSocNSW2). A report from a surprising source, *The Townsville Daily Bulletin* (August 1953) gave information on the society. It stated that the Australian Branch of the (British) AES had been meeting in Sydney since March 1949 and that it published a monthly bulletin, *Entomological Notes and News*, and reached out to people interested in insects in any way, from butterfly collectors to pest controllers.[7] The information was perhaps passed to the newspaper by member J.G. Brooks, whose postal address was in Cairns. He was a dentist and a keen coleopterist, and had been a member of the Entomological Society of Queensland since 1930.[8]

There were no publications in 1952 (Fairey was ill) but in 1953 the society reappeared under a new name and became the Entomological Society of NSW (same name as the 19th century society) and with a new name for its journal, *The Australian Entomologist*, (Vol. 1, No. 1, August 1953, to Vol. 1 No. 5, May 1955).[9] *The Townsville Daily Bulletin* gave details of the first issue and its contents. Trove's ocr version of this report describes the newsletter as a very modest issue "constating of four pagaa and a cow"[10] and notes by A.E. Smith, D.P. Sands, B. H. Finch, B. W. Salkilld and K. Fairey. Mr B.W. Salkilld was by then the president, and the editorial panel was made up of Salkilld, (Mrs) Harford and Len Willan. In his inaugural message, Salkilld explained with regret that Ken Fairey's health had forced him to cut back on his activities and he was unable to continue as editor. The Editorial Panel wrote that "the past was a gloomy affair" with conflict among members and clashes of personalities resulting in various administrative problems and loss of members. Don Sands, a young member at the time, recalled that there was friction between Chadwick and Fairey, and that the CSIRO people (Geoff Snowball, Garth Lukins) did not want to

---

[6] The Museum is reorganising its collection database and no object number or details are available at present.

[7] https://trove.nla.gov.au/newspaper/article/62492752, *Townsville Daily Bulletin*, Sat 22 Aug 1953 Page 5.

[8] E.B.Britton (1975). *News Bulletin of the Australian Entomological Society* **11:**75-79

[9] Chadwick later stated that this was a new society with members from the AES AB but independent of it. This seems to be incorrect, as Salkilld (president in 1953) mentions survival and "ups and downs", of "our society", and mentions Fairey's ill-health. A continuing society is strongly indicated.

[10] Read "consisting of four pages and a cover". *Townsville Daily Bulletin* Sat 14 Aug 1954, p.5

be involved in this, perceiving it as a disagreement between the Forestry members (Fairey, Moore) and Agriculture people (Chadwick, Shanahan) (Sands, pers. comm.). Phil Hadlington (Forestry) became part of the Chadwick faction. Snowball had advised the young people not to involve themselves in the factional war. A particular point at issue was the focus on young amateurs in the society - Chadwick wanted to build up a society of professionals and leave the amateurs to their own devices. This was ironical in the light of future events. No minutes of meetings were published at any stage, so the details of the disaster that had befallen the society can only be obtained from other sources, especially the Circulars of the Society of Entomologists, Sydney (SES) (see below) and personal recollections of former members.

THE END OF ENTSOCNSW2

EntSocNSW2 continued with the *Australian Entomologist* until 1955. In September 1953 it published a pleasant account of a collecting trip to Barrington Tops (L.S. Willan), and an urgent request from the Chief of the Division of Wood Technology for members to collect and provide data on the distribution of the phasmid *Podacanthus wilkonsoni*, in anticipation of a plague. It usually listed the councillors. In 1954, the officers of the society were Salkilld, President, Mosse-Robinson (who died later in the year) Vice President, D.P. Sands, Secretary, I. Morhaus, Treasurer, and the remainder made up of Willan, Librarian, and Councillors Miss Vera Levitt, whose favourite invertebrates were spiders, including funnel webs[11], and Mrs Harford, a member of the Editorial Panel. The society had clearly attracted a group of very bright young people to its membership during the early years, with many continuing to successful careers in entomology or other areas of science.

In February 1955 the AGM expressed concern about the Society's future. In the March issue of the *Australian Entomologist*, acting Honorary Editor J.W. Nash urged members to take a more active part in the Society's affairs, in terms of writing, attending meetings and field trips and recruiting members. And paying their subscriptions. The same issue contained a news story about a funnel web spider killing a tiger in Taronga Zoo. (If correct, this is surprising, as few animals besides humans are badly affected by funnel web venom, to the extent that it was very difficult to establish an animal model for testing anti-venoms etc). By the April issue, the new council consisted of Nash, President, Salkilld, Vice President, Ray, Secretary, no Treasurer. The rest of the issue was taken up with a posthumously published list of butterflies collected by Mosse-Robinson. In May 1955, Vol. 1, No. 5 appeared. It included the same solicitations for contributions from members as had been in just about every issue of the three different vehicles. Vera Levitt wrote two and a half pages on leaf-curling spiders. Don Sands wrote nearly three on blues he had seen near his home. (The pages, by the way, are very small at 14 cm by 21.5 cm). An unnamed member, perhaps the editor, wrote about ways of advancing entomology in Australia, proposing close liaison of the different existing societies and implying that a federation of societies was a good model. Other sensible suggestions were included. And then: nothing. No announcement of closure. No more publications. No farewell to members. Nothing. Len Willan explained the decline as partly caused by a drifting away of his age group as they were studying, starting businesses and even setting up house.

According to Marks and Mackerras (1972), some members moved to the Entomological Section of the Royal Zoological Society of NSW when it re-started in 1957, and an unsuccessful attempt was made to start the original society again in 1959. Vera Levitt was one of the former members involved in this attempt.

THE FIRST SCHISM
THE SOCIETY OF ENTOMOLOGISTS, SYDNEY

In late 1952, C.E. (Clarry) Chadwick called a meeting to discuss the formation of a new society. The eight people present[12] agreed to go ahead and appointed as temporary officers Chadwick (President), Turner (Secretary) and

[11] Levitt married M. H. Gregg, a member of RZS and SES, in 1960. She described a new species of mouse spider from the Northern Territory, *Missulena pruinosa* Levitt-Gregg 1966 and was later an honorary associate of the Australian Museum. The funnel web spider *Hadronyche levittgreggae* Gray 2010 was named for her.

[12] These are listed in SES Circular **119**: 4, 1962. Additional to the temporary office holders were Turner's wife and daughter, Miss M. Richards, Hardy and Hasemer. G.H. Hardy, as early as 1923, had supported the concept of a national entomological society, but his group decided that it was preferable at that time to form a Queensland society.

Hadlington (Treasurer). Chadwick wrote to everyone he knew to encourage them to attend the inaugural meeting. A copy of the letter addressed to Miss K.M.I. English is included in the bound copies of circulars of the society[13]. The letter said that "there was sufficient interest in an entomological society of good standard and run on sound lines" (an obvious swipe at EntSocNSW2) and it proposed that the main activity would be to have invited speakers at each meeting. The society set out to appeal to people interested in any aspect of entomology, as had EntSocNSW2. Looking back on the origins of the Society 25 years later, Chadwick, in his presidential address, said: "In 1952 the second Entomological Society of NSW was formed, largely from members of the amateur group, but independently of it.[13] One feature of this amateur society was that its young and inexperienced members had a distaste for professional entomologists. This characteristic, and the general repute of the society, did not endear it to a few of its members and to some non-members who were convinced that the support of professional entomologists was essential if an enduring and worthwhile society was to be formed."[14] It is not known how this distaste was demonstrated: we have shown already that the despised amateurs were more than ready to learn from sympathetic professionals, and many of them were destined for successful careers in entomology whether as "amateurs" or professionals. What makes someone a professional entomologist anyway? Chadwick added that only four or five of the original group (KDF's group) joined the new society.

On 20 February 1953 the first meeting of the new society was held. Ninety-five members had already been recruited and 52 turned up at the meeting The name of the new society was to be The Society of Entomologists, Sydney.[15] Officers were elected: C.E Chadwick, President, E.A. Atkinson, Vice President, N. Turner, Secretary, P. Hadlington, Treasurer, plus three non-executive members. The names of Foundation members were listed in the minutes. Chadwick was the only person from the list of March 1950 to appear as a foundation member of the new society, but new members had joined EntSocNSW2 since the 1950 list and some were to add themselves to SES. The new society's stated *raison d'être* was much the same as that of EntSocNSW2 with less emphasis on young beginners, and it was meeting in the same city and on the same night as the older society (and in the same building, Science House).

No first names, just initials. Titles for women. Some names among the foundation members that would be familiar to many included L. Barton-Brown, M. Casimir, Miss K.M. English, G.H. Hardy, P. Hely, A.K. O'Gower, G.J. Shanahan, A.R.Woodhill, E.H. Zeck, T. Greaves, S.J. Paramanov, E.F. Riek, E.J. Reye, R.V. Southcott and student member John Balderson. In April, A.J. Flick[16] joined the society. G.F. Snowball (CSIRO) joined in August. A report provided later by Chadwick in the *Victorian Naturalist* detailed the aims and officers of the Society.[17] The society jogged along successfully through the 1950s, with meetings at 7.30 pm on the first Wednesday of each month except January and February at Science House in Gloucester Street. Attendance varied from fewer than 10 to 60, with an annual average usually in the 20s. Peak numbers were drawn by topics in applied entomology. The meetings were very formal, and started with reading the minutes from the previous month's meeting, followed by members' exhibits and notes. Then the speaker. The speakers generally provided the society with the full text or at least a summary of their lecture - or, at some stages, the lectures were transcribed longhand by the secretary and friends from tapes made at the meeting. They were typed out with impressive accuracy by member Beverley Jones and sent to each member. As the lectures sometimes ran to eight closely-typed foolscap pages, plus the other business matters of the meeting, the production and distribution of the Circular was not a trivial task. Occasionally this work was acknowledged in the annual report. Most of the speakers were well-known local or visiting entomologists, including some from the USA, and their topics were varied and professionally presented. The speaker in December 1955 was Dr Mary Fielding, a young woman recently arrived from England to take up a position in CSIRO in Canberra. We knew her later as Mary Carver, expert on aphids and their parasitoids.

---

[13] This contention is not supported by the publications of EntSocNSW2. See above.

[14] Entomological Society of Australia (NSW), Circular 283, April 1978.

[15] The Sydney Morning Herald (NSW : 1842 - 1954) Wed 25 Feb 1953 Page 2.

[16] "How can you be sure there are no borers in the floor, white ants in the door, silverfish galore? Get the Flick man, that's your answer, remember one Flick, and they're gone." Radio advertising jingle, *ca* 1950s.

[17] Chadwick, C.E. (1953). A new scientific society. *Victorian Naturalist* **70:**116. This is the Journal of the Field Naturalists' Club of Victoria, with the first volume published in the mid-1860s. Obtainable online through the Biodiversity Heritage Library. Chadwick was a member of the society.

The annual report for 1955 showed a decline in total membership as resignations and unfinancial members exceeded new memberships, but meetings continued to attract reasonable audiences, with an average of 20. The family-friendly field excursions were well attended. In 1957 the secretary was Fred'k P. Crook (*sic*), who had an engagingly informal style of writing the circular. There was no mention of the position of "Circular Editor",[18] later held with distinction by Murray Fletcher among others. The Society announced that it would be taping lectures for loan to members unable to attend meetings. On more than one occasion it published notices from commercial entities trading internationally in butterfly specimens, with interests in selling overseas species and buying Australian native ones. Apparently members were entitled to discounts on various retail products. At the end of every issue of the circular was a paragraph headed "Reproduction". For some reason DFH never got used to this and always expected some interesting content. But in fact it was just about copyright.

At the August meeting, the speaker was Keith Campbell, ex-Spitfire pilot,[19] a member and frequent Council member of the society from its beginnings until his death. In the typical formal style of the society at that time, he was recorded as "Mr. K.G. Campbell, D. F. C., B. Sc. For., Dip. For."

The meetings always included a section for Notes and Exhibits. One stood out above the usual insects: a photo of the Zoology II and III classes at Sydney University in 1913, shown by Miss Irwin-Smith and including herself, Miss KMI English, George Clark, Anthony Musgrave (best known for his Bibliography of Australian Entomology)[20], RJ Tillyard (first Chief of Entomology in CSIR),[21] SJ Johnson,[22] C. Hamblin and E. Flynn. DFH remembers meeting Miss English some 50 years later, working in the Macleay Museum on tabanids.

Meetings were initially in Science House, sometimes in the Shell Theatrette, sometimes in the Australian Museum, and sometimes the CENEF[23] rooms. In 1963, a special meeting was held in St Phillip's Church Hall.

Chadwick retained the position of president until the 1961 meeting, when it was taken by K.E.W. Salter,[24] a Sydney University academic with a penchant for thynnid wasps. Salter had earlier been curator of the Macleay Museum and had joined SES in 1958.[25] Could this change in the presidency have been a gentlemen's agreement, or was it perceived by the membership that a change was due? Salter was re-elected in 1962, with Courtenay Smithers, Curator of Insects, Australian Museum, as Vice President, and Chadwick a council member. Table 1 provides a list of the presidents of the Society.

Salter had the misfortune of a fire in his office in the Zoology Department, and lost much of his research and teaching material. One of his students recalls that, because of this, he felt unable to start his invertebrate zoology course with the usual Protozoa and leapt straight into the sponges.[26]

Other executive positions experienced some churn during the 1950s. Sometimes there was an obvious reason - one secretary resigned because of his wife's ill-health, another presumably because he had been moved to Leeton. The first secretary (Turner) and his wife both resigned from Council within a few months of election. There were eight treasurers in the first ten years.

---

[18] See later. The lack of a formal position was used to discredit the then editor by the president.

[19] Keith Campbell's remarkable life including his reconnaissance missions over war-time Germany was recorded and is available at https://australiansatwarfilmarchive.unsw.edu.au/archive/htmlTranscript/1514. See also https://www.iwm.org.uk/collections/item/object/205451861for a photo of Keith in his flying days.

[20] See https://adb.anu.edu.au/biography/musgrave-anthony-7716 (accessed 18 Apr 2024).

[21] https://csiropedia.csiro.au/Tillyard-Robert-John/(accessed 18 Apr 2024).

[22] Probably SJ Johnston, lecturer in Zoology and successor to Haswell as professor of Zoology.

[23] Church of England National Emergency Fund, based at St Andrew's Cathedral

[24] Keith Eric Wellesley Salter (1908-1969). *Journal of the Entomological Society of Australia (N.S.W.),* **8:** 41–42

[25] *Circular of the SES*(1960) **96:** p. 46 (list of members with addresses and interests).

[26] N.N.Tait, pers. comm. Noel Tait had been taken to a meeting of SES by Salter and appears in the circular simply as "Mr Tait". He was not inspired to go again, but he became an academic at Macquarie University and taught Invertebrate Zoology, year about with DFH. By then the Protozoa had been removed to a separate Kingdom. Noel is well-known for his work on Onychophora.

Field excursions for collecting insects were instituted from 1955 and became so popular that it was proposed in 1957 to hold them monthly. Those were the days when a crowd of people could walk into a national park and catch and kill anything with six legs (but not pick the wildflowers). Can anyone imagine getting permits to do it now?

The society published a list of members at the end of 1959. Forty foundation members were still listed , indicating that about 55 had left the society, but the numbers remained strong at 108. The Society continued on its established pattern of meetings with speakers, show and tell, excursions, December social events, and a thorough account of all these activities in circulars was typed on foolscap on manual typewriters and collated and posted to all members.

The story of this society will be continued below.

C. E. Chadwick (1909-2004)

Since Clarence Earl Chadwick[27] was associated with all the various 20th century entomological societies in NSW and founded several of them, he deserves his own section. *General and Applied Entomology* published an obituary (with permission from the Society for Insect Studies)[28] providing an outline of his life and achievements. It does contain errors and some are corrected in the current paper. In brief, Chadwick was born in 1909 in northern NSW (the birth was registered in Murwillumbah), matriculated from Lismore High School and proceeded to the University of Sydney where he graduated with a BSc in 1932. He was one of AJ Nicholson's last students before Nicholson moved to CSIR.[29] He moved into the teaching profession, spending some time in the Broken Hill area, and his teaching included primary, secondary and technical college levels. Teaching was a reserved occupation so he was not required to enlist for service in the Second World War. Moving to Wollongong in 1945, he founded the Illawarra Natural History Society.

In 1947 he was appointed as the systematic entomologist for the Department of Agriculture's insect collection, with the task of expanding and maintaining it as well as answering queries from the public. He was based initially in the city (Department of Agriculture Building, Farrer Place) but moved to Rydalmere in 1960 where he worked until his retirement in 1974. After retirement, he still visited the collection, and it seems that he regarded it as his personal property. The new curator at Rydalmere, Eberhard Schicha, was obliged to put restrictions on his attendance, facilities and activities.[30] Chadwick became an honorary at the Australian Museum.

Chadwick had a complex relationship with the various 20th century entomological groups, as will emerge in the course of this history. The first of these were AES-AB and The Society of Entomologists, Sydney (SES), as we have seen above. His obituary includes a list of over 100 publications, but many were unrefereed notes in circulars of the various entomological societies he successively founded. He put a great deal of time and effort into the societies, but this was overshadowed by his apparent need to be the only voice in the affairs of each of them and his sometimes fractious relationships with their members.

To end on a more positive note, Chadwick left money to the Australian Museum which has been used, as he wished, to provide new storage cabinets for the collection. Additional funds were invested to provide an annual post-doctoral fellowship in Biodiversity, to be held at the Museum.[31]

A PARALLEL SOCIETY - THE ROYAL ZOOLOGICAL SOCIETY OF NSW ENTOMOLOGY SECTION

This group, a resurrection of RZSNSW1, ran from 1957 to 1989, and seemed to provide a repository for people disaffected with SES (and its continuation under other names), although there were always some people who were

[27] He spelt the abbreviation of his first name "Clarry" and we have used this spelling except when quoting directly from written material by others. His first name is sometimes recorded in publications of the various societies as "Claridge". This is perhaps a mis-hearing of "Clarence."

[28] (No author) (2005). *General and Applied Entomology* **34:**1-6**.**

[29] *Circular of RZSNSWES* (1986) **43:** 15.

[30] Fletcher, pers. comm.

[31] https://australian.museum/get-involved/join/foundation/story-of-a-bequest-clarence-e-chadwick/

simultaneously happy members of both. It seems better to follow its history in full here rather than attempt to interleave it with the history of SES etc. This inevitably results, however, in references to events, to be described later, that happened during the history of other societies (see below).

The Entomological Section of the Royal Zoological Society of New South Wales was established in October 1921 by lepidopterist G. A. Waterhouse,[32] who was chairman, with G.M. Goldfinch[33] secretary. The section was initially successful, meetings being held every second month and later every month. Many members were also members of the Linnean Society of NSW, a more general natural history society founded by Sir William Macleay after the cessation of EntSocNSW1 (see above). The section was discontinued after 1930 because of falling membership and attendance. It was re-established in 1957, apparently at the instigation of marine biologist Elizabeth Pope of the Australian Museum, who was a councillor of RZSNSW.[34] L.C. Haines[35] was chairman and M. H. Gregg[36] was secretary. Laurie Haines was one of the members of the then-defunct EntSocNSW2 who had remained loyal to Ken Fairey and had not joined SES. Chadwick and other members of SES/EntSocAust (NSW) attended the inaugural meeting (1957) and everyone concluded that the two groups could coexist without conflict. Unfortunately there are no minute books available to provide information before 1969.[37] The section produced "Communications" from 1961- generally short notes from the members on observations of various insects. Early contributors included Ian Mosse-Robinson, Len Willan, Courtenay Smithers, Laurie Haines, John Peters, E.O. Edwards (father of Ted Edwards), Don Sands, Max Moulds, Max Gregg, P. Colman, N. Darwin-Allen, M. Dowling. More names appear in the Communications, a total of 18 contributors. Someone mentioned meeting Rex Gilroy in Katoomba, so he was probably also a member. Haines also mentioned Fairey, Chadwick, Levitt, Marlow, Willan, Harford, Salkilld, Keast, Davis, Bollinger, Jones and Crook as early attendees. As with the previous society, in 1963 editor Len Willan had to make urgent pleas for material to fill the pages of the Communications. Ill-health forced Max Gregg to resign from the position of president in October 1963. The last Communication is dated January 1964, but Courtenay Smithers is noted as representing RZS on the council of AES in 1965.[38] As indicated above, there seems to have been a gap, at least in recorded activities, from 1964. The unnamed author of the 30 year history mentioned records of talks and field trips but gave no specific information.

After Max Gregg's retirement from the presidency, the Section continued under new management with a young Rex GF Gilroy at the helm. DFH was inveigled into giving a talk on her PhD work to his group - it must have been 1965 or 1966 and took place at the Australian Museum. Seeing that one of the main items on their agenda was "Sightings and Captures", it was not surprising that their eyes glazed over when the talk was about aphid polymorphism. But the president, while thanking the speaker, announced strongly that "the last thing we want is professional entomologists!" It gradually became clear that he meant people who caught Australian butterflies for sale overseas. Rex Gilroy became well-known for his pursuit of yowies in the Blue Mountains. He died in 2023 but his website is still online as well as other reports of his work.[39]

The RZS entomological group became silent soon after, although the Section claimed to have been operating continuously for 30 years up to 1987. It was once again active in a small way in the 1970s but the group was not

[32] Uncle of D. F. Waterhouse, future chief of the CSIRO Division of Entomology, and a strong influence on his early life and interests. https://csiropedia.csiro.au/Waterhouse-Douglas-Frew/, 8 June 2024.

[33] Goldfinch trained as an entomologist and became an expert on some moth groups but was also interested in shells and was employed for a time as conchologist at the Australian Museum. https://www.eoas.info/biogs/P001893b.htm. 8 June 2024.

[34] Haines, L. (1987). Circular of the Entomology Section **52**: 27 - 29.

[35] Laurie Haines was a piano teacher but also a keen moth collector in his spare time. His attempts to collect moths at streetlights using a step-ladder attracted the attention of the law. Not understanding the importance of moth collecting, they decided he was not of sound mind and took him to Gladesville Mental Hospital! (Willan, pers. comm.)

[36] Gregg later became President of the Parramatta Flora and Fauna Society. Parsons, pers. comm.

[37] Unknown author (1979) *Circular of the Entomology Section*. **49**: 13- 14.

[38] Fletcher, MJ and Monteith, GB (2016). History of the Australian Entomological Society. *Austral Entomology*,.**55:** 121-131

[39] https://australianyowieresearchcentre.com (accessed 11 April 2024)

strong, as members had dropped out "to do degree's" and it was proving difficult to find officers in 1979 (Sundholm and Chadwick acting officers). The group appeared inviable because its officers had resigned, A last-ditch appeal in their newsletter secured Ian Stiff as Chairman, Robin Gunning as secretary, and Allen Sundholm as the newsletter editor.[40]

Unexpected help soon came galloping over the horizon.

Following the coup of 1979 (below), a number of members left SES/ ESANSW and joined the RZS group, where Clarry Chadwick took the reins. It continued publishing a circular, in the same format as that of ESANSW, still on foolscap, and conducting activities similar to those of the latter society, with speakers, notes and exhibits, personal notices etc. It continued meeting at the Australian Museum as a successful group until 1989, when the Board of RZSNSW decided to enforce certain requirements on its existing sections. Some of these conditions seemed quite reasonable, for example that at least 10 members of each section must be members of RZS. The Entomology Section did not meet this criterion and appears to have been quite offended by it. "Nobody interested in entomology is going to pay $15 to join what is virtually a vertebrate zoology society..."[41] It seems they had been collecting their own ($3.50) membership fees but did not pass them through the parent society, partly on the basis that they would then go to support the vertebrate interests of the bulk of society members. They even got "reimbursement" monies from RZS, presumably for room hire. Assertions by some former members that the RZS had "kicked them out" are not really consistent with events. Furthermore, "Legal advice is that we could be disqualified from the use of the term Entomology Section of RZS". One might question how they had got away with it for so long. They were advised to form a new independent body (secession was not an option), and they proposed to form a new group to be called "The Entomology Group, N.S.W." A meeting was called for February 1989 to vote on this proposal. The notice of this meeting appeared in Circular 62 of RZS Entomology Section in February 1989. The group ended up with the name "The Society for Insect Studies" and is still functioning in 2024. More information appears below

One can sympathise with the Entomology Section in respect to other regulations placed on their operations by RZSNSW, for example being forbidden to "distribute any publication outside the membership of the Section". It is usual for like-minded societies to exchange circulars, journals etc. On the other hand, it was reasonable to restrict them from activities such as making public statements in the name of RZS (of which they weren't even members).

THE SOCIETY FOR INSECT STUDIES, 1989 - PRESENT

In 1989, the board of the Royal Zoological Society of New South Wales moved to assert conditions on its sections (see above), and both the Entomology and the Malacology sections were disbanded. Chadwick and the other members of the Entomology group (many of them previously from EntSocNSW3, following the schism of 1979) continued under their own banner as The Society for Insect Studies, with about 50 members. The Society welcomed members interested in any branch of entomology, as had its predecessors. Some of the members went as far back as the Ken Fairey days, e.g. Chadwick, Willan, Fairey himself. Some of the members also belonged to EntSocNSW3. Chadwick had founded The Society of Entomologists in 1953 to break away from the amateurs, but the group who had followed him into RZSNSW and thence into SFIS were mainly amateurs. Ken Fairey was happy to remind Chadwick of the inconsistency.

Chadwick remained president until 2000, a few years before his death in 2004. Now aged over 90, he was happy to relinquish the administrative work of running the society and did not involve himself in its further management or activities. A rapprochement between the two remaining societies (SFIS and EntsocNSW3, Oleg Nicetic President) now became feasible, and a joint meeting of the councils was held, deciding that members of each society would be welcome at activities organised by the other, and that there would be annual joint council meetings and exchange of publications.[42]

According to recently retired SFIS president Graham Owen, "Clarry ran the Society like a Masonic Lodge. Everything was a secret." But: "The main activities & objectives of SFIS were to protect the habitat & the insect

---

[40] Robin Gunning pers comm.
[41] Unknown author (1987). *Circular of the Entomology Section* **62:** 45.
[42] *Circular of the Entomological Society of NSW* (2003), **535:** 14-15

fauna that lives within long before it became a woke pursuit. We incorporated it into our logo.[43] Our unwritten ethos was that we were for fun & learning, to stimulate discussion & scientific study of all insect & associated invertebrates. To try & understand the evolution through fossil, amber & other evolutionary processes. To provide a social environment that was welcoming & non threatening to newcomers. To provide public talks. To provide excursions across the Sydney Basin. To undertake excursions interstate. To provide a Circular to our members, copies of which are held by the State Library, The National Library & the British Museum".[44]

Among the popular activities of the new society were the frequent field trips, during which members learned from each other about the insects they found. As in Ken Fairey's society, young people were encouraged (they usually came with their parents), and many members were enthusiastic about building up their own collections, later to be donated to public institutions. The society had an impressive peak membership of around 150. It publishes an attractive Circular and previously had an active Facebook page. It does not publish a scientific journal. Since it continues as a successful Society, now in its 35th year, it is not appropriate to attempt a detailed history, as its members are much better placed to undertake this when they decide the time is right.

The internet has changed the way the field work is carried out, and senior members, including former president Graham Owen, are dismayed by the move from serious collecting towards iNaturalist approaches, whereby members photograph everything they find, make up a "vernacular" name and post online without any detailed observation of the anatomy. They also express concern about the future of entomological research in Australia, citing drastic cuts to staff of the ANIC[45] and entomology sections in museums, and reduced access to existing collections. This concern is shared by all entomologists.[46]

Public interest can be gauged to some extent by attendance at Science Week events or public displays, but "If Science Week is any kind of a gauge, we had 6 500 people visit our stand at the Museum last year. They were 5 deep most of the day. I doubt we could have catered for more. While the interest & excitement that our stand created was rewarding on a personal basis, it created fewer than 10 new applications for membership. This must be a sign of the times. If the story can't be conveyed on one screen of a mobile phone, then it is too long"[47].

THE SECOND SCHISM (1962)

Back to The Society of Entomologists, Sydney, formed by Clarry Chadwick in 1953 as a "professional" society as opposed to the Entomological Society of NSW (2), aka Ken Fairey's group, perceived by Chadwick as an amateur group.

During 1962, the idea of a national entomological society was gathering strength, and various meetings were held to discuss suitable models. Proponents were drawn from many sources. One of the issues was funding for a national research journal. At the time, the senior state society (ESQ[48]) was the only one with a functioning journal, and they had offered to cede it to the proposed national body. Discovery of a meeting held in Sydney at ANZAAS[49] in 1962 evoked an intemperate response from the council of SES (Salter was president), accusing the Queensland society of "attempting to run the whole continent" and stating that "the meeting was chaired by a then-member of this Society" with implications that this member was guilty of treachery as he had engaged in these discussions and provided a list of entomologists to ESQ without discussing any of this with Council. He was not named but was easily identified as then-vice president Courtenay Smithers. Obviously, his position was no longer tenable in SES but he was already a member of RZSNSWES2 and had produced an account of the meeting for their Communication No. 15 (October

[43] It had also been on every page of the RZSNSW Entomology Section since 1981.
[44] Minor changes to the presentation have been made.
[45] Australian National Insect Collection, Canberra.
[46] An enquiry from DFH to Dr David Yeates (Director of ANIC) received no response.
[47] Owen, pers comm.
[48] Entomological Society of Queensland.
[49] Australian and New Zealand Association for the Advancement of Science. It had enormous meetings at 18 monthly intervals, with over a dozen sections. Attendees could cruise the whole program. The rise of taxon- or discipline-based societies resulted in a steep drop in conference attendance during the 1990s and the large conferences ceased, but ANZAAS continues in a new guise.

1962). Other SES members of the same opinion about the proposed national body also moved their allegiance to RZS. Smithers's boss, Australian Museum director J.W. Evans, was closely involved in the national discussions and no doubt encouraged Smithers to become active, although he needed little urging, as lack of a national society had been one of his first observations on arriving from Southern Africa. Smithers had passed on a list of entomologists and their contact details to ESQ, probably including, or based on, the list of SES members published in 1959.[50] Whilst the management at SES might have seen this as treachery, they themselves had already sent this list to people who were members of both ESQ and SES. There was a perceived need for ESQ to expand its membership on a national level, partly to provide a sound financial basis for its journal (a real scientific journal with original refereed papers, unlike *The Australasian Entomologist* and *The Australian Entomologist*).[51] It was desirable also to have a geographically diverse group of members to discuss the structure of the proposed national society. ESQ experienced a 70% increase in membership as a result of canvassing interstate entomologists. It was not the intention of the ESQ to become the national society.

SES, however, reacted with a high level of suspicion and one might even say paranoia, and responded by sending out a circular in October 1962 to all the state societies, proposing a federation format for the national society, with all existing state societies joining on an equal footing, and in preparation for this, changed its name early in 1963 to The Entomological Society of Australia (N.S.W.), expecting others to follow the same format. Simultaneously, it was proposing to start publishing its own journal (see below). "These actions were regarded by many entomologists as an attempt to impose a structure and title on the proposed national body before the views of Australian entomologists had been gauged".[52] Circulars from 1962-3 frequently referred unfavourably to the proposed national society and the data used for decision-making. Chadwick represented the NSW society at meetings to discuss the proposals.

In September of 1962 it had been proposed that the society should publish a journal, to be titled the *Journal of the Society of Entomologists, Sydney,* the first part to be issued at the end of November. Various principles were laid down for contributions to the journal. They were not very onerous. Acceptance was to be entirely at the will of the editor - no referees required. It was, however, intended to be a step ahead of the AES AB/EntsocNSW2's "journals" in scope and scientific originality. The gestation period turned out to be nearly two years, and the society changed its name in the meantime.

ENTOMOLOGICAL SOCIETY OF AUSTRALIA (N.S.W.) 1963-1977

In 1963, Chadwick returned to the presidency, and the first volume of the journal was published in July 1964, under the title *The Journal of the Entomological Society of Australia (N.S.W.)*. There was by then an editorial committee with the role of accepting papers. Chadwick was chairman. It contained about 10 papers plus summaries of meetings and notes. The actual dates of publication often do not correspond to the nominal date on the cover, meaning that strictly speaking, any citation should be qualified with the actual date of publication, e.g. " Chadwick, CE (1967)...... *Journal of the Entomological Society of Australia (N.S.W.)*. **4:** xx-xy, (published November 1968)." The distinction between nominal and publication date is not relevant since 2019 when publication commenced. No journal was published from 1971 to 1973 inclusive. A summary of the journal issues appears in Table 1.

Chadwick's Presidential Address in 1964 seemed out of character in some respects. He expressed a need for more active volunteers. He had tried to involve younger members, but "had picked a loser or two". He said, quite rightly, that rotation of officers every year was desirable, but, surprisingly, that "the society should have a new president every year" but not one "selected for beauty alone". He added that amateurs were not inferior individuals.[53]

The circulars for 1964 and 1965 continued to give updates on proposals for AES, none considered satisfactory. When the Australian Entomological Society became a reality on 17 August 1965, no mention was made of it in the circular, either then or later.

[50] Circular of The Society of Entomologists, Sydney, (1959). **84:** p. 68.

[51] The *Journal of the Entomological Society of Australia (NSW)*, later *General and Applied Entomology*, started publication in 1964.

[52] Marks, EN and Mackerras, IM. (1972). *Australian Journal of Entomology*, **11:**81-90.

[53] Circular of the Entomological Society of Australia, NSW, **136**: p. 5ff.

Table 1. Summary of issues of journals. Volumes 1- 9 issued under the title *Journal of the Entomological Society of Australia (N. S. W.)*, and all others under the title *General and Applied Entomology*. Nominal Year = membership subscription year. Published date equivalent to issue date and taken as day after printing.

Vol. No.	Nominal year	Date of publication	Vol. No.	Nominal year	Date of publication
1	1964	1/07/1964	27	1996	28/06/1996
2	1965	30/12/1965	28	1998	11/08/1998
3	1966	23/06/1967	29	2000	15/06/2000
4	1967	27/11/1968	30	2001	15/06/2001
5	1968	18/12/1969	31	2002	30/06/2002
6	1969	21/01/1971	32	2003	30/06/2003
7	1970	23/12/1971	33	2004	30/06/2004
8	1974	31/01/1974	34	2005	30/06/2005
9	1976	31/01/1976	35	2006	30/06/2006
10	1978	20/07/1978	36	2007	30/06/2997
11	1979	28/02/1979	37	2008	30/06/2008
12	1980	31/03/1980	38	2009	30/06/2009
13	1981	30/04/1981	39	2010	30/06/2010
14	1982	31/05/1982	40	2011	? ? 2011
15	1983	31/07/1983	41	2012	? ? 2012
16	1984	28/09/1984	42	2013	30/10/2014
17	1985	30/09/1985	43	2014	30/10/2015
18	1986	10/10/1986	44	2016	? ? 2016
19	1987	30/10/1987	45	2017	31/08/2017
20	1988	31/07/1988	46	2018	31/10/2018
21	1989	31/08/1989	47	2019	6/03/2020
22	1990	31/10/1990	48	2020	10/03/2021
23	1991	20/11/1991	49	2021	20/12/2021
24	1992	29/01/1993	50	2022	30/11/2022
25	1993	15/12/1993	51	2023	23/02/2024
26	1995	30/04/1995	52	2024	Pending

Notes Journal not published in nominal years 1971-73, 1975, 1977, 1994, 1997, 1999. Vos. **24, 42** have page headers showing dates corresponding to the nominal year, although the actual publication was later. Vols. **47** and **49** have no publication date on the cover but the delivery dockets show the dates as in the table. For Vols, **40, 41** and **44** the precise publication dates are not known; only the year can be given. The current format in larger size with glossy blue cover, insect line drawing and circular logo commenced with Vol.**28**, 1998.

According to Geoff Monteith in his account of the life of Dr E.N. ("Pat") Marks, she had to make a personal approach to Chadwick to get NSW on board to support the proposed International Congress of Entomology to be held in Canberra in 1972.[54] As late as mid-1972, ESANSW was still being implored, this time by Phil Carne, to affiliate with AES and support the ICE. The president agreed to put it to a postal vote of members[55] and in September it was announced that it had been approved "by a substantial majority". By this time, the ICE (22-30

[54] Monteith, GB (2006). *Australian Entomologist*, **33:** 171-178.
[55] Circular of the Entomological Society of Australia, NSW (1972) **224**.

August) was already over, but ESANSW had been given a table there and had handed out a leaflet "*Entomology in NSW*".

The presidential address in 1973 was about some changes in the society from its beginnings, in particular the rising proportion of professional entomologists among the members. The journal was proving costly to print and mail out, and members' subscriptions did not cover the cost. The work of the editor and his team was made more difficult when people submitted handwritten papers (!). It was important that younger members take positions on council so that they could take over the management. He encouraged the young people by disparaging their knowledge and training, hence also disparaging the academics and universities.

Circular 243 of May 1974 foreshadowed Chadwick's retirement from the Department of Agriculture at the age of 65.

In 1976, the Presidential Address was largely directed at the Australian universities, concluding that the University of Queensland was the only one offering a satisfactory training in entomology, based on the amount of time specifically spent on entomology in the first three years of university study. The people employed in the NSW Department of Agriculture, it can be concluded, were not adequately trained. Perhaps worse still were those who had been trained in the Faculty of Science rather than the Faculty of Agriculture. "A person having done a degree in general zoology may choose an entomological subject for a higher degree and hey presto! he becomes an entomologist! This appears to be entry by the back door and can hardly enhance the standing of the profession." That takes DFH and other women trained in the Faculty of Science off on the grounds of training and of gender. Next he turned his weapons on "the misfits who have attained administrative power". Various members requested the circular editor (Alan Clift, *de facto*) to publish some points in rebuttal especially Chadwick's omission of the entomology taught in the fourth year of the Agricultural Science degree at the University of Sydney. Clift duly did so[56] but Chadwick dismissed any complaints and said his (CEC's) comments were impersonal. He also castigated Clift for calling himself the Circular Editor as there was no such position in the Constitution. The self-justifications were still going in the June newsletter. It is difficult to understand how Chadwick thought that his audience would not see his comments in a personal light. It was clearly war.

THE ATTEMPTED COUP OF 1978

In 1970, the Science Services Branch of the NSW Department of Agriculture was restructured and research areas related to chemistry and biology, including entomology, were relocated to the Sydney suburb of Rydalmere, where Department of Agriculture activities were already in place. Gordon Pasfield was Chief Entomologist at Rydalmere but the position was abolished in 1975. Max Casimir, a foundation member of the society, became Director of Entomology and Victor Edge was Deputy. The move coincided with the early professional lives of young entomologists trained in the Faculty of Agriculture at the University of Sydney by Fred McDonald, as well as some young science graduates. This cohort was a potential source of active young members of the society and many of them joined. The journal was a convenient vehicle for their publications, based, as they were, on insects relevant to agriculture and horticulture in NSW.

In 1975 and 1976 Council included the following people from the Department of Agriculture at Rydalmere: Chadwick (retired), President and Editor, Clift, assistant secretary, Elshafie, business manager, Brown, councillor. Mrs N. Anderson, otherwise known as Jenny, was a non-Rydalmere councillor. The Editorial Committee included Casimir, Snowball and Hickman. Vic Edge encouraged the young scientists to join the society and stand for positions on Council. At the 1977 AGM, Andrew Beattie[57] and Richard Faulder became Councillors. The October circular notes Paul Hughes, Marilyn Fox, Fred McDonald, Dinah Hales as new members followed by Robert Ryan in November, and Robin Gunning and Ian Stiff in February 1978.

February 1978 saw the 25th anniversary of the Society, and plans were made to celebrate it with a barbecue at Cumberland State Forest. But before that came the AGM and election of officers. Alan Clift, who had been a member of Council since 1972, was persuaded to stand for the position of President. There was a good turn up at the meeting but Chadwick had recognised the threat and acquired a large number of proxies from members who did not

[56] Circular of the Entomological Society of Australia, NSW, May (1976) **264**.

[57] "Andrew Beattie" is GAC Beattie, of Rydalmere and UWS/WSU, not AJ Beattie of Macquarie University.

normally attend meetings. He read some of the associated messages to the meeting and one person wrote "young people think they know everything". Chadwick prevailed over Clift thanks to the proxies and thus 1978 continued as 1977 had begun. Keith Campbell was still vice president and Ted Taylor the forever treasurer, both of them from Forestry. Elshafie was still business manager. There were, however, considerable changes to Council, which now included Andrew Beattie as secretary, Fred McDonald of the University of Sydney as editor, and councillors Hamilton, Hughes and Brown, all from Rydalmere, and Mick Catley, from the federal Department of Primary Industries.[58] Winds of change.

Circular 292 of February 1979 provided the Annual Report for 1978. It gave the ordinary membership at around 100, and the program for the year had included 8 meetings with speakers. The Presidential Address from Chadwick for the year was entitled "Twenty Five Years of Effort". It included some amusing anecdotes, and a general history of the society. Chadwick took issue with Marks and Mackerras in their 1972 history of the formation of the AES for their slightly frivolous account of the instability of entomological societies in NSW, and also their description of the current society as a "breakaway group", and he claimed that "no more than four or five at most had belonged to the preceding amateur group"[59]. It is impossible to check this assertion because there was no up-to-date published list of members of the original group. The structure of the AES and its history was again reviewed unfavourably. The rise of television was mentioned as a cause of reduced meeting attendance. One could suggest other causes: many of the members worked at a distance from the city and had enough people with like interests in their own workplaces not to feel the need for out-of-hours meetings. Some of them had young families. And they found the meetings' atmosphere of grey formality and repression unattractive.

THE COUP OF 1979

Young people don't know everything but they learn quickly. The membership grew in 1978 - Ris, Loudon, Clancy, Read, Westcott, then during August, Bishop, Dominiak, Fletcher, Forrester, Goodwin, Greenup, Perry, Schicha, Treverrow and Wright. Then Smithers (returning), Hosking and Spooner-Hart. The number of members listed in the Annual Report[60] was 124 including 8 company associates, plus 8 unfinancial. DFH was overseas at the time of the 1979 AGM but we have an account from a member who was present.

"I remember the AGM in 1979. Andrew Beattie had got me to join the NSW Ento Soc before the meeting so I could add to the votes against Clarrie Chadwick. I remember John Hamilton (who didn't have a bad word to say about anybody) telling me that Clarrie was "very difficult" in the committee meetings of the ESNSW. I didn't know Clarrie, despite his having been the curator of the very collection I was now working with, and went to the AGM with an open mind, prepared to vote for Clarrie if I felt it was warranted. However, Clarrie gave his Presidential Address prior to the election of office bearers and he unleashed an unbelievable attack on those who opposed him. Everybody who worked at BCRI was dismissed as being "applied chemists" with no interest in Entomology at all. I knew that most of the people at BCRI were working to reduce pesticide use. This required understanding the ecology of the main pests and looking at ways to manipulate their environment to bring them under control. I noted that he made no exception for Eberhard and me who were taxonomists and had nothing to do with applied entomology (let alone applied chemistry!) so I joined the vote against him. Clarrie was soundly beaten by Alan Clift for the Presidency and refused to stand as Vice President until Ted Taylor had a quiet word with him and persuaded him to stand....and he was not elected to the Vice Presidency either and then he refused to stand for the committee at all. He never returned to the Ento Soc NSW." [61]

The committee elected was composed of Alan Clift, President, Keith Campbell, Vice President, Andrew Beattie, Secretary, Graham Brown, Assistant Secretary, Ted Taylor, Treasurer, Editor Fred McDonald, Business Manager Mostafa Elshafie, and other councillors John Hamilton, Andy Ramage, Erik Shipp and Don Smith. The Editorial Panel included Vic Edge, Dinah Hales, Erik Shipp and Courtenay Smithers.

---

[58]Circular of the Entomological Society of Australia, NSW. (1978) **283**.
[59] The membership policy of the "amateur society" had always been inclusive and it had hoped to represent every entomologist in Australia.
[60] *Circular of the Entomological Society of Australia, NSW*. (1979) **292**.
[61] Fletcher, pers. comm.

UNDER NEW MANAGEMENT, 1979-1995

The new council of The Entomological Society of Australia (NSW) now had to get its act together and decide on its program for the future. Circular 294 of March 1979 included the outcomes of the AGM and is on... A4 paper! It carried a drawing of *Extatosoma* (Phasmatodea) by Alan Westcott, the first of a series of masthead line drawings by various contributors.

Circular 305 showed the 1980 executive as Jenny Anderson (President), Don Smith (Secretary) and Ted Taylor (Treasurer). The headline insect was an excellent drawing of a beetle, *Monochirus multispinosus*, by Alan Westcott.

This Circular reported the results of a Special General Meeting to consider changing the name of the Society from its bulky and by now irrelevant title to the simple and obvious Entomological Society of NSW. A vote of 51 members present unanimously supported the change. Young[62] people don't know everything - probably no-one mentioned that this was the third society to bear this name. The former president Chadwick threatened the Society with legal action for its procedures in changing the name, and "someone" challenged the Council elections on the basis of insufficient notice.[63]

The Circular announced that the speaker at the June meeting would be Ian Mahood[64] of the National Parks and Wildlife Service. His talk mentioned the plans of the service to protect certain insect species, and asked for the Society's opinions. The Society had not really thought about the ramifications of this proposal, but asked for opinions from outside the immediate audience. Geoff Monteith was one respondent and was strongly of the view that species should be protected by habitat conservation rather than restrictions on collecting. Smithers and McAlpine of the Australian Museum held views somewhat different from Monteith's. The Council of the Society examined the arguments and put their considered views to the relevant government bodies. No changes in the law were made at the time.

Their path forward was not made easier by the fact that Chadwick was a life member and received all the Society's communications. Gone but not forgotten, or forgetting. The Society's next few years, up to at least 1983, were made difficult by Chadwick's written complaints about every action taken by the new committee, not to mention the actions taken in 1978-79, when "one individual"[65] had made council meetings very unpleasant with his overbearing "demands", for example that the Society should move with the times and change from foolscap to A4.[66] This individual was characterised as a "prickly-bearded anarchist" and Chadwick suggested that the prickly cocoon of the moth *Chelepteryx* would make a suitable emblem for the society. The behaviour of the anarchist in organising opposition to Chadwick's re-election in 1979 was considered unconscionable, but apparently stacking the 1978 election with proxies was not. Chadwick addressed to the Society his "Review of Events", with space for a co-signatory from the Community Justice Centre. It was typed single-spaced with narrow margins and covered 6 pages (foolscap of course).[67] The president and secretary of the Society in 1982 and 1983 were Courtenay Smithers and Harley Rose respectively. It fell to them after discussion with Council to put together a response.

Rose had joined the University of Sydney in 1973 as lecturer in entomology. His teaching and research were in the areas of insect toxicology and pesticide resistance, but on the lighter side, he became an expert on giant burrowing cockroaches.[68] Some of Chadwick's complaints are outlined below.

Alarmingly, "someone" whose papers had always been accepted in the past had been asked to make revisions to his paper. He refused to do so and sent the paper to an overseas journal where it was accepted without change. On a more serious matter in this document, Chadwick accused the society of not having had its finances properly audited.

---

[62] By "young" think up to say mid-30s.

[63] *Circular of the Entomological Society of NSW (*1980). **303**

[64] Ian Mahood was a National Parks ranger and post-graduate student at Macquarie University. He was tragically killed in a helicopter crash while doing fieldwork in western NSW in 1981, and his colleague Leong Lim (also a Macquarie post-graduate) was severely injured.

[65] Not named, but it was Andrew Beattie (self-identified). Andrew had deeply disliked these times of conflict

[66] Document from CEC to the society, unsigned and undated, probably 1982.

[67] Copies of this document and of a draft reply by the Society are in DFH's possession.

[68] https://archives-search.sydney.edu.au/nodes/view/30929, photo of H. Rose and D .Rugg with giant cockroaches. Doug Rugg succeeded Rose as secretary of the Society, 1984-1986.

It turned out that this accusation was based on the fact that there was a new auditor, because the long-time auditor had retired. Chadwick wrote that the old auditor had told him that he wouldn't have given a certificate, but maybe the auditor felt it was better to placate than argue. The new auditor was a chartered accountant and presented the accounts according to current auditing practice. He was probably better qualified for the job than Council members Tristram and Hadlington, who had audited the accounts in the first few years.

Chadwick continued his line of "anarchy " and "aggression even against school children". In the latter case, he appeared to be referring to a proposal to run a workshop for amateurs described in the Circular as a workshop "to be aimed initially at high school students".[69] Perhaps it could have been better phrased as "designed for high school students" but the meaning is clear and has nothing to do with "aggression". Another of Chadwick's rather distasteful attacks was against the Society for conferring life membership on "someone" who was not qualified for it. It turned out to be "Nik" Nikitin, who had been CEC's assistant at Rydalmere. The Circular later published parts of his autobiography which certainly records significant work before coming to Australia (see below), but the Council probably did not know of this work at the time and the nomination might have been technically outside the concept of a life member.

The real crux of Chadwick's complaints in this document was the matter of the "Handbook Fund" to which he had donated small amounts of money over time. It was clear to the current council that there would never be sufficient funds in this account to produce a handbook and they had moved the money into another account that paid more interest, but had not "confiscated" or spent it. Whilst most of the councillors were fairly new, Ted Taylor had been treasurer since 1969 and knew the history of these donations. The council declined to enter into conciliation but returned the money in question, plus the interest, suggested at a rate of 9% by Chadwick. The return of $252.28 to CE Chadwick was noted in the financial statement at the 1984 AGM. It seems he chose not to follow the suggested alternative option of having the money donated to a charity of his choice.

Chadwick and some of the members, especially those not employed in entomological research, support or teaching, had gone to the Royal Zoological Society of NSW Entomology Section after the 1979 election. An unnamed person who was also a member of EntSocAust(NSW) was said to have "demanded" that the RZSNSW Entomology Section be disbanded, with the motive of "obtaining more members for the society they had just left". We have not been able to identify this person. For "demanded", Chadwick's favourite word for any contrary idea, "suggested" could probably be used.

The Society continued on a stable course. The Council was filled and most positions turned over every couple of years. Membership remained above 100. There were excellent and varied talks at the monthly meetings. Although the Society now saw itself as concentrating more on the interests of working entomologists, it welcomed anyone with an interest in insects or other terrestrial arthropods. The Society ran some excellent symposia, such as "Entomological Education in the 80's" (*sic*, should be 80s), discussions on conservation of insects, a hands-on workshop of techniques for amateurs (55 attendees, September 1982), a sub-group for taxonomists. We made a tape-slide series about insects for secondary students studying the Species Concept, but didn't make much money from it. There was also a very successful Book Fair in 1985 run by the Society in the person of Max Moulds at the Australian Museum.

"Home" for the meetings was still at the Australian Museum. One of the rooms we met in contained a stuffed emu. It was generally added to the attendance record as "Emu, *ex officio*." Meetings were held at the varied locations where members worked, including CSIRO's *Kooyong* at Warrawee, the Army's malaria research unit at Ingleburn, Quarantine at Rosebery, universities. Renovations to the Museum pushed us out for a time and the meetings moved mainly to BCRI at Rydalmere. The move seemed unpopular with members who worked in the city or lived far from the venue, and attendance suffered.

Presidential addresses were thoughtful and covered specific interests or more general ones such as the future of books, the desirable characteristics of a society like ours, and so on. Weekend collecting trips were organised, sometimes at the University of Sydney's Field Station "Warrah" at Pearl Beach. The annual dinner moved around to

[69] *Circular of the Entomological Society of NSW* (1982) **320.**

various interesting venues. In 1992 Angie Condello and Vic Cherikoff created a very entertaining menu in the form of a published scientific paper with every item or component given its scientific name including family. Insects featured prominently in the meal. Angie did the cooking, Vic supplied the insect components.
The journal appeared as close as possible to schedule, though with some changes of rules for contributors, largely aimed at maximising cost recovery and providing a vehicle for publication by actual members. A common refrain from the various editors begged for submission of more papers and quick revision if required.

The Circular also continued to appear on schedule. Murray Fletcher seemed set to be the forever Circular Editor, a title that tickled his sense of humour. He carried out the role from 1982 to 1989 inclusive, sometimes simultaneously with executive roles including president and secretary. After 1989 Peter Gillespie became Circular Editor. The tradition of changing the headline insect in the Circular every year continued, with black and white drawings from Alan Westcott, Marnie Holmes, Dan Bickel and Eren Turak featured in the first few years.

In 1983 there were proposals to update the Constitution, including requirements of nomination of new potential members and the procedures for dissolution of the Society.

A fascinating series in the Circulars of 1986 was the autobiography of MI ("Steve" or "Nik") Nikitin, published with permission of his sister after Steve's death earlier in the year.[70] A White Russian, Steve spent his early life in Siberia. He was a keen entomologist from his childhood. He and his mother moved to Manchuria, and he recounted close encounters with the local wildlife, including tigers, raccoon dogs and wildcats. Moving to Harbin, he attracted the attention of staff in the Museum. He later was employed there and rose through the ranks to director. His work inspired the local powers to give him the title of Doctor. He survived the Japanese invasion and the USSR invasion. Both were damaging to the museum. During this period he played a major part in successful management of epidemics of malaria and plague. Finally the Communist Chinese invasion caused the Nikitins to look for a new home in Australia, where his sisters already lived. Unfortunately but not surprisingly, work suiting his interests and qualifications was hard to find. Eventually he got a job as Chadwick's assistant in the insect collection of the Department of Agriculture. His overseas qualifications and experience would have fitted him for a more senior position and one can only assume that he disliked the power imbalance and lack of recognition of his previous work. Chadwick, on his side, did not find him a satisfactory assistant (partly because he was for long periods engaged in fieldwork not associated with the collection)[71], but he provided an obituary in the RZSNSWES circular. For some reason "me" and "my assistant" are underlined in the obituary.[72]

In 1987 we were sorry to hear of the closure of the School of Public Health and Tropical Medicine at the University of Sydney, with their entomologists dispersed to other locations, including Westmead Hospital. A small highlight in the year was a letter from a young boy who hoped we could send him tropical butterflies. He finished his letter "PS Please send them DEAD".

A landmark for the Society was its incorporation in 1988. Despite the good membership numbers, meeting attendance was disappointing. Andrew Beattie stimulated attendance by personally phoning members prior to each meeting. One could suggest many reasons for the low numbers. One of the authors (Hales), listed a set of factors limiting her meeting attendance: a full-time academic job and three young boys (and their sports, and the shopping and housework) was just about enough, especially when the venues were far from home. This was not to deny the benefits of expanding one's horizons! She also had a commitment to AES as a NSW councillor, editorial board member and later President. Many of the other members at the time could tell similar stories.

In 1989, DFH's role as AES Councillor meant that the task of organising the week-long AES conference fell on Sydney entomologists, including members of EntSocNSW. Thanks to the work of Ken Brown, John Macdonald, Andrew Beattie, Alan Clift, Christine Stone and Dan Bickel, the meeting in May at Macquarie University was a success. Highlights included the presence of Victor Eastop, aphid taxonomist from the Natural History Museum, London, and a dinner organised by Ken Brown at Taronga Zoo. The mosquito people from the Army arrived in full

[70] *Circular of the Entomological Society of NSW* (1986) **359, 360, 361.**
[71] Chadwick, CE. (1988). The history of a collection. *Circular RZSNSW Entomology Section*, **57:** 3-12.
[72] Chadwick, CE. (1987). Obituary, MI Nikitin, 1911-1986. *Circular RZSNSW Entomology Section*, **49:** 15-16

officers' uniform, driven right up to the gates by a uniformed soldier! The rest of us came in chartered buses. There was a small disaster with morning tea arrangements. Everything, including the new mugs with the logo, was set out in the courtyard waiting for the scientific session to finish. We should have predicted that wandering students would consider this an open invitation. We lost some of the mugs and some of the morning tea.

Unfortunately we had once again annoyed Clarry, this time by innocently choosing the Botany Bay weevil for a logo. A historic local insect, after all, but as we later discovered, also the logo of the RZSNSW Entomology Section from 1982 and continued as its members moved away to form the Society for Insect Studies.

EntSocNSW3 members were heavily involved in organising later AES meetings, at Tamworth (1994, Robin Gunning), Manly (2001, Robert Spooner-Hart) and Orange (2008, Murray Fletcher). From the early 2000s AES paid a professional conference organiser to do the general work required for this sort of large meeting, but in the earlier ones it all fell on the local committee. The Manly meeting (run by Robert Spooner-Hart and committee, without the services of a professional organiser) was disrupted by the failure of Ansett Airlines, on which many delegates had booked their flights. The Orange meeting did have a paid organiser and it was an excellent meeting - Murray Fletcher made sure that the food was sumptuous. The papers were good too.[73]

First the Australian Museum, and then BCRI at Rydalmere, undertook refurbishments that left us without a regular venue for meetings. Back in the Museum, we unsuccessfully begged the director (Des Griffin) for a reduction in payments for room rental.

There had been talk about decentralisation of the activities at BCRI, but in the middle of 1990 it was announced that BCRI would stay as and where it was, in Rydalmere[74]. In his presidential address in 1991, Graham Brown explained to us why entomologists were better than computers.

In 1992, the Circular obtained its own ISSN identity, ISSN 1037 - 3020.

1993 marked the 40th anniversary of the society, and all past presidents were invited to a celebratory dinner and gave brief talks on the Society's history. Chadwick did not attend, so the early history was covered by Brown. The talks are published in Circular 437, 1993.

In 1995 Fred McDonald turned 60 and decided to retire from the University of Sydney (but not, of course, to give up his work on heteropterans). He had trained many entomologists in the Faculty of Agriculture, and the occasion was celebrated at the University's Sports Pavilion. Fred gave a talk to the Society about his years of teaching, the difficulties of providing adequate lab work, and the changing backgrounds and motivations of students.[75]

In October 1995 the Society again ran a workshop for amateurs, with Robert Spooner-Hart as convener. Good value at $50 for the two days, but apart from the benefits to attendees, it was hoped also to attract new members. The paperwork for this event included, for the first time, the circular logo now used on *Tarsus* and the journal. We have not been able to determine the designer's name or the circumstances in which it was commissioned, or otherwise acquired. Any information would be gratefully received, so that this talented person can be acknowledged.

Grant Herron gave an eerie story of the prescient behaviour of sarcophagid flies following the death of a family member.[76] And in 1995, the news came that BCRI was to be closed and the staff dispersed.[77] This was not quite terminal, as there was to be an appeal process.[78]

[73] *Tarsus* (2008) **584:** 36-38
[74] *Circular of the Entomological Society of NSW* (1990), **401:** 12.
[75] *Circular of the Entomological Society of NSW* (1995), **449:** 11 **-** 12
[76] *Circular of the Entomological Society of NSW*, (1995) **450:** 14.
[77] *Circular of the Entomological Society of NSW* (1995) **454:** 52
[78] *Circular of the Entomological Society of NSW* (1995) **455:** 59

THE DISASTER OF 1996

The Society continued on unruffled seas. But storm clouds were not far away. An appeal against the decision was mounted and evidence was heard by a parliamentary committee, of which Eddie Obeid was one of the members. The appeal was lost, as announced in August 1996. Rydalmere was to be closed and most of its staff were to be relocated to country centres, including Orange, Yanco, Wagga Wagga, EMAI[79] etc. Sometimes husband and wife were slated for relocation to different parts of the state. Some staff chose to retire or to leave the Department and seek academic positions or work as consultants.[80]

Alan Westcott, president in 1995, had foreshadowed the event and pointed out that the actual number of people affected was quite a small proportion of the total membership of 216, and that a meeting of the Society had been confident in the continued success of the society. But the end result for the Society was that many active members were dispersed from Sydney. For example, the Council for 1995 had seven members from BCRI, and they were responsible for ten of the jobs. In 1996, five Rydalmere people were carrying seven of the major jobs on Council. The positions of Secretary and Circular Editor were vacant.

Rydalmere closed finally in January 1997. The BCRI people might remain paid-up members, but, if in country centres, they could not be present at meetings and work on Council would be difficult. No Zoom, and email and the internet were relatively new. And we lost our main venue for meetings and production base for the circulars. People who resigned from the Department of Agriculture but remained in Greater Sydney were often faced with longer travel times or relocation to be closer to work. Relocation can have wider effects than on the individual. Schooling and partner's job could be compromised too. All these factors weakened the Society.

But the show must go on. Despite the loss of the person-power base of Council for the preceding years, a full Council was elected at the 1997 AGM. Robert Spooner-Hart was president, Alan Clift, one of those who had resigned from the Department of Agriculture, was vice president. Ted Taylor was the forever treasurer. Alan Westcott and Mary-Ann Terras, destined for EMAI, were taxonomy editor and public officer respectively. The councillors included Peter Gillespie (Orange), and Oleg Nicetic, part of Andrew Beattie's team who had relocated to the University of Western Sydney at Hawkesbury. The largest group of entomologists in the Sydney area was now at Richmond. UWS, incidentally, had acquired the Rydalmere location as its UWS (Nepean) campus. This must have been a done deal at the time of the appeals against the closure of BCRI, because Eddie Obeid criticised DFH for not having got it for Macquarie University. It showed that the appeal was a waste of everyone's time.

PICKING UP THE PIECES 1997 - 2017

1997 saw a full council elected with Robert Spooner-Hart as president. Gith "Gitte" Strid's drawing of a winged bulldog ant was chosen as the masthead drawing.[81] Gitte has served for many years as Business Manager, with responsibilities for journal distribution and management of the Society's stall at the Ku-ring-gai Wildflower Garden.

The meetings followed the traditional pattern with invited speakers, whose contributions were summarised in the Circular. About nine meetings with speakers were held each year, plus the AGM meeting in March and Annual Dinner in December. Generally there was no Society activity in January. Add to this excursions and special events, and the Society could claim to be as active and proactive as before the dispersal of the Rydalmere people. Associates and postgraduate students from the University of Western Sydney - Hawkesbury took up council positions and contributed greatly to the running of the Society: for example in 1999, with Robert Spooner-Hart as President, four other UWS-H people were on council (Basta, Hossain, Howpage, Nicetic). Oleg Nicetic was subsequently president and is now at the University of Queensland. Albert Basta continued working at UWS. Several young women also contributed strongly in this phase of the Society's life: Isla Carswell, Mary Cannard, Tanya James, taking on major roles such as secretary and circular editor. Back then, the circular had to be prepared and printed, as many as eight pages of double column text, then mailed individually to each member. It was a demanding task. They followed in

[79] Elizabeth Macarthur Agricultural Institute, at Menangle, closer to Wollongong than Sydney.

[80] *Circular of the Entomological Society of NSW* (1995) **455:** 52

[81] The course Biology of Insects at Macquarie University included instruction from a professional biological illustrator. Strid and Turak had both taken this course.

the footsteps of Mrs Alison Nicholls, who had held the position of secretary in the early 1990s. In 2001, the Society actually had double the required number of councillors, eight nominees, four elected and the other four co-opted!

Some meetings were held at Macquarie University, with the security men on the gates being fairly generous about not charging for parking. But to everyone's horror, after one meeting in 1998, members were shocked to receive parking fines issued by the police![82] The venue naturally became unpopular but was still used from time to time, with members now aware that they needed to pay for parking, even if there was no-one on the gate. In a later court action, Mary-Lynne Taylor and colleagues managed to get the fines repealed.

Age was sometimes an issue. Alan Westcott had remarked on the age range of the membership "from twelve to over 70!" Robert Spooner-Hart in his 1998 presidential address referred to himself as "an old bugger" at 50. 26 years later, he is still a full-time academic and researcher. His 50th birthday had been noted for his enactment of his own metamorphosis, crawling in a sleeping bag to represent the larval stage, then emerging as a winged adult. While he was probably thinking in terms of a lepidopteran, his friends pointed out that, seeing the sleeping bag "larva" had no legs, and the adult only two wings, he was not a butterfly but a blowfly.[83] In hindsight, 70 was young and 50 was very young. A number of the active members now are 80+.

The Society organised ambitious long distance field trips, e.g. to Narrabri Cotton Research Station (1998), Orange (2001), Griffith, including Leeton and Yanco, (2002).

In 1999, ironically, Rydalmere (now UWS) once again became our home for some meetings, even in the same room. The society organised a seminar day for postgraduate students. Some were so delighted with the possibilities of Powerpoint that their slides, with backgrounds of flowers and foliage, were almost unreadable. That's one of the reasons for having practice sessions, and the Society placed this seminar day on its calendar to be run in alternate years.

The year 2000 was not only the millennium, but also the date of circular 500, published prior to the February meeting of the Society, but with page numbering following on from the previous year. By convention, new page numbering started in the circular after the AGM. At the AGM the taxonomic editor Dan Bickel spoke of the journal's problems. Basically, if there were not enough worthwhile submitted papers, the journal came out late. If the journal came out late, it was regarded as unreliable and people didn't submit papers, resulting in a downward spiral. Garry Levot was elected Editor (Applied). Table 2 shows the data on production and issue of the journal.

The year 2000 was also the year of the Sydney Olympics. The entomological highlight was the vast number of early-migrating bogong moths attracted by the powerful mercury vapour lights around the venues, terrifying both athletes and visitors, invading toilet blocks, entering air conditioners and setting off alarms. Advice from CSIRO lepidopterist Ted Edwards was "Learn to like them." Long time member Andy Ryland of The Beneficial Bug Company had warned the Olympic Authority three years previously that this problem would quite likely emerge, but no action was taken.[84] Graham Goodyer gave a talk to the Society on the biology of the Bogong moth and the history of research on it.[85]

Later in 2000, the Society announced that its first website was up and running: www.entsocnsw.netfirms.com. It was set up and managed by recently-graduated Max Hales, software engineer. Council members were invited to provide mini CVs but the email address was incorrectly written in the circular and unsurprisingly, nothing arrived. It was a long way from the bells, whistles and technicolour of the current site, but it was a start.[86]

---

[82] *Circular of the Entomological Society of NSW* (1998), **485:** 22
[83] *Circular of the Entomological Society of NSW* (1998), **481:** 4-5.
[84] *Circular of the Entomological Society of NSW* (2000), **508:** 39-40.
[85] *Circular of the Entomological Society of NSW* (2001), **514:** 12-14.
[86] *Circular of the Entomological Society of NSW* (2000), **503:** 12.

The Society ran another postgraduate student workshop in 2001. Our current vice-president, Nigel Andrew, was awarded the prize for the most outstanding presentation.[87] Our current secretary, Khalid Ahmad, was one of the speakers in the 2003 event.[88]

2003 saw the Society celebrate 50 years of continuous activity with a special dinner at the Epping RSL Club on 28 June. A wonderful audio-visual display was arranged by Oleg Nicetic, and Robert Spooner-Hart organised an exciting game of "Bug Bingo". Almost all the past presidents were there - Graham Brown, Clift, Fletcher, Macdonald, Moulds, Nicetic, Smithers, Spooner-Hart and Westcott. Clarry Chadwick was invited but, by then in his 90s, did not attend. A citation was read recognising his long-distinguished service to entomology in NSW.[89] Spooner-Hart and Westcott wrote a paper on the Society's history, published in *General and Applied Entomology*.[90]

In the year 2004, our pages seemed to be full of obituaries. Don Scambler, one of the elders of the Society, had died in December 2003. Graham Young and Graeme Baker (both had been contemporaries of DFH at Sydney University and both had spent time as entomologists in Papua New Guinea) died in February 2004. Work in PNG was usually with teams of local assistants, who were learning about integrated pest management as well as helping with the physical work. Graham, and presumably also Graeme, were fluent speakers of Neo-Melanesian. Graham asked his team how much pay-back they thought they could get if he (Graham) was killed by a rival group. The answer was quickly given: "a second-hand Toyota Landcruiser, or the money for one". Graham and Graeme knew each other well and Graham had been determined to speak at Graeme's funeral, and to describe his work as an excellent orthopterist.[91] They knew that their days were numbered, with different forms of cancer. Graham died quite suddenly from pneumonia on 18 February, and Graeme only three days later. Then in April we lost Graham Clancy. Four excellent entomologists and active members of the society and of course people we counted as friends.

The Society issued a FAX-back survey to members to canvass views on directions for the Society to make sure it survived into the future. Twenty years on, we are still surviving and publishing, but still discussing the rather dark future.

Here endeth the reading of the bound volumes of printed circulars, the last one being No. 554, March 2005, announcing the upcoming AGM (at Ermington) and a BBQ and light-trapping evening to be held at Cumberland State Forest in association with the Society for Insect Studies. Mary Cannard retired from the role of circular editor.
The Circular now moved to online production only, and took on the new title *Tarsus* **563**. (Most) past issues are available on the Society's website, https://www.entsocnsw.org.au. Unfortunately, at this stage Nos 555- 562 and 564 are not included in the collection. Issue 563, February 2006, leads with the usual sort of problem, enunciated this time by the President, Martin Horwood, not enough of something, in this case not enough speakers to fill the year's program in advance. This followed a year when Council had been short of four councillors and there had been no quorum at the AGM. Nobody had taken up the role of Circular Editor in 2005 and the President had had to do it.[92]

The Office of the State Cabinet knocked back our suggestion of a State Insect Emblem. (We had suggested the Botany Bay weevil). "It is now up to the State Heritage Commission to follow this up with the Government." It seems NSW still has not named an insect as an emblem of the state.

Tarsus 563 featured a photo of a giant bed bug cuddling Stephen Doggett, medical entomologist, who was the February speaker. Notes on termites by Ted Taylor, and by DFH on the recent International Aphid Symposium in Fremantle, took up a couple of pages, and the upcoming AGM was advertised. Despite poor attendance at the AGM, a full council was elected for 2006 with some interesting "new blood" among the councillors, Robin Parsons and

---

[87] *Circular of the Entomological Society of NSW* (2001), **517:** 33.
[88] *Circular of the Entomological Society of NSW* (2003), **540:** 40.
[89] *Circular of the Entomological Society of NSW* (2003), **537:** 34-35.
[90] Westcott, A.E and Spooner-Hart, R.N. (2003). 50th anniversary of the Entomological Society of NSW Inc. *General and Applied Entomology*, **32:**1-3.
[91] Beattie, pers. comm.
[92] *Tarsus* (2006) **565:** 11.

Graeme Smith. Gith Strid by now certainly deserved the informal title of the (almost) forever Business Manager. Not quite forever, as Mark Stevens in Yanco performed the role from 2010 to 2014.
Martin Horwood's presidential address was, however, an account of disappointments of the previous year - lack of attendance by members at meetings, lack of willingness to take on council roles, lack of participation in organised excursions, complaints about change (e.g. from print to the online circular).[93] Future president Bob Ryan of BOC was the speaker at the April 2006 meeting.

Tarsus 567 (July 2006) gave notice of intention to update the Constitution, including removal of the need for an external auditor because of the cost, in a time where we were experiencing extra expenditure related to room hire and printing. There is the second part of a timeline of entomology. The first part had appeared in *Tarsus* 566, and both were adapted from http://en.wikipedia.org/wiki/Timeline_of_Entomology_-_Prior_to_1800. There are some photos of show and tell exhibits, including one shown by DFH, of aphids on a purchased (unnamed) seedling. There are two remarkable things about this. One is that the aphids are captioned as rose aphids. They certainly don't look like rose aphids even in the low-resolution photo and maybe this was an editorial error. After all, for the general non-aphidophile public all aphids are rose aphids. The other is that in the photo DFH was wearing the very same fleece garment as she was often wearing while writing this. The following *Tarsus* set the identity record straight - they were banana aphids and the seedling was *Caladium* sp., an indoor plant with large coloured leaves. It didn't do too well. Standard fare for *Tarsus* at the time included an account of the previous speaker's presentation, Show and Tell, and an "Insect of the Month" with photos and text.

The December *Tarsus* (#572) advertised the first of our Christmas dinners to be held at the Boatshed Café, La Perouse. Ted and Mary-Lynne Taylor had for some time organised the dinner, providing arthropod-themed table decorations, a quiz, and prizes, and this time had chosen a restaurant in their own area. It was, as usual, a great success. The major item in this edition was an article about mosquitoes - the previous month's talk. The speaker was Cameron Webb, still the media's go-to man for any news event featuring mosquitoes. His main advice was that domestic mosquito traps were not really much use. Less known is that Cameron is a Science Superhero and that he has another life as a sound recordist and musician.[94]

2007 started badly when the position of president could not be filled at the AGM. The Circular Editor for the preceding years, Simone McMonigal, also resigned, to travel the country with partner Warrick Angus. We were sorry to lose them. Warrick was a councillor of the Society, and the two of them had organised an excellent barbecue and hands-on visit to Taronga Zoo. Warrick later reported on his experience filming Dawson's Burrowing Bee in Western Australia, with a camera crew working for a David Attenborough series. We see them later at Crocodile Island, winning awards.[95]

The position of Circular Editor was accepted by Graeme Smith. The presidential address (Martin Horwood) again mentioned lack of participation by members and financial stresses on the society. He also mentioned the need for an effective website. The original web manager had gone to live and work in England. Lowan Turton from Agriculture had become the administrator, but the free website was limited in what it could do. We could no longer pay an auditor. Partly because of cost, and partly because of poor attendance, meetings were reduced to alternate months. Following Martin Horwood's presidential comments, Hales wrote a couple of pages summarising some of the challenges faced by the Society and admitted that she had no answers.[96] Membership was falling, having reached 67, plus the usual unfinancials. But in 2024 we are still going.

2008 provided a turnaround with Barbara May taking on the presidency and all council positions filled.[97] A full list of presidents appears in Table 2. The new web site, www.entsocnsw.org.au, was up and running, and capable of taking large files. Graeme Smith was doing an excellent job in charge, and the website was filled with interesting

[93] *Tarsus* (2006) **566:** 16
[94] https://www.chiefscientist.gov.au/2017/04/australian-science-superheroes-cameron-webb
[95] https://landcareaustralia.org.au/wp-content/uploads/2016/media_release/MR_Winners_NT-2309.pdf, https://www.abc.net.au/news/rural/2011-11-16/crocodile-island-rangers-hope-to-snap-up-funding/6175404
[96] *Tarsus* (2007) **576:**99-100
[97] *Tarsus* (2008) **581:**2

material, including *Tarsus* and *General and Applied Entomology*. Some of the less visible members came up with questions, answers, book recommendations and so forth.

Table 2. Presidents of the Entomological Society of NSW (including SES) 1953-2024.
*** Jenny Anderson and Barbara May have been the only female presidents.[98]**

Name	Year(s)
CE Chadwick	1953-1960
KEW Salter	1961-2
CE Chadwick	1963-1978
AD Clift	1979
JM Anderson*	1980-1981
CN Smithers	1982-1983
MS Moulds	1984- 1985
MJ Fletcher	1986-1987
JA Macdonald	1988-1990
GR Brown	1991-2
AD Clift	1993
AE Westcott	1994-1996
RJ Spooner-Hart	1997-2000
O Nicetic	2001-2003
M Horwood	2004-2006
Vacant	2007
BA May*	2008
R Parsons	2009-2010
Vacant	2011
RF Ryan	2012-2024

The Society held another successful postgraduate student workshop in June 2008 at Charles Sturt University, Orange, and attracted student participants from Charles Sturt, Wollongong, Macquarie and Sydney Universities. University staff and council members were also present. Awards were given for best presentation and scientific illustration.[99]

Tarsus 585 (March 2009) included a summary of a talk by AL Roach of Heritage Pest Management, about conservation of museum specimens of all kinds in the face of insect pests. It was interesting to hear of the role of oxygen-scavenging chemicals in this context. Graeme Smith (announced at a recent Society dinner as the King of the Silverfish, because of his extensive work on the taxonomy of this group) gave an account of an international meeting on subterranean biology, held in Fremantle and including cave excursions. Silverfish like caves. At the AGM the major positions had been filled, with Robin Parsons as President, Martin Horwood, Vice President, Mary-Ann Terras as secretary, Ted Taylor as Treasurer, Gith Strid-Nwulaekwe as Business Manager, but only one Councillor. Issue 586 (May 2009) contained a paper from Garry Webb on invasive ant species, and Garry Levot reported the

[98] The membership numbers have always been male-biased, but the rarity of female presidents cannot be regarded as discrimination; there were certainly years when anyone could have stepped forward to hold this office. The paucity of women is more likely due to lack of experience and confidence in management.

[99] *Tarsus* (2008) **583:**24-25

publication of Vol. 37 of *General and Applied Entomology*, after a gap in the series. And so it continued, with reports on meetings, summaries from speakers, show and tell, and now also, questions from the public. We hope they all got answers of some kind. One of the questions came from a member of the public who pointed out superficial similarities between prawns and insects. Having taught Invertebrate Zoology for some years, DFH looked up the latest molecular phylogeny and was amazed to find that insects were considered by the authors to be crustaceans, in the Pancrustacea, and that what we had considered to be primitive crustaceans were in fact primitive insects.[100]

Garry Levot was editor of *General and Applied Entomology* from 2000 to 2010, when Robin Gunning took on the job. For a few years, the Society had elected a separate Taxonomic Editor (Bickel, Westcott), but after these members left the Society the experiment was discontinued.

Tarsus **593** (September 2010) was a bumper issue including an account of Andrew Beattie's work on citrus, a long article from a non-member on observations of the development and identification of a rarely recorded moth and a number of show-and-tells from the previous meeting. Graeme Smith was the Circular Editor, and Mark Stevens the Business Manager. There were three councillors, so not quite a full council. *Tarsus* **593** also announced the publication of the 2010 issue of the journal (*General and Applied Entomology*, **39**), with Robin Gunning as the new editor. She deserves the "forever" title, none more so, as she is still carrying out this role.

But 2011 saw another period of impending crisis as membership declined and council positions were difficult to fill. The President (Parsons) and Circular Editor (Smith) had indicated that they were standing down and there were no volunteers to take up their roles at the AGM. Bob Ryan, however, a councillor in the previous year, became Vice-President. The retiring president, like Martin Horwood before him, wondered whether this should be the end. Meetings were no longer to be held at Ermington.[101] With no Circular Editor, no issues of *Tarsus* were produced for the remainder of the year. A summary of successful site visits during 2011 was given by Bob Ryan in his vice-presidential address.[102] Bob became president at the beginning of 2012. Again a year passed with no Circular Editor, but issue 598 appeared in March 2013, prepared by Graeme Smith although he had stepped down from the editor's role.

During 2016, the Society's journal *General and Applied Entomology* commenced online publication to the membership of papers on acceptance, though for some years members also received a hard copy of the full journal when officially published.

In 2017, the Society suffered a heavy blow with the sudden death in April of our wonderful treasurer, Ted Taylor. An obituary appeared in the Society's journal.[103] A proposal was received for a student prize to be named the Ted Taylor Prize, and this subsequently came into being, with Nigel Andrew (Vice President) as coordinator.

The pattern of *Tarsus* **602** (February 2017) was similar to those of previous years, as a single business report, generally indicating an understaffed Council and a gradual fall in membership. This is not to say that the Society had no activities - it still did the Ku-ring-gai Wildflower festival (Gitte chief organiser). The annual dinner was a constant item on the calendar: Mary-Lynne Taylor continued to organise it after Ted's passing, and DFH took over Ted's role of quiz person. We continued to publish the journal, and had occasional visits, but no longer had the bimonthly meetings with speakers. Attendance had become so weak that it was embarrassing to the Society and both disrespectful and disappointing to speakers who had put time into preparing their presentations. Annual reports mentioned a decline in membership and an absence of contributions to *Tarsus*. The latter was not surprising since there was no editor to whom contributions could be sent.

In November 2017, President Bob Ryan sent the following letter to members.

---

[100] *Tarsus* (2010) **591:**4

[101] *Tarsus* (2011) **596:**2

[102] *Tarsus* (2012) **597:**3-5

[103] Hales, D.F. (2017) *General & Applied Entomology* **45:** Page number not available.

Dear Member,
The Entomological Society of NSW [EntSoc NSW] was founded some 65 years ago (1953) with the aims of advancement and dissemination of entomological knowledge in all its aspects. This was achieved through regular meetings and the production of both a newsletter and a Journal.

In the 1980's the large number of entomologists employed at the Department of Agriculture at Rydalmere acted as a strong nucleus which became the geographical hub of the Society. With the closure of the Rydalmere facility and the dispersion of entomologists throughout the state, the Society entered a long period of decline. Meetings with speakers were reduced to bi-monthly events. The Circular was produced after each meeting with the speakers talk and the Journal produced annually. In spite of having good speakers, the time pressures of modern life and the difficulty of members getting to meetings meant that numbers attending meetings declined to a level where we could not justify inviting speakers. The Circular became an annual electronic publication just prior to the AGM and activities of the Society declined to a Christmas party, a stall at the Ku-Ring-Gai Wildflower festival and the AGM. The Journal however continued to thrive and is valued by members as a means to publish their work. Membership is reducing as members pass away or change their priorities and new membership applications are negligible. The digital age has greatly altered the way people interact.

The Council has reached the stage that we do not see a future for the Society as it stands and will propose at the 2018 AGM that the Council wind up the affairs of the Society. The 2018 issue [Vol. 46] of General & Applied Entomology [GAE] will be the last to be produced.

A postal vote in response to this recommendation will be sent to members during 2018. In the absence of any member nominating to take over the Presidency of the ESNSW at the 2018 AGM, the current Council will form a working group to manage an orderly closure of the Society's affairs. Any assets remaining at the end of this period will be distributed to Societies with similar objectives as those of the EntSoc NSW (e.g. the Australian Entomological Society).

In Summary:
At the 8th Nov'17 Council Meeting a motion to close the EntSoc NSW was passed unanimously.
This decision by Council needs to be ratified by current EntSoc NSW members. The first stage is to communicate to EntSoc NSW members this decision and inform members this proposal will be a motion at the 2018 AGM (Mar'18: proxies will be accepted). If EntSoc closure motion is approved, a ballot will be sent to EntSoc NSW members to formalise the termination of the EntSoc NSW.

If the motion to close is approved by a minimum 2/3rd of the members who cast a vote, the Council will finalise the transfer of assets to another like-minded Society. The Final GAE Journal will be Volume #46 (the GAE Editor is now accepting papers for Vol. 46 which has a proposed publication date in second half of 2018). The recommended EntSoc termination and asset transfer is proposed to be finalised in 2018.

This decision is not taken lightly and has been on the EntSoc meeting agendas for a number of years, the concern was always the retention of the GAE Journal. This decision will prompt the EntSoc Council to makes it best endeavours to transfer the GAE Journal to a Society with similar objectives as those of EntSoc NSW (e.g. The Australian Entomological Society) before terminating the GAE Journal.

Robert Ryan,
EntSoc NSW President
11 November, 2017.

The death of Ted Taylor had been a great loss to the Society, but the membership seemed to have been electrified into some kind of action, and the major positions on Council were filled, Robin Parsons taking on Ted's position as Treasurer. Council withdrew its plan to wind up the Society. The position of Circular Editor remained vacant and a few issues were produced by DFH as acting editor. Had the phoenix risen again? Not quite. Late in 2018, Hales and Smith gave notice of another motion to wind up the Society. This came about because of the resignation of some of the new Council members, for reasons of work, health, or other projects taking priority. Unexpectedly, at the 2019 AGM at Ryde-Eastwood Leagues Club all major council positions were filled, with Garry Webb taking the role of

Tarsus Editor. Hales withdrew the motion, and the council has continued with little change until the present, with excellent *Tarsus* editions coming out on schedule under Garry's management. Thomas Heddle as Assistant Editor of *Tarsus* combined this work with finishing his PhD. Some members, however, were overloaded with the need to take on more than one role and assist newcomers in pivotal positions on Council. Treasurer Robin Parsons was outstanding in his efforts to maintain a functioning Society and was later offered life membership for his contributions.

2020-2022 were the years of COVID. Council learned to do Zoom meetings with Professor Nigel Andrew (Vice President) as host, but even these were poorly attended. *Tarsus* appeared regularly, full of interesting links and local news, and the journal continued thanks to the long-serving editor, Dr Robin Gunning.

In the middle of 2024, the Society's continuing President, Bob Ryan, died suddenly at home. A eulogy by RP appeared in *Tarsus*[104] and an obituary by DFH and RP appeared *Myrmecia*, the news bulletin of the Australian Entomological Society (November 2024).[105]

A Zoom meeting in September 2024 of Council and associates exhibited little confidence in the Society's future. It was well-known that many scientific and other societies, even the Australian Entomological Society, were experiencing loss of members (one such Sydney-based society was described to the first author as "the walking dead"). The young people of the late 1970s and early 1980s are now old people in their late 70s or early 80s. We do have some excellent younger people and would be delighted to see them volunteering to take up roles on Council.

There is a tendency among professional scientists to put their efforts into discipline-based societies (e.g. Genetics, Ecology) rather than taxon-based ones. It was recognised also that our Society had, for some years, had little to offer its members other than *Tarsus* and the opportunity to publish in *GAE*. Valuable as these are, a Society cannot exist without the engagement of its general membership. Frequent pleas for contributions to *Tarsus* and *GAE* and to take positions on Council have failed to elicit much activity. An organisation persists as long as there is a need for it. Perhaps, in its 72nd year, there is no longer a need for the Entomological Society of NSW and it may be near its end.

But we have said this before.

ACKNOWLEDGEMENTS

This history would not have been possible without the almost complete set of printed circulars provided by Max Moulds, who also gave us material accumulated by the late Barry Salkilld. The online issues of *Tarsus* (various editors) appear on the Society's website in an almost complete series. Thanks to all the editors who have worked so hard to provide and circulate this historical record of the Society's life, and to the website administrators who have made *Tarsus* available on line. Don Sands, Len Willan, Murray Fletcher, Graham Owen, Robin Gunning, Alan Westcott, Gitte Strid-Nwulaekwe, Robert Spooner-Hart, Harley Rose and Andrew Beattie provided personal recollections, the first two dating back to the early days in Ken Fairey's society.

It has been a pleasure and sometimes a sadness to revisit the history of the Society - good times, good friends - too many of them no longer with us. Lots of younger people who, we hope, are having successful careers. Times of prosperity, times of darkness.

It seems proper to sign off in the style of the 1950s: Dr. D. F. Hales, B. Sc. (Hons. 1), Ph. D., Grad. Dip. L. A. H., formerly of Macquarie University, and Mr. Robin Parsons, Public Officer and Treasurer of the Entomological Society of New South Wales

Submitted 22/11/2024 Accepted 19/12/2024

[104] *Tarsus* (2024) **635:** 2-3.

[105] *Myrmecia* (2024) **60:** (4)**:** 7-8.

This page is left blank intentionally.

TEMPERATURE VARIATION IN MOUNDS OF *COPTOTERMES LACTEUS* (HILL) OVER A FOUR YEAR PERIOD IN SOUTHEASTERN AUSTRALIA

Garry. A. Webb

Sumitomo Chemical Australia, 51 Rawson St, Epping NSW 2121 Australia
Email: garrywebb1@outlook.com

Summary
The internal and external temperatures of ten *Coptotermes lacteus* (Hill) mounds in south-eastern Australia were monitored for four years to determine the relationship between internal mound temperatures and ambient conditions. The ambient environment of these mounds ranged in temperature from -5 to 40° C over the study period. Variation in in-situ ambient temperature (measured by external mound temperature probes) was similar to ambient temperature recorded for the region (nearby weather station). However, internal mound temperatures were highly moderated and remained within a narrow range on a daily basis and always near the maximum daily temperature. During winter, when ambient temperatures were reduced below zero, internal mound temperature rarely declined below 15° C. On the rare occasions that ambient temperature reached above 35° C, internal temperatures remained at or about 35° C.
Keywords: *Coptotermes lacteus*, mound temperature, temperature regulation

INTRODUCTION

Termites are capable of constructing some of the most elaborate nests of any insect groups on earth, housing over a million individuals (Arab *et al.* 2017, Evans *et al.* 1999, Gay and Greaves 1940, Korb 2003, Lee *et al.* 2017). They are capable of tightly regulating the internal temperature and humidity of the nest by structural and behavioural means to optimise survival of the colony (Argawal 1980, Cameron *et al.* 2008, Field and Duncan 2013, Holdaway and Gay 1948, Joseph *et al.* 2016, Korb 2003, King *et al.* 2015, Watson and Abbey 1986). Many species construct earthen mounds which provide insulation from temperature extremes in both hot and cold climates (Bristow and Holt 1987, Field and Duncan 2013, Korb 2003, Korb and Linsenmair 1999, Malaka 1977, Watson and Abbey 1986) while others may construct nests in living or dead trees, stumps and fallen timber as well as in built structures (Greaves 1962, 1964, 1965, Horwood *et al*. 2010, Lee *et al*. 2017, Nobre and Nunes 2008) with similar thermoregulatory outcomes.

Coptotermes lacteus is common along the east coast of Australia from southern Queensland to eastern Victoria forming large well insulated mounds reaching ca. 2 m in height and up to 2 m in diameter (Gay and Greaves 1940, Hill 1942). *Coptotermes lacteus* is not considered to be a species of economic importance (Hill 1942) but is a useful surrogate for more destructive species because of its discrete and easily accessible colonies (Webb 2017a). Despite this, the dynamics of temperature regulation in *C. lacteus* mounds has not been extensively studied. Greaves (1964) noted that the thick outer clay wall of *C. lacteus* mounds provided more efficient insulation than the thinner wall of the smaller nests built by *Nasutitermes exitiosus* (Hill) in similar environments. *Coptotermes lacteus* also appears to be more cold tolerant than *N. exitiosus* (Gay and Greaves 1940). Despite ambient variations of up to 17 ºC in winter, temperature variation in the nursery area of the *C. lacteus* mound remained less than 1 ºC. Later work by Ewart and French in the 1980's (Ewart and French 1986, French *et al.* 1997) confirmed that *C. lacteus* was capable of maintaining a core nursery temperature much higher than the ambient temperature, or for that matter other locations in the mound, a differential of 15-20 ºC. However, they seem incapable of maintaining a constant core temperature across seasons with ambient temperatures spanning a range of close to 30ºC.

More recent work associated with studies on baiting colonies of *C. lacteus* with the benzoylphenylurea compound bistrifluron (Webb 2017a and b) and northern mound-building *Coptermes acinaciformis* (Froggatt) (Evans 2010) have provided additional data on the effects of colony collapse on the temperature dynamics of the mound. Colonies quickly lose the ability to maintain an optimum temperature in the mound as colony health declines. This study is a continuation of the work on *C. lacteus* in that it utilises the mound temperature data of untreated colonies from these studies in 2011 and 2012 together with continued monitoring of these untreated mounds through to September 2015, a period of 4 years from commencement of the baiting studies. The aim of the study was to determine the extent to which *C. lacteus* regulates internal mound temperature.

MATERIALS AND METHODS

During the period between spring 2011 and Autumn 2012, a series of trials were established to evaluate the efficacy of bistrifluron termite bait (Xterm® Defence Against Termites, Sumitomo Chemical Australia Pty Ltd, Sydney, Australia) on *C. lacteus* near Robertson in southern New South Wales (Australia), 150 km south of Sydney (Lat: 34.58° S Long: 150.59° E). The field sites were in montane pasture and forest (altitude ca. 700 m). Average annual rainfall for the area is 1659 mm which is spread fairly evenly across the year. Average summer (January) minimum and maximum temperatures are 16 and 26 °C respectively and the average winter (July) range is 6-16 °C. (Moss Vale weather station).

Eleven untreated mounds were evaluated during those trials for a range of measures to assess colony health including the ability to repair the mound after experimental damage (see Webb 2017a and Webb 2017b for further detail) and maintenance of internal core temperature. The monitoring of temperature in the treated mounds in these trials ceased when the mounds were excavated to evaluate continuing colony viability but monitoring continued in untreated mounds until September 2015, four years after the commencement of the first trial. One untreated mound from the second trial was found to be devoid of termite activity during the trial and the colony considered dead. Hence only 10 untreated mounds were used for ongoing temperature monitoring. All mounds were large with mean height of 1.72 m (range 1.6-2.0 m) and mean diameter at ground level of 1.73 m (range 1.5 – 2.0m).

Temperature Monitoring

A 25 mm hole was drilled horizontally into the side of each mound at 50 cm in height above ground and a 40 cm length of PVC tube was inserted which encased a tight fitting wooden dowel. The hole was always positioned on the south side of mound but varied in some cases from SW to SE. On each end of the dowel a temperature iButton (DS1921H) (Thermodata Pty Ltd, Brisbane, Australia) was secured using electrical conduit tape, one to record internal mound temperature and the other for ambient temperature. Each end of the PVC tube was capped with a PVC cap to prevent termite entry. The inner cap was positioned in the carton material and the outer cap just on the outside of the clay casing. To read the Thermodata buttons, the outer cap was removed and the internal wooden dowel removed. Data from the Thermodata buttons was downloaded using a dedicated reader and software on a regular basis, usually monthly during the baiting phase of the trial then approximately 3 monthly from then on. Internal mound temperatures were recorded every 4 hours from initial installation of the temperature probes on 11 November 2011 in trial 1, on 29 November 2011 in trial 2 and 1 February 2012 in trial 3 (Webb 2017a, b). The baiting phase of each of these trials concluded on 30 January 2012, 30 March 2012 and 31 May 2012 for trial 1, 2 and 3 respectively. Temperature probes in the ten untreated mounds were allowed to continue operating past the end of these baiting studies, through till September 2015. There were periods of inactivity for a few probes ranging from 1 week to 3 months due to probe failure. Failed probes were replaced as they were discovered.

DS1921H had a lower temperature limit of 14.5 ºC and maximum of 45 ºC. On 6 May 2013, all DS1921H buttons were replaced with DS1921G buttons which had an extended range of -40 to 85ºC. The trade-off was the increase in temperature increments from 0.1 ºC to 0.5 ºC.

Statistical analysis

Pearsons product moment correlation (Statistix ver. 10, Analytical Software, Florida) was used to evaluate the relationship between ambient temperature measurements for the local weather station and the external probes on mounds. Otherwise, all other data is presented graphically.

RESULTS

Relationship between ambient temperature measures

The mean temperature profile recorded with probes placed at the mound surface to record in-situ ambient temperature was similar to local weather station records (Figure 1). Mean maximum and minimum daily temperatures for the in-situ outer probes were highly correlated with daily records from the local weather station (n = 1418 days) ($r = 0.947$, $p < 0.001$ and $r = 0.743$, $p < 0.001$ respectively). When the period which utilised the less sensitive I-buttons (up to May 2013) (n = 877 days) was excluded the correlation between minimum temperature was even higher ($r = 0.994$, $p < 0.001$). This resulted from the differential in the lower limit of these new probes (-40 ºC) vs 14.5 ºC for the original probes. Temperature ranges recorded in situ were generally more constricted than local weather station ranges (Figure 1). This is more clearly seen on an average monthly basis particularly for minimum temperatures (Figure 2).

Figure 1: Overlay of daily temperature ranges for the local weather station (grey) and the outer temperature probe (red). (Probes were replaced in May 2013 to allow temperature recordings below 14.5 ºC (the lower capacity of the earlier probes).

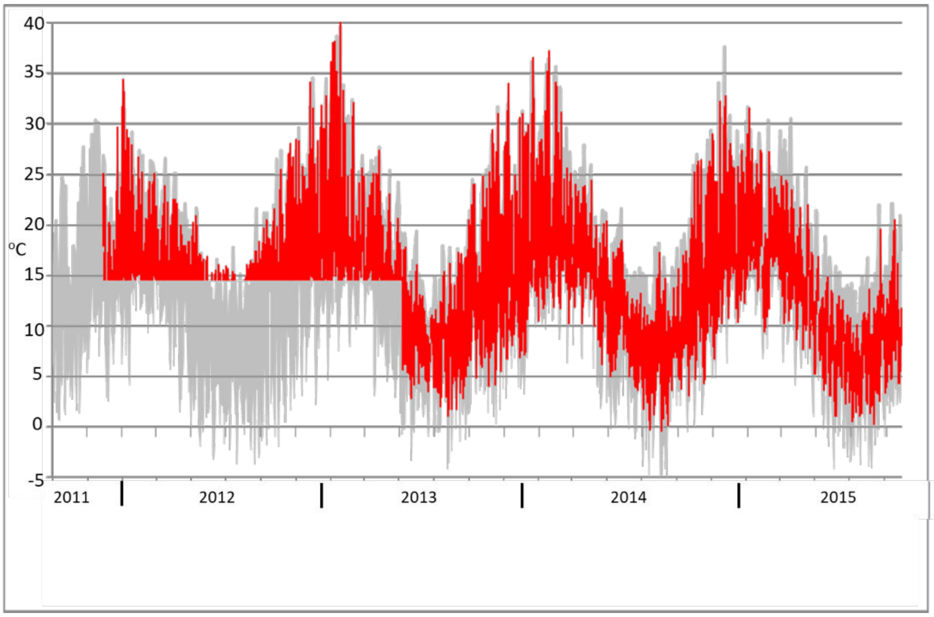
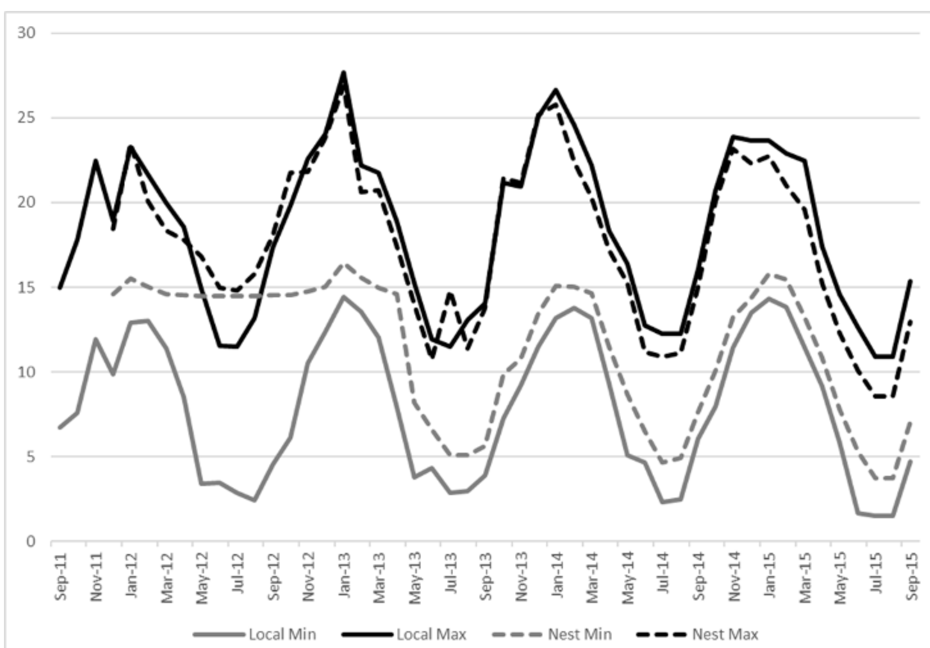


Figure 2: Relationship between weather station records and the in-situ outer probes showing monthly mean maximum and minimum temperatures. NB. Probes were replaced in May 2013 to allow recording of temperatures below 14.5 ºC.



Mound core temperature

Mean internal daily core temperature range was very tight (1-2 ºC) (Figure 3) and consistently so across seasons and years. With the exception of extreme summer temperatures, the mean internal temperature was almost always higher than the mean external temperature, particularly in winter (Figure 3) and similarly on a monthly basis (Figure 4). This was despite a large difference between individual mounds in their maximum temperatures across most of the study period (Figure 4). During summer, maximum internal mound temperatures ranged as high as 38 ºC (2014) and as low as 23 ºC (2011) for any one mound. During summer, minimum temperatures ranged from as high as 26 ºC (2015) and as low as 23 ºC. The year 2011 was generally the coolest while the following three summers were similar to each other.

Figure 3: Mean daily internal core temperature range (black) relative to daily external mound temperature range (grey). NB. Probes were replaced in May 2013 to allow recording of temperatures below 14.5 ºC.

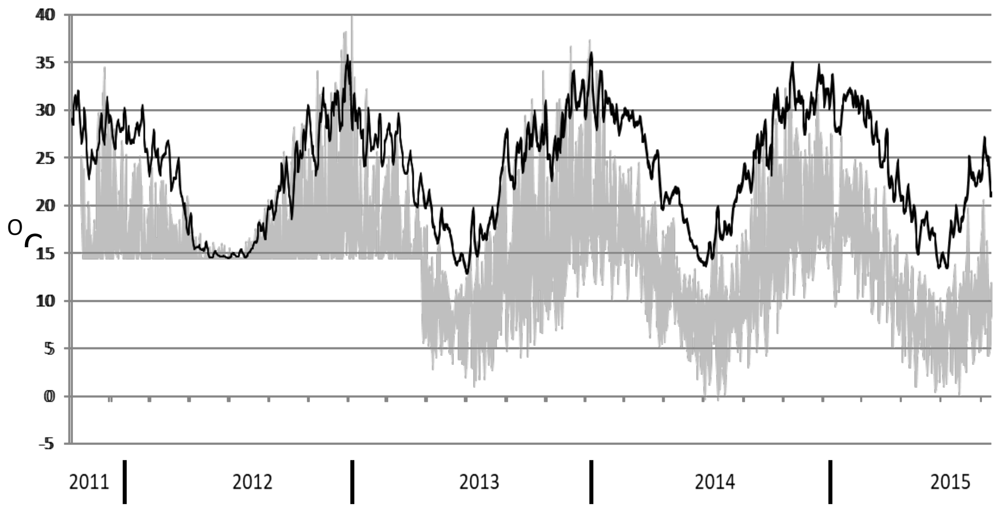


Figure 4: Mean monthly internal mound minimum and maximum temperatures with SEM bars (fine black lines), absolute monthly minimum and maximum internal mound temperatures (thick black lines) and monthly mean ambient temperature range from nearby weather station (vertical bars). NB. Temperature probes were changed in May 2013 to record temperatures below 14.5 ºC.

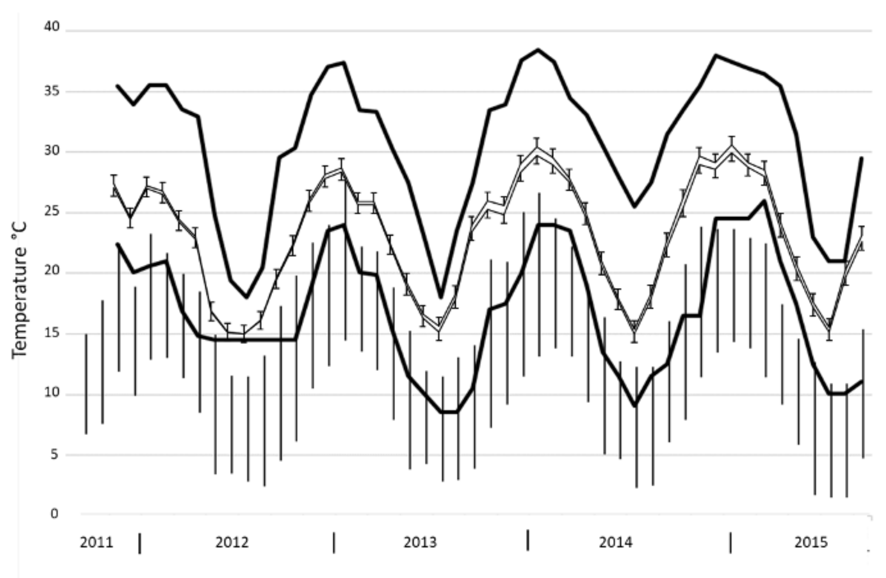


Figure 5: Mean and maximum daily temperature change internally. Average Monthly (above) and Average Daily (below). Grey lines represent daily or monthly fluctuations and dark lines represent average daily or monthly fluctuations. NB. Probes were replaced in May 2013 to allow recording of temperatures below 14.5 ºC.

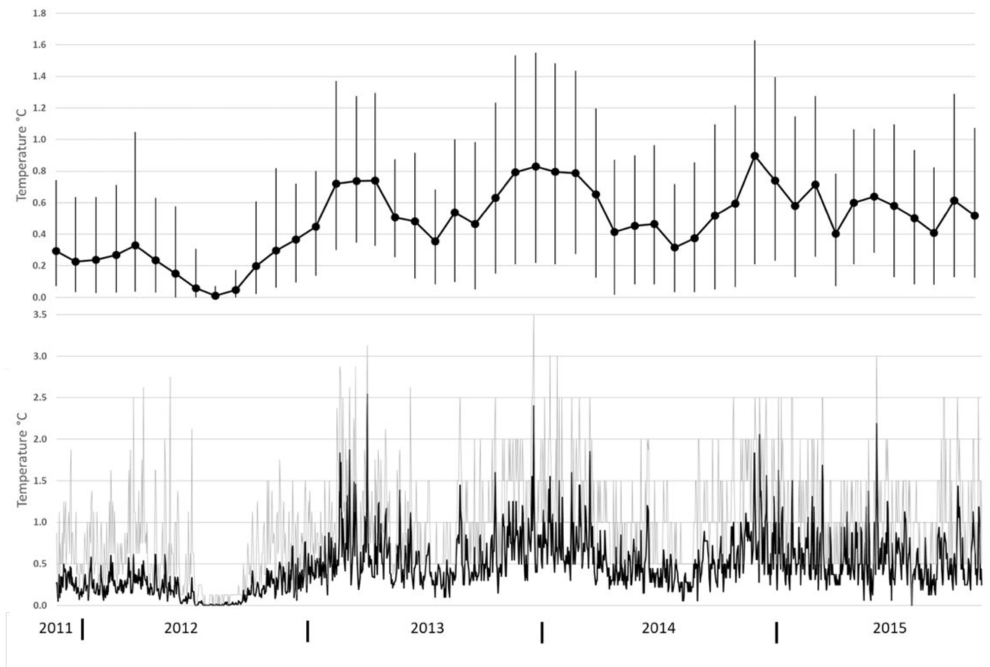
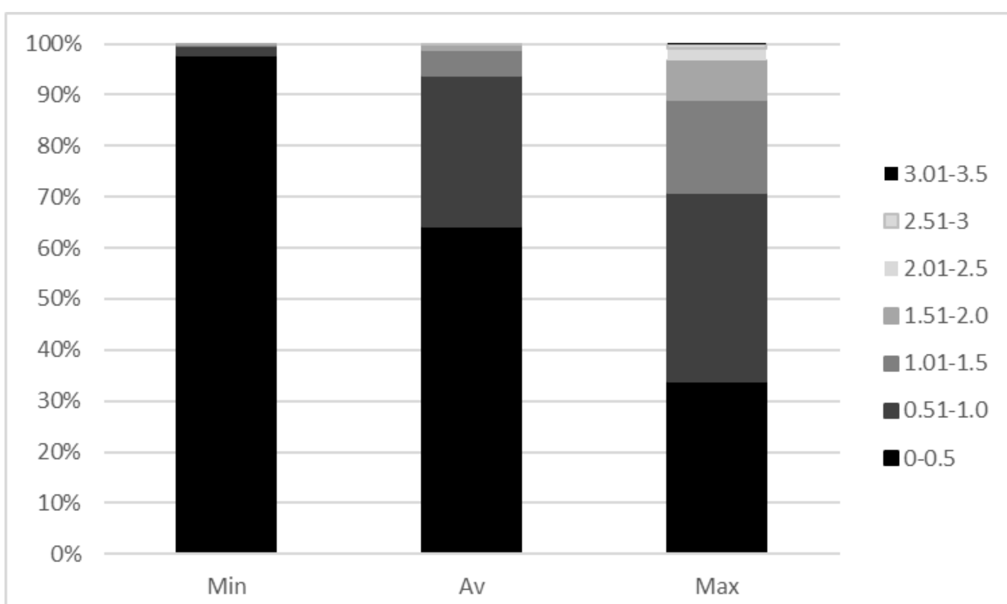
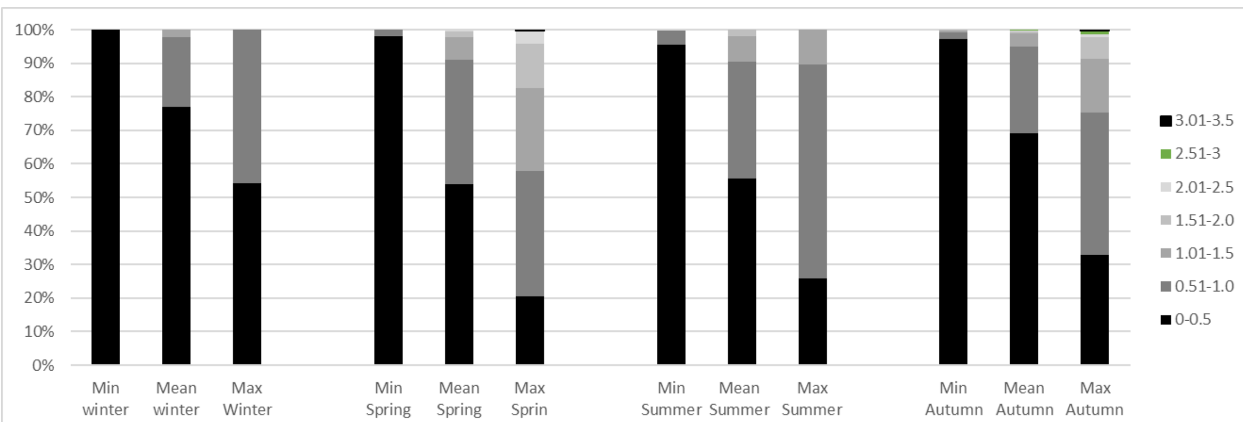


Figure 6: Percentage of average minimum, mean and maximum daily internal mound temperature differences in 0.5 ºC increments during the study (n = 1418 days).



The daily internal mound temperature fluctuated between seasons (Figure 5) with lowest variation occurring during winter and the highest during summer. On a monthly basis the minimum average variation was ca. 0.4 ºC for winter and summer was ca. 0.8 ºC when the period up to May 2013 is excluded. The summer season of 2011-12 and subsequent winter period had lower average temperatures than the corresponding periods of the subsequent 3 years. However, these average value masked variations evident at the daily level which reached up to 3.5 ºC (December 2013) (Figure 6). On a daily basis, the vast majority (98%) of differences for the minimum temperature were 0.5 ºC or less (Figure 6). For the maximum daily difference just 33% of days fell into the lowest category (0.5 ºC or less) (Figure 6). Clearly, there was higher variation in maximum daily difference than minimum daily difference. When dissected by season (winter, spring, summer and autumn) (Figure 7) it was clear that the minimum temperature range remained relatively low (0.5 ºC or less) across all seasons but for spring, summer and autumn the maximum temperature range was variable with just 20, 25 and 32% respectively in the lowest category.

Figure 7: Percentage of average minimum, mean and maximum daily internal mound temperature differences in 0.5 ºC increments for the four seasons (n = 321-368 days).



Dealing with averages across a large data set like this obscures some important differences between mounds. For instance, the lowest mean core temperature was 13 ºC while the mean external mound temperature was close to zero. The absolute lowest core temperature was 8.5 ºC whilst the accompanying ambient temperature was -1 ºC.. Even at such low temperatures these mounds were able to survive. Similarly, the highest mean core temperature was 32.5 ºC while the mean external mound temperature was 38.2 ºC. The absolute highest core temperature was 37.1 ºC whilst the accompanying ambient temperature was 39.7 ºC.

DISCUSSION

Despite living in an environment that may experience extremes of ambient temperature from well below zero in winter to 40 ºC in summer, *C. lacteus* colonies are remarkably adept at maintaining hospitable conditions in their mounds, particularly in the centre of the mound where the nursery resides. Previous studies have shown that colonies are able to maintain nursery temperatures well above (ca. 15-20 ºC) the surrounding soil and ambient air temperatures but like most other species they are unable to maintain a constant temperature across seasons (Ewart and French 1986, French *et al*. 1987, Greaves 1964, Watson and Abbey 1986).

Coptotermes lacteus was able to maintain a very tight daily range of temperature (1-2 ºC) in the core of the mound across all seasons and all years despite significant daily variation in ambient temperature of up to 20 ºC or more at the mound surface or in ambient temperature. This was tightest during winter (ca. 0.5 ºC) and highest during summer (up to 3 ºC but mostly ca. 1.5-2 ºC). Summer daily internal mound temperatures (excluding 2011-12) ranged up to 35-36 ºC. For 2011-12 the maximum daily temperature was 32 ºC. For the summers of 2013-14 and 2014-15 (after the instalment of the more sensitive I-buttons) the winter minimum temperature of the core of the mounds was in the range of 13-14 ºC. Individual mounds showed a wider range of core temperatures during the study from the absolute lowest at 8.5 ºC in winter (2012) to the absolute highest at 37 ºC in summer (2012-2013).

Termites are effective at maintaining internal nest temperature well above ambient in winter and have also been shown to reduce extreme summer temperatures through various behavioural means (e.g. colony movement within the mound, termite aggregation to increase metabolic heat, transporting water into the nursery, creating voids in the upper and outer reaches of the mound to capture condensation, creating vents to exhaust gases, creating voids to capture higher temperature gases etc.) (Bristow and Holt 1987, Gouttefarde *et al.* 2017, Hu and Song 2007, Jones and Oldroyd, 2007, King *et. al.* 2015, Korb 2003, Ndlovu and Perez-Rodriguez 2018). Large mounds can also contribute to mound temperature stability (Field and Duncan 2013, Korb and Linsenmair 2000). *C. lacteus* does not appear to create obvious vents or voids that some arid zone species do, but it does utilise colony movement to position the brood in the optimal position depending on the season (Ewart and French 1986) and aggregation during winter may also contribute to temperature stability. Presumably, the creation of large mounds in a successful colony, also contributes to temperature stability. Most mounds used in this study were relatively large being ca. 1.7 m in height and ca. 1.7 m in diameter at ground level and therefore presumably better able to deal with extremes of temperature.

Field and Duncan (2013) also used I-buttons to record mound temperature of *Trinervitermes trinervoides* (Sjostedt) in South Africa. As with *C. lacteus* mounds of *T. trinervoides* are closed ventilation systems with no external openings. Mound size influenced the thermodynamics of *T. trinervoides* colonies but in *C. lacteus* during this study, mounds were generally of similar size, which avoided variation based on mound size. Nevertheless, there was still substantial variation in core temperature attributable to factors other than mound size. This variation could be accounted for by mound location and microclimate or size of the colony and particularly size of the brood. Field and Duncan (2013) also found that *T. trinervoides* maintain internal temperature well above that of ambient temperature in all seasons.

Some practical considerations of trial design may have influenced the results in this trial. For instance, I-buttons were set to record temperature every 4 hours. Therefore, the absolute maximum and minimum temperatures for any one day may have been missed. However, to set this frequency any lower e.g. hourly or less, would have required replacement of I-button on a regular basis. The temperature differential in the PVC tube between the outer and inner probes may have been moderated by air movement along the wooden dowel. However, given the dramatic differences in average temperatures over a long period of time between inner and outer I-buttons, this was not likely to impact the outcome of the trial. During this study temperature probes were placed at a set height above ground and not necessarily targeting the nursery area of the mound, although these probes may have intercepted the nursery at various times of the year as it was moved around in the mound for optimal conditions. It was not possible in such a trial to target the nursery at all times of the year and over several years. However, the placement at a consistent height above ground would not likely compromise the outcomes of this study. During the baiting phase of the trials, mounds were experimentally damaged using a 100mm diameter coreholer through to the inner core of the mound to assess speed of repair. For untreated mounds, repair was rapid – often within 24 hours after damage. Hence, this was not likely to influence the results of this study, particularly when results are mostly presented as mean daily and monthly values. Despite these potential limitations on the study, it is clear that the overwhelming weight of evidence suggests that colonies may vary in absolute temperature ranges but on average they maintain a very tight range of internal mound temperature.

This study has shown how remarkably adept *C. lacteus* is in maintaining temperature control with mounds within the limitations of ambient temperature across the year. While internal core temperature cannot be maintained between seasons, *C lacteus* colonies are able to maintain internal core temperatures near the maximum possible at any time of the year. It is also clear that *C.lacteus* mounds can vary dramatically in internal core temperature at any point in time between each other and yet all colonies survive.

ACKNOWLEDGEMENTS

Two anonymous referees provide helpful comments on the manuscript.

REFERENCES

Agarwal, V.B. (1980). Temperature and relative humidity inside the mound of *Odontotermes obesus* (Rambur) (Isoptera: Termitidae). *Proceedings of the Indian Academy of Science (Animal Science)* **89**: 91-99.

Arab, A. and Costa-Leonardo, A.M. (2005). Effect of biotic and abiotic factors on the tunneling behavior of C*optotermes gestroi* and *Heterotermes tenuis* (Isoptera: Rhinotermitidae). *Behavioural Processes* **70**: 32-40.

Bristow, K.L. and Holt, J.A. (1987). Can termites create local energy sinks to regulate mound temperature?. *Journal of Thermal Biology* **12**: 19-21.

Cameron, D.A., Ivers D.J., Evans T.A and Myerscough, M.R. (2008). Optimal prediction strategies in two species of mound-building termites. *Bulletin of Mathematical Biology* **70**: 189-209.

Evans, T.A. 2010. Rapid elimination of field colonies of subterranean termites (Isoptera: Rhinotermitidae) using Bistrifluron solid bait pellets. *Journal of Economic Entomology* **103**: 423-432.

Evans, T.A., Lenz M. and Gleeson P. V. (1999). Estimating population size and forager movement in a tropical subterranean termite (Isoptera: Rhinotermitidae). *Environmental Entomology* 28: 823-830.

Ewart, D.M. and French, J.R.J. (1986). Temperature studies on two mounds of *Coptotermes lacteus* (Isoptera). *IRG/WP/ 1295, International Research Group on Wood Preservation Meeting, Avignon, France, 1986. pp. 1-9*.

Field, M.A. and Duncan, F.D. (2013). Does thermoregulation occur in the mounds of the harvester termite, *Trinervitermes trinervoides* (Sjöstedt) (Isoptera:Termitidae). *African Entomology* **21**: 45-57.

French, J.R.J., Donaldson, R. and Ewart, D.W. (1987). Electronic monitoring of temperatures in air, a termite mound, trees and soil. *Australian Forest Research* 17: 79-82.

French, J.R.J, Rasmussen, R.A., Ewart, D.M. and Khalil, M.A.K. (1997). The gaseous environment of mound colonies of the subterranean termite *Coptotermes lacteus* (Isoptera: Rhinotermitidae) before and after feeding on mirex-treated decayed wood bait blocks. *Bulletin of Entomological Research* 87: 145-149.

Gay, F.J. and Greaves T. (1940). The population of a mound colony of *Coptotermes lacteus* (Frogg.). *Journal of the Council for Scientific and Industrial Research* **13**: 140-149.

Gouttefarde R., Bon, R., Fourcassie V., Arrafut, P., Haifig I., Baehr C. and Jost C. (2017). Investigating termite nest thermodynamics using a quick-look method and the heat equation. *BioRxiv*, 161075. https://doi.org/10.1101/161075

Greaves, T. (1962). Studies of the foraging galleries and the invasion of living trees by *Coptotermes acinaciformis* and *C. brunneus* (Isoptera). *Australian Journal of Zoology* **10**: 630-651.

Greaves, T. (1964). Temperature studies of termite colonies in living trees. *Australian Journal of Zoology* **12**: 250-62.

Greaves T. (1965). The buffering effect of trees against fluctuating air temperature. *Australian Forestry* **29**: 175-180.

Hill, R.F. (1942). Termites of the Australian region. *CSIR, Melbourne,* Australia.

Holdaway, F.G. and Gay F.J. (1948). Temperature studies of the habitat of *Eutermes exitiosus* with special reference to the temperatures within the mound. *Australian Journal of Scientific Research Series B* **1**: 464-493.

Horwood M., Westlake, T. and Kathuria, A. (2010). Control of Subterranean Termites (Isoptera: Rhinotermitidae) Infesting Power Poles. *Journal of Economic Entomology* **103**: 2140-2146.

Hu X.P. and Song D. (2007). Behavioural responses of two subterranean termite species (Isoptera: Rhinotermitidae) to instant freezing or chilling temperatures. *Environmental Entomology* **36**: 1450-1456

Jones, J.C. and Oldroyd, B.P. (2007). Nest thermoregulation in social insects. *Advances in Insect Physiology* 33: 154-185.

Joseph, G. S., Seymour, C. L., Coetzee, B. W. T., Ndlovu, M., De La Torre, A., Suttle, R., Hicks, N., Oxley, S. and Foord, S. H. (2016). Microclimates mitigate against hot temperatures in dryland ecosystems: termite mounds as an example. *Ecosphere* **7** (11):e01509. 10.1002/ecs2.1509.

King, H., Ocko, S., & Mahadevan, L. (2015). Termite mounds harness diurnal temperature oscillations for ventilation. *Proceedings of the National Academy of Sciences* **112**: 11589-11593. *doi:10.1073/pnas.1423242112*

Korb J. (2003). Thermoregulation and ventilation of termite mounds. *Naturwissenschaften* 90: 212-219

Korb, J. and Linsenmair, K.E. (1999). The architecture of termite mounds, a result of a trade-off between thermoregulation and gas exchange? *Behavioural Ecology* **10**: 312–316.

Korb, J. and Linsenmair, K.E. (2000). Thermoregulation of termite mounds: what role does ambient temperature and metabolism of the colony play? *Insectes Sociaux* **47**: 357–363.

Lee, T.R.C., Evans, T.A., Cameron, S.L., Hochuli, D.F., Ho, S.Y.W. and Lo, N.J. (2017). Ecological diversification of the Australian *Coptotermes* termites and the evolution of mound building. *Biogeography* doi:10.1111/jbi.12878

Malaka, S.L.O. (1977). Temperature studies of the mounds and environment of *Amitermes evuncifer* Silvestri (Isoptera: Termitidae). *Australian Journal of Zoology* **25**: 711-19.

Ndlovu M. and Perez-Rodriguez, A. (2018). Temperature fluctuations inside savannah termite mounds: do size and plant shade matter?. Journal of Thermal Biology 74: 23-28.

Nobre, T. and Nunes, L. (2007). Non-traditional approaches to subterranean termite control in buildings. *Wood Material Science & Engineering* 2: 147-156, DOI: 10.1080/17480270801945413.

Watson, J.A.L. and Abbey H.M. (1986). Seasonal cycles in *Nasutitermes exitiosus* (Hill) (Isoptera: Termitidae) II. Nest temperature. *Sociobiology* **11**: 255–273.

Webb, G.A. (2017a). Efficacy of bistrifluron termite bait on *Coptotermes lacteus* (Isoptera: Rhinotermitidae) in southern Australia. *Journal of Economic Entomology* DOI: 10.1093/jee/tox133.

Webb, G.A. (2017b). Elimination of *Coptotermes lacteus* (Froggatt) (Blattodea: Rhinotermitidae) colonies using bistrifluron bait applied through in-ground bait stations surrounding mounds. *Insects* **8**; doi:10.3390/insects8030098

Webb, G.A. and McClintock C.M. (2015). Elimination of the mound-building termite, *Nasutitermes exitiosus* (Isoptera: Termitidae) in south-eastern Australia using bistrifluron bait. *Journal of Economic Entomology* **108**: 2702-2710.

Submitted: 29 November 2024. Accepted: 23 December 2024

GUIDE FOR CONTRIBUTORS

1. **General and Applied Entomology** is usually published annually, subject to availability of suitable papers.

2. Entomological contributions of a high standard will be eligible for consideration for publication if submitted by a member of the Entomological Society of New South Wales. Material by non-members may be submitted through a member of the Society, but preference may be given to members' manuscripts at the discretion of the editor in consultation with Council.

3. **Manuscripts.** Manuscripts may be submitted as MSWORD documents to Dr Robin Gunning via email <rgunning@bigpond.com> or journaleditor@entsocnsw.org.au

4. The title is to be placed above the text on the first page followed by the author's name and address. All manuscripts will be sent to at least one external referee. Up to 8 keywords should be provided and placed immediately following the Summary.

5. Manuscripts unsuitable for publication will be returned to the author/s, who may be given an opportunity to revise their papers in light of editorial comment.

6. No manuscript that has been published elsewhere, either wholly or in essential part, will be accepted for publication.

7. Papers which exceed 20 printed pages may only be accepted at the discretion of Council.

8. **Style and Format.** With regard to style and format, authors are referred to the most recent issue. Font: Times New Roman, 12 point 1.5 line spacing, no page numbers and no paragraph formatting please.

9. **Tables** must be grouped together at the end of the manuscript. The preferred location in the text must be indicated. Tables must be numbered consecutively using arabic numerals.

10. **Graphs, line drawings and photographs** will be referred to as figures. They must be numbered consecutively whether appearing in groups or not. Numbering must be done in arabic numerals. Magnifications must be indicated by scale lines on the figures. Inclusion of magnifications in captions is not acceptable. Authors should send clear photographic copies of original line drawings or high resolution scanned image files. Originals are best submitted at 1.5 to 2 times the required size. Electron micrographs, photographs of sections, insects etc., should be submitted at the size authors wish them to be published. Labels should be in Times Roman font. Graphics submitted on electronically must be separate files, not embedded in the documents. They should be black and white only. JPG files are most acceptable.

11. **Colour work** may be accepted by arrangement. The author may be required to pay additional printing costs.

12. **Nomenclature.** The appropriate international rules of nomenclature should be used for all organisms. Names should be given in full with authorities when first used but may be abbreviated subsequently if there is no ambiguity. Common names should be avoided in titles and abstracts. Editorial policy will conform with the Articles and Recommendations of the International Code of Zoological Nomenclature.

13. Common names of pesticides listed in 'Pesticides Synonyms and Chemical Names', latest edition, Australian Department of Health, Canberra, should be used where possible. Trade names, if used, should be placed in inverted commas and full chemical definition given when first mentioned.

14. **Units.** The International System of Units should be used for exact measurement of physical quantities.

15. **References** should be quoted as follows:-

Carter and Zeck (1937) or (Carter and Zeck 1937) and listed:-
Carter, H.J. and Zeck, E.H. (1937). A monograph of Australian Colydiidae.
Proceedings of the Linnean Society of New South Wales. **62**: 181-208.

Periodical titles should not be abbreviated.

16. For general information on the writing of scientific papers, reference may be made to the guides on the subject published by the CSIRO Melbourne.

17. **Proofs.** No paper will be published until the author or his nominee has had an opportunity to read and correct a page proof. Prompt return of proof is requested. Authors are held responsible for correcting omissions or errors that can be checked against the original manuscript. Authors may be charged for correction of errors or alterations on the text for which the author is responsible.

18. **Page charges: When at least one author is a financial member** of the Entomological Society of NSW, there is no charge. For unfinancial members or non-members $40 per page if black and white only and $60 per page if coloured. No reprints are provided. After payment of page charges (if due) the corresponding author will be emailed a PDF version of their paper.

NB: All potential contributors should complete a copy of the Society's "**Conditions for Levying of Page Charges**" either online from the website or by email from the Editor or Treasurer (Email: membership@entsocnsw.org.au) and return it to the Treasurer's address.

GENERAL AND APPLIED ENTOMOLOGY

Gen. appl. Ent.

The Journal of the Entomological Society of New South Wales Inc.

VOLUME 52 (2024)

CONTENTS

Printed by: Arrowprint