THE SUN-MOTHS (LEPIDOPTERA: CASTNIIDAE) OF VICTORIA, WITH A DETAILED STUDY OF THE PALE SUN-MOTH (*Synemon selene* KLUG, 1850)

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requirements for the degree of Master of Applied Science

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Abstract

The sun-moths (family Castniidae) are a distinctive group of monocot-feeding diurnal Lepidoptera that contains a high proportion of threatened species worldwide. Seven of the eight Victorian *Synemon* species are considered as threatened. This study has determined through extensive fieldwork that most of these species are now restricted to very small remnants of their particular habitats. These findings have been integrated into a review of the current distribution, biology and habitat requirements of all the Victorian species. This has enabled recommendations for their long-term conservation and management to be made.

Special attention was paid to the Pale Sun-moth (*Synemon selene* Klug, 1850) because it appeared to be nationally endangered and without a government strategy for its conservation. Also, there was strong circumstantial evidence of complete parthenogenesis within all of its Victorian populations. The Victorian occurrences are shown to be parthenogenetic, although specimens of both sexes are known from a ?now-extinct population near Two Wells, South Australia. It was also established that these parthenogenetic populations include five distinct morphs, two or three of which occur sympatrically at four localities in the Wimmera area.

Parthenogenetic populations of these morphs cannot interbreed, this potentially restricting their genetic diversity. The extent of genetic diversity was examined with all parthenogenetic Victorian morphs of *S. selene*. DNA sequencing of 1515 bp of the *COI* gene revealed a maximum divergence level of 12 bp between some of the morphs and 1 to 2 bp within some morphs. This level of genetic diversity implies that these morphs have continued to evolve in the absence of males through time. This study has highlighted the special academic interest of *S. selene* and the urgent need for its adequate conservation. Some important directions for future research on the species are also discussed.

Statement of Authorship

Except where explicit reference is made in the text of the thesis or as outlined in the explanatory paragraph below, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been relied upon or used without due acknowledgement in the main text and bibliography or acknowledgements of the thesis.

Due to the urgent conservation needs of all but one of the Victorian *Synemon* spp. (Lepidoptera: Castniidae), I was commissioned in 2000 by the former Department of Natural Resources and Environment to compile two *Flora and Fauna Guarantee Act* 1988, Action Statements. The first of these was for five of the threatened *Synemon* species that occur in Victoria and the second was for the five Victorian morphs of *S. selene*, all of which are threatened. Much of the material that these two F. & F. G. Action Statements contain was drawn from earlier drafts of several of the chapters of this thesis. In 2003 some of this information was extracted from these two F. & F. G. Action Statements by Marriott (2003) and published as a non-refereed paper in the *Victorian Entomologist* 33 (6): 91-94, without my prior knowledge or permission. Therefore, although I have listed this paper in the bibliography of the thesis, I have not cited it anywhere in the text. Nor have I cited my corrigenda to this paper that was also published in the *Victorian Entomologist* 34 (3): 32-33, in 2004.

Signature of author: Fabian Douglas. Date: 10 June 2008

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Mrs. Wendy Cloke (University of Ballarat): provided technical support with photography and microscopic studies etc., as this work progressed.

Dedication

This thesis is dedicated to the memory of my late friend, colleague and mentor, Mr. O. F. (Frank) Noelker. Between 1986 and 1996 Frank accompanied me on many field trips throughout western Victoria, while I was working on Coleoptera and Lepidoptera (including the Castniidae). He was with me on that memorable day during February 1991 when we rediscovered the Pale Morph of the Pale Sun-moth (*Synemon selene* Klug, 1850), after it had not been seen alive for fifty-two years. It was Frank who saw and succeeded in capturing the first specimen. For a detailed account of the nomenclature and history of *Synemon selene* see Chapter 6 of Part 3 of this work.

DSE Research Permit under which this work was carried out

Research work on the *Synemon species* that are listed under Section 10 of the Victorian *Flora and Fauna Guarantee Act* 1988 was carried out under the Department of Sustainability and Environment *Wildlife Act* 1975 and *National Parks Act* 1975 Research Permit Number 10000667 (File Number FF380107).

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Introduction

What are sun-moths?

All of the sun-moths are currently placed in the family Castniidae. They are diurnal or rarely crepuscular ditrysian Lepidoptera that are usually colourful and invariably have broad wings and clubbed antennae. In many respects they bear a strong resemblance to the butterflies. However, in most instances, camouflage from predators is afforded by the uppersides of the forewings, which are cryptically or disruptively coloured and are folded roof-wise over the abdomen, in such a way that they conceal the usually brightly coloured hindwing uppersides, during periods of inactivity. In the majority of species the upperside of the hindwings and the underside of the forewings and hindwings are patterned in shades of red, orange, yellow or white and have areas and/or markings of black or dark brown. Also, with many species, all of the darker areas of the wing surfaces have a soft, iridescent greenish-blue sheen that is especially noticeable when live specimens are viewed in sunlight. As well as this, some of the South American and south-east Asian species have basal and/or median areas of metallic blue or greenish-blue colouration on the upperside of the hindwings.

The wingspans of sun-moths vary from approx. 2.7 to 3 cm for the Orange Sun-moth (*Synemon nais*) from southern mainland Australia to approximately 15.5 cm for the huge *Eupalamides cyparissias* from Guyana, Surinam, Brazil, Peru and Bolivia. Although most female sun-moths are usually about one quarter larger than the males of the same species, accentuated sexual dimorphism in the family is rare. A notable exception to this is the Golden Sun-moth (*Synemon plana*) from south-eastern Australia. In this species the male has the upperside of the hindwings rich bronzy-brown while the female is semi-flightless and has the upperside of the hindwings bright yellow or yellowish-orange with a few small black spots. Another feature of the sun-moths is that a number of the South American species are convincing (?Batesian) mimics of distasteful butterflies, such as species belonging to the Heliconiinae, a subfamily of the Nymphalidae.

The known larvae of sun-moths all feed on monocotyledonous plants. Some plant genera utilized by various species in Australia include *Lomandra* (Lomandraceae), *Austrodanthonia* (Poaceae) and *Lepidosperma* (Cyperaceae), while some of the Neotropical sun-moths use plants belonging to the families Arecaceaee, Bromeliaceae, Orchidaceae and Musaceae as larval hosts. Depending on the species, the larvae either construct galleries inside the rhizomes etc. of these plants where they feed internally on their tissues or they tunnel through the soil to eat their roots. Pupation takes place inside the final larval gallery, from which the empty pupal casing is left protruding after adult eclosion (emergence).

Common (1990) placed the sun-moths (family Castniidae) in their own superfamily, the Castnioidea. However, Edwards *et al*. (1999) included the family Castniidae in the superfamily Sesioidea, which according to their work also contains two other families of largely diurnal moths, the Brachodidae (little bear moths) and the Sesiidae (clear-wing moths). It appears that the sun-moths have a Gondwanan origin as they occur in Australia (excluding Tasmania), south-east Asia and Central and South America, but strangely, are not known from Africa, New Zealand, New Caledonia or New Guinea.

Why study the Victorian sun-moths?

It seems that to a large extent the study of Australian sun-moths has been neglected by lepidopterists. The reason for this appears to be that although the sun-moths are diurnal, they are not systematically collected by people who are interested in butterflies. Despite the fact that they are brightly coloured and charismatic day flying Lepidoptera, they are often simply dismissed as ‘moths’ by many professional and amateur butterfly enthusiasts. The consequences of this are that although the sun-moths are a very well defined group, they tend to be banished to the seemingly daunting multitude of mostly nocturnal moth families that to a large extent, are only seriously studied by a limited number of professionals. It is a great pity that many entomologists tend to unwittingly reflect the widely held and erroneous concept that moths are dull coloured pests that destroy crops and clothing. One only has to look at the imbalance between the amount of popular books on Australian butterflies versus Australian moths that have been published during the past two hundred years to gain an understanding of this situation. This is further exacerbated (as far as sun-moths are concerned) by the very best books on Australian moths only being able to cover the sun-moths in a very incomplete manner, owing to the amount of information that they must contain on the other (so called) moth families. For example, Common (1990) deals with the family Castniidae (sun-moths) in some detail, but only illustrates nine Australian species and mentions ten Australian species and three overseas genera (and one overseas species) in the text.

When the sun-moths are considered from an unbiased viewpoint it becomes apparent that they are a most distinctive family of Lepidoptera. So much so, that they were placed by Common (1990) in their own superfamily, the Castnioidea. It seems that, although the Castniidae are not very closely related to any other lepidopterous family, their vernacular ‘moth’ label has not helped to raise a wide appreciation of what the sun-moths really are: a unique part of the world’s insect fauna with a likely Gondwanan ancestry of considerable antiquity. It is ironic that the largely diurnal habits of modern sun-‘moths’ (in both Australia and Central and South America) are an indication that the whole family may have been mainly or entirely diurnal for a very long time, considerably longer it seems than the (?more recently evolved) butterflies. This is hypothesized because while the butterflies are widely considered to be a comparatively derived (i. e. recent) group of ditrysian Lepidoptera, Common and Edwards (1981) refer to the Castniidae (sun-moths) as ‘relatively primitive Ditrysia’.

For such a colourful and interesting family it is most extraordinary that at the time of writing (29 December 2005) only 24 of the 44 known Australian species have been formally described (E. D. Edwards pers. comm.). Further, the situation where only one species, the Golden Sun-moth (*Synemon plana*) has been given a widely used common name, is a clear indication that much more work needs to be done on the Australian Castniidae. However, it is commendable that E. D. Edwards, the late E. S. Nielsen and others at the CSIRO Division of Entomology have been, or are currently in the process of rectifying this problem. They are achieving this by: (a) having published a check list of the Australian Lepidoptera (Edwards *et al*. 1996) and (b) by undertaking a major revision and producing a monograph (that is still in progress) of the Australian Castniidae (E. D. Edwards in prep.). The following paragraph outlines this important project:

In 1991 the (Australian) CSIRO Division of Entomology obtained a grant to commence fieldwork on the Australian Castniidae, with the aim of publishing an up to date monograph on the entire castniid fauna of Australia. Initially the project was co-ordinated by Mr. E. D. (Ted) Edwards and the late Dr Ebbe S. Nielsen. During the ensuing years this fieldwork was continued by Mr. E. D. Edwards, as funding opportunities and available time permitted. To date, the project has resulted in a substantial increase in knowledge of the taxonomy, biology and distributions of the Australian *Synemon* spp. It has also shown that a number of these species are threatened with extinction as a result of the widespread clearing of natural habitats that has taken place since European settlement. As it is likely that this monograph will probably be published in 2009, it is important that anyone who is holding specimens and/or data on the biology or distributions of the Australian Castniidae should contact Mr. E. D. Edwards. He can be reached at the following address: C/o CSIRO Division of Entomology, G. P. O. Box 1700, Canberra, A. C. T. 2601. Email: ted.edwards@csiro.au

Another reason for working on the Victorian species of this interesting group of Lepidoptera was the very high proportion of endangered species that the family Castniidae contains. Of the eight species that are known to occur in Victoria only one is secure (Douglas 1993), while all of the others are considered to be vulnerable, endangered, critically endangered or are presumed to be extinct within state limits (DNRE 1999). Obviously, a very important aspect of this work was to determine why this situation has occurred and to provide guidelines for the long-term conservation of the threatened Victorian species. Therefore, the primary aim of this work was to research the current conservation status of the entire Victorian sun-moth fauna and to obtain and document additional information on the habitat requirements, biology and taxonomy of as many of these species as possible. A secondary aim was to raise the profile and public awareness of sun-moths and to highlight the urgent conservation needs of several species in Victoria. Further, it was considered to be important that a reasonably user friendly and up to date reference on the family Castniidae would be available to organizations such as the Department of Sustainability and Environment and the Trust for Nature (Victoria). It is also hoped that this work will provide some encouragement to those who have an interest in Lepidoptera to study the Castniidae more closely.

The endangered Pale Sun-moth (*Synemon selene*) especially deserved close study as at the time this work was commenced, it appeared that all of the known Victorian populations were parthenogenetic. This was suspected because a male ratio of approximately 50% had been collected historically near Two wells in South Australia, while a male of this species had never been collected or recorded within Victoria.

Unfortunately, it appears that this clearly non-parthenogenetic South Australian occurrence of the Pale Sun-moth is now extinct as a result of wholesale destruction of its habitat. It was of further interest that some of the supposedly parthenogenetic Victorian specimens of this species showed distinctive morphological differences to the majority of other (?parthenogenetic) specimens from Victoria. This seemed to indicate that some distinct 'morphs' of the species had evolved in Victoria that were possibly unable to interbreed with one another, if they did prove to be parthenogenetic.

It was deemed to be necessary to divide this work into three parts. Part 1 provides an overview of the taxonomy, biology and possible origin of the world's Castniidae and includes a chapter on the apparent adaptation of many of the Australian *Synemon* spp. to survive fire. Part 2 covers several aspects of the Victorian sun-moth fauna, including diagnostic descriptions of the species, notes on their distributions and specific habitat requirements and information on their biology. Part 3 encompasses a detailed study of the above-mentioned Pale Sun-moth. This includes chapters on the apparent parthenogenesis and genetic divergence in the Victorian occurrences of the species and includes other chapters on similar topics to the chapters of Part Two, which are outlined above. For the titles of the three parts of this work and the titles of the chapters that they contain, refer to the table of contents above, on pages two and three.

Unless otherwise stated, all of the photographs and line drawings that appear throughout this work are by the author.

Part 1:

Taxonomy, Biology and Distribution of the World’s Sun-moths

Part 1

Chapter 1

Taxonomy, Morphology and Distinguishing Features of the Sun-moths (Lepidoptera: Castniidae)

Introduction

Until at least the early 1900s the Castniidae (sun-moths) were thought to comprise a lepidopteran family that represented ‘an intermediate state of development’ between the butterflies (sometimes referred to as Rhopalocera) and the moths (sometimes referred to as Heterocera), (Froggat 1907). For this reason they were commonly known as ‘connecting-link moths’ (Froggat 1907), or ‘butterfly-moths’ (Tindale 1985).

However, by 1940 the prominent lepidopterist Dr A. Seitz was beginning to realise that despite their appearance and diurnal habits, the castniids are not closely related to any of the butterfly families. This is shown by his thoughts on this subject, which are expressed in volume 6 of ‘*The Macrolepidoptera of The World*’ (Seitz 1940). The following quotation is perhaps his most pertinent sentence in this work, when referring to the possible ancestry of the Castniidae: ‘They can only be considered as ancestral inasmuch as their separation from the parent stock must have taken place at an early date, viz., when the distinction between butterflies and moths had not yet assumed the high degree of difference it has today’. Although this historic point of view about the taxonomic status of the Castniidae is interesting, it should be mentioned here that the ‘distinction’ between some of the higher ditrysian moth families and the butterflies is not as great as it was once thought to be. For example, Scoble (1986, 1992) placed the family Hedylidae in the superfamily Hedyloidea and grouped this superfamily in the ‘Rhopalocera’ with the two widely accepted butterfly superfamilies (Hesperioidea and Papilionoidea). Prior to this, the members of the family Hedylidae were considered by Prout (1910) to belong to the subfamily Oenochrominae of the Geometridae, a large cosmopolitan family of ditrysian moths. Scoble (1992) includes the Castniidae in the lower ditrysian families of ‘primitive’ heteroneurous Lepidoptera. This seems to be an indication that they are only distantly related to the higher ditrysian families of ‘highly evolved’ heteroneurous Lepidoptera, which include some of the moth families and all of the butterfly families.

The following work cites some of the most recent opinions of taxonomists on the true affinities of the Castniidae and also discusses how the members of this unusual family of Lepidoptera can be distinguished from the superficially similar but unrelated butterflies and day moths.

Taxonomy of sun-moths

With their strongly clubbed antennae, broad wings and bright colouration the Castniidae bear a strong resemblance to butterflies. However, they are now thought to be related to the Brachodidae (little bear moths), the Sesiidae (clearwing moths) and more distantly to the Cossidae (wood moths and goat moths), (E. D. Edwards pers. comm. 2000). Although Common (1990) and Scoble (1992) both placed the sun-moths in their own superfamily, the Castnioidea, Edwards *et al*. (1999) included the families Castniidae, Brachodidae and Sesiidae in the superfamily Sesioidea. The inclusion of these three families in the superfamily Sesioidea is based on a number of similarities between the morphology of their early stages as well as their adult morphology (Edwards *et al*. 1999).

According to Edwards *et al*. (1999), the family Castniidae is probably monophyletic. These authors treat the two subfamilies of the Castniidae (Tascininae and Castniinae) as sister groups. Although the Tascininae is a small south-east Asian subfamily with only five known congeneric species, four described and one undescribed (Fukuda 2000), the subfamily Castniinae contains two fairly large tribes, the Castniini and the Synemonini. The tribe Castniini occurs in Central and South America, while the tribe Synemonini is confined to mainland Australia and Kangaroo Island, near the south-eastern coast of South Australia (E. D. Edwards pers. comm. 2000). A more detailed account of the number of known species and the worldwide distribution of the genera of the Castniidae is presented in Chapter 3 of Part 1.

Adult morphology and distinguishing features of sun-moths

Wing venation.

According to Scoble (1992), the wing venation of castniids is largely complete, with the majority of veins present in all of the species. In some species the chorda is present. Vein M is present in the cell of the forewing and hindwing and is always close to the cubital stem. Edwards *et al*. (1999) state that the forewing cell is open in the subfamily Tascininae while with the Castniinae it is usually closed (by discocellular veins). In both the forewing and hindwing, vein CuP is sometimes present. However, Common (1990) states that while vein CuP is usually present in the forewing, it is often absent in the hindwing. In the forewing, vein 1A+2A is forked at the base while in the hindwing it is usually not forked. Vein 3A is always present in the hindwing and the hindwing cell is open. Another feature of the hindwing is that veins Rs and M1 are stalked (united into a single vein) towards the base of the wing. It is this stalked section of veins Rs and M1 that form the leading edge of the (open) hindwing cell (pers. obs. of *Synemon selene* and *S. plana* 2000).

Genitalia.

Male genitalia:

The male genitalia of the Castniidae are well sclerotized (Common 1990, pers. obs. of *Synemon selene* 2000). In the subfamily Castniinae the uncus is divided or bifurcate but is variable in structure (Holloway 1998) and can be separate or fused with the tegumen (Edwards *et al*. 1999). The gnathos is present and its arms are not fused (Edwards *et al*. 1999). The tegumen is broad and is dorsally lobed, and often the vinculum has a short saccus (Common 1990). Edwards *et al*. (1999) state that the saccus is bifurcate with arms that project into the eighth abdominal segment. The juxta is sclerotized and the aedeagus is slightly to strongly curved (Common 1990, pers. obs. of *Synemon selene* and *S. plana* 2000) and in some instances there is a short coecum penis but no cornuti (Common 1990). There is also an expanded or enlarged phallobase (Edwards *et al*. 1999, pers obs. of *Synemon selene* 2000). The unadorned valvae are broad and in *Synemon* spp. have a short apical spine (Common 1990, pers. obs. of *Synemon selene* and *S. plana* 2000). The valvae in at least two *Synemon* spp. are also sparsely clothed in (?sensory) setae, which are especially long in the dorsal post costal area (pers. obs. of *Synemon selene* and *S. plana* 2000).

The male genitalia of the subfamily Tascininae exhibit some notable differences to the Castniinae. These are described in the following quotation from Holloway (1998): ‘Unusual features are the great depth of the vinculum, and fusion of the valves and gnathos (as ‘gnathus’) closely around the anellus’.

Female genitalia:

In the subfamily Castniinae the female genitalic form is modified to a greater or lesser extent to include an elongated extensible ovipositor. This is comprised of abdominal segments V111 to X and, depending on the genus, it may be heavily or lightly sclerotized and can be comparatively broad and short or long and slender (Edwards *et al*. 1999, Miller 1986, pers. obs. of *Synemon selene* and *S. plana* 2000). In at least some of the *Synemon* spp. the apex of the ovipositor is laterally clothed in stiff (?sensory) setae (pers. obs. of *Synemon selene* and *S. plana* 2000). The apophyses are well developed in the Castniinae, with those of *Synemon* spp. being very long, particularly the apophyses posteriores (Common 1990, pers. obs. of *Synemon selene* 2000). However, Common (1990) states that the apophyses of the other genera (?of the Castniinae, as distinct from the Castniidae) are much shorter than in the *Synemon* spp. The ductus bursae can vary in length and can be straight, coiled or tightly spiralled (Edwards *et al*. 1999). According to Common (1990) and pers. obs. of *Synemon selene* (2000) the ductus bursae and corpus bursae are membranous. However, Edwards *et al*. (1999) state that the ductus bursae may be membranous or sclerotized. Although a signum is present in the corpus bursae of some species it is absent in others (Common 1990). It is absent in the corpus bursae of *Synemon selene* (pers. obs. 2000).

Within the subfamily Tascininae some notable features of the female genitalia are that the ovipositor is only moderately extensile (Holloway 1998) and that the papillae anales (at the apex of the ovipositor) are clothed in long setae (Fukuda 2000). The very long and slender ductus bursae and the (attached) corpus bursae extend to the full length of the abdomen (Holloway 1998). Holloway (1998) says that the signum is absent in the subfamily Tascininae, while Fukuda (2000) states that it may be present or absent.

General adult morphology and distinguishing features of sun-moths.

While most of the morphological features that distinguish the Castniidae can be variously found in several other groups of Lepidoptera, it is usually not difficult to determine which taxa belong to this distinctive family. Superficially the Castniidae resemble the majority of butterflies, belonging to the superfamilies Hesperioidea and Papilionoidea, but in all except one case the sun-moths can be separated from these by the presence of a frenulum at the base of the hindwing. The single exception is the male of the Regent Skipper Butterfly, *Euschemon rafflesia*, an Australian species that is unique among all known hesperioid and papilionoid butterflies because it has a well-developed frenulum and retinaculum (Braby 2000, pers. obs. 2000). However, the males of the Regent Skipper Butterfly can be easily separated from all of the Australian sun-moths by the morphology of their antennae, which (as with many other skipper butterflies) have strongly backward hooked clubs at their outer ends. Although the antennae of the Australian sun-moths are also apically clubbed, the clubs are never prominently hooked. In male castniids the frenulum takes the form of a single bristle like structure (at the anterior base of the hindwing) that fits into the retinaculum, a small membranous, hook-like protrusion on the underside of vein Sc, near the leading edge of the forewing. With female castniids the frenulum is composed of a minimum of two (pers. obs. of *Synemon selene*) to a maximum of sixteen (Edwards *et al*. 1999) bristles that also arise from the anterior base of the hindwing. These bristles are usually set into a small patch of specialized scales on the underside of the forewing, near the basal end of vein CuA. Whether the frenulum is held in place by a retinaculum or an area of specialized scales, its purpose is to lock the forewings and hindwings together during flight. The frenulum can also be found in many other (but not all) families of Lepidoptera.

It is also possible that some species of the Agaristinae, a largely diurnal subfamily of the Noctuidae that are commonly known as day moths, could be mistaken for sun-moths. One of the most reliable ways of separating day moths from sun-moths is by the structure of their antennae. With day moths the antennae are either filiform, narrowly bipectinate or terminate in a very slender, slightly hooked club. In comparison with this, the antennae of sun-moths are never filiform or bipectinate and are much more strongly (and usually more abruptly) clubbed at their apices than they are in the Agaristinae that have clubbed antennae.

Generally, the majority of Australian sun-moths (*Synemon* spp.) can also be distinguished from butterflies and day moths by their colouration, and from butterflies by the way they fold their wings when resting. With only a few exceptions, the Australian sun-moths have cryptic colouration on the upperside of their forewings while the upperside of their hindwings and the underside of their forewings and hindwings are usually brightly coloured. In most instances the colouration of butterflies and day moths differs from this in that these taxa mainly have the upper-sides of their forewings and hindwings similarly (and often brightly) coloured. In addition to this, many butterflies have cryptic colouration on the underside of their hindwings and also on the apical area of their forewing undersides, a distribution of protective colouration that is rare in the Castniidae.

While at rest, most of the sun-moths fold their wings in a roof-wise position above their abdomens so that the brightly coloured uppersides of their hindwings are concealed. An exception to this are the males of the Golden Sun-moth (*Synemon plana*), which sometimes rest with their wings folded in the same manner as described below for the majority of butterflies. When resting, nearly all of the butterflies fold their wings above their bodies (the thorax and abdomen) so that the usually colourful uppersides of their wings are held together and hidden from view.

The long retractable ovipositors of *Synemon* females are another morphological feature that can be used to separate these taxa from the females of most other families of Lepidoptera. With all of the *Synemon* spp. the ovipositor is withdrawn into the abdomen when not in use, but can often be seen when a female uses it to probe the base of its larval host plant or nearby soil for suitable oviposition sites. In most instances it is also clearly evident after death because, as they die, the females often partially protrude their ovipositors. The result of this is that in most preserved specimens of *Synemon* spp. the ovipositors of the females are very obvious.

Some early misconceptions about the classification of sun-moths

Although Edwards *et al*. (1999) state that there is no disagreement at present about the taxa that are included in the family Castniidae, there were some earlier misconceptions about this matter. Some of these involved the erroneous inclusion of skipper butterflies (family Hesperiidae) in the Castniidae. Perhaps the most notable instance of this is Froggat (1907) who placed the Regent Skipper Butterfly, *Euschemon rafflesia* (as *E*. '*rafflesiae*') in the Castniidae. It seems that the unique males of this species (having a frenulum) could have led him or his colleagues to arrive at this taxonomic conclusion. Smart (1977) also mentions that in early literature, the North American Megathyminae (a subfamily of the Hesperiidae) were 'treated as members of a moth genus *Castnia*'. *Castnia* is a Neotropical genus of the Castniidae.

Illustrations

Figure 1. Typical example of a sun-moth species, male (right) and female of an undescribed *Synemon* sp. (aff. *magnifica*) from Kangaroo Island, South Australia. Scale bar = centimetres.

Figure 2. Female frenulum and specialized frenulum holding scales (near central-base of forewing) of a sun-moth, (Terrick Terrick Morph of the Pale Sun-moth, *Synemon selene*). About 13 times life size.

Figure 3. Male genitalia of a sun-moth: lateral view of aedeagus, (Two Wells Morph of the Pale Sun-moth, *Synemon selene*). About 85 times life size. Australian National Insect Collection, slide number: CAST. 11826. Slide prepared by E. D. Edwards, 1997. Illustration by F. Douglas, 2000.

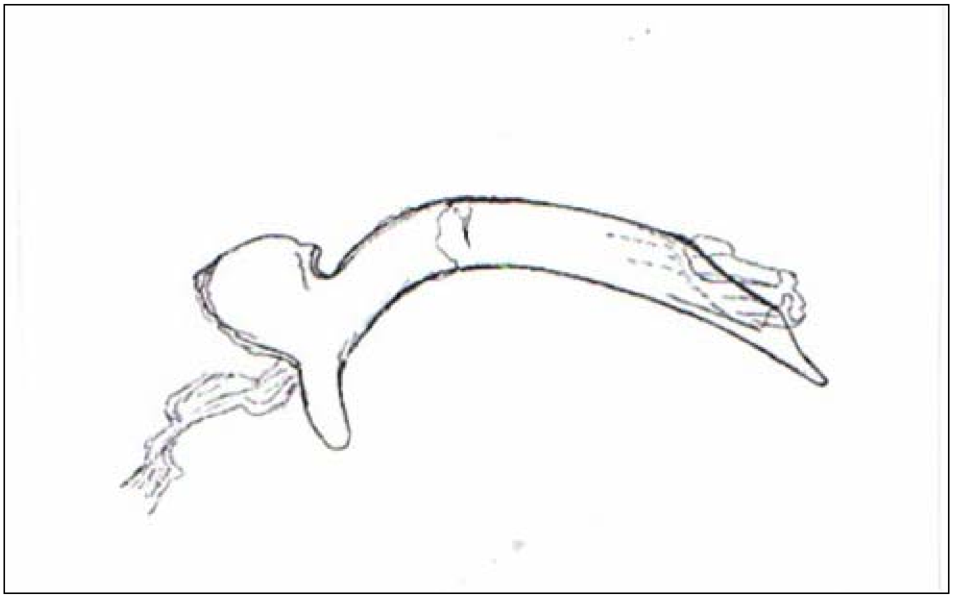
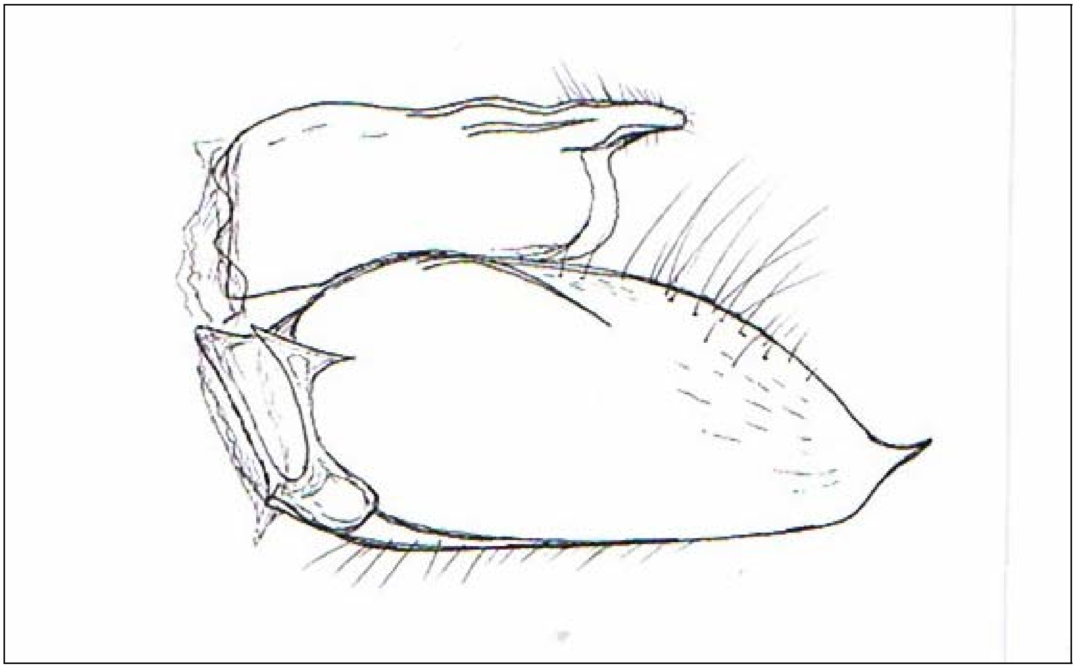


Figure 4. Male genitalia of a sun-moth: lateral view of tegumen and right valva (clasper), (Two Wells Morph of the Pale Sun-moth, *Synemon selene*). About 70 times life size. Australian National Insect Collection, slide number: CAST. 11826. Slide prepared by E. D. Edwards, 1997. Illustration by F. Douglas, 2000.



Part 1

Chapter 2

Biology of the Sun-moths

Introduction

The following provides an up to date overview of what is currently known about the biology of the world's sun-moths, order Lepidoptera: family Castniidae. Several comparisons are made between biological aspects of the Australian tribe Synemonini and the Neotropical tribe Castnini, both of the subfamily Castniinae. The results of original research work on the biology and behaviour of six species in the Australian genus *Synemon* are documented. Information was also obtained from personal communications with several entomologists and referral to a number of important references on the Castniidae, all of which are cited. Nomenclature of the Castniidae follows Edwards *et al*. (1999), Edwards (1996) and Lamas (1995). Names used for the other superfamilies, families and subfamilies of Lepidoptera follow Braby (2000), Scoble (1992) and Common (1990). Widely accepted or proposed common names for some of the *Synemon* species are given in brackets after their scientific names first appear in the following text, but are not repeated.

Although the sun-moths are primarily diurnal, bear a strong resemblance to butterflies and are often brightly coloured, they have not been studied to the same extent as the butterfly families, order Lepidoptera: superfamilies Hesperioidea (skippers) and Papilionoidea (all other butterflies). This situation is regrettable, as it is now apparent that many of the castniids have become 'threatened' or 'endangered' because their habitats have been alienated in various ways (Edwards *et al*. 1999). Broadly, this situation has occurred without the benefit of prior knowledge of their distributions, relative abundance or precise biological requirements. For example, the widespread clearing of natural ecosystems for agriculture has seriously fragmented the distributions of many of the Australian *Synemon* species. The extent of habitat fragmentation is so severe in some cases that several species are now restricted to very small and disjunct remnants of the particular ecosystems they require (pers. obs. 1987 to 2005). It also seems likely that some of the South American and south-east Asian castniids are currently threatened with extinction as a result of the widespread deforestation that has taken place in those two regions, especially during the past two decades. Because of this, it is important that an increased research focus is placed on the Castniidae so that additional information can be obtained on the biology and distributions of as many species as possible and appropriate decisions made about their conservation and management.

Despite a few excellent publications on the biology, morphology and taxonomy of sun-moths during the past ten years, there is still much to be learned. A striking example of this situation is that until very recently nothing at all was known about the biology of the south-east Asian *Tascina* species, which constitute the Tascininae. This represents an entire subfamily of the Castniidae (Edwards *et al*. 1999, Fukuda 2000). However, a few recent observations of the behaviour of the males of *T. metallica* are documented in this work. To the author's knowledge, this is the first time that any aspect of the biology of any species in the subfamily Tascininae has been recorded.

Adult behaviour

Flight behaviour.

The adults of the Castniidae are primarily diurnal, with most species only flying during periods of sunshine (pers. obs. 1986 to 2006 [Australian spp.], M. F. Braby pers. comm. 2002 [Neotropical spp.], Edwards *et al*. 1999 [Australian and Neotropical spp.]). By contrast, Edwards *et al*. (1999) also suggest that some species such as the Neotropical *Eupalamides cyparissias* may be crepuscular and that the Australian *Synemon* species occasionally fly at sundown. Despite this, more recent (2002) personal communications from E. D. Edwards have indicated that it is probably unusual for *Synemon* spp. to fly during the evening. His written comments on this subject are as follows: 'I have seen two tropical species active in the late or very late afternoon. *Synemon wulwulam* on the Barkley Tableland flew during the late afternoon but this may have been because strong winds had displaced adults earlier in the day and they were trying to regain the habitat patches. The second case was with a *Synemon* sp. near McArthur River N. T. where I took specimens almost at dusk. Maybe they were disturbed by our camp. Subsequent experience with this species has not suggested that they regularly fly at dusk. Certainly none came to light'. Personal observations of six species of *Synemon* in Victoria have shown that on suitably sunny days, most of the adult activity takes place between about 10 am and 2 pm (Australian Eastern Standard Time).

However, some or perhaps all of the *Tascina* species may be at least semi-crepuscular. This is suspected because several males of *T. metallica* have recently been observed and some collected as they flew in rainforest, at 2 to 15 metres above the ground, in the late afternoon, i.e. '4.30 pm to 5.00 pm'. On the same occasion/s, it was also noted that the males of *T. metallica* occasionally settled on leaves, with the head and antennae facing downwards and the abdomen orientated upwards. As with most other sun-moths, these resting males folded their wings over the abdomen in the usual roof-wise position, with the forewings covering the hindwings (B. Malangis pers. comm. 2005). To the author's knowledge, this reversed orientation of resting males has not been reported previously in any of the Castniidae. These observations on the behaviour of *T. metallica* males were made near Roxas, Palawan Island, in the Philippines.

The flight of most of the sun-moths is rapid and is usually fairly direct, with the wings kept in motion continuously. In some species, e.g. *Synemon jcaria* (Reddish-orange Sun-moth) and *S. nais* (Orange Sun-moth) the males select a dead twig or similar perch from which they watch over the surrounding area for receptive females or rival males. When conspecific males are seen they are rapidly pursued by other territorial males before the individuals return to their favoured resting-places or select new vantage-points. In other species, e.g. *Synemon parthenoides* (Orange-spotted Sun-moth) and *S. plana* (Golden Sun-moth) the males tirelessly patrol their breeding areas, searching for newly emerged females that have not mated. Although the less active *Synemon* females are usually more difficult to find than the mate-seeking males of their particular species, they tend to spend much time searching for their correct larval host plants. It is while doing this that they are most likely to be observed.

Unlike many other families of Lepidoptera, it seems that the Castniidae are unable to raise their body temperature by shivering or vibrating their thoracic muscles prior to flight. It appears that this inability to raise the body temperature at will prevents the sun-moths from flying during periods of cool and cloudy weather. Perhaps the very cold and dry conditions that are thought to have occurred during the glaciations of the Pleistocene period may also explain the apparent absence (?prehistoric extinction) of the family Castniidae within Tasmania, New Zealand and the colder parts of South America.

Adult feeding behaviour.

Some of the Australian Castniidae have a non-functional haustellum and cannot feed as adults. These species rely on nutrients that are stored in their bodies during the larval stage to sustain them throughout their brief adult lives. Two examples of ‘non-feeding’ spp. are *Synemon plana* and *S. selene* (Pale Sun-moth). In both of these taxa the non-functional haustellum is vestigial and is greatly reduced in size (E. D. Edwards pers. comm. 2002 [*S. plana*] and pers. obs. [*S. selene*]). Some other *Synemon* spp. have a fully developed haustellum and at least some of these are obviously able to feed. This is concluded following personal observations made on two such species (*Synemon discalis* [Small Orange-spotted Sun-moth] and *S. parthenoides*) while they were feeding at flowers. Common (1990) also mentions that ‘*Synemon* adults have occasionally been observed feeding at flowers’. As Fukuda (2000) states that the ‘tongue’ (haustellum) is ‘absent’ in the subfamily Tascininae, it seems that the adults of all of the south-east Asian Castniidae would be unable to feed. In sharp contrast to this, it appears that many (and possibly all) of the Neotropical Castniidae are able to feed as adults. This statement is based on Common (1990) who mentions that the ‘Neotropical species are said to visit flowers to feed’. Seitz (1940) also notes that the Neotropical species of Castniidae are especially attracted to ‘white or bright red flowers’ and ‘show a preference for the honey of the blossoms of flowering trees’. Further, Seitz (1940) describes how ‘the *Castnia* runs, buzzes and springs from flower to flower, dipping its strong proboscis rapidly into one corolla after another.’

Courtship and mating behaviour.

The females of at least some, and most likely all, *Synemon* spp. emerge from their pupae with fully developed eggs in their ovaries and commence oviposition soon after mating. After *Synemon* females have mated they apparently cease to evoke persistent courtship behaviour in passing males of their species (pers. obs. 1987 to 2005). For this reason it seems likely that *Synemon* females, and possibly the females of other genera in the family Castniidae, only mate once and that a single mating provides sufficient spermatozoa to fertilize all of the ova that each female lays.

The cues that the males of *Synemon* spp. use to distinguish virgin females are uncertain. However, a personal observation of the behaviour of *Synemon parthenoides* may indicate that pheromones as well as visual stimuli are involved. On the occasion in question (6 November 2000) it was noticed that a male of *S. parthenoides* was repeatedly attempting to copulate with another male of the same species that had recently been hit (in flight) by a passing vehicle. Although the injured male was still alive, the dorsal surface of its thorax had been cracked by its impact with the vehicle and it was unable to fly. As conspecific males of this species do not normally try to copulate with each other, it appeared that the injured male had become attractive to the other male because of its fractured thorax. A plausible explanation for this aberrant mating response could be that the fracture had allowed some volatile components of the insect's body fluids to dissipate into the air. Perhaps the accidental emission of such volatile substances may have caused the injured male to be wrongly perceived by the other male as a recently emerged female that had not yet mated. This unusual observation was made in an open mallee-heath habitat in the south-eastern Big Desert, approximately 28 kilometres west-south-west of Rainbow, Victoria, (Australia).

Obviously, more observations and the results of various experiments would be required to clarify this matter. However, it is suspected that recently emerged females of *Synemon* spp. may deliberately or inadvertently release pheromone/s into the air that clearly signal their virgin condition to mate-seeking males. If the body fluids of *Synemon* spp. are the source of such pheromones, it is likely that the recently dried wing and body scales of virgin females would contain higher concentrations of these volatile substances than the scales of older females that had already mated and started to oviposit. This may explain why ovipositing *Synemon* females are usually not disturbed by courting males and why the males will pay little attention to these females in flight as they search for suitable areas of larval host plants. Perhaps *Synemon* females have specialized scales (possibly similar to the androconia of certain male Lepidoptera) on their bodies or wings. These could act as a temporary reservoir for male attracting pheromone/s for long enough after emergence to ensure that mating takes place.

When a male of either *Synemon parthenoides* or *S. discalis* locates a newly emerged (receptive) female of its own species, a brief courtship flight usually follows. In both of these species, this starts with the male rapidly pursuing the female for a distance of about one metre. After this, the female slows down and commences to search for a more or less vertical and obstruction-free (usually dead) twig on which to land. During this searching phase of the courtship flight, the male closely follows the female's every move. For most of the time he stays behind her at a distance of about three to six centimetres. When a suitable landing site is found the female lands first and remains in the same position, while the male usually lands about four to six centimetres below her. Then, without delay, the male walks (upwards) towards the female. As the male nears the female he curls his abdomen forward so that his (voluntarily splayed out) genitalia can come into contact with the genitalia of the female and mating can commence. During copulation, mating pairs of *S. parthenoides* and *S. discalis* usually remain motionless, in a head uppermost position. The male rests slightly below the female on the opposite side of the twig, so that both sexes are facing in the same direction. They also fold their wings in a roof-wise position so that the cryptically coloured uppersides of their forewings cover and conceal the brightly coloured uppersides of their hindwings.

In their paper on the life history and early stages of *Synemon magnifica* (Magnificent Sun-moth), Common & Edwards (1981) stated that ‘courtship has not been observed’ but in the next sentence they briefly described the courtship flight of the species. They also described its mating behaviour and included a photograph of a mating pair in their work. The information that these authors provided clearly indicates that *S. magnifica* has very similar courtship behaviour to *S. parthenoides* and *S. discalis* and also adopts the same atypical mating position as these species. Within the Lepidoptera, the mating position of the above-mentioned *Synemon* spp. (and possibly all other Castniidae) is most unusual. So far as can be determined, all of the other families of Lepidoptera usually mate in such a position that the heads of the copulating pair face in more or less opposite directions (pers. obs. of many families of Lepidoptera over many years).

Conversly, the mate location behaviour of *S. plana* differs from the three preceding species of *Synemon* and is possibly unique within its genus (and other genera of the Castniidae). The mate location strategy of *Synemon plana* is described in the following manner by Common (1990): ‘The females of *S. plana*, however, seem reluctant to fly, and sit with their forewings raised displaying the brightly coloured hind wings, to which searching males appear to respond’. O’Dwyer & Attiwill (2000) also allude to the unusual mate location technique of this species in their cited reference: ‘Although able to fly, females tend to lie in wait and flash their wings to attract the attention of patrolling males (Harwood *et al*. 1995).’ While the mating position that *S. plana* assumes is largely similar to that of other observed species, the following differences are noteworthy: (a) Mating pairs usually rest on the ground or on the outer foliage of *Austrodanthonia* (Wallaby-grass) tussocks or sometimes other plants. (b) While mating the male usually rests beside (instead of opposite) the female. See Chapter 4 of Part 2 of this work for further notes on the courtship behaviour of *S. plana*.

The duration of mating times seems to vary greatly between some *Synemon* spp. and may also vary among individual pairs of a given species. This statement is based on the following observations of mating pairs:
(A) *Synemon magnifica*:
(i) 1145 to 1500 hours, Australian Eastern Standard Time (Common & Edwards 1981).
(B) *Synemon parthenoides*:
(i) 1515 to 2110 hours, Australian Eastern Daylight Saving Time (pers. obs.).
(ii) 1610 to 1835 hours, Australian Eastern Daylight Saving Time (pers. obs.).
(C) *Synemon plana*:
(i) 1221 to 1226 hours, Australian Eastern Daylight Saving Time (pers. obs.).
(ii) 1243 to 1250 hours, Australian Eastern Daylight Saving Time (pers. obs.).

With many species of diurnal Lepidoptera, copulating pairs are able to fly without separating if they are disturbed. In a given subfamily it is usual for one sex to be the active or ‘carrying partner’ while the other sex does not attempt to fly and keeps the wings closed or folded in the normal resting position. Common & Waterhouse (1981) state that with some species of butterflies either sex may be the carrying partner but also refer to work on this subject that was carried out by Shields & Emmel (1973). The findings of Shields & Emmel (1973) regarding the sex of the ‘carrying partner’ within several of the butterfly subfamilies are as follows:
(A) Pierinae and Danainae: the male carries the female.
(B) Papilioninae, Satyrinae and Hesperiinae: the female carries the male.
(C) Acraeinae, Nymphalinae and Lycaeninae: either sex can be the active or flying partner.

The few observations that have been made to date indicate that, depending on the species, either sex can be the carrying partner within the Australian sun-moths (tribe Synemonini of the subfamily Castniinae). The observations that led to this tentative conclusion are listed below:
(A) *Synemon parthenoides*: female was the carrying (flying) partner in observations of two mating pairs (pers. obs.).
(B) *Synemon discalis*: female was the carrying (flying) partner in an observation of one mating pair (pers. obs.).
(C) *Synemon nais*: female was the carrying (flying) partner in an observation of one mating pair (pers. obs.).
(D) *Synemon collecta* (Striated Sun-moth): although the male was the carrying (walking) partner of one mating pair that was observed by Dunn (2000), the pair could not be induced to fly.

The relatively larger wingspans and body size of the females of *Synemon parthenoides*, *S. discalis* and *S. nais* may explain why in these three species, the female is the carrying partner. The carrying partner reversal in the mating pair of *S. collecta* is consistent with this hypothesis, since females of this species are only slightly larger than the males. The wingspan measurements of both sexes of the four above-mentioned species are as follows:
(A) *Synemon parthenoides*: about 3.5 to 3.7 cm. for males and 4.2 to 4.4 cm. for females.
(B) *Synemon discalis*: about 3.1 to 3.3 cm. for males and 3.5 to 3.9 cm. for females.
(C) *Synemon nais*: about 2.7 cm. for males and 3 cm. for females.
(D) *Synemon collecta*: about 3.7 to 3.9 cm. for males and 3.8 to 4.1 cm. for females.
These wingspan measurements are from apex to apex of the forewings of mounted specimens. These specimens were set in the conventional manner, i.e. so that the inner margins of both forewings are at right angles to the longitudinal axis of the body.

Seitz (1940) described the courtship behaviour of some of the Neotropical species of Castniidae but concluded with the following: ‘I have never seen a pair belonging to this family in copulation and therefore am convinced that normally this act takes place while the insects are on the wing’. Although mating pairs that have been disturbed (of at least some of these species) are probably capable of flying after they have commenced to copulate, it is most unlikely that they only mate while flying. This is substantiated by the preceding observations on the mating behaviour of some of the closely related Australian *Synemon* species and also by Seitz himself. He wrote the following about the courtship behaviour of *Castniomera* (as *Castnia*) *atymnius*. 'The wary female flies into the bushes and settles on a vertical branch with its head upwards and its wings open ready for flight; the male sits about half a yard lower down, minutely observing the female. On the slightest provocation the latter flies off, and the male rushes after it in continuous headlong pursuit'. It seems probable that if the pair of *C. atymnius* that was observed by Seitz had not been disturbed, the male would have eventually approached the female and the pair would have mated in a similar resting position to that of the *Synemon* spp.

Oviposition behaviour.

Oviposition behaviour is basically similar in all but one (*Synemon selene*) of the several *Synemon* species that have been personally observed from 1987 to 2005. Oviposition commences with the female landing on the ground near a plant that it presumably perceives to be suitable as a larval host. The female then walks to the base of the plant and climbs into its lower foliage so that the posterior end of its abdomen is just clear of the soil surface. After attaining this upright position, the female commences to probe the soil against the base of the plant with its long extendible ovipositor. At times (with some species more frequently than others) the tillers or leaf axils of the plant are also probed. When a suitable oviposition site is found, the ovipositor is usually inserted more deeply and the female becomes less active while the egg/s are being laid. After this, the ovipositor is withdrawn into the abdomen and flight is resumed. Alternatively, the female may sometimes move to a new position around the base of the same plant and recommence probing. Just prior to and after oviposition the wings are usually raised and lowered rhythmically and held in a partly spread-out position so that the inner marginal half of the brightly coloured hindwing uppersides are visible. During actual oviposition the wings are often held in a closed (butterfly like) position above the thorax so that their uppersides are almost touching and their undersides can be seen.

The oviposition behaviour of *Synemon selene* differs from what appears to be normal for other (observed) *Synemon* species. It may be unique within the family Castniidae. *S. selene* females do not intentionally climb into the foliage of their larval host plants (as described above) before ovipositing. Instead, they simply land on the bare ground inside areas of their putative larval host plants and randomly probe the numerous small cracks that occur naturally in the clayey soil of their habitat. It is within these crevices that they finally oviposit, sometimes at distances of ten centimetres or more from the nearest live vegetation. The reason for this unusual oviposition behaviour is probably that the adult flight period of *S. selene* is during late summer when the clayey soil in the areas where it occurs has dried out and become extremely hard. It seems that it is a much easier alternative for *S. selene* females to oviposit directly into the above-mentioned crevices instead of attempting to penetrate the soil at the base of their (suspected) larval host plants.

Although the number of ova that are laid by the *Synemon* species at the culmination of each probing sequence is uncertain, it was found that on one occasion a female of *S. selene* had laid six eggs into a single oviposition site before withdrawing its ovipositor. It seems possible though that some of the other *Synemon* spp. may only lay one egg at each oviposition site. This is indicated by Common & Edwards (1981) who found that the ova of *S. magnifica* 'occurred singly' and had been deposited in the soil against the tillers of the larval host plant (at depths of up to one centimetre) and also between its old leaf bases. Because the ova of *Synemon* species are usually very difficult to locate in the field the fully extended ovipositors of some species were measured, so as to provide an indication of the maximum depths in the soil at which their eggs could be deposited. The lengths of the fully extended ovipositors of the examined species are as follows:
(A) *Synemon parthenoides*: 1.4 cm. (two specimens examined).
(B) *Synemon discalis*: 1.4 cm. (one specimen examined).
(C) *Synemon plana*: 1 cm. (one specimen examined).
(D) *Synemon selene*: 1.5 cm. (two specimens examined).
These measurements are of abdominal segments eight to ten. In *Synemon* species these segments are modified to form an especially long tapered ovipositor that is scaleless and can be completely withdrawn into the abdomen when not in use.

The comparatively short ovipositors of many of the Neotropical Castniidae (see Miller [1986] for diagrams of female genitalia) suggest that these species may oviposit among the leaf bases, rhizomes or pseudobulbs of their respective larval host plants or in some instances, directly into their growing crowns. The latter type of oviposition site is substantiated by Miller (1986) who states that the 'adult females (of *Eupalamides cyparissias conspicua*) normally oviposit in the crown of the palm', which in this instance was the introduced African Oil Palm, *Elaeis guiniensis*.

It also seems likely that the south-east Asian species of Castniidae (*Tascina* spp.) would oviposit amongst or into sheltered parts of their (?epiphytic) larval host plants. This is suspected because the illustration in Fukuda (2000) of the female genitalia of *T. dalattensis* shows that the ovipositor and apophyses are especially short in this (?arboreal) species and do not appear to be adapted for oviposition into debris or soil.

Incubation times of ova and larval hatching behaviour

Incubation times of ova.

Some incubation times that have been recorded for the ova of the family Castniidae are as follows:
(A) *Synemon parthenoides*: 25 to 27 days (pers. obs.).
(B) *Synemon magnifica*: 'about' 21 days (Common & Edwards 1981).
(C) *Synemon jcaria*: 39 to 41 days (pers. obs.).
(D) *Synemon selene*: 24 to 93 days with most hatching at 53 days (pers. obs.).
(E) *Synemon plana*: 31 days (pers. obs.).

(F) Neotropical Castniini: (species not listed) ‘approximately’ 10 to 14 days (Miller 1986).

Pre-hatching and hatching behaviour of larvae.

For a fortnight or more before they hatch, the ova of *Synemon selene* slowly change colour from cream to deep pink. This colouration is brought about by the increasing pigmentation of the developing larvae and is not caused by a colour change of the semi hyaline chorions of the ova. This is clearly shown by empty ova, which immediately become a semi transparent whitish colour after the predominantly purplish-pink (first instar) larvae of this species have hatched. Miller (1986) also describes how, in the few species of Neotropical Castniini that she reared, the colour of the ova changes from whitish to, depending on the species, a pinkish or greenish hue as the larvae developed. All of these observations differ somewhat from those of Common & Edwards (1981), who found that the ova of *Synemon magnifica* are ‘whitish when first laid, becoming deep orange after 48 hours if fertile’. As it seems that such a rapid colour change could not be attributed to the pigmentation of slowly developing larvae, it is possible that it is brought about by chemical changes in the fertile ova of *S. magnifica*.

Miller (1986) noted that in the (studied) Neotropical Castniini ‘the larva lies recurved within the egg chorion, generally recurved over about the second abdominal segment’. Personal observations of the ova of *Synemon selene* showed that, although the developing larvae seemed to lie in a non-recurved position, they were capable of movement inside the chorion for a period of several days before they hatched. This larval movement could be induced by applying gentle pressure to the chorion with a pair of flexible ‘featherlight’ forceps and after such stimulus was usually easy to observe. It was found that after movement during the final stage of development, the larvae of *S. selene* sometimes lay within the chorion in a similar recurved position to what was described by Miller (1986) for the species of Castniini that were studied.

Unlike certain larvae in some other families of Lepidoptera, e.g. Hesperiidae (pers. obs.), Papilionidae (D’Abrera 1971), Anthelidae (pers. obs.) and other unspecified families (Common 1979), it appears that the larvae of the Synemonini and Castniini do not eat the chorion after they have hatched. This is substantiated by Miller (1986), who gives the following description of the hatching process for the species of Castniini that she reared: ‘Prior to emergence, it (the larva) gently splits the chorion along one of the five longitudinal lamellae, approximately one-fourth to one third the distance from the micropyle. The larva then emerges without consuming any of the egg chorion’. Personal observations of *Synemon parthenoides*, *S. jcaria*, *S. plana* and *S. selene* also indicated that the larvae of all these *Synemon* species eat little or none of the chorion after hatching and only chew out enough of it to permit them to hatch successfully.

Further personal study of *Synemon parthenoides* and *S. selene* found that the larvae hatch in a similar way to Miller’s (1986) description (cited above) of how the larvae of the tribe Castniini hatch. However, the hatching behaviour of these *Synemon* species differed from that of the Castniini in the following ways:

(A) The larvae do not always hatch at the micropyle end of the ovum but sometimes emerge from its opposite end.
(B) The larvae do not hatch from the ovum by splitting the chorion along one of the 'five longitudinal lamellae' but chew out a roughly circular escape hole between two or more of the longitudinal ridges (lamellae).

Post hatching behaviour of larvae.

Within the Synemonini, the behaviour of recently hatched larvae may vary from one group of closely related species to another. The first instar larvae of *Synemon magnifica* are thought to crawl up the tillers of their larval host plants to a height of several centimetres above the ground, where each larva tunnels into a tiller to commence feeding (Common & Edwards 1981). In contrast to this, it was noted by the author that the first instar larvae of both *Synemon selene* and *S. plana* (?both grass root feeders) appeared to be negatively phototactic (sensitive to light) and showed a strong instinct to crawl downwards. It was found that if recently hatched larvae of either of these two species were placed onto soil, they searched for small crevices into which they would crawl and soon disappear from sight.

Miller (1986) found that the first instar larvae of *Telchin* (as *Castniomera*) *licus, Eupalamides cyparissias* and *Prometheus cochrus* 'actively searched for food'. This is an indication that the larvae of these and at least some other species of the Castniini may exhibit similar post-hatching behaviour patterns to those suspected for *Synemon magnifica* by Common & Edwards (1981). Referring to her experiences with attempting to rear the larvae of the above-mentioned species of Castniini, Miller (1986) states that, 'The larvae are cannibalistic and must be separated upon emergence'. This cannibalistic tendency was never observed in several cohorts of *Synemon selene* larvae and one cohort of *S. plana* larvae that were kept together in their respective containers for several days after they had hatched.

Larval and pupal behaviour

Larval behaviour.

All known larvae of the Castniidae either feed internally on the tissues of their host plants or tunnel through the soil to feed on their roots or rhizomes, (Edwards *et al*. 1999, Scoble 1992). Although a particular plant may sometimes have more than one larva feeding on its tissues at one time, the individual larvae are solitary, each constructing its own silk-lined feeding gallery or galleries as it grows. It is usual for the larvae of Castniidae to retain their frass inside sections of their excavated galleries (Edwards *et al*. 1999). Although Miller (1986) concurs, she also says that the larvae of *Telchin* (as *Castniomera*) *licus* 'would ravenously excavate a tunnel into the (cultivated banana) rachis and leave a mound of rounded fecal pellets at the entrance to the burrow'. If disturbed, the first instar larvae of Neotropical castniids 'do not exhibit' an ability to move backwards, while the later instars of these species can 'readily move backward when disturbed and shy away from bright light' (Miller 1986). Personal observations demonstrated that if gently touched with a camelhair brush, the first instar larvae of *Synemon selene* could move forwards or would veer away to either side but also showed little inclination to move backwards. However, it is likely that the second to final instars of all the *Synemon* species would be able to move backwards if the need arose. This assertion is partly substantiated by personal observations of the mid to late instar larvae of *Synemon jcaria*, which were able to move forwards or retreat backwards to the base of their feeding galleries.

Further, the larvae of *Synemon jcaria* are able to repair external damage to the walls of their feeding galleries (pers. obs. 2000). As they mature, the larvae of this species will eventually hollow out entire rhizomes of their host plant (*Lomandra effusa*, Scented Mat-rush, Lomandraceae) by feeding on their internal tissues. If a hollowed out rhizome that contains a live (mid to late instar) larva is partly opened, the exposed larva will seal up the fracture without delay. The materials that it uses to do this appear to be a combination of larval silk, finely chewed fibrous particles of the host plant and frass. Depending on possible variables such as the mean air temperature and amount of damage to the gallery, the exterior of the rhizome will usually be completely resealed within about one to four days.

The endophagous and/or subterranean habits of castniid larvae should provide them with a certain amount of protection from various predators and parasitoids. However, Common & Edwards (1981) once found some dead larvae of *Synemon magnifica* that may have been attacked by a species of fungus. They also discovered 'narrow excavations' in the soil around the bases of some of the larval host plants (*Lepidosperma viscidum*, Sticky Sword-sedge, Cyperaceae) of *S. magnifica* and surmised that these might have been dug out by bandicoots (Marsupialia: Peramelidae) that had been foraging for the larvae of this species.

Prepupal behaviour of larvae.

With the Australian *Synemon* species, and possibly with all Neotropical and south-east Asian Castniidae, pupation probably occurs in the final larval gallery. Depending on the species, this can be within the tissues of the larval host plant or in the soil. The pupae of the Neotropical species of Castniidae are found inside pupal cells constructed of plant fragments (Edwards *et al*. 1999). Before pupating, it is likely that most or possibly all of the larvae of these Neotropical species construct their pupal cells within their final larval galleries in the fleshy parts (stems, rhizomes, pseudobulbs etc.) of their larval host plants. According to the following reference cited by Miller (1986), the larvae of *Telchin* (as *Castniomera*) *licus* seal off the entrance to the pupal tunnel with 'a thin, hyaline "window" (of larval silk) as observed by Korytkowski and Ruize (1979a)'.

Prior to pupation the larvae of at least one species of *Synemon* (*S. magnifica*) construct a short, above ground extension of the final larval/pupal gallery. This structure takes the form of a silk lined 'chimney' that is exteriorly covered in particles of plant debris and soil and is usually about two centimetres high (Common & Edwards 1981).

Pupal behaviour.

Common & Edwards (1981) point out that, as in the Cossidae, Sesiidae and Tortricidae, the third to seventh (male) or third to sixth (female) abdominal segments of *Synemon* pupae are flexible and can be moved at will. The pupae of *Telchin* (as *Castniomera*) *licus* and *Castnia eudesmia* can 'rotate' abdominal segments 'A2-A8' (Miller 1986), so apparently, the pupae of the Neotropical Castniidae also have very flexible abdominal segments. As well as having flexible abdomens, the pupae of many (possibly all) Castniidae have a series of short, heavily sclerotised spines that are arranged in transverse rows on the dorsal surface of their abdominal segments (tergites). According to Edwards *et al*. (1999), there are two rows of these spines on segments two to seven and single rows on segments eight and nine in male pupae, with female pupae differing from this in that they only have a single row of spines on segment seven. Personal observations of living pupae of *Synemon jcaria* have indicated that the flexibility and structure of the abdominal segments in the pupae of Castniidae are probable aids to pupal mobility, via traction. When an occupied pupal gallery of this species is partly opened, the pupa it contains is capable of moving either forwards or backwards to an undamaged section of its pupal gallery. The pupae of *Synemon magnifica* are also able to move 'forward or backward' and could be found in any part of their vertical pupal tunnels (Common & Edwards 1981). It appears that this pupal mobility would enable the soil dwelling pupae of some of the *Synemon* species to retreat to the bottom of their pupal galleries during unfavourable conditions such as extremely hot weather or fire.

Just prior to eclosion (adult emergence), the pupae of Castniidae protrude from their pupal galleries so that the head, thorax and first few abdominal segments are exposed. This enables the adults to emerge without unnecessary obstruction. Although the known pupal exuviae of the Castniidae are left in situ after the adults have emerged, those of some *Synemon* spp. are occasionally found lying loose on the ground, probably as a result of being blown out of the entrances of their pupal tunnels during windy conditions.

Larval host plants and duration of life cycle

Larval host plants.

Although all of the known larval hosts of the Castniidae are invariably monocotyledons, Miller (1986) notes that a dicotyledonous plant (*Eryngium* [miss-spelt *Erynium*] *paniculatum*) in the family Apiaceae is the larval host of *Geyeria uruguayana*. However, Edwards *et al*. (1999) states that this anomalous record is unconfirmed.

The confirmed larval host plants of the Central and South American Castniidae (tribe Castniini) belong to several monocotyledonous families (Miller 1986). These are as follows:
(A) Bromeliaceae (utilized by genera *Castnia*, *Xanthocastnia*, *Hista*, *Athis*, *Synpalamides*, *Haemonides* and *Yagra*).

(B) Musaceae (utilized by genera *Castniomera*, *Telchin* [as *Castniomera*] and *Xanthocastnia*).
(C) Poaceae (utilized by genus *Telchin* [as *Castniomera*]).
(D) Arecaceae (utilized by genera *Corybantes* and *Eupalamides*).
(E) Orchidaceae (utilized by genus *Athis*).

Edwards *et al*. (1999) also lists the Marantaceae as one of the larval host plant families that the Castniidae utilize, but does not include any information about which genus/era of the tribe Castniini are associated with this plant family.

The larvae of the Australian Castniidae (tribe Synemonini, genus *Synemon*) are known to (or in some cases *thought to) feed on a number of plant species that belong to four monocotyledonous families. These are as follows:
(A) *Lomandra* spp. (Lomandraceae), (E. D. Edwards pers. comm. 1992 and pers. obs. 1993 to 2006).
(B) *Lepidosperma* spp., a **Gahnia* sp. and a **Schoenus* sp. (Cyperaceae), (Common & Edwards 1981, and/or pers. obs. 1989 to 2005).
(C) *Austrodanthonia* spp., *Chrysopogon* spp. and an **Austrostipa* sp. (Poaceae), (E. D. Edwards pers. comm. 2002 and/or pers. obs. 1991 to 2005).
(D) An *Ecdeiocolea* sp. (Ecdeiocoleaceae), (E. D. Edwards pers. comm. 2002).

Recently, Braby and Dunford (2006) have found that *S. plana* appears to be utilizing two additional genera of the Poaceae as larval hosts. While one of these two genera (*Bothriochloa*) is native to Australia, the other genus (*Nassella*) is introduced from South America (Chile).

Nothing is known about the larval host plants of the south-east Asian Castniidae (subfamily Tascininae, genus *Tascina*) (Fukuda 2000, Edwards *et al*. 1999). As well as this, all of the *Tascina* species are reputed to be exceedingly rare in the field and also in collections. This curious situation may indicate that these species complete their life cycles in the forest canopy and could have larvae that feed on the pseudobulbs or rhizomes of epiphytic monocotyledons, or perhaps within the growing crowns of palms (Arecaceae). Although it is possible that the larvae of *Tascina* species feed internally on the pseudobulbs of epiphytic orchids (Orchidaceae), it is noteworthy that, to the author's knowledge, none of the cultivated varieties of these plants have ever been reported as being utilized as larval hosts. It also appears that to date, the early stages of *Tascina* spp. have not been found inside the pseudobulbs of any orchid spp. that have been collected from the wild. Further, the complete absence of any host plant records for this enigmatic genus may be an indication that the larvae of all the *Tascina* species feed on a single species of plant or a closely related group of (rainforest) plants that are not normally cultivated.

Duration of life cycle.

The small amount of available information on the life histories of the Castniidae has shown that the duration of life cycles could vary considerably between the Central and

South American Castniini and Australian Synemonini. Despite being larger species in most instances, the Castniini may require less time to complete a generation than most or all of the Synemonini. This is suggested because Edwards *et al*. (1999) states that *Telchin licus* spends four and a half months in the larval stage, while Common & Edwards (1981) found that *Synemon magnifica* takes a period of at least twenty months to complete its larval development (instars). Although much more information is needed to clarify this apparent discrepancy, it appears that many of the Synemonini would require a longer period of time to complete their life cycles because they often inhabit drier and in some regions, seasonally cooler habitats than most of the Castniini. The Synemonini may also need a protracted period of time to go through a generation because they usually feed on comparatively small plants. While they are often smaller species themselves, it seems that on average, they would probably have more limited food resources than the majority of the Castniini.

Mimicry in adult Castniidae

Mimicry in the tribe Castniini of the subfamily Castniinae.

A number of species belonging to 'at least half of the genera in the neotropical Castniini' appear to have mimetic relationships with other diurnal Lepidoptera (Miller 1986). However, it is still unclear whether Batesian and/or Mullerian mimicry occurs in these mimetic species of Castniini. In the following sentences, Miller (1986) elucidates the apparent lack of knowledge on this subject. 'Unfortunately there is little information concerning the biochemical properties of the respective food plants associated with neotropical Castniinae, and it is not possible to determine whether most (mimetic) Castniinae are involved as typically Batesian mimics/models or as distasteful Mullerian mimics. Low population numbers have prevented examination of palatability spectra within the group to determine whether or not defensive chemicals are sequestered or synthesized. Due to the widespread diversity of color pattern and wing maculation in the Castniinae in addition to the larval feeding habits, it is possible that both types of mimetic associations may exist.' However, as many (and possibly all) of the diurnal Lepidoptera that appear to be the models for mimicry in the Castniini are probably distasteful or poisonous to potential predators, it is likely that a significant proportion of the mimetic Castniini are (palatable) Batesian mimics. While the known mimetic associations within the Castniini are extensive and complicated it is interesting to note that Miller (1986) also states that 'Not all of the mimetic associations within the neotropical Castniinae have been identified.'

Miller (1986) summarized the mimetic species of Castniini and their potential models. However, it was deemed necessary to include an amended version of this summary here, due to the somewhat confusing layout, occasional miss-spells and in many instances out-dated nomenclature that Miller (1986) used in the original summary. In this version, the nomenclature of the Castniini has been brought into line with Lamas (1995). The nomenclature of the potential models follows Braby (2000), Scoble (1992) and/or Common (1990) for the arrangement of the families and subfamilies and Lewis (1985) and/or Smart (1977) and Lamas (1979) for the nomemclature of the genera and species. Some species of mimetic Castniini are listed as mimics of two or more potential models because these taxa are probably involved in complex ‘mimicry rings’ which seem to be beneficial to all of the involved species. The species and/or genera and subfamilies and/or families of the potential models and the corresponding species and/or genera of mimetic Castniini that are cited by Miller (1986) are as follows:

Family Hesperiidae:

Subfamily Pyrginae:

Potential models, *Autochton* spp. / mimics, *Castnius* spp.

Subfamily/ies: (subfamily/ies not listed).

Potential models, *Phanus* spp. / mimic, *Frostetola gramivora*.

Potential model, *Pythonides limea* / mimics, *Mirocastnia pyrrhopygoides* (females only), *M. smalli*.

Potential model, *Sostrata cronion* / mimic *Mirocastnia* spp.

Family Papilionidae:

Subfamily Papilioninae: (subfamily not listed).

Potential model, *Parides ascanius* / mimic, *Prometheus cochrus*.

Potential model, *Parides chabris* / mimic, *Tosxampila mimica*.

Potential model, *Parides hahneli* / mimic, *Tosxampila mimica*.

Potential model, *Parides* ?*triopas* (as *Parides* sp.) / mimic, *Gazera heliconioides obidona* (as *Gazera peruviana*).

As *Parides triopas* is one of the few *Parides* spp. that resembles *Gazera heliconioides* and the distributions of these two taxa appear to be at least partly sympatric, it seems that *P. triopas* would probably be involved in the same ‘mimicry ring’ as *G. heliconioides*. Because *Parides* spp. are thought to be distasteful to vertebrate predators, it is likely that *P. triopas* would be one of the unpalatable models that *G. heliconioides* mimics. According to Smart (1977) *P. triopas* occurs in ‘Guyana’ while Lewis (1985) says that it occurs in ‘Amazon, Guianas’. The distribution of *G. heliconioides* is as follows: ‘Amazonas’, Seitz (1940), ‘Brazil’, Lamas (1995), Seitz (1940), Miller (1986), ‘Ecuador’, Seitz (1940), ‘French Guiana’, Lamas (1995), ‘Guiana’, Seitz (1940), ‘Guyana’, Lamas (1995), ‘Paraguay’, Lamas (1995), Seitz (1940), ‘Peru’, Lamas (1995), Seitz (1940), Miller (1986), ‘Surinam’, Lamas (1995) and ‘Venezuela’ Miller (1986).

Potential model, *Papilio zagreus* / mimic, *Zegara* (as *Gazera* [*Zegara*]) *zagraea*.

Family Pieridae:

Subfamily Dismorphiinae: (subfamily not listed).

Potential model, *Dismorphia crisia foedora* / mimic, *Haemonides cronis*.

The author has noted that the striking similarity between *Patia* (*Dismorphia*) *orise* and *Gazera heliconioides* may indicate that *P. orise* is also involved in the same mimicry complex as *G. heliconioides*, either as a Batesian mimic or a Mullerian mimic. Further, the distributions of these two species overlap throughout a substantial area. Smart (1977) states that *Patia* (as *Dismorphia*) *orise* occurs in ‘Guyana’ while Lewis (1985) notes that it occurs in ‘Guianas, Bolivia’. It also occurs in Peru (M. F. Braby pers. comm. 2002).

Subfamily Pierinae (subfamily not listed):

Potential model, *Perrhybris* (miss-spelt *Perhybris*) *lorena jumena* / mimics, *Haemonides cronida*, *H. cronis*.

Potential model, *Perrhybris* (miss-spelt *Perhybris*) sp. / mimic, *Haemonides cronis*.

Family Nymphalidae:
Subfamily Acraeinae:
Potential model, *Actinote parapheles* / mimic, *Riechia acraeoides*.
Potential model, *Actinote pellenea* / mimic, *Riechia acraeoides*.
Subfamily Danainae (as family Danaidae):
Potential model, *Ituna ilione ilione* / mimics, *Gazera heliconioides*, *G. heliconioides obidona* (as *Gazera peruviana*).
Subfamily Heliconiinae (as family Heliconiidae):
Potential model, *Heliconius ethilla thielei* (miss-spelt *thieli*) / mimics, *Duboisvalia ecuadoria pellonia* (as *Gazera* [*Boisduvalia*] *pellonia*), *Duboisvalia* (as *Gazera* [*Duboisvalia*]) *simulans*.
Potential model, *Heliconius ismenius ismenius* / mimic, *Zegara zagraea zegraea* (as *Gazera* [*Daguana*] *columbina*).
Potential model, *Heliconius numata aulicus* / mimics, *Duboisvalia ecuadoria pellonia* (as *Gazera* [*Boisduvalia*] *pellonia*), *Duboisvalia cononia duckei* (as *Gazera* [*Duboisvalia*] *duckei*).
Subfamily Ithomiinae (as family Ithomiidae):
Potential model, *Hyposcada fallax* / mimic, *Duboisvalia ecuadoria pellonia* (as *Gazera* [*Boisduvalia*] *pellonia*).
Potential model, *Mechanitis egaensis* / mimic, *Duboisvalia* (as *Gazera* [*Duboisvalia*]) spp.
Potential model, *Melinaea ethra parallelis* / mimic, *Zegara zagraea zagraea* (as *Gazera* [*Daguana*] *columbina*).
Potential model, *Melinaea marsaeus messenina /* mimic, *Duboisvalia ecuadoria pellonia* (as *Gazera* [*Boisduvalia*] *pellonia*).
Potential model, *Melinaea mneme* / mimic, *Duboisvalia ecuadoria pellonia* (as *Gazera* [*Boisduvalia*] *pellonia*).
Potential model, *Thyridia ceto* / mimics, *Gazera heliconioides*, *G. heliconioides obidona* (as *Gazera peruviana*).
Potential model, *Thyridia hippodamia cetoides* / mimic, *Gazera heliconioides obidona* (as *Gazera peruviana*).
Subfamily Satyrinae (as family Satyridae):
Potential model, *Taygetus* sp. / mimic, *Ceretes marcelserres*.
Family Lycaenidae:
Subfamily Theclinae (subfamily not listed):
Potential model, *Eumaeus minyas* / mimic, *Castnius eumaeus* (Although Miller [1986] described this ‘distinctive’ and ‘unique’ taxon from a single female, the name *eumaeus* was not applied to any of the species or subspecies in the genus *Castnius* by Lamas [1995]. For this reason the name *Castnius eumaeus* is used here very tentatively).
Subfamily Riodininae (as family Riodinidae):
Potential model, *Xenandra pelopia* / mimic, *Oiticicastnia* (as *Cyerina*) *erycina*.
Family ?Aganaidae (as family Hypsidae):
Common (1990) states that the family Aganaidae ‘is widely distributed in the Ethiopian, Oriental and Australian regions’ but does not say that this family occurs in the Neotropical region. For this reason it seems that the two species which Miller (1986)

assigned to the family ?Aganaidae (as Hypsidae) may correctly belong in the family Arctiidae.

Subfamily/ies (subfamily/ies not listed):

Potential model, *Anthomyza heliconides* / mimic, *Gazera heliconioides obidona* (as *Gazera peruviana*).

Potential model, *Chetone angulosa* / mimic, *Zegara zagraea zagraea* (as *Gazera* [*Daguana*] *columbina*).

Family Arctiidae:

Subfamily Pericopinae (as family Pericopidae):

Potential model/s, ?*Preicopis* sp/p. (genera not listed) / mimics, *Castnius* spp.

Smart (1977) mentions that *Pericopis hydra* is thought to be involved in a mimetic relationship with *Haemonides candida houlbertina* (as *Castnia strandi*), while Miller (1986) simply states that the subfamily Pericopinae (as family Pericopidae) contains potential models that may be mimicked by *Castnius* spp. Miller (1986) also notes that the family Arctiidae (as distinct from the subfamily Pericopinae) contains potential models for mimicry in the Castniini, but does not list any of the genera involved as models and/or mimics.

Subfamily/ies (subfamily/ies not listed):

Potential model/s, (genera not listed) / mimic/s (genera not listed).

Family Noctuidae:

Subfamily Agaristinae:

Potential model/s, (genera not listed) / mimics, *Castnius* spp.

Subfamily/ies (subfamily/ies not listed):

Potential model/s, (genera not listed) / mimics, *Amuata* spp., *Corybantes* spp., *Eupalamides* spp.

Miller (1986) indicated that the family Noctuidae (as distinct from the subfamily Agaristinae) contains some species that are thought to be involved in mimetic associations with the three above-mentioned genera of the Castniini. Although Miller (1986) does not list any subfamily/ies here, it appears that outside the subfamily Agaristinae, the Catocalinae would be the most likely subfamily of the Noctuidae to contain models for (?Batesian) mimicry in the Castniini. This assumption is based on the adult morphology and colouration of many Catocalinae, which to some extent resembles the genera of the Castniini that Miller (1986) alludes to in this context.

At least some of the mimetic Castniini have also evolved behaviour patterns that enhance the resemblance they bear to their distasteful models. Miller (1986) states the following in regard to the behavioural resemblance of '*Gazera*' spp. to their distasteful *Heliconius* models: 'Individuals of *Gazera* (*Duboisvalia*) land on bushes in the forest understory, and with the wings upright, gently move the wings together over the thorax similar to many species of *Heliconius*. The wings are then extended outward several times prior to settling down in the typical stegopterous position of the neotropical Castniinae'.

Possible mimicry in the tribe Synemonini of the subfamily Castniinae.

Dunn (1996) suggests that *Synemon laeta* may 'partially' mimic two other similarly coloured diurnal lepidopterans with which it often flies. These are *Vanessa kershawi*

(Australian Painted Lady, family Nymphalidae) and *Trapezites eliena* (Eliena Skipper or Orange Ochre, family Hesperiidae). Although further observations of *S. laeta* are required to fully determine if it has a mimetic relationship with either of these two species, the preliminary observations that were made by Dunn (1996) are repeated here. ‘On the wing, the bright black and orange hindwing coloring, and their rapid flight presented a striking resemblance to *V. kershawi* with which they flew during December. The trapezitine skipper present in autumn also has similar coloring to the hindwing, is a rapid flier, and like *S. laeta* settles on *Lomandra*, its larval host. Although circumstantial, both broods of the sun moth flew in company with an abundant and similar colored lepidopteran, the autumn brood being associated with a species of similar behaviour. Perhaps the coloring of the *S. laeta* hindwing is aposematic and the moth partially mimics these diurnal species?’

Possible mimicry in the subfamily Tascininae.

Holloway (1998) mentions that the collector (C. J. Brooks), of the only known specimen of an undescribed species of *Tascina* from Sumatra, had attached a label to the specimen saying that ‘it resembled a skipper butterfly in flight and was originally mistaken for such’.

The author has also noted that there is a superficial similarity of colouration and markings between the *Tascina* spp. and some of the skipper butterflies (family Hesperiidae), belonging to the subfamilies Coeliadinae and Pyrginae, known as awls and flats respectively. This may indicate that certain species of awls and/or flats could be potential models for (?Batesian) mimicry in the Tascininae. As some of the species in these two subfamilies of the Hesperiidae are entirely or semi-crepuscular, it also seems possible that some or perhaps all of the *Tascina* spp. fly mainly at dawn and/or dusk as well. While several males of *T. metallica* (that are alluded to earlier in this chapter) have recently been observed whilst flying in the late afternoon, no conspecific females were collected or even seen at this time of the day (B. Malangis pers. comm. 2005). This suggests that the females of this species don’t start to fly until the onset of evening. Curiously, after obtaining some male specimens of *T. metallica* it was noticed that these had exceptionally large eyes in comparison to all the males of many studied species of South American and Australian Castniidae. It appears that the especially large eyes of the males of *T. metallica* may be a special adaptation to aid the location and pursuit of females in twilight conditions. Perhaps the scarcity of all the *Tascina* spp. in collections can at least be partly attributed to such behaviour.

The resemblance of the *Tascina* spp. to some of the large skipper butterflies in the subfamily Coeliadinae could be enhanced by a resting position that the *Tascina* spp. may assume in certain circumstances. This is suggested because the characteristic colouration of the forewing and hindwing undersides of the *Tascina* spp. is very similar to many coeliadine skipper butterflies. In particular, the apices of the forewing undersides and all or most of the hindwing undersides are inconspicuously coloured in shades of brownish-black or rusty brown. This type of colouration is most unusual in the Castniidae and suggests that the *Tascina* spp. may sometimes adopt a butterfly-like resting position, i.e.

with the upper surfaces of the wings pressed together above the body. If the *Tascina* spp. were to assume this resting position, especially with the forewings lowered between the hindwings so that all but their apices were concealed, then as in many similarly coloured skipper butterflies, only the cryptically coloured areas of the forewing and hindwing undersides would be visible. The most likely situation for such a resting position to be adopted by the *Tascina* spp. would be by both sexes during long periods of inactivity or by ovipositing females. At such times a convincing resemblance to the difficult to catch and fast flying skipper butterflies and/or concealment from predators, would doubtless increase their chances of survival. While such a butterfly-like resting position is unusual in the Castniidae, it occurs commonly in the Hesperiidae, including the subfamily Coeliadinae, but curiously not in the subfamily Pyrginae, which usually rest with the wings spread open and more or less orientated towards the substrate.

Parthenogenesis in Castniidae

Refer to Chapter 3 of Part 3 for a detailed account of how it was determined by the author that the Victorian morphs of *Synemon selene* (Pale Sun-moth) are parthenogenetic.

Illustration

Figure 1. ***Gazera heliconioides,*** **a typical example of a mimetic sun-moth in the tribe Castniini of the subfamily Castniinae. This South American species is involved in a very complex mimicry ring that includes a number of Batesian and/or Mullerian mimics in the families Papilionidae, Pieridae, Nymphalidae and ?Arctiidae. Scale bar = centimetres.**

Part 1

Chapter 3

The Origin and Distribution of the World's Sun-moths

Introduction

The following chapter provides an overview of the known distribution of the world's sun-moths (family Castniidae). This is considered in the light of geological events that are thought to have taken place in the Southern Hemisphere during and since the Cretaceous period, from approximately 130 million years ago. The connection is made so that possible origins (from a biogeographical point of view) of the family Castniidae can be proposed, and some idea can be gained of the likely antiquity of this Lepidopteran family. For reference purposes an outline of the current world distribution of the subfamilies and genera of the Castniidae is also given. This includes listings of the number of known species that each genus contains.

The origin of the world's sun-moths

It is now widely accepted that the sun-moths (family Castniidae) probably have a Gondwanan origin, as they are represented in the faunas of the Oriental, Australian and Neotropical regions (Common 1990, Edwards *et al*. 1999). The Castniidae appear to be absent from Africa, as no species have been discovered there to date. This may be an indication that they had not yet evolved when Africa rifted from Gondwana, an event that is thought to have occurred during the early Cretaceous period, approximately 130 million years ago (Braby *et al*. 2005).

Alternatively, the Castniidae may have already been present in Gondwana when the separation of Africa occurred, but were not widely distributed. If this was the case, it is possible that ancestral stocks of Castniidae did not occur on the portion of Gondwana that eventually became Africa. Or, if they were present, perhaps they did not adapt to subsequent climatic and ecological changes that may have taken place in Africa as it moved northward, and became extinct as a result. It also seems possible that there could be one or more extant species of Castniidae in Africa that still await discovery.

The possibility that the Castniidae were already present in Gondwana by the time that India rifted from its coastline, approximately 120 million years ago (White 1994), is raised by the presence of the subfamily Tascininae in south-eastern Asia. It seems that the ancestors of this subfamily may have travelled northwards on the Indian terrane and then dispersed into south-east Asia after India collided with Asia during the early Tertiary period, approximately 45 to 50 million years ago (White 1994). After this subfamily of the Castniidae had dispersed into south-east Asia it seems to have died out in India, as there are no known species that occur there. However, the absence of any Castniidae in India could indicate that the ancestor/s of the Tascininae arrived in south-east Asia by travelling on a smaller Gondwanan terrane. This might have been derived from the northern edge of the Australian tectonic plate, as a fragment of north-western Australia or western New Guinea (Irian Jaya), which drifted ahead of Australia before colliding directly with a part of south-eastern Asia.

All of the known Castniidae that occur in Australia (tribe Synemonini) and the Neotropical area (tribe Castniini) are placed together in the subfamily Castniinae. As their current classification implies, the Australian and Neotropical stocks of Castniidae are considered to be more closely related to each other than either one of them is to the Tascininae (Holloway & Hall 1998). Conceivably, the tribes Synemonini and Castniini could have diverged (as a consequence of vicariance) well after some stock of an earlier common ancestor that they share with the Tascininae had already been separated from Gondwana, on a north bound terrane. Refer to the appendix to this chapter for a flow chart that summarises the possible origin and present world distribution of the family Castniidae, as a hypothetical phylogeny.

Distribution and genera of the world's sun-moths

Family: Castniidae.

Subfamily: Tascininae.

Genus: *Tascina* Westwood, 1877. According to Fukuda (2000) there are five known species in the genus *Tascina*, one of which is undescribed. However, it is possible that the population of *Tascina metallica* Pagenstecher, 1890, that occurs in Sarawak and Kalimantan on the Indonesian island of Borneo may represent another undescribed species. This hypothesis is based on the distinctive markings and morphology of one of the only two known specimens of *T.* ?*metallica* from Borneo that is figured in Holloway (1998). When this (male) specimen was compared with seven males from Palawan Island, Philippines (the type locality of *T. metallica*), it was apparent that it differed from the specimens from Palawan Island in the following ways. The apex of the most complete forewing (though slightly damaged), appears to be more rounded and not weakly falcate, while the termen of the hindwing is less rounded. The white band on the upperside of the forewing is straighter, is not constricted just before it reaches the tornus and is a little broader. The dorsal surface of the abdomen appears to be a much darker shade of blue. It is a larger taxon, with a wingspan of approx. 8.9 cm., while the males from Palawan Island have an average wingspan of about 6.5 cm.

The genus *Tascina* has a disjunct distribution in south-east Asia. It occurs in Singapore, the Philippines (Palawan Island only), Myanmar (Burma), Malaysia, Indonesia (Sumatra and Borneo) and Vietnam. The information on the distribution of this genus was obtained from Fukuda (2000), Edwards *et al*. (1999) and Holloway (1998). Apparently, all of the

Tascina species are exceptionally rare in collections. The small amount of available information on their biology suggests that they occur in the canopy layer of rainforest habitats.

Subfamily: Castniinae.

Tribe: Synemonini.

Genus: *Synemon* Doubleday, 1846. The genus *Synemon* contains 24 described and 20 undescribed species (E. D. Edwards pers. comm. 2003). Species of *Synemon* are found in all the mainland states of Australia and also on Kangaroo Island, with the highest degree of species diversity occurring in Western Australia. To date, no species of *Synemon* have been discovered in Tasmania, New Guinea or New Zealand. *Synemon* species occur in a wide range of habitat types, which include woodlands, heathlands and native perennial grasslands.

Tribe: Castniini. This arrangement of the Neotropical castniine genera, and the number of species that are included in each genus, follows Lamas (1995). The accompanying information on the distribution of each genus was also extracted from Lamas (1995). Many genera of this tribe occur in rainforest habitats where some are noted for their involvement in complex ‘mimicry rings’ with other families of diurnal Lepidoptera.

Genus: *Eupalamides* Hubner (1819). This genus contains five species and occurs in Bolivia, Guyana, Surinam, Brazil, French Guiana and Peru.

Genus: *Amuata* Houlbert, 1918. A genus containing four species that occurs in Ecuador, Colombia, Peru, Bolivia, Panama and Mexico.

Genus: *Lapaeumides* Oiticica, 1955. This genus contains three species that seem to be confined to Brazil.

Genus: *Corybantes* Hubner (1819). This genus contains four species and occurs in Ecuador, Brazil, Peru, Surinam, Colombia and Panama.

Genus: *Athis* Hubner (1819). A large genus of fourteen species that occurs in Brazil, Colombia, Mexico, Panama, Peru, Ecuador, Honduras, Surinam, Venezuela, Trinidad and French Guiana.

Genus: *Hista* Oiticica, 1955. This genus appears to be confined to Brazil and contains two species.

Genus: *Yagra* Oiticica, 1955. Another genus that seems to be confined to Brazil and contains two species.

Genus: *Imara* Houlbert, 1918. A genus of two species that occurs in Brazil, Paraguay and Uruguay.

Genus: *Synpalamides* Hubner (1823). This genus contains five species and occurs in Mexico, Brazil and Paraguay.

Genus: *Feschaeria* Oiticica, 1955. A monotypic genus that is known from Guyana and Brazil.

Genus: *Spilopastes* Houlbert, 1918. A monotypic genus that is confined to Brazil.

Genus: *Ircila* Houlbert, 1918. Another monotypic genus. It occurs in Haiti.

Genus: *Haemonides* Hubner (1819). This genus includes three species and occurs in Peru, Guyana, Surinam, Brazil and Trinidad.

Genus: *Castnia* Fabricius 1807. A widespread genus that contains six species. It occurs in Mexico, Venezuela, Chile, Brazil, Paraguay, Bolivia, Surinam, Trinidad and Argentina.

Genus: *Castniomera* Houlbert, 1918. This monotypic genus occurs in Mexico, Panama, Nicaragua, French Guiana, Costa Rica, Brazil, Honduras, Colombia and Ecuador.

Genus: *Telchin* Hubner (1825). A monotypic genus that occurs in the following ten countries: Brazil, Colombia, Trinidad, Peru, French Guiana, Surinam, Guyana, Nicaragua, Bolivia and Ecuador.

Genus: *Erythrocastnia* Houlbert, 1918. This monotypic genus occurs in Surinam, French Guiana and Brazil.

Genus: *Xanthocastnia* Houlbert, 1918. A monotypic genus that occurs in Surinam, French Guiana, Brazil, Bolivia, Ecuador, Peru, Colombia, Costa Rica and Mexico.

Genus: *Geyeria* Buchecker (1880). This genus contains three species and occurs in Brazil, Uruguay and Argentina.

Genus: *Riechia* Oiticica, 1955. This monotypic genus occurs in Brazil and Argentina.

Genus: *Tosxampila* Oiticica, 1955. A genus that contains two species and is confined to Brazil.

Genus: *Castnius* Hubner (1819). This genus contains two species and occurs in Peru, Surinam and Brazil.

Genus: *Prometheus* Hubner (1824). This monotypic genus is restricted to Brazil.

Genus: *Cretes* Schaufuss, 1870. A genus containing two species that is restricted to Brazil.

Genus: *Divana* J. Y. Miller, 1982. This monotypic genus occurs in Panama, Nicaragua and Colombia.

Genus: *Gazera* Herrich-Schaffer (1853). A monotypic genus that occurs in Brazil, Peru, Surinam, Guyana, French Guiana and Paraguay.

Genus: *Duboisvalia* Oiticica, 1955. This genus contains three species and occurs in Ecuador, Colombia, Peru, Brazil, Bolivia and Venezuela.

Genus: *Zegara* Oiticica 1955. This genus contains two species and occurs in Ecuador, Colombia, Costa Rica and Panama.

Genus: *Mirocastnia* J. Y. Miller, 1980. A genus containing three species that occurs in Peru, Ecuador and Panama.

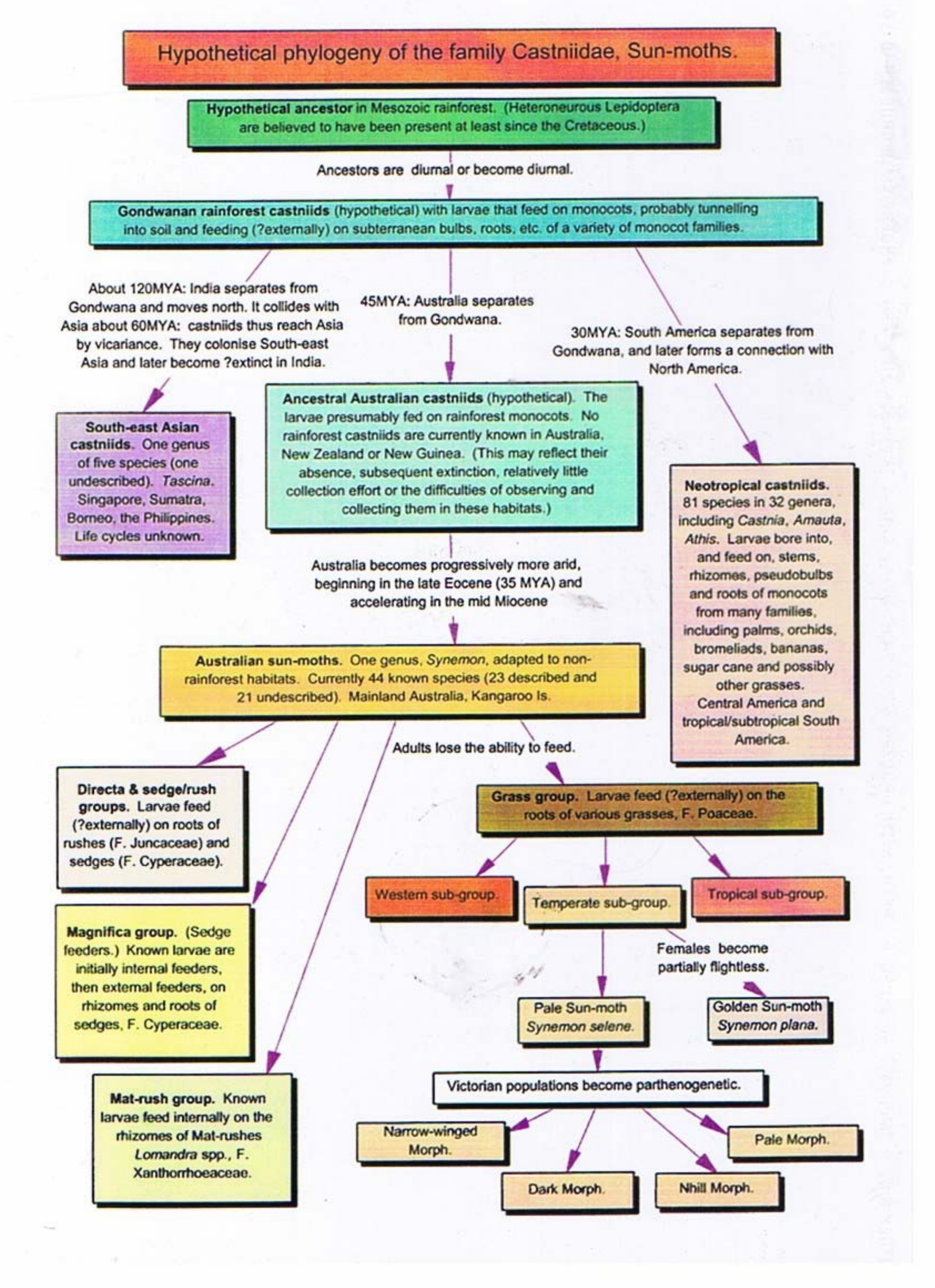
Genus: *Frostetola* Oiticica, 1955. This monotypic genus is confined to Brazil.

Genus: *Oiticicastnia* Lamas, 1995. A monotypic genus that is confined to Ecuador.

Genus: *Paysandisia* Houlbert, 1918. This monotypic genus occurs in Uruguay and Argentina.

Appendix

Appendix 1. Flow chart that summarizes the possible origin and present world distribution of the family Castniidae, as a hypothetical phylogeny (prepared by Dr G. Ambrose and the author).



Hypothetical phylogeny of the family Castniidae, Sun-moths.

Hypothetical ancestor in Mesozoic rainforest. (Heteroneurous Lepidoptera are believed to have been present at least since the Cretaceous.)

Ancestors are diurnal or become diurnal.

Gondwanan rainforest castniids (hypothetical) with larvae that feed on monocots, probably tunnelling into soil and feeding (?externally) on subterranean bulbs, roots, etc. of a variety of monocot families.

About 120MYA: India separates from Gondwana and moves north. It collides with Asia about 60MYA: castniids thus reach Asia by vicariance. They colonise South-east Asia and later become ?extinct in India.

South-east Asian castniids. One genus of five species (one undescribed). *Tascina*. Singapore, Sumatra, Borneo, the Philippines. Life cycles unknown.

45MYA: Australia separates from Gondwana.

Ancestral Australian castniids (hypothetical). The larvae presumably fed on rainforest monocots. No rainforest castniids are currently known in Australia, New Zealand or New Guinea. (This may reflect their absence, subsequent extinction, relatively little collection effort or the difficulties of observing and collecting them in these habitats.)

Australia becomes progressively more arid, beginning in the late Eocene (35 MYA) and accelerating in the mid Miocene

Australian sun-moths. One genus, *Synemon*, adapted to non-rainforest habitats. Currently 44 known species (23 described and 21 undescribed). Mainland Australia, Kangaroo Is.

30MYA: South America separates from Gondwana, and later forms a connection with North America.

Neotropical castniids. 81 species in 32 genera, including *Castnia*, *Amauta*, *Athis*. Larvae bore into, and feed on, stems, rhizomes, pseudobulbs and roots of monocots from many families, including palms, orchids, bromeliads, bananas, sugar cane and possibly other grasses. Central America and tropical/subtropical South America.

Directa & sedge/rush groups. Larvae feed (?externally) on roots of rushes (F. Juncaceae) and sedges (F. Cyperaceae).

Magnifica group. (Sedge feeders.) Known larvae are initially internal feeders, then external feeders, on rhizomes and roots of sedges, F. Cyperaceae.

Mat-rush group. Known larvae feed internally on the rhizomes of Mat-rushes *Lomandra* spp., F. Xanthorrhoeaceae.

Adults lose the ability to feed.

Grass group. Larvae feed (?externally) on the roots of various grasses, F. Poaceae.

Western sub-group.

Temperate sub-group.

Tropical sub-group.

Females become partially flightless.

Pale Sun-moth *Synemon selene*.

Golden Sun-moth *Synemon plana*.

Victorian populations become parthenogenetic.

Narrow-winged Morph.

Dark Morph.

Nhill Morph.

Pale Morph.

Part 1

Chapter 4

Ability of Australian Sun-moths to Survive Fire

Introduction

All of the grassland, woodland and heathland habitats in which the Australian *Synemon* species occur are subject to fires during the drier months. Whether the fires are at ground level or reach the canopy, they usually incinerate the foliage and rhizomes or tillers of the larval host plants of *Synemon* spp. Although some fires leave a mosaic of burnt and unburnt areas, the chances of an entire habitat remnant being burnt out are more likely if it is small or infested with exotic annual grasses and forbs that dry out and desiccate over summer. While many *Synemon* spp. appear to be fire adapted, having subterranean early stages, a few others have larvae that feed within the above ground level rhizomes of their respective larval host plants. With all else being equal, the latter species would be expected to be much more vulnerable to fire, given that the fire season would always coincide with two or more generations of their larvae and/or pupae. This is suspected because of the likely two to three year life cycles of all the *Synemon* spp. The following account is necessarily anecdotal, given the unpredictability of fire and its scarcity in sun-moth sites during the research phase of this work. However, an impression is given of how two of the (?fire adapted) *Synemon* spp. responded to a fire event.

This opportunity to observe how two of the Australian *Synemon* spp. are effected by fire occurred during October 1998. The species in question were the Small Orange-spotted Sun-moth (*Synemon discalis*) and the Orange-spotted Sun-moth (*S. parthenoides*). This situation arose directly after an area where these two species occur sympatrically in the Victorian Big Desert was completely burnt out by an uncontrolled bushfire. The locality where this took place is in the south-eastern Big Desert, on the western side of Chinaman's Well Track, 0.6 km NNW of its junction with the Netting Fence Road. This is approximately 28.5 km WSW of Rainbow, in north-western Victoria. The area was burnt on 17 October, just prior to the adult flight periods of both of these species.

Following this event, the site was visited on several occasions so that data could be collected on various aspects of the post-fire behaviour of the adults. The relative abundance of adults of both species was also recorded, so that a comparison could be made with data collected during the previous and subsequent adult flight periods of 1997 and 1999. The above-mentioned fire was particularly intense, with no living vegetation above ground level being left unburned, or at least uncharred. The habitat within the area is a largely treeless, low growing heathland that contains a sedge dominated, species-rich community of dicotyledonous and monocotyledonous plants. To the author's knowledge, this is the first time that the response of any *Synemon* spp. to fire has been observed in the field and then documented.

Impact of fire on larval host plants

There is strong circumstantial evidence to suggest that in the Big Desert the main larval host plants of *Synemon discalis* and *S. parthenoides* are, respectively, Desert Saw-sedge (*Gahnia lanigera*) and Black Rapier-sedge (*Lepidosperma carphoides*), both perennial tufted sedges, belonging to the family Cyperaceae. Shortly after the fire it was noted that all plants of both species had been burnt to such an extent that only low hummocks of charred leaf bases were left standing. It seemed that accumulated sand around the bases of these plants had protected their rhizomes and roots to some extent.

The recovery of *L. carphoides* was particularly rapid, with a substantial amount of new foliage resprouting from the rootstock within 29 days. By this time the plants of *G. lanigera* were also starting to produce new growth in this manner. However, the recovery of this species was slower, with all of the plants only having a very sparse covering of foliage. When the area was visited a year later it was found that all of the plants of both species had a normal amount of foliage, with many of the *G. lanigera* plants carrying an abundance of seed heads.

Numbers of *Synemon* adults recorded after the fire

Although there was an apparent decline in the number of *Synemon discalis* adults that emerged during the adult flight period that immediately followed the fire, some were recorded. However, it appeared that there was no reduction in the number of *S. parthenoides* that emerged at the site during this time (Table 4.1). This is surprising, given that local populations of almost all of the other lepidopteran families would be largely decimated by fire. It thus becomes apparent that these two species are well adapted to survive their habitats being burnt. This ability to survive fire can not only be attributed to their subterranean early stages but also to the likelihood that their life cycles take two to three years to complete, which means that a significant proportion of their populations would probably be underground at all times. All of the adults (of both spp.) that were recorded at the SE Big Desert site during the 1998 flight period would probably have emerged within the area that had been burnt out. This seemed likely because there were no adjacent areas of suitable habitat for these two species that had not been burnt. Also, when the site was visited on 16 November (30 days after the fire) a number of pupal exuviae of *Synemon* ?*parthenoides* were found protruding from the ground near recovering Black Rapier-sedge plants. It is noteworthy that all of these highly combustible pupal exuviae were located within the formerly burned area. This is conclusive evidence that occurrences of the *Synemon* spp. that have subterranean early stages are able to survive the areas that they occupy being burnt. However, it is also apparent that other factors such as parasitoides and below average annual rainfall could cause the numbers of any *Synemon* spp. to fluctuate at a given site from year to year.

Table 4.1. Numbers of *Synemon discalis* and *S. parthenoides* adults observed prior to and following a bushfire that completely burned through their habitat in the area surrounding the southern end of the Chinaman's Well Track, SE Big Desert, Victoria

Day	**Month**	**Year**	***Synemon discalis***	***Synemon parthenoides***
30	Oct.	1997	1 female.	1 male.
3	Nov.	1997	1 male & 1 female.	>40 males & 2 females.
4	Nov.	1997	2 females.	>10 males & 2 females.
5	Nov.	1997	>10 males & 6 females.	>10 males & 1 female.
19	Nov.	1997	1 male & 1 female.	>10 males & 8 females.
21	Nov.	1997	1 male.	>10 males & 9 females.
17	**Oct.**	**1998**	**Site burnt out by wildfire.**	
1	Nov.	1998	None recorded.	>40 males & >10 females.
3	Nov.	1998	1 female.	9 males & 4 females.
9	Nov.	1998	1 male & 2 females.	>40 males & >40 females.
15	Nov.	1998	None recorded.	>10 males & >10 females.
16	Nov.	1998	1 female.	>10 males & >10 females.
23	Nov.	1998	None recorded.	>10 males & 6 females.
31	Oct.	1999	2 males & 8 females.	9 males & 8 females.
12	Nov.	1999	1 male & 1 female.	>10 males & >10 females.

Semi-scaleless condition of some adults that emerged after the fire

Throughout the adult flight period that followed the fire, it was found that about 20% of the adult *S. parthenoides* had one or both of the forewing uppersides largely devoid of scales. A similar semi-scaleless condition was also noticed on the forewing uppersides of one of the specimens of *S. discalis* that was recorded after the fire. As it is the forewing uppersides that face outwards through the pupal cuticle, it seemed that this semi-scaleless state might have been brought about by the pupae being exposed to higher than normal temperatures for a brief period during the fire. This is especially likely to have taken place while the wing scales of the adults in question were developing. Although this speculation is based on circumstantial evidence, it is significant that the author has not observed adult sun-moths in this condition at any other time.

Post-fire mate location and mating behavior

When the burnt area was visited on 16 November (30 days after the fire) only one recently emerged female of *S. discalis* could be located. At the same time there were about ten males and ten females of *S. parthenoides* flying around the site. On two separate occasions the female *S. discalis* was closely followed by a courting male *S.*

parthenoides. In both instances this courtship flight culminated in the female *S. discalis* landing on a roughly vertical stick with its head orientated upwards, while the male *S. parthenoides* landed just below it and then walked upwards while curving the posterior end of its abdomen forward and trying to mate. It was observed that both of the male *S. parthenoides* made repeated but unsuccessful attempts to link their genitalia with the female *S. discalis* before finally flying away.

It seems that the comparatively lower number of *S. discalis* that emerged after the fire caused this unusual interaction to take place between this species and *S. parthenoides*. There is little doubt that under normal circumstances the female *S. discalis* would have been quickly found and mated with by a passing male of her own species. This is suspected because while searching for potential mates, the males of *S. discalis* seem to fly more rapidly than the males of *S. parthenoides*. However, these observations are an indication that differences in genitalic structure between these two species may be all that prevents them from occasionally hybridizing. Further, this incident implies that the males of *S. parthenoides* could largely use visual cues as a primary means of mate location and may not entirely rely on pheromones to identify a potential mate. An alternative explanation is that the females of these two (presumably closely related) species attract their mates with very similar pheromones.

When courted by (conspecific) males, receptive females of *S. parthenoides* were not always able to find a more or less vertical stick on which to land while mating took place. This was because much of the upright vegetation in the area had been burnt away. The lack of suitable mating sites caused some of the females to behave unusually by landing on the ground to mate instead of selecting a higher and possibly safer situation for this purpose, where attack by terrestrial predators such as ants would be less likely to occur.

Post-fire larval host plant selection by ovipositing females

At 23 days after the fire, it was noted that ovipositing females of *S. parthenoides* could recognize recovering plants of *Lepidosperma carphoides* that had only just begun to grow new foliage. It seemed that a very small amount of new growth was all that was needed for these plants to be selected as potential larval hosts. In some instances, females of this species were seen ovipositing at the base of plants that had only regrown their leaves to a height of approximately 4 to 5 cm. This contrasted sharply with the behavior of the few ovipositing females of *S. discalis* that were located during the weeks that followed the fire. The *S. discalis* females appeared to be hampered in their selection of the correct species of larval host by the recently burnt condition and very sparse new growth of the *Gahnia lanigera* plants. They seemed reluctant to oviposit and on a few occasions were observed ovipositing at the base of *L. carphoides* as well as *G. lanigera*. In many cases the *G. lanigera* plants were recovering so slowly and had such a small amount of foliage that they may not have been recognized as living larval host plants. At times, this situation probably induced the *S. discalis* females to oviposit at the base of the more rapidly recovering, though possibly unsuitable, plants of *L. carphoides*.

Discussion

The observations described in this chapter have shown that the population densities and sex ratios of the two species monitored (in the SE Big Desert) did not appear to be substantially effected by the fire. However, the resultant injuries (indicated by the semi-scaleless condition of some adults), courtship difficulties and the temporary loss mating and oviposition sites could conceivably lead to a population decline of both of the species in future years. The two site visits during the following year (1999) suggest that this is not so, but they represent a small and incomplete sample of adult flight period data. However, the likelihood of a two to three year long life cycle in the *Synemon* spp. would probably reduce the overall negative impact that a fire would have on the numbers of adults that emerged during any one of the three subsequent (annual) adult flight periods. Any future opportunities to document the post-fire responses of sun-moth populations and compare these with populations of the same species at unburnt sites should be taken up. This would enable recommendations to be developed regarding the potential use of control burning and/or the exclusion of fire from sun-moth sites as management strategies.

Of the eight species of sun-moths that occur in Victoria, it is probable that only one would be prone to local extinctions as a result of bush fires. This species is the Reddish-orange Sun-moth (*Synemon jcaria*). This is because its larvae feed internally on the rhizomes of Scented Mat-rush (*Lomandra effusa*), Lomandraceae. As the greater portion of these rhizomes project above the soil surface, it is almost certain that the ova, larvae and/or pupae of *S. jcaria* would be destroyed in the event of its larval host plants being burnt. However, it is also possible that under some circumstances, the larvae or pupae (being mobile within their galleries) would be able to survive a comparatively less intense fire by retreating downwards into the partly buried sections of the rhizomes. This is suspected because *Lomandra* spp. are known to be capable of recovery after fire, by regrowing from nodes that are situated at the bases of their rhizomes, i.e. that the heat from a fire is not always sufficient to kill an established plant (pers. obs. 1998 to 1999). The apparent vulnerability of *S. jcaria* to fires may partly explain why it seems to have such a disjunct and local distribution in Victoria. At present, nothing is known about how long it takes populations of this species to recover after fire or, to recolonise formerly occupied areas of suitable habitat that have been burnt out.

However, it seems likely that most of the Australian sun-moths would be well adapted to survive their habitats and larval host plants being burnt. This could be reasonably supposed because, like the two spp. observed, the majority of the Australian species have subterranean larval and pupal stages and utilize deep-rooted perennials as larval host plants. Plants of this type are also adapted to survive bush fires and may even benefit from periodic burning, which converts dead plant material to a fertile bed of ash (Lunt 1997).

Illustrations

The following photographs were taken at the above-mentioned locality in the south-eastern Big Desert, Victoria. It is the only known area where the Small Orange Spotted Sun-moth (*Synemon discalis*) and the Orange-spotted Sun-moth (*S. parthenoides*) occur sympatrically.

Figure 1. Appearance of the site on 21 November 1989 (prior to the fire). Note the dark coloured plants of *Gahnia lanigera* and *Lepidosperma carphoides* in the foreground. These are the suspected larval host plants of *Synemon discalis* and *S. parthenoides* respectively.

Figure 2. Appearance of the site on 24 October 1998 (seven days after it was burnt).

Figure 3. Burnt plants of *Gahnia lanigera* and *Lepidosperma carphoides* (seven days after the fire). Plant of *G*. *lanigera* is on the left.

Figure 4. Empty pupal casing of *Synemon parthenoides* (30 days after the fire).

Figure 5. Recently emerged male of *Synemon parthenoides*, showing a largely scaleless condition on the right forewing upperside (29 days after the fire).

Figure 6. Recently emerged female of *Synemon discalis*, exhibiting a semi-scaleless condition on the uppersides of the forewings (17 days after the fire).

Figure 7. Pair of *Synemon parthenoides* atypically mating on the ground (30 days after the fire).

Figure 8. Male *Synemon parthenoides* attempting to mate with a recently emerged female *S. discalis* (30 days after the fire). Male on left (note its semi-scaleless forewing upperside).

Figure 9. Appearance of the site at 29 days after the fire.

Figure 10. Recovering plant of *Gahnia lanigera* (29 days after the fire).

Figure 11. Recovering plant of *Lepidosperma carphoides* (29 days after the fire).

Figure 12. Female *Synemon parthenoides* ovipositing at the base of a recovering plant of *Lepidosperma carphoides* (29 days after the fire).

Figure 13. Appearance of the site at one year after the fire.

Figure 14. Recovered plant of *Gahnia lanigera* (one year after the fire).

Figure 15. Recovered plant of *Lepidosperma carphoides* (one year after the fire).

Part 2:

The Identification, Distribution, Biology and Conservation of the Victorian Sun-moths

Part 2

Chapter 1

Descriptions of the Victorian Sun-moths (*Synemon* spp.)

Introduction

All of the sun-moth species that occur in Victoria were described between 1846 and 1911. As some of these descriptions are difficult to obtain and possibly ambiguous, it was deemed necessary to include detailed descriptions of the wing surfaces of the eight Victorian species in this work. When these descriptions are cross-referenced to the following illustrations, the identification of any of these species should be relatively easy. For descriptions and illustrations of the six morphs of the Pale Sun-moth (*Synemon selene*) see Part 3, Chapter 1.

General description of Australian sun-moths

The known Australian sun-moths (family Castniidae) are all placed in the genus *Synemon* Doubleday, 1846. This genus contains 24 described and 20 undescribed species (E. D. Edwards pers. comm. 2003). *Synemon* species are broad winged, colourful, day flying Lepidoptera with strongly clubbed antennae and relatively slender bodies. With the majority of Australian species, the upperside of the forewings are cryptically or disruptively coloured, while the forewing undersides and both surfaces of the hindwings are usually patterned in shades of white, yellow, orange, red or pinkish-red on a blackish base colour. The wingspans of the known Australian species range from about 2.5 cm to about 5 cm.

The diurnal habits of Australian sun-moths are so rigidly defined that if passing cloud blocks out the sunshine they will immediately settle and not take flight again (unless disturbed) until the sunlight returns. They usually fly rapidly, within a metre of the ground. While flying, they keep their wings in motion continuously. When sun-moths rest for short periods they often raise and lower their wings rhythmically, showing their brightly coloured hindwings. However, when resting for longer periods the hindwings are concealed by the cryptically coloured forewings that are folded roof-wise above the abdomen and harmonize perfectly with the surrounding debris and soil surface crust. Unlike most of the moth families, the sun-moths are unable to align their antennae along the sides of the thorax when at rest.

Descriptions of the Victorian sun-moths

Note on the wingspans and descriptions of the following species.

The cited wingspans of the following species are measurements that were taken between the forewing apices of correctly set specimens (as seen in the accompanying illustrations).

The wing areas and wing veins that are cited in the following descriptions are illustrated on page 14 and explained in detail on pages 13 to 15 of ‘Butterflies of Australia’ by I. F. B. Common and D. F. Waterhouse (1981).

Synemon parthenoides R. Felder, 1874, Orange-spotted Sun-moth

Brief description.

This is a comparatively large species, with a wingspan of about 3.5 cm for males and 4.4 cm for females.

The upperside of the forewings are blackish-grey, with small black and white markings that are more pronounced in the females. The undersides of the forewings are boldly patterned in black and orange and have a few obscure whitish markings toward their apices.

The upperside of the hindwings are black with bright orange spots and markings. The hindwing undersides are similar except that there are also a few indistinct whitish markings near their apices.

Detailed description of wing surfaces.

Male:
Forewing upperside.
Base to submedian area: black, overlaid with grey scales. Submedian to median area: black with a scattering of grey scales along veins and enclosing an obscure, small white spot at outer end of cell. Median to postmedian area: black, enclosing a suffused patch of grey scales that has a blackish centre and commences at vein M3 and reaches the inner margin. Postmedian to subterminal area: black with a small, white subapical marking between the costa and vein M1, that is crossed by fine blackish lines along the veins. This white marking is followed on its outer edge by a crescent-shaped patch of grey scales between the costa and vein M3. It has a blackish centre and is crossed by a scattering of grey scales along the veins. Subterminal to terminal area: black, heavily overlaid with grey scales. Termen: very narrowly black. Scale fringe: black.
Forewing underside.
Base to median area: black with an overlay of orange scales covering basal two thirds of cell. Remainder of cell black, immediately followed by an orange area that encloses a

very obscure, small whitish marking at outer end of cell. Median to subterminal area: orange, crossed by a black band that commences at the costa and broadly reaches the subterminal area on either side of vein CuA1. At its costal end this black band is immediately followed by a small, white subapical marking between the costa and vein R5, which is crossed by fine orange lines along the veins. Subterminal to terminal area and apex: black, enclosing a series of nine small terminal spots, the apical two or three of which are greyish-white while the remainder are orange. Termen: very narrowly black. Scale fringe: blackish-grey, becoming light grey at apex.

Hindwing upperside.

Base to submedian area: black, heavily suffused with orange scales, except for interior of cell, which lacks the orange suffusion. Submedian to median area: black, enclosing an orange spot at outer end of cell and progressively becoming overlaid with orange scales towards the inner margin. Inner margin: blackish, very heavily overlaid and suffused with orange scales. Costa and apex: black. Median to subterminal area: black, enclosing a large, subapical orange spot and an orange marking between vein CuA1 and the inner margin. Between vein 1A+2A and the tornal area, this marking narrows and is displaced towards the termen before it curves inwards and merges into the suffusion of orange scales along the inner margin. Subterminal to terminal area: black, enclosing a series of two small, squared orange spots between veins M1 and M3 and three larger, roughly squared orange spots between veins M3 and 1A+2A. Termen and tornus: narrowly black. Scale fringe: black, becoming orange at apex and tornus.

Hindwing underside.

Base to median area: black, heavily overlaid with orange scales and partly enclosing a large orange spot at outer end of cell. Median to postmedian area: black. This black median to postmedian area abuts the outer edge of the orange cell spot. Costa and inner margin: black, heavily overlaid with orange scales. Apex: black, enclosing two small grey streaks between veins Sc+R1 and M1. Postmedian to subterminal area: black, enclosing a whitish tinged, orange subapical spot and an orange marking between vein CuA1 and the inner margin. Between vein 1A+2A and the inner margin this orange marking is displaced outwards, towards the tornal area. Subterminal to terminal area: black, enclosing a series of two very small, squared orange spots between veins M1 and M3 and three larger, roughly squared orange spots between veins M3 and 1A+2A. Termen and tornus: very narrowly black. Scale fringe: greyish-orange at apex, greyish-black along the central section and becoming orange as it reaches the tornus.

Female:

Forewing upperside.

Similar to male, except white cell spot more prominent and followed by an obscure, whitish postmedian marking between veins M3 and CuA2. The white subapical marking is also larger than in the male and forms a crescent shaped band between the costa and vein M3.

Forewing underside.

Similar to male, except whitish markings more prominent, with the white subapical marking broader, crescent shaped and reaching vein M3. Also, in the orange section of the median to subterminal area, there is an additional obscure, whitish postmedian marking between veins CuA1 and CuA2.

Hindwing upperside.
Similar to male, except all of the orange spots and markings are a little larger. Also, with some specimens there is an extra, very small orange spot near the costa.
Hindwing underside.
Similar to male, except all of the orange spots and markings are larger. As well as this, the orange postmedian marking between vein CuA1 and the inner margin and the squared, orange subterminal spot that is nearest the apex, are both tinged with white. The two grey apical streaks are more emphasized and there is also a very indistinct, small orange spot near the costa.

Synemon discalis Strand, 1911, Small Orange-spotted Sun-moth

Brief description.

A medium sized species, with a wingspan of about 3.1cm. for males and 3.5 cm. for females.

The uppersides of the forewings are blackish-grey with a slight bronze sheen and obscure blackish and whitish markings. On their undersides they are pale orange with black and white markings.

The hindwing uppersides are black with a series of prominent bright orange spots, while their undersides are blackish with pale whitish-orange markings.

Detailed description of wing surfaces.

Male:
Forewing upperside.
Base to postmedian area: black, very heavily overlaid with bronze tinged grey scales. Median to postmedian area: partly enclosing a black marking inside cell, at its outer end. This black marking is immediately followed on its outer edge by a small, crescent shaped white marking on the discocellular veins. The black cell marking is also connected on its lower edge to a black V-shaped marking. This narrows as it runs inwards to a central point between veins CuA2 and 1A+2A and then outwards to vein 1A+2A, where it stops. Postmedian to terminal area: black, overlaid with bronze tinged grey scales. Postmedian to subterminal area: transversely crossed by a black marking that commences at the costa and extends slightly outwards to merge with a series of four suffused, black subterminal spots, which reach the tornus. At the costa this black marking is immediately followed by a small white subapical marking that is crossed by blackish lines that follow the veins. Apical area: blackish, with a reduced overlay of bronze tinged grey scales. Scale fringe: blackish-bronze.
Forewing underside.
Base to submedian area: black, with all but outer end of cell suffused orange. Submedian to subterminal area: pale orange, becoming greyish towards the inner margin and with a postmedian black marking. This commences near the costa, runs through the outer end of cell and concludes as it merges with a subterminal band of small, partly coalesced black

spots. At the costa this black marking is immediately followed by a small, elongate, whitish subapical marking that is crossed by pale orange lines along the veins. Subterminal to terminal area: pale orange, becoming whitish towards apex and crossed by black lines along outer ends of veins. Costa and termen: very narrowly blackish. Scale fringe: greyish, becoming paler towards apex.

Hindwing upperside.

Base to submedian area: orange with a heavy suffusion of blackish scales. Submedian to median area: black, enclosing an orange spot, just inside outer end of cell. Costa and apex: black. Median to subterminal area: black, enclosing a large, subapical orange spot and a transverse orange marking between veins CuA1 and 1A+2A. In some specimens (about 40%) this orange marking extends to vein M3 and joins the subapical orange spot, thereby forming a continuous postmedian to subterminal transverse orange band. Subterminal to terminal area: black, enclosing three squared orange spots and in some instances one or two very small orange markings in the apical area. Inner marginal area: orange, overlaid with black scales and bordered along its inner edge by a black line along vein 1A+2A. Tornus: black, partly enclosing a narrow, orange subtornal band that is interrupted by the black line along vein 1A+2A. This stops it from merging with the postmedian to subterminal transverse orange marking. (See the special note that follows this description.) Termen: black. Scale fringe: black with a bronzy sheen, tinged pale orange at subapical and tornal areas.

Hindwing underside.

Base to submedian area: black, heavily overlaid with greyish-orange scales. Submedian to postmedian area: black, with cell enclosing a whitish orange spot at its outer end and with costa greyish and inner margin suffused dull orange. Postmedian to subterminal area: black, enclosing or partly enclosing a whitish-orange subapical spot and a pale orange marking between veins CuA1 and 1A+2A. Subterminal to terminal area: black, enclosing a series of three squared, pale orange spots. In some specimens the orange postmedian to terminal spots and markings are large enough to coalesce or partly coalesce, causing some of the surrounding black areas to become restricted or poorly defined. Apex: grey, crossed by fine black lines along veins. Tornus: pale yellowish-orange. Scale fringe: greyish-black, becoming whitish-orange at subapical and tornal areas.

Female:

Forewing upperside.

Similar to male, except markings more prominent. White subapical marking extended to reach vein M2 or sometimes M3 and postmedian area enclosing a suffused, whitish postcellular marking between veins M3 and CuA2. In addition to these differences, the blackish subapical area is crossed by a faintly indicated, transverse greyish line.

Forewing underside.

Similar to male, except that with some specimens the postmedian black marking is restricted to the outer end of cell and does not extend to the subterminal band of black spots. In addition, the whitish subapical marking is larger and usually extends to vein M2 or M3, so that it crowns the outer edge of the postmedian black marking.

Hindwing upperside.

Similar to male, except scale fringe becomes whitish-orange (instead of pale orange) at subapical and tornal areas.

Hindwing underside.

Similar to male, except slightly paler, with basal overlay of greyish-orange scales more extensive.

Special note.

At the only site where this species is known to occur in the (Victorian) Big Desert, it flies with the superficially similar Orange-spotted Sun-moth (*Synemon parthenoides*) with which it can be easily confused. However, the Small Orange-spotted Sun-moth can be distinguished by its smaller size, narrower wings, paler wing undersides and predominantly bronzy-grey rather than blackish-grey forewing uppersides. In addition to these differences, the Small Orange-spotted Sun-moth can be distinguished by a black line that follows vein 1A+2A through the orange tornal band on the upperside of the hindwing. With the Orange-spotted Sun-moth this orange band is slightly displaced towards the termen between vein 1A+2A and the inner margin but narrowly reaches the inner margin of the hindwing upperside without interruption.

Synemon jcaria R. Felder, 1874, Reddish-orange Sun-moth

Brief description.

A medium sized species, with a thicker body form and narrower forewings than any of the other Victorian sun-moths. It has a wingspan of about 3.5 cm. for males and 3.8 cm. for females.

The forewings are greyish with indistinct black and white markings on their uppersides. Beneath they are orange and grey with black and white markings.

The uppersides of the hindwings are bright reddish-orange with two small black central markings and black borders. Beneath they are orange with additional grey and small whitish markings.

Detailed description of wing surfaces.

Male:

Forewing upperside.

Base to submedian area: brownish-black, heavily overlaid with light grey scales. Submedian to median area: blackish-brown, displaced towards basal area along inner side of discocellular veins before reaching costa and tapering to a point just before reaching inner margin. Median to subterminal area: brownish-grey, heavily overlaid with light grey scales and enclosing a small whitish spot at outer end of cell and a post cellular blackish marking between the costa and vein M2. Subterminal to terminal and apical areas: brownish-grey, heavily overlaid with light grey scales. Subterminal to terminal area enclosing an indistinct, blackish transverse band between veins M2 and 1A+2A.

Subapical area enclosing an elongated whitish costal marking, immediately followed by a similar blackish marking. Scale fringe: greyish-black.

Forewing underside.

Base to submedian area: orange with inner margin whitish-orange. Submedian area enclosing a black marking inside cell, towards its outer end and another black marking just below lower side of cell. Submedian to postmedian area: orange, becoming paler towards tornus and enclosing a small white spot at outer end of cell. Postmedian to subterminal area: black, becoming greyish towards termen. Postmedian to subapical area: black, partly enclosing a slightly crescent shaped, transverse white marking that is tinged orange along its inner margin and crossed by very fine greyish lines along veins. This white marking is immediately followed along its outer edge by a series of four small, black subapical spots that are all crowned with small white markings at their outer edges. These small black spots decrease in size as they leave the costa. Subterminal to terminal area: grey, becoming slightly orange towards tornus and crossed by fine black lines that follow outer ends of veins. Termen: very narrowly marked with a fine black line. Scale fringe: pale grey.

Hindwing upperside.

Basal to subterminal area: bright reddish-orange. In the submedian to median area this colour partly encloses a short, transverse, crescent shaped black marking from outer end of the cell to central costa and also encloses a small black marking between veins CuA2 and 1A+2A. From the inner edge of this small black marking a suffused blackish streak follows vein 1A+2A to the basal area. Subterminal to terminal area: black with a central influx of bright reddish-orange that forms four small, poorly defined terminal spots. Costa: narrowly greyish-white with a fine inner band of blackish-brown that joins the black subterminal to terminal area. Scale fringe: blackish, becoming orange as it reaches the tornus.

Hindwing underside.

Base to subterminal area: orange with outer half of costa grey. Submedian to subterminal area partly encloses a black subapical marking that almost reaches the costa. The submedian to subterminal area also encloses a black spot just inside outer section of cell and a small black marking below outer end of cell. All three of these black markings in the submedian to subterminal area are followed near their outer edges by faint whitish markings. Subterminal to terminal area: grey at apex, progressively becoming blackish towards tornus, crossed by very fine black lines along veins and with a black line along its inner edge. There is also a central influx of orange into the subterminal to terminal area between veins M3 and CuA1. On each side of this orange influx, there is a small, enclosed area that is also tinged with orange. Termen: marked with a very fine black line. Tornus: orange, narrowly bordered black on outer edge. Scale fringe: pale grey, gradually becoming orange towards tornus.

Female:

Forewing upperside.

Similar to male, except markings are a little more prominent.

Forewing underside.

Base to submedian area: orange with a slight scattering of black scales and also enclosing a small black marking inside outer half of cell, near costa. Submedian to subterminal area: bright orange, becoming paler towards tornus and enclosing a small white spot at outer end of cell and a suffused black marking below outer end of cell. Postmedian to subapical area: black, enclosing a large orange patch that is confluent with a small, white subcostal marking. Subterminal to terminal area: orange, becoming greyish-white at apex and crossed by fine black lines along veins. Termen: marked with a very fine black line. Scale fringe: grey.

Hindwing upperside.

Similar to male, except that the black marking from the outer end of cell to central costa is strait and the black marking between veins CuA2 and 1A+2A is followed near its outer edge by a faint whitish spot. In addition to these differences, the central influx of reddish-orange in the subterminal to terminal area is more exaggerated than it is in the male and forms five (instead of four) terminal orange spots that are more clearly defined.

Hindwing underside.

Similar to male, except that the scale fringe becomes white at the apex and the central influx of orange in the subterminal to terminal area has two enclosed areas of orange on each side.

Synemon nais Klug, 1850, Orange Sun-moth

Brief description.

This is the smallest sun-moth that occurs in Victoria, with a wingspan of about 2.7 cm. for males and 3 cm. for females.

The upperside of the forewings are light brown with pale whitish-fawn markings. On their undersides they are orange with black markings.

The upperside of the hindwings are orange with a blackish-brown inner section that surrounds an orange spot. Near the outer edges they have a row of small black spots that are surrounded by orange. They are similarly coloured on their undersides.

Detailed description of wing surfaces.

Male:

Forewing upperside.

Basal to median area: dark brownish-fawn, overlaid with a scattering of pale greyish-fawn scales and extending beyond cell to enclose a transverse, whitish-fawn, crescent shaped marking. Postmedian to terminal area: brownish-fawn, heavily overlaid with pale greyish-fawn scales and enclosing an indistinct and irregular subterminal band of darker brownish-fawn. Overlay of pale greyish-fawn scales heaviest along inner edge of the postmedian area, creating an impression of an irregular, whitish-fawn transverse line that is displaced towards the subapical area of the wing, before it reaches the costa. Scale fringe: brownish-fawn.

Forewing underside.

Base to median area: black, overlaid with orange scales towards base. Median to subterminal area: orange with a large black spot at outer end of cell and a very narrow extension of the black basal area along the lower side of cell. Subterminal to terminal area: orange with a terminal row of faint whitish spots, followed on outer edge by a fine black terminal line. The subterminal area also encloses a small black subapical marking and a faint blackish subtornal marking that curves inwards towards the cell. Scale fringe: greyish-white.

Hindwing upperside.

Basal to median area: brownish-black, enclosing a large, bright orange spot near outer end of cell and narrowly following costa to apex. Median to terminal area: bright orange, enclosing a subterminal row of five small brownish-black spots between veins M1 and 1A+2A. In some individuals the central spot between veins M3 and CuA1 is only faintly indicated or missing. Termen: narrowly brownish-black. Scale fringe: brownish-fawn.

Hindwing underside.

Costa: blackish, heavily overlaid with orange scales. Base to postmedian area: blackish, overlaid with orange scales, especially towards the inner margin and enclosing an L-shaped orange marking at outer end of cell. Postmedian to terminal area: orange with a very narrow, black terminal line and very fine black lines following the outer ends of the veins. In addition to this, the postmedian to terminal area encloses a series of five, black subterminal spots between veins M1 and 1A+2A. Scale fringe: greyish-black.

Female:

Forewing upperside.

Similar to male, except markings more prominent and overlay of pale greyish-fawn scales heavier.

Forewing underside.

Base to submedian area: orange. Submedian to median area: blackish with outer end of cell orange and enclosing a very faint whitish spot. Median to postmedian area: orange, enclosing a large, post-cellular black spot. Postmedian to subterminal area: orange, enclosing a series of five small, elongated, subapical black spots, which are all immediately followed on their outer edges by very small whitish-orange markings. Subterminal to terminal area: pale orange, with termen very narrowly greyish-black. Scale fringe: greyish-fawn.

Hindwing upperside.

Similar to male, except bright orange areas a little more extensive. Brownish-black costal area reduced to reveal an additional small, brownish-black spot between veins Rs and M1.

Hindwing underside.

Base to median area: orange, tinged blackish and enclosing a large orange spot at outer end of cell. This orange spot is immediately followed on its outer edge by a black marking that almost reaches the costa. Median to terminal area: bright orange, with termen very narrowly greyish-black. The postmedian to subterminal area encloses a series of six, black subterminal spots between veins Rs and 1A+2A. Scale fringe: greyish-fawn.

Synemon theresa Doubleday, 1846, Cryptic Sun-moth

Brief description.

A small species, with a wingspan of about 3.1 cm. for males and 3.5 cm. for females.

The forewing uppersides are predominantly brown with obscure brownish-fawn markings and a small central whitish spot. Their undersides are brownish-black and dull orange with a row of small black spots near their outer edges. In the female the brownish-black areas are replaced with pale grey.

The uppersides of the hindwings are dull orange with a row of brown spots near their outer edges. They also have a brownish inner section that encloses a dull orange spot. With the male their undersides they are brownish-black with pale orange markings while the female has the brownish-black areas replaced with grey and also has a row of black spots near the outer edges.

Detailed description of wing surfaces.

Male:

Forewing upperside.

Base to submedian area: dark brown, with areas between veins overlaid with lighter brownish scales. Submedian to postmedian area: dark brown, enclosing a small white spot at outer end of cell and a series of three elongate, brownish fawn spots between veins CuA1 and 1A+2A. Postmedian to terminal area: dark brown, overlaid with lighter brownish-fawn scales and enclosing a series of four elongate subapical spots that are all only faintly indicated in dark brown. Scale fringe: dark brown.

Forewing underside.

Base: brownish-black, progressively becoming dull orange towards the termen. The ground colour encloses three dull orange postmedian patches and a row of five black spots that extend through subterminal area from the costa. Scale fringe: light brown with a slight bronzy sheen.

Hindwing upperside.

Base to median area: brown, overlaid with bronze scales and enclosing a dull orange spot within the outer end of cell. Median to terminal area: dull orange with the veins faintly emphasized in brown and enclosing a series of four very obscure brown spots in the postmedian to subterminal area. Costa and scale fringe: brown.

Hindwing underside.

Base to terminal area: brownish-black with a scattering of pale orange scales, enclosing two pale orange spots in the median area and a terminal row of pale, dull orange spots that progressively become larger towards the tornus. Inner margin: dull orange. Scale fringe: light brown with a bronzy sheen, tinged light orange at the tornus.

Female:

Forewing upperside.

Similar to male, except that the markings are more accentuated and the elongate subapical spots number five instead of four.

Forewing underside.

Base: pale grey, gradually becoming pale orange towards termen. Median area with a pale brown suffusion outlining a pale orange patch in cell. Subterminal area: pale orange, enclosing a row of five black spots that extend through the subterminal area from the costa. Termen: very narrowly black. Scale fringe: pale brownish-grey.

Hindwing upperside.

Similar to male, except that the base to median area is not overlaid with bronze scales and the termen is narrowly dark brown. In addition to this, the series of brown spots in the postmedian to subterminal area are all much larger, more clearly defined and number five instead of four. These spots are divided by a central influx of dull orange between veins M3 and CuA1 that isolates them into a subapical group of two and a subtornal group of three.

Hindwing underside.

Base to median area: pale grey, becoming darker towards median area and enclosing a pale orange spot in cell. Postmedian to subterminal area: pale orange, crossed by grey along the veins and enclosing a subterminal row of blackish spots. Tornus: pale dull orange. Termen: very narrowly black. Scale fringe: pale brownish-grey, very slightly tinged pale orange at the tornus.

Synemon collecta Swinhoe, 1892, Striated Sun-moth

Brief description.

A medium sized species, with a wingspan of about 3.9 cm. for males and 4.1 cm. for females.

The uppersides of the forewings are dark brown with whitish striations and markings. These markings are more pronounced in the female. In the male the underside of the forewings are patterned in brownish-orange and whitish-orange while in the female they are predominantly pale orange and white with a row of small black spots near their outer edges.

The uppersides of the hindwings are dull orange with a row of brown spots near their outer edges. As well as this, they have a blackish-brown inner area that encloses a dull orange spot that is more clearly defined in the female. In the male their undersides are marked in light brown, brownish-gray and whitish-orange. They also have a row of blackish-brown spots near their outer edges. With the female, the undersides of the hindwings are pale orange with a few white markings and a row of black spots near their outer edges.

Detailed description of wing surfaces.

Male:

Forewing upperside.

Basal to submedian area: dark brown with lower edge of cell highlighted by a whitish streak and a faint scattering of whitish scales between veins. Submedian to median area: dark brown enclosing a small, white transverse marking at outer end of cell. Median to subterminal area: dark brown with a slight overlay of whitish scales between veins and a series of seven elongated, dark brown spots in the postmedian to subterminal area. These spots are slightly accentuated by whitish edges and are separated by a whitish streak between veins M3 and CuA1 into a subapical group of four and a subtornal group of three. Termen: narrowly whitish-brown. Scale fringe: dark brown.

Forewing underside.

Base to submedian area: pale greyish-brown with a very fine fawn line along costa. Submedian to subterminal area: pale brownish-orange, becoming slightly darker towards tornus and enclosing a very faint whitish-orange spot at outer end of cell and a suffused brownish-orange post cellular marking. Subterminal to terminal area: pale brownish-orange, becoming whitish-orange towards apex. The subapical area encloses a transverse row of four very small, darker brownish-orange subapical spots and is crossed by brownish-grey streaks along veins. Scale fringe: light bronzy-brown.

Hindwing upperside.

Costa and base to median area: dark blackish-brown, enclosing a very small dull orange spot inside the cell, near its outer end. Median to terminal area: burnt orange with veins slightly emphasized in brown and enclosing a transverse series of four small, brown subterminal spots, that is divided centrally into a subapical group and a subtornal group. Tornus: dark brownish-orange. Scale fringe: dark brown.

Hindwing underside.

Base to median area: light brown, becoming greyish-brown towards inner margin and enclosing a dull whitish-orange spot at outer end of cell. Median to terminal area: dull whitish-orange, narrowly crossed by light brown streaks along veins and enclosing a transverse series of five blackish-brown subterminal spots that is divided into a subapical group of three and a subtornal group of two by an interruption between veins M3 and CuA1. Scale fringe: brown, becoming paler brownish-orange towards tornus.

Female:

Forewing upperside.

Entire ground colour of wing whitish-fawn with venation boldly accentuated in dark brown, creating a striated appearance. Markings as in the male except that in the postmedian to subterminal area, the series of spots are all more heavily edged with whitish scales and they number five instead of four in the subapical group. The white marking at outer end of the cell is longer and narrower than it is in the male and is angled so that its lower end points towards the tornus. Termen: narrowly dark brown with a slight overlay of whitish scales. Scale fringe: brown.

Forewing underside.

Base to postmedian area: pale orange, with costa and inner margin broadly white. This area of the wing also encloses a faint whitish marking between outer end of cell and inner margin and a narrow white marking at outer end of cell that is angled so that it points towards the tornus. Postmedian to subterminal area: pale orange, partly enclosing a subapical, transverse white marking that joins the costa and is narrowly crossed by orange streaks that follow the veins. Subterminal to terminal area: pale orange, enclosing a transverse series of five black subapical spots that are all immediately followed on their outer ends by five white apical spots. Both lines of these spots become progressively smaller as they leave the apical portion of the costa. Termen: very narrowly black. Scale fringe: grey.

Hindwing upperside.

Similar to male, except that the orange cell is spot much larger, the orange median to terminal area is brighter and the termen is narrowly dark brown. The whole series of brown spots in the subterminal area are larger and darker than in the male and sometimes number three instead of two in the subapical group.

Hindwing underside.

Base to postmedian area: pale orange, enclosing a whitish spot at outer end of the cell and with a whitish streak that follows vein 1A+2A. Postmedian to terminal area: whitish-orange, enclosing a transverse series of five black subterminal spots. As in the male, these spots are divided by a space between veins M3 and CuA1 into a subapical group of three and a subtornal group of two. Termen: very narrowly black. Scale fringe: off-white.

Synemon plana **Walker, 1854, Golden Sun-moth**

Brief description.

The Golden Sun-moth is unique within the family Castniidae because it has semi-flightless females and exhibits sexual dimorphism to a high degree. Another unusual feature of this species is that when it is alive, it has light green eyes. However, this eye colour rapidly changes to brown in preserved specimens. It is a small to medium sized species, with a wingspan of about 3 cm. to 3.2cm. for males and 2.5 cm. to 3.1 cm. for females. The male is predominantly brown with delicate white markings on the upperside of the forewings and a pale brown and brownish-white underside.

The female has similar colouration on the upperside of the forewings but has bright yellow or yellowish-orange hindwing uppersides with a few small black spots toward their outer edges. The underside of the female is entirely off-white with a few small, indistinct blackish spots near the apices of the forewings and some small black spots near the edges of the hindwings. The occurrence of this species at Nhill (in NW Victoria) is unusual in that a small percentage of the females have the normal yellowish-orange colouration of the hindwing uppersides replaced with creamy white.

Detailed description of wing surfaces.

Male:

Forewing upperside.

Base to submedian area: brown, overlaid towards basal area with whitish scales between the veins. Submedian to median area: brown, enclosing a small white spot at outer end of cell and a short whitish streak between outer end of cell and the costa. Median to postmedian area: brown, partly enclosing a large, dark brown patch between vein CuA1 and the inner margin. This dark brown patch is slightly concave along its inner edge and almost reaches the tornus. Except for where it abuts the inner margin, it is narrowly edged with white. Postmedian to subterminal area: brown, partly enclosing a crescent-shaped patch of dark brown that is concave along its inner edge, broadly commences at the costa and concludes at vein M2. Along all but its costal boundary, this dark brown patch is also narrowly edged with white. Subterminal to terminal area: brown, enclosing a series of small, whitish terminal markings that commence near the apex between veins R4 and R5 and reach the tornus. These small markings are crescent-shaped with their concave sides facing inwards. In some specimens they are preceded by faint whitish streaks that follow the veins. Apex: brown. Termen: very narrowly dark brown (between the whitish terminal markings and the scale fringe). Scale fringe: brown.

Forewing underside.

Base to median area: brown, enclosing an area of suffused whitish scales inside cell and an obscure whitish marking at outer end of cell. Costa: broadly whitish with a scattering of brown scales. Median to postmedian area: brown. Postmedian to subterminal area: brownish-white towards apex and broadly brown towards tornus. Subapical to apical area: white with a brownish tinge, enclosing two small, subapical brown spots between veins R5 and M2. Tornus: brown. Scale fringe: light brown.

Hindwing upperside.

Base to terminal area: brown, crossed by obscure dark brown lines along veins, tinged bronze or greenish-bronze toward inner margin and enclosing two dark brown subtornal spots between veins CuA1 and 1A+2A. In some specimens these spots are very faintly edged with brownish-white. Costa: broadly dark brown. Termen: very narrowly dark brown, sometimes with an extremely narrow inner edge of brownish-white, towards the tornal area. Tornus: brown. Scale fringe: light brown.

Hindwing underside.

Base to postmedian area: light brown, very heavily overlaid with whitish scales and partly enclosing an obscure whitish marking at outer end of cell. Costa: broadly brownish-white, so that it just reaches the costal end of the cell marking. Postmedian to terminal area: brownish-white, enclosing a series of three subapical brown spots between veins Rs and M3 and two obscure, brownish subtornal spots between veins CuA1 and 1A+2A. All five of these spots are crowned with dull white, crescent shaped markings around their inner edges. With the subapical group of spots, the centre spot is the largest, while the two neighboring spots (on either side) are small and indistinct. Apex, termen, tornus and inner margin: brownish-white with faint brownish lines along the veins. Scale fringe: light brown.

Female:

Forewing upperside.

Similar to male, except that the brown areas of the wing are sometimes lightly suffused with whitish scales and are a lighter shade of brown in some specimens.

Forewing underside.

Base to subterminal area, costa and inner margin: creamy-white with veins faintly indicated in brownish-yellow. Subapical to apical area: creamy-white, with a very obscure, brownish costal marking and enclosing two small and suffused brownish subapical spots. Tornal area: tinged yellowish. Scale fringe: off-white with a very narrow, brown edging.

Hindwing upperside.

Base to postmedian area: yellow or yellowish-orange, with a scattering of blackish scales along vein 1A+2A. Postmedian to subterminal area: yellow or yellowish-orange, enclosing two small, brownish-black subapical spots between veins M1 and M3 and three similar brownish-black subtornal spots between veins CuA1 and 1A+2A. In some specimens the subapical spot that is furthest away from the apex (between veins M2 and M3) is missing. Also, all of the subtornal group of spots are sometimes very faintly edged with brownish-white. Subterminal to terminal area: yellow or yellowish-orange, crossed by very fine, brownish-black lines along outer ends of the veins. Apex and termen: narrowly blackish-brown. Tornus: narrowly blackish-brown. The tornal colouration sometimes extends along vein 1A+2A to merge with the nearest of the three subtornal spots. Scale fringe: whitish-brown, becoming whitish towards the apex and tornus.

Hindwing underside.

Base to terminal area: white, enclosing five small blackish-brown spots. Two of these are in the subapical area, between veins M1 and M3 and three are situated near the tornus, between veins CuA1 and 1A+2A. As on the upperside of the hindwing, the subapical spot that is furthest away from the apex is missing in some specimens. Apex, termen and tornus: very narrowly blackish-brown. Scale fringe: white with an extremely fine, brown edge.

Synemon selene Klug, 1850, Pale Sun-moth

Refer to Chapter 1 of Part 3 for descriptions and illustrations of the six morphs of *Synemon selene* (Pale Sun-moth).

Illustrations

The numbered scale bars in the following illustrations denote centimetres.

Unless otherwise stated, the specimens that were used in the following illustrations are currently held in the Australian National Insect Collection (CSIRO Division of Entomology).

Figure 1. *Synemon parthenoides* (Orange-spotted Sun-moth). Photo: D. R. Crouch.

Left: female. Chinaman's Well Track at 0.6 km NW of junction with Netting Fence Rd. SE Big Desert, at 28.5 km WSW of Rainbow, Victoria. 3 Nov. 1997 F. Douglas (specimen held in F. Douglas coll.).

Right: male. Nhill-Murrayville Rd. at 39.3 km (by road) north of Yanac, central Big Desert, Victoria. 7 Nov. 1997 F. Douglas (specimen held in F. Douglas coll.).

Figure 2. ***Synemon discalis*** **(Small Orange-spotted Sun-moth). Photo: T. Crouch.**

Left: female. Chinaman's Well Track at 0.6 km NW of junction with Netting Fence Rd. SE Big Desert, at 28.5 km WSW of Rainbow, Victoria. 31 Oct. 1999 F. Douglas (specimen held in F. Douglas coll.).

Right: male. Data as for the preceding (female) specimen (specimen held in F. Douglas coll.).

Figure 3. *Synemon jcaria* (Reddish-orange Sun-moth). Photo: T. Crouch.

Left: female. Milmed Track at 9.6 km west of junction with Booligal Rd. E. Big Desert, at 25.5 km NW of Rainbow, Victoria. Mature larva coll. on 5 Mar. 2000 Adult emerged on 24 Jan. 2001 Larval host: *Lomandra effusa*. F. Douglas (specimen held in F. Douglas coll.).

Right: male. Milmed Track at 14.6 km west by north of Junction with Booligal Rd. E. Big Desert, at 30.5 km NW of Rainbow, Victoria. 26 Jan. 1991 F. Douglas (specimen held in F. Douglas coll.).

Figure 4. ***Synemon nais*** **(Orange Sun-moth).**

Left: female. Nundroo Homestead, South Australia. 21 Oct. 1968 Britton, Upton, Balderson.

Right: male. 35.07S. 147.03E. 3 km ENE of Walpeup, Victoria. 27 Oct. 1993 E. D. Edwards & E. S. Nielsen.

Figure 5. ***Synemon theresa*** **(Cryptic Sun-moth).**

Left: female. Specimen only bears a white number label that reads '2'. The data for the locality and collector of this specimen is probably the same as for the (following) male specimen of this species.

Right: male. Specimen bears a white number label that reads '6108' and a mauve label that reads '*theresa* Doubl. Klug. Adelaide, Behr'. This and the preceding specimen were photographed at the Australian National Insect collection (CSIRO Division of Entomology) while on loan from the Berlin Museum, Germany. It is likely that both of these historic specimens were collected by H. H. Behr during the mid 1840s, while he was staying in the Adelaide region of South Australia. The most plausible explanation for Klug's name also appearing on the data label of the male specimen is that it would probably have been Klug who identified it as *Synemon* '*theresa*' at a later date.

Figure 6. ***Synemon collecta* (Striated Sun-moth).**

Left: female. 36.11S. 147.33E. Shelly, Victoria. 760 m 28 Dec. 1990 E. D. Edwards.

Right: male. Data as for the preceding (female) specimen.

Figure 7. ***Synemon plana*** **(Golden Sun-moth).**

Left: female. York Park, Barton, Australian Capital Territory. 23 Nov. 1982 T. V. Rangsi.

Right: male. 35.18S. 149.60E. Yarralumba, Australian Capital Territory. 14 Nov. 1988 E. D. Edwards & R. D. Edwards.

Part 2

Chapter 2

Distribution and Conservation Status of the Victorian Sun-moths

Introduction

The widespread clearing of native habitats for various types of agriculture has clearly had a negative impact on the populations of all but one of the eight known species of Victorian sun-moths. In particular, the alienation of native grasslands and woodlands across central and western Victoria has caused the distributions of the majority of these *Synemon* spp. to become so restricted that they are now regarded as vulnerable, endangered, critically endangered or are presumed to be extinct within state limits. This situation reflects very poorly on our understanding and management of Victoria's natural (or pre-European) ecosystems. When it is considered that the sun-moths have existed for at least 100 million years and were already inhabiting Australia 45 million years ago when it rifted from Gondwana, it is extraordinary and unfortunate that so many of the Victorian species are now facing extinction.

Distribution of the Victorian sun-moths

Synemon parthenoides (Orange-spotted Sun-moth)

This is the only sun-moth that could currently be classed as a common species in western Victoria. It is widely distributed throughout the Big Desert, the Little Desert National Park and adjacent areas of uncleared land, as well as in suitable habitat within the Grampians National Park and surrounding areas (all pers. obs. 1986 to 2006). The Orange-spotted Sun-moth also occurs in far SW Victoria, where it was recorded by Dr D. Britton in early January 1991, near the SE boundary of the Lower Glenelg National Park, at approximately 36 km E by S of Nelson (D. Britton pers. comm. 2001). There are also some older Victorian records (specimen data dated 1884 to 1951) of this species from Bendigo, Ararat (as 'Arrarat'), Dunneworthy (as 'Dunworthy', at approximately 16 km NE of Ararat), Murtoa, and Hattah (Museum of Victoria data). In addition to these confirmed records, it is possible that a population of sun-moths that was observed by Mr. Ian Faithfull in late December 1987, near Dergholm in SW Victoria, may have belonged to this species. This supposition is based on the time of the year that the adults were flying and a description of the type of habitat they were frequenting (I. Faithfull pers. comm. 2001).

According to Common (1990), *Synemon parthenoides* is ‘a dry country species ranging through western Victoria and South Australia’. However, McQuillan & Forrest (1985) seem to have confused this species with *S. sophia* (White, 1841), which is only known from the south of Western Australia (E. D. Edwards pers. comm. 2000). Although McQuillan & Forrest (1985) state that *S. sophia* occurs in Victoria and South Australia as well as southern Western Australia, there is little doubt that all of the Victorian and South Australian specimens to which they allude are actually *S. parthenoides* R. Felder, 1874 (Orange-spotted Sun-moth). Two South Australian localities where McQuillan & Forrest (1985) say that ?*S. parthenoides* (as *S. sophia*) occurs are ‘the western slopes of Mt. Lofty and the remnant Aldinga scrub’. *S. parthenoides* also occurs on Kangaroo Island (L. Hunt pers. comm. 2004, A. Kallies pers. comm. 2006). There are also some old South Australian specimens in the Museum of Victoria from Ashbourne (1 specimen dated Nov. 1895) and Blackwood (3 undated specimens).

Synemon discalis (Small Orange-spotted Sun-moth)

Within Victoria this species has only been recorded at the three following localities in the Mallee region:

(1) In the south-eastern corner of the Big Desert, throughout an area of about 2 hectares on the western side of Chinaman’s Well Track, at 0.6 km north-west of its junction with the Netting Fence Road.

(2) Calder Highway at 6 km north of Hattah. This record is based on a single female that was collected by Mr. A. Atkins on 9 October 1995, as well as observations of approximately 12 additional individuals on the same occasion (A. Atkins pers. comm. 2005).

(3) Within the ‘study area’ of the proposed Nowingi Long Term Containment Facility, on the western side of the Calder Highway at 10 km north of Hattah. This comparatively large population of the species was discovered by Mrs. J. T. Noelker and the author during October 2005. For a detailed account of this discovery, see Appendix 2 to Chapter 6 of Part 2. This is an unpublished report (by the author) that was prepared for the Department of Sustainability & Environment during 1995.

Outside Victoria, the Small Orange-spotted Sun-moth occurs in limited areas on the Yorke and Eyre Peninsulas in South Australia and at Mount Ragged (in Cape Arid National Park) and Norseman in Western Australia (E. D. Edwards pers. comm. 2000). There are also Western Australian records of this species from Warwick and Waroona (Museum of Victoria data) and from 74 km. south of Yalgoo. This record is represented by one (male) specimen that was collected by Mr. M. Powell on 29 November 2001.

Common (1990) states that *Synemon discalis* is ‘widely distributed in western Victoria and South Australia’. However, this is an error, as this species has a restricted distribution in Victoria and South Australia. From available data, it appears that *S. discalis* was not known to occur in (western) Victoria until 1995.

***Synemon jcaria* (Reddish-orange Sun-moth)**

In Victoria the Reddish-orange Sun-moth has been recorded in the Kiata Native Plants and Wildlife Reserve at Kiata in the Wimmera area (K. V. Hateley pers. comm. 1989, pers. obs. 1990 to 2005) and in the Mallee region at several localities in the eastern and central Big Desert. The Big Desert localities are as follows:

(1) Central Big Desert: Nhill-Murrayville Road at 33 km (pers. obs. 1989) and 43 km (W. N. B. Quick pers. comm. 1987) north of Yanac, near the western boundary of Wyperfeld National Park.

(2) Eastern Big Desert: Milmed Track at 9.5 to 9.6 km, 10.2 km, 13.9 to 14.6 km and 17.9 to 18.1 km (pers. obs. 1991 to 2006) and at 10.7 km (E. D. Edwards pers. comm. 1992) west to WNW of its junction with Booligal Road, Wyperfeld National Park. In the widely used Third Edition of the C. F. A. Region 17 Rural Directory of the Wimmera area (1997), ‘Booligal Road’ is ?miss-spelt as ‘Bullygall Road’.

Survey work (carried out in 2004, 2005 and 2006) has determined that the populations in the Kiata Native Plants and Wildlife Reserve, and on the Milmed Track (at 9.5 to 9.6 km and 10.2 km west of its junction with Booligal Road) in Wyperfeld National Park are extant.

In addition to the above localities, this species has recently been discovered by Dr R. P. Field within the ‘study area’ of the proposed Nowingi Long Term Containment Facility (A. Yen pers. comm. 2005). This area is on the western side of the Calder Highway at 10 km north of Hattah.

There are also Victorian records (circa late 1800s to early 1900s) of *S. jcaria* from Kewell, the ‘Western District’ and the ‘Wimmera’ (Museum of Victoria data).

Beyond Victoria, this species is known to occur in central New South Wales, near Mount Hope (E. D. Edwards pers. comm. 2000) and at Round Hill (A. Sundholm pers. comm. 2005). It also occurs at the southern end of the Yorke Peninsula and in the Barossa Valley in South Australia and in Western Australia at Mount Ragged and the Darling Range (E. D. Edwards pers. comm. 2000). A more precise locality where this species occurs on the Yorke Peninsula (S. Aust.) is 12.5 km south of Warooka (O. F. Noelker pers. comm. 1993, pers. obs. 1993). Two more localities in Western Australia where this species has been collected (by Mr. M. Golding) are 9 km SSE of Peak Eleanora, Lort River (at approximately 120 km NNE of Esperence) and at ‘Valema Farms’ near Corrigin (M. Powell pers. comm. 2000 and 2002 respectively).

Synemon nais (Orange Sun-moth)

The Orange Sun-moth has a restricted distribution in Victoria, where it is only known to occur at three small sites near Walpeup. It formerly occurred at Sea Lake (E. D. Edwards pers. comm. 1993, Museum of Victoria data), but it now appears that this population is extinct (O. F. Noelker pers. comm. 1991). The Walpeup sites are as follows:

(1) Walpeup Recreation Reserve, on the northern side of the sports oval (pers. obs. 1995).

(2) Remnant habitat on the western side of the main entrance road to the Walpeup Mallee Research Station (pers. obs. 1999).

(3) A small Bushland Reserve (and adjacent roadside verges) on both sides of the Ouyen Highway, at 2 to 3 km ENE of Walpeup (pers. obs. 1988 to 2004).

Beyond Victoria, this species occurs in South Australia, at Nundroo Homestead, approximately 135 km W by N of Ceduna (Australian National Insect Collection data) and near Ceduna and in the Nullarbor Plain area (E. D. Edwards pers. comm. 2005). It also occurs near Mundrabilla in the far SE of Western Australia (E. D. Edwards pers. comm. 1993). Common (1990) mentions Madura as another Western Australian locality where this species has been recorded.

Synemon theresa (Cryptic Sun Moth)

This species has not been recorded in Victoria for approximately one hundred years. It occurred formerly at Castlemaine, Ararat and Beechworth (Museum of Victoria data). There is also one (?very old) female specimen in the Museum of Victoria that bears a data label that simply reads ‘Kewell’. It therefore seems likely that Kewell (at 12.5 km NNE of Jung) in the Wimmera area of western Victoria would have been another historic locality for *S. theresa*.

Outside Victoria, this species is known to occur in South Australia, where an extant population has been recently discovered in remnant habitat at Waterfall Gully, a suburb of Adelaide (Young & Hunt 2005). Near Adelaide, it also occurred formerly at Burnside and Parkside (Museum of Victoria data). Further afield, it occurred at ‘Slapes Gully’ on Mount Lofty and in the Clare Valley, where the most recent specimen was collected by Mr. Norman B. Tindale during the early 1960s (E. D. Edwards pers. comm. 2000).

Synemon collecta (Striated Sun-moth)

There appears to be only one extant population of this species in Victoria. This population occurs near Shelley on the Murray Valley Highway, approximately 35 km west of Corryong. It occupies a small area (about 50 m wide by 300 m long) along the south-east side of the road (E. D. Edwards pers. comm. 2000). In 1987 Mr. E. D. (Ted)

Edwards also recorded a few individuals at the airstrip to the SW of Shelley. However, this area was converted into a pine plantation in 1989 (G. Johnson pers. comm. 2005). Historic Victorian records from Brighton, Stawell, Hamilton and Beremboke (on the western side of the Brisbane Ranges) date from the early 1900s (Museum of Victoria data). There is also a specimen in the Museum of Victoria (ex-D. Holmes coll.), from Slaty Creek (approximately 10 km NNE of St. Arnaud), Victoria that is dated 16 September 1945.

The species has also been recorded from the Northern Tablelands of New South Wales, from Armidale to Barrington Tops (E. D. Edwards, pers. comm. 2000). It still occurs at Armidale (N. S. W.), where Dr D. Britton located a population during 2000 in the Armidale Arboretum (D. Britton, pers. comm. 2006). Another extant population may occur at 5 km west of Gunnedah, were Mr. R. Mayo collected a specimen in 2001 (G. E. Wurtz pers. comm. 2003). Some older records from New South Wales include Belltrees (approximately 28 km ENE of Scone) and Tenterfield (Museum of Victoria data).

A paler form of *S. collecta* occurs in Queensland, where it has been recorded from Brisbane, Esk, Millmerran (as ‘Milmerran’), Westwood (approximately 50 km SW of Rockhampton) and Stanthorpe (as ‘Stanhope’), (Museum of Victoria data, P. Marriott pers. comm. 2006). There are also records from near the Carnarvan Range, Collinsville and near Mitchell (E. D. Edwards pers. comm. 2006).

***Synemon plana* (Golden Sun-moth)**

Although the Golden Sun-moth is now regarded as a nationally endangered species there are a number of historic records from near Bathurst to the Southern Tablelands in New South Wales, the Australian Capital Territory and central and western Victoria to Bordertown, South Australia (E. D. Edwards pers. comm. 2004). It seems that the widespread alienation of native grassland habitats that followed European settlement has caused a significant contraction in the distribution of this species. The Victorian localities that are still known to hold (or are likely to hold) extant occurrences of the Golden Sun-moth are as follows:

(1) Nhill Sun-moth Reserve, 1.4 km east of Nhill, on the north side of Belcher Street at 500 m east of its Junction with the Nhill-Netherby Road (pers obs. 1990 to 2005). At this locality *Synemon plana* occurs sympatrically with the Nhill Morph of *S. selene* (Pale Sun-moth).

(2) A small grassy woodland remnant on private farmland at 2.4 km SW of Nhill (on the northern side of the Western Highway), (pers. obs. 2002 to 2003).

(3) A small grassy woodland remnant on private land at 4.3 km. WNW of Kiata (on the southern side of the Western Highway), (pers. obs. 2003).

(4) Salisbury Bushland Reserve on the south side of the Western Highway, at 4 km WNW of Kiata (K. V. Hateley pers, comm. 1989, pers. obs. 1989 to 2003).

(5) Hamilton Golf Course at the Hamilton Community Parkland (T. R. New pers. comm. 2000).

(6) Private grazing property near Dunkeld (Dear 1996).

(7) Private grazing property at 9 km NE of Woorndoo (approximately 51 km ESE of Dunkeld) (Dear 1996).

(8) A roadside verge at Hexham (Dear 1996).

(9) The grounds of the old police station at Fryerstown (J. Landy pers. comm. 1998, pers. obs. 1999).

(10) The NE and western lower slopes of Mount Piper and a site at 2.5 km east of Mount Piper, near Broadford (D. Britton pers. comm. 2001).

(11) Pepper Mountain (approximately 5.5 km ESE of Moyhu in the King River Valley, at about 30 km south of Wangaratta), (I. Faithfull pers. comm. 2001).

(12) Craigieburn Grassland, near Whittlesea (S. Hadden pers. comm. 2004).

(13) Cooper Street Grassland, near Hume City (S. Hadden pers. comm. 2004).

(14) A site near Central Springs, Vaughan (P. Marriott pers. comm. 2004).

(15) Private property at Taggerty (A. Jelinek pers. comm. 2004).

(16) A site at Eynesbury (approximately 10 km south of Melton), (B. Fox pers. comm. 2006).

The two following localities represent records from the early 1990s or earlier, so it is possible that the species may have died out at these sites:

(1) 1 km. north of Tallarook, on the western side of the Hume Highway (D. F. Crosby pers. comm. 1992).

(2) The summit of Junction Hill on the Yea Spur, approximately 8 km NE of Flowerdale (D. Britton pers. comm. 1993).

There are also many specimens of *S. plana* in the Museum of Victoria's collection of Castniidae. Some of these are from additional Victorian localities that are not listed above. These localities and the dates of the records are as follows: Ararat (1906-1907), Castlemaine (1907-1917), Dunneworthy (as 'Dunworthy', at approximately 16 km NE of

Ararat), (1929), Kiata (1939), Maryborough (no date) Alexandra (1984), Mansefield (1905), Nagambie (1932), Clarkefield (1983), Gisborne (1919), Riddell (1897), Romsey (1897), Woodend (1908), Broadmeadows (1906), Glenroy (1919), Keilor (1906), Bendigo (1934), Beaconsfield (no date), Altona (1929) and Eildon (1963). Clarke & O'Dwyer (2000) also list Burrumbeet, Monbulk and Bright as former Victorian localities where this species occurred and O'Dwyer *et al*. (2000) state that Williamstown was another historic location for *S. plana* in Victoria.

Common (1990) simply states that *S. plana* 'occurs in small colonies in grassy areas on the southern tablelands of New South Wales and in Victoria'. According to Braby & Dunford (2006) it is now known that there are extant occurrences at 31 sites in the Australian Capital Territory and 42 sites in N. S. W., all within 85 km of the northern and NE borders of the A. C. T. An indication of the past abundance of this species can be found in Froggat (1907) who stated that '*S. hesperoides*' (a junior synonym of *S. plana*) 'is common in Victoria'.

Synemon selene (Pale Sun-moth)

See Chapter 2 of Part 3 for the distribution of the six morphs of *Synemon selene* (Pale Sun-moth).

Conservation status of the Victorian sun-moths

Synemon parthenoides (Orange-spotted Sun-moth)

Listed as secure in Victoria by Douglas (1993).

Synemon discalis (Small Orange-spotted Sun-moth)

Listed as critically endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Nominated during November 2005 for listing as endangered (nationally) under the Commonwealth Government *Environment Protection and Biodiversity Conservation Act* 1999.

Synemon jcaria (Reddish-orange Sun-moth)

Listed as an indeterminate (data deficient) species in Victoria by Douglas (1993).

Listed as vulnerable in Victoria by Venn (1993).

Listed as vulnerable in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon nais **(Orange Sun-moth)**

Listed as threatened in accordance with Section 10 of the *Flora and Fauna Guarantee Act* 1988.

Listed as endangered in Victoria by Douglas (1993).

Listed as endangered in Victoria by Venn (1993).

Listed as endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon theresa **(Cryptic Sun-moth)**

Listed as threatened in accordance with Section 10 of the *Flora and Fauna Guarantee Act* 1988.

Listed as extinct in Victoria by Douglas (1993).

Listed as endangered, possibly extinct in Victoria by Venn (1993).

Listed as extinct in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon collecta **(Striated Sun-moth)**

Listed (under *Synemon* sp. aff. *collecta*) as endangered in Victoria by Douglas (1993).

Listed (under *Synemon* nr. *collecta*) as possibly endangered in Victoria by Venn (1993).

Listed as critically endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon plana **(Golden Sun-moth)**

Listed as threatened in accordance with Section 10 of the *Flora and Fauna Guarantee Act* 1988.

Listed as regionally and nationally endangered by Douglas (1993).

Listed as endangered in Victoria by Venn (1993).

Listed as endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Listed as critically endangered (nationally) under the Commonwealth Government *Environment Protection and Biodiversity Conservation Act* 1999.

Outside Victoria, this species is listed as endangered under the Australian Capital Territory *Nature Conservation Act* 1980 and also (listed as endangered) under the New South Wales *Threatened Species Conservation Act* 1995.

Synemon selene **(Pale Sun-moth)**

Refer to Chapter 2 of Part 3 for the conservation status of the six morphs of *Synemon selene* (Pale Sun-moth).

Part 2

Chapter 3

Habitats of the Victorian Sun-moths

Introduction

The habitats of the eight species of sun-moths that occur, or once occurred in Victoria include woodlands, heathlands and grasslands. Essentially, the primary prerequisite for a given species to occur in a particular area is the presence of its larval host plant or plants. For this reason, it is important that occurrences of these plants are adequately protected in Victoria's reserve system, with priority being given to national parks.

As an aid to the recognition of areas where sun-moths may occur in Victoria, the scientific and common names of their known and/or suspected larval host plants are typed in bold lettering, so that they can be easily seen in the following text. In some cases, species of plants are listed that were not previously thought to be putative larval hosts of some of the *Synemon* spp. Their inclusion here is based on direct observations made by the author of these plants being repeatedly selected by the ovipositing females of certain *Synemon* spp., at one of more of the localities where they occur. Each plant that falls into this category is indicated by an asterisk before its scientific name when it first appears in the habitat description of the relevant *Synemon* species.

Victorian sun-moth habitat profiles

Synemon parthenoides (Orange-spotted Sun-moth)

(A) Big Desert: heathland or more usually mallee-heath (open-scrub) communities on pale sands, with undulating east-west dune systems. The most important components of the flora are ***Lepidosperma carphoides*** (**Black Rapier-sedge**) and/or ****Schoenus racemosus*** (**Tufted Bog-sedge**) and to a much lesser extent ****Lepidosperma viscidum*** (**Sticky Sword-sedge**). When mallee eucalypts are present the most abundant species are *Eucalyptus leptophylla* (Narrow-leaved Red Mallee) and *E. costata* (Yellow Mallee). Other plant species that typify areas in the Big Desert that would be likely to hold populations of the Orange-spotted Sun-moth are as follows: *Callitris verrucosa* (Scrub Cypress-pine), *Exocarpos sparteus* (Broom Ballart), *Banksia ornata* (Desert Banksia), *Allocasuarina pusilla* (Dwarf She-oak), *Baeckea behrii* (Broom Baeckea), *Leptospermum coreaceum* (Green Tea-tree), *Calytrix tetragona* (Common Fringe-myrtle) and *Adenanthos terminalis* (Gland Flower).

(B) Little Desert: heathland on pale sandy soil that contains occurrences of ***Lepidosperma carphoides*** (**Black Rapier-sedge**). Some other plant species that are often present in this habitat are *Banksia ornata* (Desert Banksia), *B. marginata* (Silver Banksia), *Leptospermum myrsinoides* (Heath Tea-tree), *Calytrix tetragona* (Common Fringe-myrtle), *Allocasuarina pusilla* (Dwarf She-oak) and *Xanthorrhoea australis* (Austral Grass-tree). Although larger trees are usually scarce in areas of the Little Desert where the Orange-spotted Sun-moth occurs, there are sometimes isolated stands of *Eucalyptus arenacea* (Brown Stringybark), *E. leucoxylon* (Yellow Gum) and *Callitris rhomboidea* (Oyster Bay Pine).

(C) Grampians and surrounding areas: open woodland and species-rich heathland communities on sandy, sandy-loam or stony soils, with occurrences of ***Lepidosperma carphoides*** (**Black Rapier-sedge**). The dominant tree species in the open woodland habitats are usually *Eucalyptus leucoxylon* (Yellow Gum), *E. melliodora* (Yellow Box) *E. arenacea* (Brown Stringybark), *E. microcarpa* (Grey Box) and *Allocasuarina verticillata* (Drooping She-oak). Although the heathlands where the Orange-spotted Sun-moth occurs in the Grampians district are floristically diverse, some characteristic plants of these areas are as follows: *Callitris rhomboidea* (Oyster Bay Pine), *Leptospermum continentale* (Prickly Tea-tree), *L. scoparium* (Manuka Tea-tree), *L. myrsinoides* (Heath Tea-tree), *Calytrix tetragona* (Common Fringe-myrtle), *Eucalyptus arenacea* (Brown Stringybark), *Banksia ornata* (Desert Banksia), *B. marginata* (Silver Banksia), *Allocasuarina muelleriana* (Slaty She-oak), *Grevillea aquifolium* (Variable Prickly Grevillea), *Xanthorrhoea australis* (Austral Grass-tree) and *Conospermum mitchellii* (Victorian Smoke-bush).

(D) Kentbruck area: the habitat where *Synemon parthenoides* has been observed in this district of south-western Victoria is heathland on a pale sandy soil, with a gently undulating topography. A species of ***Lepidosperma*** that was noticed in the area is probably ***L. carphoides*** (**Black Rapier-sedge**). Some other common plants in this habitat are two *Banksia* spp. that were probably *B. ornata* (Desert Banksia) and *B. marginata* (Silver Banksia), a species of Stringybark which was probably *Eucalyptus arenacea* (Brown Stringybark), *Leptospermum* spp. that would be likely to include *Leptospermum myrsinoides* (Heath Tea-tree) and a *Xanthorrhoea* species which may have been *Xanthorrhoea australis* (Austral Grass-tree) (D. Britton pers. comm. 2001).

Synemon discalis (Small Orange-spotted Sun-moth)

(A) Big Desert site: low lying, open heathland on greyish-white sands. The dominant plant species within this area are as follows: ****Gahnia lanigera*** (**Desert Saw-sedge**), ****Lepidosperma carphoides*** (**Black Rapier-sedge**), *L. viscidum* (Sticky Sword-sedge), *Triodia scariosa* (Porcupine Grass), *Dampiera rosmarinifolia* (Rosemary Dampiera) and *Kunzea pomifera* (Muntries). Although trees and shrubs are scarce at the site there are a few specimens of *Eucalyptus leptophylla* (Narrow-leaf Mallee) and *Leptospermum coriaceum* (Green Tea-tree) near its margin.

(B) Hattah/Nowingi area: an undulating mallee (open-scrub) community on east-west orientated dunes with a reddish coloured sandy soil. The most abundant mallee eucalypt species in the area are *Eucalyptus socialis* (Grey Mallee) and *E. costata* (Yellow Mallee). Although the ground flora is dominated by *Triodia scariosa* (Porcupine Grass), the area also contains scattered occurrences of ***Gahnia lanigera*** (**Desert Saw-sedge**). Some of the other plants that characterise this habitat are: *Lepidosperma viscidum* (Sticky Sword-sedge), *Lomandra effusa* (Scented Mat-rush), *Westringia rigida* (Stiff Westringia), *Halgania cyanea* (Rough Halgania), *Leptospermum coriaceum* (Green Tea-tree) and *Baeckea behrii* (Broom Baeckea).

Synemon jcaria (Reddish-orange Sun-moth)

(A) Kiata Native Plants and Wildlife Reserve: mixed open-forest on grey loamy soil. Some of the dominant plant species at the main site where the Reddish-orange Sun-moth occurs are as follows: *Eucalyptus largiflorens* (Black Box), *E. leucoxylon* (Yellow Gum), *Bursaria spinosa* (Sweet Bursaria) and ***Lomandra effusa*** (**Scented Mat-rush**). At this locality *Synemon jcaria* occurs sympatrically with the endangered Eltham Copper Butterfly, *Paralucia pyrodiscus* (formerly subspecies *lucida*).

(B) Big Desert sites: mallee-heath (open-scrub) on pale, sandy soils and mallee (scrub) communities in low lying swales, variously on loamy, grey soil and/or pale orange, gritty, clay. The single confirmed breeding site that has been found to date in the Big Desert is in the latter type of habitat. This site is dominated by the following plants: *Eucalyptus dumosa* (Dumosa Mallee), *E. costata* (Yellow Mallee), *Baeckea behrii* (Broom Baeckea), *Melaleuca lanceolata* (Moonah), *M. uncinata* (Broom-Honey-myrtle), *Acacia calamifolia* (Wallowa) and ***Lomandra effusa*** (**Scented Mat-rush**).

(C) Nowingi site (Long Term Containment Facility study area): low-lying areas of mallee (scrub) on calcareous soils, between large east-west orientated reddish coloured sand dunes. The most abundant mallee species at the site is *Eucalyptus socialis* (Grey Mallee), while the ground flora is dominated by *Triodia scariosa* (Porcupine Grass), the area also contains occurrences of ***Lomandra effusa*** **(Scented Mat-rush)**, *Westringia rigida* (Stiff Westringia) and *Myoporum platycarpum* (Sugarwood).

Synemon nais (Orange Sun-moth)

Walpeup sites: the habitat of this species in the Walpeup district is low woodland. It has a reddish, loamy soil and is characterised by a floristically diverse community of open grassy areas that are interspersed with dense stands of trees and shrubs. The grassy areas are dominated by ***Austrodanthonia setacea*** (**Bristly Wallaby-grass**) and ***Austrostipa*** species (**spear-grasses**) with ****A. scabra*** (**Rough Spear-grass**) being one of the most common species. The more abundant tree and shrub species that occur in this habitat are as follows: *Callitris gracilis* (Slender Cypress-pine), *Casuarina cristata* (Belah), *Alectryon oleifolius* (Cattle-bush), *Dodonaea viscosa* subsp. *angustissima* (Narrow-leaf Hop-bush), *Acacia hakeoides* (Hakea Wattle), *Pimelea microcephala* (Mallee Rice-flower), *Hakea leucoptera* (Silver Needlewood) and *Senna artemisioides* (Desert Cassia).

Synemon theresa (Cryptic Sun-moth)

As no extant populations of this species are known in Victoria, its exact Victorian habitat requirements are unclear. The locality data of historic specimens indicates that it probably inhabited grassy open woodland (with *Eucalyptus* spp. as the dominant tree species) on well-drained and possibly stony soils. The ground flora was probably dominated by ***Austrodanthonia*** species (**wallaby-grasses**) and *Austrostipa* species (spear-grasses) or possibly ***Themeda triandra*** (**Kangaroo Grass**).

Synemon theresa belongs to the temperate subgroup of the grass-feeding group of *Synemon* spp. The main larval host plants of the other four species in the temperate subgroup are thought to be *Austrodanthonia* spp. (E. D. Edwards pers. comm. 2000, pers. obs. 1990 to 2005). However, it appears that the larval host plant of the population of *S. theresa* that has recently been discovered at Waterfall Gully, South Australia may be *Themeda triandra* (Young & Hunt 2005).

Synemon collecta (Striated Sun-moth)

Shelley site: within Victoria, the natural habitat of this species is uncertain, as the only known extant Victorian population occurs in a mowed firebreak along the margin of a pine plantation. However, it seems likely that *Synemon collecta* would have originally inhabited grassy open woodland and grassland habitats that were dominated by ***Austrodanthonia*** species. The firebreak where the Striated Sun-moth occurs at Shelley is dominated by ***A. laevis*** (**Smooth Wallaby-grass**) (E. D. Edwards, pers. comm. 1993).

Synemon plana (Golden Sun-moth)

(A) Western Victoria.

(1) Nhill (Nhill Sun-moth Reserve, Belcher Street): gently undulating grassland on reddish loamy soil. The dominant grasses are species of ***Austrodanthonia*** and ***Austrostipa*** with ***Austrodanthonia setacea*** (**Bristly Wallaby-grass**) and *****Austrostipa scabra*** (**Rough Spear-grass**) being the two most abundant species. It is significant that this locality holds a population of *Maireana rohrlachii* (Rohrlach's Bluebush), which is usually an uncommon species throughout its distribution. Some of the other plants that occur in this habitat are as follows: *M. enchylaenoides* (Wingless Bluebush), *Atriplex semibaccata* (Berry Saltbush), *Rumex dumosus* (Wiry Dock), *Oxalis perennans* (Grassland wood-sorrel) and *Goodenia pinnatifida* (Cut-leaf Goodenia). The presence of

a remnant specimen of *Eucalyptus largiflorens* (Black Box) at the site suggests that there may have originally been a scattering of these trees in the area.

(2) Salisbury Bushland Reserve: very gently undulating grassy open woodland on reddish and greyish loamy soils. The dominant tree species are *Eucalyptus largiflorens* (Black Box) and *E. leucoxylon* (Yellow Gum). In the south-east corner of the reserve where the highest concentration of Golden Sun-moths occur, the most common grasses are ***Austrodanthonia setacea*** (**Bristly Wallaby-grass**) and *Austrostipa* species (Spear-grasses). Although understory shrubs are scarce in this habitat, there are isolated stands of *Bursaria spinosa* (Sweet Bursaria).

(B) South-western Victoria.

Hamilton Golf Course: slightly undulating, grassy open woodland on a light sandy-loam soil. ***Austrodanthonia*** species (**wallaby-grasses**) are abundant at the site where the Golden Sun-moths were observed and *Eucalyptus* species are the dominant trees in the general area (T. R. New pers. comm. 2001).

(C) Central Victoria (Nos. 1 & 2, D. Britton pers. comm. 2001, No. 3, I. Faithfull pers. comm. 2001).

(1) Lower slopes of Mount Piper: open grassy areas in a Box-Ironbark woodland habitat with grey, clayey soil that contains broken down fragments of sandstone and quartz. The groundflora is dominated by ***Austrodanthonia*** species, including ***A. carphoides*** (**Short Wallaby-grass**). Some of the open grassy areas where the Golden Sun-moth occurs near Mount Piper contain sparse stands of *Acacia pycnantha* (Golden Wattle) and/or *A. mearnsii* (Black Wattle).

(2) Summit of Junction Hill, on the Yea Spur (near Flowerdale): a grassy, box-stringybark open woodland habitat on broken down granitic (gritty) soil. The open areas of this hilltop habitat are dominated by ***Austrodanthonia*** species (**wallaby-grasses**).

(3) 5.5 km east-south-east of Moyhu ('Pepper Mountain'): grassy open woodland on a hillside that is dominated by ***Austrodanthonia auriculata*** (**Lobed Wallaby-grass**) on rocky soil. Some other plants that occur at this locality are as follows: ***A. pilosa*** (**Velvet Wallaby-grass**), *Elymus scabrus* (Common Wheat Grass), *Brachyloma daphnoides* (Daphne Heath), *Acacia dealbata* (Silver Wattle), *Eucalyptus polyanthemos* (Red Box), *E. macrorhyncha* (Red Stringybark) and *E. goniocalyx* (Long-leaved Box).

(4) Fryerstown site: grassy eucalypt woodland on greyish, somewhat stony soil, with an undulating to hilly topography. The ground flora is dominated by an ***Austrodanthonia*** species that is probably ***A. setacea*** (**Bristly Wallaby-grass**). Two of the most common tree species in the area are *Eucalyptus melliodora* (Yellow Box) and *E. polyanthemos* (Red Box).

Synemon selene **(Pale Sun-moth)**

Refer to Chapter 7 of Part 3 for the habitat of *Synemon selene* (Pale Sun-moth).

Part 2

Chapter 4

Biology of the Victorian Sun-moths

Introduction

To date, several authors such as E. D. (Ted) Edwards (1997a) and I. F. B. Common (1990), have documented various aspects of the biology of some of the Australian sun-moths. However, the subterranean nature of the early stages of most of the Australian species has made it difficult to study their larval and pupal biology and to determine the larval host plants.

Unless otherwise stated, the following biological information on the Victorian *Synemon* spp. is based on direct observations and studies that have been made or carried out by the author since 1986, with the majority of the work being done since this project was commenced in 1997.

General biology of the Victorian sun-moths

As adults, all of the Victorian sun-moths have relatively brief lives of approximately four to ten days (depending on the species). The adults of some sun-moths have a reduced haustellum and do not feed (Fukuda 2000, pers. obs. 1989 to 2005). These species rely on nutrients that are stored in their bodies during the larval stage to sustain them throughout their short adult lives. Two Victorian examples of such species are the Golden Sun-moth (*Synemon plana*) and the Pale Sun-moth (*S. selene*), (pers. obs. 1991 to 2005). In most instances sun-moths have a rapid and fairly direct flight and beat their wings continuously while flying. All eight of the Victorian species are diurnal and they rarely fly higher than one metre above the ground.

Female sun-moths mate and then commence oviposition shortly after emergence from their pupae. They are able to do this because all of their eggs are fully matured during the pupal stage. The females have long, retractable ovipositors that are used to deposit their eggs beneath the soil, at or near the base of their respective larval host plants. However, in some instances, the eggs can be deposited amongst the tillers and/or old leaf bases of the host plant. After hatching, the larvae tunnel through the soil to feed on the roots of their host plants. Alternatively, in some species the larvae bore directly into the host plant's rhizomes where they commence to feed. In all but one of the extant Victorian species, each mature larva constructs more or less vertical, silk lined tunnel (?from its final feeding site) to just below the surface of the soil. It is here that the larvae of these species finally pupate. The exception to this is the Reddish-orange Sun-moth (*Synemon* *jcaria*) which has larvae that feed at or above ground level, inside the rhizomes of their larval host plant, where they eventually pupate. The known pupal exuviae of the Victorian sun-moths partly protrude from their pupal galleries after the adults have emerged.

It is not known how long any of the Victorian sun-moths take to complete their life cycles. However, Common & Edwards (1981) found that *Synemon magnifica*, a species that occurs in New South Wales, takes approximately two to three years to complete a generation. The known or suspected larval host plants of the eight species of Victorian sun-moths are invariably monocotyledons and belong to the families Cyperaceae (sedges), Lomandraceae (mat-rushes) and Poaceae (grasses).

***Synemon parthenoides* (Orange-spotted Sun-moth)**

The Orange-spotted Sun-moth is the most frequently observed species of *Synemon* that occurs in Victoria. This is due to its bright colouration, large size, wide distribution and usual abundance in the areas where it is found. The adult flight period of this species becomes progressively later as one travels southwards through its range in western Victoria. In the Big Desert it is on the wing from very late October to late November while throughout the Little Desert it flies from early November to late December. In the Grampians National Park and surrounding areas the flight period is from late November to early January.

Both Common (1990) and McQuillan & Forrest (1985) state that *Lepidosperma carphoides* (Black Rapier-sedge, Cyperaceae) is the larval host plant of this species. However, the latter publication seems to have confused *Synemon parthenoides* with *S. sophia*. See the comments regarding this matter in Chapter 2 of Part 2. Personal observations of *S. parthenoides* also showed that throughout the Little Desert National Park and the Grampians National Park, *L. carphoides* was exclusively selected as the larval host plant by ovipositing females. However, in the central Big Desert it was discovered that *Schoenus racemosus* (Tufted Bog-sedge, Cyperaceae) as well as *L. carphoides* were being consistently chosen for oviposition. Careful observation of females at this locality revealed that *S. racemosus* was always just as acceptable for oviposition as *L. carphoides*. So far as can be determined, it appears that *S. racemosus* has not been previously recorded as a putative larval host plant of *S. parthenoides*.

In the central and south-eastern areas of the Big Desert it was also noted that the bases of *Lepidosperma viscidum* (Sticky Sword-sedge, Cyperaceae) plants were occasionally probed by ovipositing females of *S. parthenoides*. However, the infrequency of these observations may indicate that this plant is not actually a larval host of the species. A clarification of this reasoning is contained within the comments in this chapter about the oviposition behaviour of the Golden Sun-moth. These appear in the seventh paragraph under the heading '*Synemon plana* (Golden Sun-moth)'.

It seems likely that the late instar larvae of the Orange-spotted Sun-moth excavate very long (?feeding) tunnels that may follow along the roots of their larval food plants. This is suspected because several pupal exuviae of this species that were found in the south-eastern Big Desert were protruding from vertical tunnels at a minimum of 10 cm to a maximum of 50 cm away from the nearest plants of *L. carphoides*.

On a number of occasions the author has observed the adults of the Orange-spotted Sun-moth visiting flowers to feed on nectar. The species of plants that were utilised for this purpose were *Kunzea pomifera* (Muntries), *Calytrix tetragona* (Common Fringe-myrtle) and *Eucalyptus costata* (Yellow Mallee), (all Myrtaceae).

Synemon discalis (Small Orange-spotted Sun-moth)

In the SE Big Desert, Vic. (at the 'Chinaman's Well Track site'), the Small Orange-spotted Sun-moth is on the wing from late October to mid November, with the largest numbers of adults being recorded in early November. Observations of this species in the Hattah-Nowingi district, Vic. have indicated that its adult flight period commences about three weeks earlier in this area and is probably from early to late October (A. Atkins pers. comm. 2005, pers. obs. 2005).

At the 'Chinaman's Well Track site' the females were mainly recorded ovipositing at the base of *Gahnia lanigera* (Desert Saw-sedge, Cyperaceae) plants but on a few occasions they were observed probing with their ovipositors at the base of *Lepidosperma carphoides* (Black Rapier-sedge) plants. At the time that *S. discalis* was discovered at 6 km north of Hattah, it was noted by Mr. A. Atkins (pers. comm. 2005) that the females were only ovipositing at the bases of *G. lanigera* plants. *G. lanigera* was also being exclusively selected (for oviposition) by two ovipositing females of *S. discalis* that were observed by Mrs. J. T. Noelker and the author, when the species was discovered during October 2005 at the 'Nowingi (L. T. C. F. study area) site'.

The apparent rarity of extensive areas of *Gahnia lanigera* (Desert Saw-sedge) in the Wimmera-Mallee area may explain why the Small Orange-spotted Sun-moth appears to have such a restricted distribution in western Victoria. Although *G. lanigera* is widespread throughout the Hattah-Nowingi area and in the Big Desert, it seems that the Small Orange-spotted Sun-moth may require unusually dense and extensive stands of this plant to maintain viable populations. At Port Lincoln in South Australia, Mr. E. D. Edwards (pers. comm. 2000) found that *S. discalis* was probably utilising two other species of small, unidentified sedges as larval food plants. He reached this conclusion because he found several pupal exuviae of this species protruding from the ground at the bases of these plants. Despite careful searches that were conducted on several occasions (by Mrs. J. T. Noelker and the author) at the 'Chinaman's Well Track (Big Desert) site', no pupal exuviae of this species were found there.

On 31 October 1999, a male of this species was observed feeding at the flowers of *Dampiera rosmarinifolia* (Rosemary Dampiera, Goodeniaceae) at the 'Chinaman's Well

Track site' in Big Desert. This observation confirms that this is another one of the Victorian sun-moths that has a fully functional haustellum and is capable of feeding as an adult.

Synemon jcaria (Reddish-orange Sun-moth)

In 1992 it was confirmed by Mr. E. D. (Ted) Edwards that the larval food plant of the Reddish-orange Sun-moth is *Lomandra effusa* (Scented Mat-rush, Lomandraceae). Unusually, instead of feeding on the roots of their larval food plant (like the larvae of most other Australian sun-moths) the larvae of this species feed internally on its rhizomes. The presence of larvae inside a plant is indicated by rhizomes with dead or dying leaves, amongst other rhizomes with healthy foliage. This characteristic foliage dieback is caused by the feeding activities of the larvae, which eventually hollow out entire rhizomes. The larvae finally pupate inside these hollowed rhizomes and after the adults have emerged, the head, thorax and first few (anterior) abdominal segments of the pupal exuviae are left protruding from the dead rhizomes. It is possible that the life cycle of this species may take two or three years to complete. This is suspected because a final instar larva that was collected at the 'Milmed Track site' (in the eastern Big Desert, Vic.) on 5 March 2000 did not pupate until the following summer and emerge as a female adult on 24 January 2001. The Reddish-orange Sun-moth has a relatively long adult flight period that commences in late January and concludes in mid March.

The adults of this species have a very rapid flight that is similar to some of the larger skipper butterflies (Lepidoptera: Hesperiidae). However, the males are reasonably easy to observe because they often establish a circumscribed territory, within an open area that surrounds a favoured vantage point. This is often an outer twig or small branch of an old fallen eucalypt limb that has had time to lose all of its foliage. They regularly return to this vantage point after rapidly pursuing conspecific males and other flying insects. It appears that a territorial male will not usually vacate such an area until it encounters a passing female that has not yet mated.

In February 1993, the late Mr. O. F. (Frank) Noelker observed four males of *S. jcaria* as they were engaged in typical 'hill-topping' behaviour. This observation was made at the summit of a large sand-hill near the major breeding area of this species on the Milmed Track, in the eastern Big Desert (Vic.). Although 'hill-topping' is a mate location strategy that is used by many different species of insects that belong to several orders, it had not been previously reported in the Castniidae. On 4 February 2006, Mr. A. Sundholm and the author visited the summit of the same sand-hill where the above-mentioned observation had been made in 1994. On this occasion a single male of *S. jcaria* was also observed while it was 'hill-topping' at the site. The behaviour that it exhibited was very similar to the territorial behaviour that is described in the previous paragraph, except that the male was only flying in a confined area that immediately surrounded the summit of the sand-hill. For a detailed discussion on 'hill-topping' behaviour, see pp. 59 – 62 of 'Butterflies of Australia' by I. F. B. Common & D. F. Waterhouse (1981).

The females of this species behave very differently to the males and are usually very difficult to locate. Although they also have a rapid flight, it appears that they spend a lot of time resting on or near the ground, on fallen leaves or dead twigs. At such times they adopt the usual long-term resting position of sun-moths, in which all of the bright colouration on their wings is completely concealed by the cryptic colouration of the forewing uppersides. The camouflage afforded by this characteristic resting position is excellent and females at rest are almost impossible to detect. They are only likely to be observed during periods of activity when they usually fly very close to the ground as they search for oviposition sites amongst plants of *L. effusa*. The ova of this species are often deposited inside the older leaf bases of the larval host plant, so that they are positioned against one of its living rhizomes (pers. obs. 2004). Presumably, this is so that upon hatching, the larva can bore directly into the rhizome and commence to feed on its internal tissues.

Synemon nais (Orange Sun-moth)

The adult flight period of the Orange Sun-moth is from mid October to mid November, with the highest numbers appearing in early November. Although this species is very colourful, its comparatively small size and rapid flight make it difficult to observe. It is not unusual for only two or three specimens to be seen during an entire day of searching at one of the known breeding sites, at the peak of the adult flight period. Although adult activity occurs throughout the day, it is at its greatest from about 10 am to noon (Australian Eastern Daylight Saving Time). The males of this species sometimes behave in a similar way to the males of the Reddish-orange Sun-moth (*Synemon jcaria*) in that they appear to hold small territories that they defend against conspecific males (pers. obs. 1990 to 2004).

During several visits to the area where this species occurs at 2 km ENE of Walpeup (Vic.), it was noted that plants of *Grevillea huegelii* (Comb Grevillea, Proteaceae) and *Westringia rigida* (Stiff Westringia, Lamiaceae) were in full flower during the peak of the adult flight period. However, no adults of the Orange Sun-moth were ever observed to visit these flowers to feed on nectar, unlike five other species of diurnal Lepidoptera that were observed to do so. Therefore, it seems that although the Orange Sun-moth has a well-developed haustellum, it may be one of the *Synemon* species that does not feed as an adult.

The few observations that have been made by the author of ovipositing females of *S. nais* indicate that *Austrodanthonia setacea* (Bristly Wallaby-grass, Poaceae) and *Austrostipa scabra* (Rough Spear-grass, Poaceae), may both be utilised as larval host plants by this species.

Synemon theresa (Cryptic Sun-moth)

Although very little is known of the biology of the Cryptic Sun-moth, E. D. Edwards (CSIRO Division of Entomology) has placed it in the temperate subgroup of the grass-feeding group of *Synemon* species. This affinity would suggest that the larval food plant/s of this species are probably species of *Austrodanthonia* (wallaby-grasses, Poaceae). However, Young & Hunt (2005) have suggested that the larval host plant of this species may be *Themeda triandra* (Kangaroo Grass, Poaceae). This is based on an observation that was made by Mr. D. A. (Andy) Young after the extant occurrence of this species, previously presumed to be extinct, was discovered at Waterfall Gully, near Burnside, South Australia. Mr. D. A. Young observed a female of *S. theresa* as it appeared to oviposit among the tillers of a plant of *T. triandra*.

The label data of historic specimens held at the Museum of Victoria and information provided by Mr. E. D. (Ted) Edwards indicates that the adult flight period of the Cryptic Sun-moth commences in mid December and finishes in early January. However, it now seems likely that the adult flight period of the species may extend at least to the end of January or early February because Young & Hunt (2005) state that adults were recorded at Waterfall Gully (S. Aust.) on 18 & 31 January 2005.

Synemon collecta **(Striated Sun-moth)**

Observations of this species at the 'Shelley site' in NE Victoria and near Armidale in New South Wales have found that the males are more easily located than females (G. E. Wurtz pers. comm. 2000 and D. Britton pers. comm. 2000, respectively). This is probably because males fly above the grass as they search for freshly emerged, unmated females. A worthwhile area of further research work on this species would be to determine whether it has a similar mate location strategy to *Synemon plana*. The mate location behaviour of *S. plana* is discussed below under the heading '*Synemon plana* (Golden Sun-moth)'.

In Victoria, the adult flight period of the Striated Sun-moth is probably from mid-late December to early-mid January (Museum of Victoria collection data, E. D. Edwards pers. comm. 2000, G. E. Wurtz pers. comm. 2000).

At Shelley, the larvae of this species probably feed on *Austrodanthonia laevis* (Smooth Wallaby-grass, Poaceae), as it is the dominant *Austrodanthonia* species at the site (E. D. Edwards pers. comm. 1992). It is likely that the larval food plants at the other historic Victorian sites would also have been *Austrodanthonia* (wallaby-grass) species.

Synemon plana **(Golden Sun-moth)**

The adult flight period of the Golden Sun-moth is earlier in the Wimmera area of NW Victoria than it is in central and SW Victoria. This is probably because of the warmer weather conditions that usually prevail somewhat earlier in the season in the Wimmera area. For example, at the Nhill Sun-moth Reserve and the Salisbury Bushland Reserve (in

NW Vic.), it is on the wing from late October to late November (pers. obs. 1989 to 2005), while at Mount Piper (near Broadford) in central Victoria, it flies from early December until about the end of the third week in January (D. Britton pers. comm. 2002). However, during late February 2005, there was an emergence of many adult *S. plana* (at least 50 + males and 10 + females obs.) at the Nhill Sun-moth Reserve (pers. obs. 2005). This 'out of season' emergence of adults followed a normal emergence of the species in the reserve during Oct./Nov. 2004. It seems that the emergence in late February could have been triggered by a period of unusually cold and cloudy weather that occurred throughout the Wimmera area in early February 2005. During one of the coldest days of this period, 3 February 2005, the maximum temperature at Horsham only reached 11 deg. Celsius. (pers. obs. 2005). Although some adults were observed at the Nhill Sun-moth Reserve during the following November (in 2005), within the normal adult flight period of the species, it was noted that no more adults appeared in Feb. 2006 (C. R. Crouch pers. comm. 2006). To the author's knowledge there are no other records of *S. plana* adults ever emerging twice per annum at a given breeding site, throughout the entire range of the species.

It now appears that the Golden Sun-moth may have a life cycle that, under normal conditions, could take at least two years to complete. This is suspected because it would have been most unlikely that the adults that emerged at the Nhill Sun-moth Reserve during late February 2005 were the progeny of those that emerged previously, in Oct./Nov. 2004. Therefore, it seems that the unseasonably cool weather in very early February 2005 had the effect of a false Winter, and thereby caused some of the (?diapausing) final instar larvae in the population to pupate prematurely and emerge as adults during late February (2005). For further information on the duration of the early stages of *Synemon* spp. see Common & Edwards (1981) and the notes above on the life cycle of *S. jcaria*.

Although the males of the Golden Sun-moth are easily observed as they the fly rapidly around the breeding sites, at about 10 to 30 cm above the sward of grasses, the females are usually much more difficult to find. This is because the females are semi-flightless and tend not to take flight unless disturbed. It seems that the semi-flightless state of the females of this species has also altered the way that the males react to each other. With other species of sun-moths, mate-seeking males will usually (but often briefly) chase all of the conspecifics of either sex that they encounter and closely follow recently emerged (receptive) females. On some occasions the males of two species have also been observed as they briefly pursued other species of diurnal Lepidoptera such as butterflies (pers. obs. 1989 to 2004, D. Britton pers. comm. 2002). In *Synemon plana*, this 'normal' behaviour pattern appears to be modified so that patrolling males will always completely ignore flying conspecifics (of either sex) and do not expend unnecessary energy by chasing any other species of day flying Lepidoptera. While flying they appear to concentrate on searching open areas of low growing *Austrodanthonia* spp. (wallaby-grasses) for newly emerged females that have not yet mated.

Common (1990) and O'Dwyer & Attiwill (2000) briefly describe the unusual mate location strategy of *Synemon plana*, which is probably unique within the family

Castniidae (refer to Chapter 2 of Part 1 of this work for quotations of these descriptions). The author has made further observations on this aspect of the biology of *S. plana* and conducted experiments to determine how the males would respond to lures of various colours. This work was conducted during November 1999, at the Nhill Sun-moth Reserve. One of these observations indicated that newly emerged females could sometimes attract patrolling males without signaling to them by exposing their hind wings. In this instance two females were located consecutively that had recently emerged and were still in the process of drying their wings, while clinging to the outer foliage of *Austrodanthonia setacea* (Bristly Wallaby-grass) tussocks. Shortly after this, both of these females were found by a passing male. The males were somehow attracted to where the females were, even though both were motionless and were not exposing their hind wings. The first time that this took place the male landed 10 cm away from the female and spent one minute walking and fluttering around the area before finding her and then copulating without delay. On the second occasion the male landed beside the female straight away and immediately copulated with her. Perhaps the newly emerged females deliberately or inadvertently release a pheromone to which the males are sensitive and can use as a means of locating them. As it is likely that there is a significant level of competition among mate-seeking males of this species, there could be a selective advantage for males that are able to quickly find and mate with virgin females that have only just emerged. In the course of this work, the female signaling behaviour this is alluded to in Common (1990) and O'Dwyer & Attiwill (2000) was also witnessed twice. In both of these instances the females were resting on the ground. They caught the attention of males that flew over them by rapidly moving their forewings forward so that the bright yellowish-orange areas of their hindwings were exposed and then successively flapping their wings about five or six times, at a speed of approximately three flaps per second. On both of the occasions, a passing male quickly responded by landing next to and then copulating with the signaling female.

To determine whether the stimulus of the female hindwing colour was enough to attract the males of *Synemon plana*, a series of five coloured lures was placed on the ground where the highest numbers of males were flying at the Nhill Sun-moth Reserve. These lures were pieces of cardboard that were cut to approximate the size and shape of a female's hind wings and were in a range of colours that included and also exceeded the (slight) natural variation in the predominant hind wing colour of the females. The colours used were creamy-yellow, yellow, yellowish-orange, orange and dark orange. The result of this experimentation was that the flying males did not show the slightest interest in any of the lures. For this reason it seems that the flapping movements (and possible pheromones) of signaling females could have an important role to play in attracting the males. It may also be possible that the females of this species have areas of scales on their hindwings that reflect ultraviolet light. If this were the case, these reflective wing areas would probably be perceived and used as a mate location cue by patrolling males. See plate 17 and page 270 of Common & Waterhouse (1981) for illustrations of (and some information on) the wing areas of *Eurema* spp. (Lepidoptera: Pieridae) that reflect ultraviolet light.

A subsequent phone conversation (in 1999) with Dr Geoff Clarke (formerly of CSIRO Division of Entomology), revealed that in the Canberra area the males of *S. plana* seemed to be attracted to pieces of brown (beer bottle) glass. Because the lures that were used in the earlier experiment at the Nhill Sun-moth Reserve were non reflective, a series of brown glass lures were also tried at this site. Once again the patrolling males at the Nhill Sun-moth Reserve did not respond to the lures at all. Although the reason for this regional inconsistency in the responses of males to brown glass lures is uncertain, the results of these experiments highlight the need for further work to be undertaken on the unusual mate location behaviour of *S. plana*.

Shortly after copulation the females commence oviposition and probably do not mate again. At this stage they are fully gravid and appear to be incapable of flying because their abdomens are too heavy. During this early phase of oviposition they walk across the ground to search for potential larval host plants. When a female finds such a plant, it climbs into the outer foliage until a roughly vertical position is attained, with the head uppermost and the tip of the abdomen just above the surface of the soil. Once in this position the female probes the soil at the base of the plant with her extendable ovipositor, which is eventually inserted into the soil or between the tillers of the plant before one or possibly more eggs are laid. After this the ovipositor is withdrawn and the search for suitable larval host plants is resumed. It was found that the females of the Wimmera populations were able to fly for distances of up to 10 m or occasionally more (in a single flight) after they had been ovipositing for long enough to reduce the weight of the eggs that they were carrying in their abdomens. This flying ability in the latter part of their adult lives would probably benefit the species because it would ensure that some eggs from each female would be laid at a considerable distance from where it had emerged. It seems that this would increase the chances of a population surviving in the event of parts of its breeding area becoming unsuitable as a result of such causes as weed invasion. According to Mr. E. D. Edwards (pers. comm. 1993), the females of the Canberra populations of the Golden Sun-moth are also capable of flying but appear reluctant to do so and may only fly after they have been disturbed.

Observations of ovipositing females at the Nhill Sun-moth Reserve revealed that *Austrodanthonia setacea* (Bristly Wallaby-grass, Poaceae) was the most frequently chosen species for oviposition and that it is probably the larval host plant at this locality. However, on a number of visits to this site, females were observed while they appeared to oviposit at the base of *Austrostipa scabra* (Rough Spear-grass, Poaceae). Although this may be an indication that Rough Spear-grass is sometimes used as an alternative larval host plant at the Nhill Sun-moth Reserve, it is also possible that these females were merely probing the soil at the base of these plants to determine if they were the correct larval host. The latter possibility is suggested because E. D. Edwards (1997a), when explaining the difficulties associated with determining the larval host plants of some of the *Synemon* species, states that ‘the female seems to identify the grass by the tip of the ovipositor and spends much time probing the wrong plants’.

O’Dwyer & Attiwill (2000) agree that *Austrodanthonia setacea* (Bristly Wallaby-grass) is a probable larval host plant of the Golden Sun-moth. They also list the following

Austrodanthonia spp. as being other likely larval food plants of this species: *A. carphoides* (Short Wallaby-grass), *A. eriantha* (Hill Wallaby-grass) and *A. auriculata* (Lobed Wallaby-grass), (all Poaceae). In addition to this Common (1990) says that the larvae of *Synemon plana* 'feed on *Danthonia laevis*', which is now *Austrodanthonia laevis* (Smooth Wallaby-grass, Poaceae). Further, Braby & Dunford (2006) have identified two more grasses as putative larval host plants of *S. plana*. These are *Nassella neesiana* (Chilean Needle Grass) and *Bothriochloa macra* (Redleg Grass), (both Poaceae). It is significant that one of these grasses (*N. neesiana*) has been introduced to Australia from South America (Chile) and that both species belong to genera that were not previously suspected to be associated with any of the *Synemon* spp.

On 4 November 1990, the late Mr. K. V. Hateley collected a female specimen of *Synemon plana* at the Salisbury Bushland Reserve (Vic.). Shortly afterwards it was discovered that this female had laid 15 eggs. A few days later they were passed on to the author. It was found that larvae had hatched from all of these ova by 5 December 1990, after an incubation period of approximately 30 to 31 days. Although the larvae were placed into the tillers of potted *Austrodanthonia setacea* (Bristly Wallaby-grass) plants, they did not survive. It seems that this larval mortality could have been caused by the higher than natural soil temperatures that they would have been exposed to during the following January. The exposure to high temperatures would have taken place because they were in pots, where they would not have been as well insulated as they probably are when living under the ground. It is also possible that the larvae succumbed to desiccation, as the moisture levels of the soil in which the potted plants were growing would undoubtedly have fluctuated more than it would in a natural situation.

A fresh pupal casing of this species was found (by the author) at the Nhill Sun-moth Reserve on 17 November 1999. This was protruding from its roughly vertical pupal gallery to a height of about 1 cm (so that the anterior end of the fourth abdominal segment was just exposed) and was 4 cm away from the closest tussock of perennial grass, which in this case was *Austrodanthonia setacea*.

On visits to the Nhill Sun-moth Reserve during the Oct./Nov. adult flight periods of 1998, 1999 and 2000, it was noticed by Mr. C. R. Crouch, Mrs. J. T. Noelker and the author that Welcome Swallows (*Hirundo neoxena*, Aves: Hirundinidae) were taking a very heavy toll of flying males. This predation seemed to increase throughout the latter half of these adult flight periods, with loose flocks of over forty birds frequently flying just above the sward and catching many of the patrolling males that were observed. It seemed that as these periods of adult activity progressed, more and more of the local population of Welcome Swallows were becoming aware that a seasonal food resource was available.

During the above-mentioned period of time it was also observed by the author that spiders, belonging to the families Araneidae (Orb-weaving Spiders) and Lycosidae (Wolf Spiders), prey on adults of the Golden Sun-moth. While dead, silk wrapped males were occasionally seen dangling in the webs of Orb-weaving Spiders, it was Wolf Spiders that seemed to be a more common predator of *S. plana*. On several occasions a large Wolf

Spider was observed as it waited just inside the entrance to its vertical tunnel for a female to walk past, while it searched for suitable oviposition sites. When this occurred, the passing female was ambushed and seized by the Wolf Spider, before being dragged back into its tunnel so that the spider could feed on it in safety. It was observed that all of the females that were successfully caught by Wolf Spiders were in a very fresh condition, an indication that they had only recently emerged and were just starting to oviposit. Clearly, such freshly emerged females would be at their slowest and most vulnerable to Wolf Spider attack because they would still be carrying most of their ova and being comparatively heavy, would not yet be able to fly properly. So, it seems that an abundance of Wolf Spiders within a given area where the Golden Sun-moth occurs could have a negative impact on their numbers from year to year, by taking many freshly emerged females before they have completed their oviposition.

At the Nhill Sun-moth Reserve, Mrs. J. T. Noelker and the author have noted that the males (only) of *S. plana* sometimes adopt a butterfly like resting position, in which the uppersides of the wings are pressed together above the body. When this resting position is assumed, the forewings are partly concealed by the hindwings, so that only their apices are visible. While the males are at rest in this position, the comparatively pale underside colouration of the hindwings and of the visible portion (apical area) of the forewings seems to afford excellent camouflage. This especially applies to males that are resting among pale coloured, partly dried grasses and forbs. In these situations it was found that males which were resting with their wings held in the normal position for *Synemon* species (i.e. with their wings held out flat, with the forewings covering the hindwings) were much more conspicuous. This was due to the predominantly dark brown colouration of the upperside of their forewings, which in most instances was in contrast to the colour/s of the surrounding vegetation.

***Synemon selene* (Pale Sun-moth)**

Refer to Chapter 8 of Part 3 for the biology *Synemon selene* (Pale Sun-moth).

Part 2

Chapter 5

A Proposed List of Common Names for the Victorian Sun-moths

Introduction

It is important for a species to have a common name. This is especially so for an endangered species because the potentially descriptive nature of a common name can create a mental image in the minds of most people. For example, the scientific name *Dacelo novaeguineae* has little or no meaning to the general public whereas the common name of the 'Laughing Kookaburra' or simply 'Kookaburra' readily identifies this species. As public awareness and participation is a major aspect of conserving endangered species, it was considered necessary to propose a list of common names for the six Victorian sun-moth species that do not already have them. These proposed common names were kept as brief as possible and were used to highlight a useful diagnostic feature for each species. Words in the names are capitalised, except after a hyphen. Associated words are connected by a hyphen rather than by creating a compound word. When not used as the latter part of the name of a particular species, the term 'sun-moth/s' is not considered a proper noun and is therefore not capitalised.

The proposed common names are listed below, with a few notes following each one on why it was chosen. Some comments are also included regarding the history and descriptive nature of the established common names (Orange-spotted Castniid and Golden Sun-moth respectively) for *Synemon parthenoides* and *Synemon plana*.

List of proposed common names

Synemon discalis Strand, 1911. Proposed common name: **Small Orange-spotted Sun-moth**.

The most obvious characteristic that distinguishes this species from *S. parthenoides* is its smaller size. As it is otherwise so similar to that species, the common name of 'Small Orange-spotted Sun-moth' seemed to be an obvious choice. However, it is acknowledged that this name is longer than it should be. Ideally, a common name should not contain so many syllables, so it is possible that this proposed name might be changed at some time in the future. Though, an argument to support the use of this proposed common name is that the well established and widely used common names for *Psychonotis caelius taygetus*, *Danis danis serapis* and *Nacaduba cyanea arinia* (all Lepidoptera: Lycaenidae) are the Small Green-banded Blue, Large Green-banded Blue and Tailed Green-banded Blue, respectively. Obviously, it was also convenient to lengthen the common names of these similar looking butterfly species with the prefixes ‘small’, ‘large’ and ‘tailed’ so that it would be easier for the layperson to distinguish them from one another.

Synemon jcaria R. Felder, 1874. Proposed common name: **Reddish-orange Sun-moth**.

This species has extensive areas of bright reddish-orange on the upperside of its hindwings. As the underside of its forewings and hindwings are also marked with areas of bright orange it was considered that the proposed common name was appropriate and that it helps to distinguish this species from *Synemon nais*, a superficially similar species that also occurs in Victoria.

Synemon nais Klug, 1850. Proposed common name: **Orange Sun-moth**.

S. nais has all of the wing surfaces (except the upperside of the forewings) boldly patterned in bright orange. For this reason, the proposed common name was chosen as it simply describes a prominent and diagnostic feature of this species.

Synemon theresa Doubleday, 1846. Proposed common name: **Cryptic Sun-moth**.

The subtle colouration of this species was largely responsible for its proposed common name. Another reason why this name seemed to suit *S. theresa* is that it appears to be a very elusive species, not having been recorded in Victoria since the early 1900s.

Synemon collecta Swinhoe, 1892. Proposed common name: **Striated Sun-moth**.

The delicate pattern of longitudinal whitish striations on the forewing uppersides of this species inspired its proposed common name.

Synemon selene Klug, 1850. Proposed common name: **Pale Sun-moth**.

As *S. selene* is the palest of all the sun-moths that occur in Victoria (and one of the palest in Australia) it seemed that the proposed common name was a logical choice for this species. Furthermore, it became obvious that it was necessary to devise a series of common names for the five Victorian parthenogenetic morphs of *S. selene*. These are listed below with some brief explanatory notes on why they are proposed.

Pale Morph: One of the palest of the five parthenogenetic morphs.

Terrick Terrick Morph: Similar to the Pale Morph, but appears to be restricted to the Mitiamo - Terrick Terrick area.

Nhill Morph: Only known to occur at one site near Nhill.

Narrow-winged Morph: Has slightly narrower wings than the other morphs.

Dark Morph: Though pale when compared to most of the other species of sun-moths, this is the darkest of the parthenogenetic morphs of *S. selene*.

Also, there is a need to distinguish the non-parthenogenetic (and possibly extinct) South Australian morph of this species from the parthenogenetic Victorian morphs. For this reason, it is simply proposed that this morph be referred to as the '**Two Wells Morph**'. This common name is proposed because this taxon is only known (with any certainty) to have occurred in the Two Wells area of South Australia.

Refer to Chapter 1 of Part 3 for detailed descriptions of the six morphs of *Synemon selene* (Pale sun-moth).

Footnote

The term 'sun-moth' has been hyphenated in these proposed common names to encourage this two-word combination to be treated as a single entity and perhaps become amalgamated in the future. Hopefully, 'sun-moth' or even 'sunmoth' will eventually be used to refer to these insects specifically. This would help to distinguish the very distinctive sun-moths (family Castniidae) from the other families of Lepidoptera.

Comments on established common names

Synemon parthenoides R. Felder, 1874. **Orange-spotted Castniid**.

The patterns of bright orange spots and markings on the upperside of the hindwings and underside of the forewings and hindwings of this species have obviously given rise to its common name. This orange colouration is one of the most obvious features of *S. parthenoides* and is even noticeable when it is flying. The common name 'Orange-spotted Castniid' was applied to this species in 'a guide to Common Moths of The Adelaide Region' by P. B. McQuillan and J. A. Forrest (1985). Although this common name is descriptive of *S. parthenoides*, the family name 'castniid' would have little meaning to most people. For this reason it would be more appropriate to refer to this species as the 'Orange-spotted Sun-moth'. Further, the use of 'sun-moth' rather than 'castniid' in the common name of *S. parthenoides* would bring it into line with the established and/or proposed common names of the other seven species of Victorian sun-moths and would clearly indicate a family affinity to the layperson. Also see the comments in Chapter 2 of Part 2 regarding the confusion between *S. parthenoides* and *S. sophia* in McQuillan & Forrest (1985).

Synemon plana Walker, 1854. **Golden Sun-moth**.

During the early 1990's it became apparent that *S. plana* was edging towards extinction as a result of widespread alienation of its habitat. This situation prompted Mr. E. D. (Ted) Edwards and the late Dr Ebbe S. Nielsen (of the CSIRO Division of Entomology) to undertake a campaign to save some of the remaining areas of native grassland where this species still occurred. As an important aspect of this campaign was to raise public awareness, Dr Ebbe S. Nielsen first applied the common name of ‘Golden Sun-moth’ to *S. plana* during the early 1990s (E. D. Edwards pers. comm. 2000). This common name is now widely accepted and is used by government departments, amateur naturalists and conservation groups throughout Victoria, the Australian Capital Territory and New South Wales.

Although the common name ‘Golden Sun-moth’ aptly describes the predominantly bright yellow or yellowish-orange hindwing uppersides of the females of *S. plana*, it is not particularly descriptive of the males, which have dark brown hindwing uppersides. This could possibly lead to confusion in the field as the semi-flightless females of *S. plana* are rarely seen while the males are reasonably easy to observe as they fly rapidly over the grass while searching for unmated females. However, as the name ‘Golden Sun-moth’ is now firmly entrenched, it would be inappropriate to propose any other common name/s for *S. plana*.

Part 2

Chapter 6

Conservation and Management of the Victorian Sun-moths

Introduction

When the current conservation status of the Victorian sun-moths is considered, it becomes apparent that a practical and commonsense approach must be taken towards their management. In most instances the reasons why such a high proportion of the eight Victorian species have become threatened are fairly obvious. For example, widespread habitat loss caused by land clearance for agriculture, followed by weed invasion of the breeding sites that remain, are two of the most common factors that have had a negative impact on five of the Victorian species that occur in native grasslands and grassy woodlands.

This chapter provides guidelines for the management of Victoria's sun-moths and lists steps that will need to be taken if this especially interesting Gondwanan element of our invertebrate fauna is to be conserved in perpetuity.

Decline of, and current threats to the Victorian sun-moths

Synemon parthenoides (Orange-spotted Sun-moth)

Although it probably had a more extensive distribution in the past, this is the only species of sun-moth that could be regarded as common in Victoria. It occurs widely in the Big Desert and Little Desert (in western Victoria) which are both large areas of heathland and/or mallee-heath (open scrub) habitats on infertile and very sandy soils. Consequently, these two 'deserts' were not widely cleared for agricultural purposes by early settlers. By the time that farming technology had increased to a point where it was possible to viably farm these areas it had become obvious that their conservation values far outweighed their worth as marginal farmland. As a result, most of the Little Desert is now included in the Little Desert National Park while much of the Big Desert is currently protected within the boundaries of Wyperfeld National Park and the Big Desert Wilderness Area.

Synemon discalis (Small Orange-spotted Sun-moth)

It appears likely that in the past the Small Orange-spotted Sun-moth had a more extensive distribution along the southern edge of the Big Desert. The wholesale clearing of natural vegetation that took place after Europeans settled the area seems to have brought this species to the brink of extinction in Victoria, as a result of habitat loss. Despite surveys carried out by the author during the past nine years at other (more northerly) sites where Desert Saw-sedge (*Gahnia lanigera*) occurs in the Big Desert, no more populations have been found to date. A possible reason for this is that although the Chinaman's Well Track site, where the Small Orange-spotted Sun-moth breeds, is restricted in area, it contains unusually dense stands of Desert Saw-sedge that seem to be particularly healthy.

A potential threat to the Big Desert population of this species could come from firebreak construction along the Chinaman's Well Track. Disturbance of this type (i.e. soil movement) would undoubtedly kill a high percentage of the Desert Saw-sedge plants, resulting in serious damage to this occurrence of the Small Orange-spotted Sun-moth. Earth moving machinery could also transport weed seeds into the area, in addition to creating areas of disturbed soil that may favour weed establishment.

Although the Hattah site does not appear to be under threat (as it is within the Hattah-Kulkyne National Park), the occurrence of the Small Orange-spotted Sun-moth in this area cannot be regarded as secure until the population's survival can be confirmed and its size assessed. When Mrs. J. T. Nolker and the author visited the site during October 2005 no adults or plants of *G. lanigera* (putative larval host plants) were located.

The prospects for long-term survival of the occurrence of Small Orange-spotted Sun-moths at Nowingi are uncertain. This situation is due to the close proximity of this population to the proposed Long Term Containment Facility (L. T. C. F.). It is situated within the L. T. C. F. 'study area' and is approximately 200 m to the SW of the western edge of the proposed L. T. C. F. 'foot print'.

***Synemon jcaria* (Reddish-orange Sun-moth)**

This species has probably suffered a significant decline in distribution as a result of habitat loss, since Europeans settled the Wimmera and Mallee areas. It seems likely that it would have inhabited many sites on the Wimmera Plain between the Big and Little Deserts.

Unlike other Victorian sun-moths, this species is probably vulnerable to local extinctions as a result of fire. Larvae feed and finally pupate inside the rhizomes of Scented Mat-rush (*Lomandra effusa*) and are not completely protected from fire by being (far enough) underground. It is likely that hollowed out rhizomes that contain larvae or pupae would be highly combustible. The Reddish-orange Sun-moth probably relies on a cyclic recolonisation of burnt areas for its survival. As sun-moths are essentially non-migratory, this would require a metapopulation, with other colonies of the species nearby. It is apparent that a loss of satellite colonies through regional habitat clearance would decrease the likelihood of a given locality being recolonised by this species after it has been burnt out.

As the known breeding sites of this species are limited, wildfire or inappropriate prescribed burning has the potential to seriously reduce its numbers. It is also possible that any type of firebreak construction along the southern side of the Milmed Track could threaten the only known Big Desert breeding site.

The breeding population at the Kiata Native Plants and Wildlife Reserve is subject to the following threats:
(1) Soil disturbance and grazing of larval food plants by rabbits.
(2) Invasion of the site by Perennial Veldt-grass (*Ehrharta calycina*).
(3) Damage to the larval food plants caused by the continued use of a vehicular track that runs diagonally through the site from its northeastern corner.

Potential threats to the population of this species in the ‘study area’ of the proposed Long Term Containment Facility at Nowingi cannot be accurately assessed until the extent and overall abundance of the occurrence is known.

Synemon nais (Orange Sun-moth)

Clearing for agriculture appears to have reduced the Victorian distribution of this species to a few small sites near Walpeup. The historic records from the Sea Lake area suggest that it may have occurred more widely throughout the central Mallee in the past.

Parts of the largest breeding site, 2 km ENE of Walpeup (on the Ouyen Highway) are threatened by weed invasion, particularly Wild Oats (*Avena fatua*). During years of good rainfall Wild Oats have the ability to colonize any areas that have been recently disturbed, for example by vehicular movements away from the road, including trail bikes. Such disturbances have already degraded some of the restricted patches of perennial grasses that are required by the Orange Sun-moth. This disturbance has also broken the cryptogamic crust (of lichens and mosses) in places, further exacerbating the potential for weed invasion of the area generally.

Although the other two sites where this species occurs near Walpeup are in good (apparently natural) condition they may be under the following threats in the future:
(1) Inappropriate firebreak construction, leading to further habitat loss and/or weed invasion.
(2) Change of land tenure and/or land management practices at the Walpeup Recreation Reserve site, causing alienation of habitat.
(3) Weed establishment (especially by Wild Oats, *Avena fatua*) along the northern boundary of the recreation reserve site.
(4) Clearing or modification of the Mallee Research Station site to use more land for agricultural research.

***Synemon theresa* (Cryptic Sun-moth)**

Although the reason why this species seems to have died out (in Victoria) is unclear, it can probably be attributed to a widespread loss of habitat as a result of clearing for agriculture. However, it is possible that undiscovered population/s of this species persist. As one of the historic occurrences of this species was at Castlemaine, it is of interest that a small population of the Golden Sun-moth (*Synemon plana*) was discovered in the 1990s at Fryerstown (J. Landy pers. comm. 1998). This offers some hope that the Cryptic Sun-moth may have also survived past disturbance from gold mining activities in the Castlemaine-Fryerstown district. The hilly terrain and stony soils of the area limit cultivation and have thus increased the likelihood of this species surviving.

***Synemon collecta* (Striated Sun-moth)**

The Striated Sun-moth seems to prefer grassy habitats with a higher rainfall than most other Victorian sun-moths. This preference has probably lead to its extinction in many parts of its former range, as it would have occupied areas that were preferentially cleared for agriculture by early European settlers. It is also possible that its (comparatively wetter) grassy habitats were especially prone to colonisation by many species of exotic grasses and broad-leafed weeds. It is likely that these plants would probably have competed successfully with the native wallaby-grasses (*Austrodanthonia* spp.) that this species is likely to depend on for its survival.

The most serious potential threat to the Shelley site would be from a change of management practices for fire control. Any type of soil disturbance (i.e. ploughing or harrowing) for firebreak construction would be deleterious to this Striated Sun-moth population and may cause its disappearance. The site may also be vulnerable to weed invasion in the medium term.

According to Mr. G. Johnson (pers. comm. 2005) the site that was formerly occupied by this species at the Shelly airstrip was destroyed in 1989, when it was converted into a *Pinus radiata* plantation.

***Synemon plana* (Golden Sun-moth)**

Historic records indicate that since Europeans settled south-eastern Australia, this species has suffered much local extinction throughout its former range. As with the other four species of Victorian sun-moths that depend on grassy ecosystems for their survival, the Golden Sun-moth is extremely vulnerable to decline as a result of commonly adopted farming practices. For example, the annual ploughing or harrowing of the soil kills a high percentage of the perennial wallaby-grasses (*Austrodanthonia* spp.) on which the larvae of this species are thought to feed. As well as this, regular ploughing of a given area encourages an artificial ecosystem of introduced annual grasses to become established which compete with any native perennial grasses that may remain. The annual application of superphosphate or other fertilizers is also strongly detrimental to the ecological stability of native grasslands and grassy woodlands because it enables highly competitive exotic grasses and forbs to colonize such areas, which progressively causes them to become unsuitable as breeding sites for the Golden Sun-moth.

The semi flightless females of this species may have been another factor that contributed to its widespread decline. While habitat loss was causing local populations to become extinct, the limited mobility of the females could have made it difficult for the species to disperse into nearby areas of suitable habitat.

Observations that have been made during the past ten years on the population of the Golden Sun-moth in the Salisbury Bushland Reserve indicate that it has undergone a significant decline since 1990. This seems to have been caused by exotic annual grasses, which have invaded its main breeding area and are now competing with the native perennial grasses. The most invasive species of these exotic grasses at the Salisbury site are Wild Oats (*Avena fatua*), Barley Grass (*Hordeum leporinum*) and Great Brome (*Bromus diandrus*). Although all of these introduced grasses are also present at the Belcher Street (Nhill) site, it appears that they have not yet had a serious impact on the population of Golden Sun-moths that occur there. This is substantiated by the consistently high numbers of adults that have been observed there during the adult flight periods of 1998 to 2005. However, it is possible that encroachment of these grasses may pose a future threat to the ecological stability of the area and the long-term survival of the Golden (and Pale) Sun-moths at this locality. According to O'Dwyer *et al*. (2000) the population of Golden Sun-moths at Mount Piper (near Broadford) may also be threatened by the invasion of exotic annual grasses, with Yorkshire Fog Grass (*Holcus lanatus*) and Rye Grasses (*Lolium* spp.) being the most common species.

Existing conservation measures for the Victorian sun-moths

Synemon parthenoides (Orange-spotted Sun-moth)

Extensive areas where this species occurs are protected within the Big Desert Wilderness Area, Wyperfeld National Park, Little Desert National Park and the Grampians National Park.

Synemon discalis (Small Orange-spotted Sun-moth)

There are no existing conservation measures for the occurrences of this species in the SE Big Desert or within the 'study area' of the proposed Long Term Containment Facility at Nowingi. The Hattah site is afforded some protection by being within the Hattah-kulkyne National Park.

Synemon jcaria (Reddish-orange Sun-moth)

The population of this species at Kiata is protected to some extent by being within the Kiata Native Plants and Wildlife Reserve.

As the Big Desert breeding site (on the Milmed Track) is included in Wyperfeld National Park it may be reasonably secure.

Synemon nais (Orange Sun-moth)

Following the final recommendations of the Land Conservation Council, the area where this species occurs on the Ouyen Highway (2 km east-north-east of Walpeup) was designated as a bushland reserve.

To date, the breeding site within the grounds of the Mallee Research Station has been retained as part of the station’s shelterbelt system and has been fenced to exclude livestock.

Synemon theresa (Cryptic Sun-moth)

There are no existing conservation measures for this species as it is presumed to be extinct in Victoria.

Synemon collecta (Striated Sun-moth)

The site where the Striated Sun-moth occurs at Shelley is slashed at least annually. This form of management may help to maintain the ecological conditions that the species requires.

Synemon plana (Golden Sun-moth)

The small population of this species at Salisbury (in the Wimmera area) is protected to some degree by being in the Salisbury Bushland Reserve.

In 1999/2000 the Hindmarsh Shire Council and West Wimmera Tree Group successfully applied for three separate grants (for land purchase and infrastructure) to establish a flora and fauna reserve encompassing most of the area where the Golden Sun-moth occurs at Belcher Street, Nhill. After additional funding (for land title transfers and legal costs) was provided by the Hindmarsh Shire Council, this reserve was officially opened on 18 November 2004 and is now known as the Nhill Sun-moth Reserve.

A population of this species that occurs in a native grassland remnant at the Hamilton Golf Course is protected because it is a part of the Hamilton Community Parkland, which is managed for passive recreation and conservation.

Although the occurrence of this species (in the grounds of the old police station) at Fryerstown is on private land, it is afforded protection by the owners, who are personally interested in the conservation of sun-moths.

The area where the Golden Sun-moth occurs at Mount Piper (near Broadford) has been protected since 1995, after Environment Australia (formerly the Australian Nature Conservation Agency) purchased the land for conservation purposes.

The occurrence of the Golden Sun-moth at Craigieburn is protected by being within the Craigieburn Grassland Nature Conservation Reserve.

The Golden Sun-moth population near Hume City is protected to some extent by being in the Cooper Street Grassland Nature Conservation Reserve. However, FKP, a large property and investment group is proposing to develop an adjacent area of 47.4 hectares, at 25 Cooper Street, Campbellfield. The following two paragraphs were extracted from a letter (dated 7 Aug. 2006) that was sent to the author by the Senior Development Manager of FKP. These paragraphs summarise several steps that will be taken by FPK to minimise the impact that the proposed development has on the area in question:

‘Through negotiations with the department of Sustainability and Environment (DSE), nearly 16 hectares of the original area of private land that supports high quality native grassland has been exchanged with the State Government to be added to the Cooper Street grasslands area. However, as the Golden Sun Moth had been recorded from a small area of degraded grassland on the remainder of the site, a referral was submitted to the Department of the Environment and Heritage (DEH) in accordance with the Environment Protection and Biodiversity Conservation (EPBC) Act.

DEH has now issued their approval for the development of the site, subject to the condition that FKP undertake two seasons of surveys for Golden Sun Moths in the region around the site in order to assist in clarifying the distribution and abundance of the moth. KFP fully supports this condition and is keen to contribute to the long term conservation of the Golden Sun Moth through these surveys and studies’.

While the occurrence of the Golden Sun-moth at Eynesbury may be threatened by a proposed housing development, it has now been decided by the reviewing Tribunal that: ‘if the pre-construction survey identifies the presence of the Golden Sun Moth in the course of the proposed road alignment, a recovery program must be prepared and implemented to the satisfaction of the responsible authority and DSE’ (Dept. of Sustainability and Environment). However, the Tribunal has also decided that permits should be issued for native vegetation removal along Eynesbury Road and the haul road and that both applications were consistent with the Incorporated Plan Overlay and the Development Plan Overlay (B. Fox pers. comm. 2006).

Wider conservation issues (all species)

Whilst Sun-moths appear to be well adapted to survive in the Australian environment, they are vulnerable to any form of major soil disturbance. Accordingly, Sun-moths are generally indicators of sites with high conservation values such as high levels of biodiversity, the presence of other rare or threatened plants and animals, and largely intact ecological communities.

Sun-moths with their bright colouration, diurnal habits and likely Gondwanan ancestry, are a charismatic and integral part of Victoria's insect fauna. As a group they are well suited to being used for public education, with respect to raising a general awareness about the need to conserve native grassland, heathland and woodland habitats as well as the multitude of species that depend on them for their survival.

Recommended conservation strategies for the Victorian sun-moths

Synemon parthenoides (Orange-spotted Sun-moth)

No conservation strategy is required for this species, as it is already well protected in Victoria's system of national parks and nature reserves (pers. obs. 1986 to 2004).

Synemon discalis (Small Orange-spotted Sun-moth)

The Department of Sustainability and Environment needs to ensure that no soil disturbance or other damage to the Chinaman's Well Track site occurs. It is imperative that the relevant regional Department of Sustainability and Environment and Parks Victoria staff knows of the whereabouts of this area so that it is not accidentally damaged.

Entomological consultants need to conduct surveys for other Victorian populations of this species. In the Big Desert these surveys should be carried out from late October to mid-November and concentrate on areas of the southern Big Desert where Desert Saw-sedge (*Gahnia lanigera*) occurs. Sites where Desert Saw-sedge occurs in the Nowingi and Hattah-Kulkyne areas should also be surveyed for this species, especially during early/mid October, because it is likely that the adult flight period is about two weeks earlier in this area.

It is strongly recommended that the Department of Sustainability and Environment should investigate the possibility of expanding the Birdcage Flora and Fauna Reserve further into the SE Big Desert. Ideally, so that its western boundary is at 1 km west of the Chinaman's Well Track, from 0 to 5.5 km NW of its junction with the Netting Fence

Road. This would officially upgrade the conservation status of the Chinaman's Well Track site and greatly improve the chances of the Small Orange-spotted Sun-moth surviving indefinitely in the SE Big Desert.

The Victorian Government should abandon plans for construction of the proposed Long Term Containment Facility at Nowingi, at least until the distribution of the species within this area surrounding the L. T. C. F. 'footprint' is more fully known.

Synemon jcaria (Reddish-orange Sun-moth)

The Department of Sustainability and Environment should close the vehicular track that presently runs from the north-east corner to the south-west corner of the western section of the Kiata Native Plants and Wildlife Reserve (on the western side of the L. D. Argall Memorial Oval). The area that was formerly occupied by the track should then be planted out with *Lomandra effusa* (Scented Mat-rush) to extend the potential breeding area of the Reddish-orange Sun-moth in the Reserve. It is most important that the seeds and/or divisions that are used for this purpose are gathered from local (Kiata) populations of the plant. However, while this work is in progress the greatest care needs to be exercised to minimise any disturbance to the larvae or pupae of the Reddish-orange Sun-moth.

The Department of Sustainability and Environment and/or Parks Victoria needs to increase the level of routine vermin and weed control at the Kiata Native Plants and Wildlife Reserve. The main pest species to be controlled immediately are the European Rabbit (*Oryctolagus cuniculus*) throughout the reserve, and Perennial Veldt-grass (*Ehrharta calycina*), around the perimeter of the main sun-moth breeding site, on the western side of the sports oval.

The Department of Sustainability and Environment should inform regional Parks Victoria staff about the location of the Milmed Track breeding site in the eastern Big Desert. This should ensure that no damage to this area occurs from firebreak construction or other works along the southern side of the Milmed Track. The protected section of the Milmed Track should extend from about 5 to 20 km east of its junction with Booligal Road.

Consultant entomologists should carry out surveys for additional populations of this species. These surveys would need to be carried out from late January to mid-March (during the adult flight period) and should concentrate on areas of native vegetation in the Wimmera and Mallee that have not been burnt recently. Special attention needs to be paid to surveying the Hattah/Nowingi area, to more fully determine the distribution of this species within the district.

Synemon nais (Orange Sun-Moth)

The Department of Sustainability and Environment should liaise with the manager of the Mallee Research Station, to ensure that no unnecessary soil disturbance occurs at the

Mallee Research Station site. Also, it is necessary to determine whether the fence around the area in question needs to be upgraded to exclude introduced animals, such as rabbits and hares.

The Department of Sustainability and Environment should also contact the management committee of the Walpeup Recreation Reserve to inform them of the reserve's conservation significance and the need to prevent unnecessary soil disturbance throughout the reserve.

The Department of Sustainability and Environment should protect the bushland reserve at 2 km ENE of Walpeup from further unnecessary soil disturbance by:
(1) Preventing trail bike riding. Consideration should be given to fencing and signage.
(2) Liaising with Vic Roads and V/Line to ensure that minimal impact to the reserve occurs from routine maintenance of the Ouyen Highway and the railway line, both of which traverse the area.

Consultant entomologists should survey areas of suitable habitat in the Walpeup, Sea Lake and Underbool areas for other populations of this species. These surveys would need to be carried out during the adult flight period, from mid-October to mid-November.

The Department of Sustainability and Environment and/or Parks Victoria should annually monitor the abundance of exotic weeds and grasses at all three of the sun-moth sites near Walpeup. It is imperative that measures are taken to control these plants if they appear to be invading the areas of native perennial grasses at any of these sites. However, it is recommended that the techniques that are used to control such plants do not involve soil disturbance of any kind.

Public awareness of the endangered status of the Orange Sun-moth and its habitat requirements has been raised by the Mallee Wildflower Festival, which up until 2001 has been held annually during the September school holidays. Although this festival is based at the Victorian Railway Institute Hall in Ouyen, a number of excursions are organized so that members of the community can visit and appreciate some of the remaining areas of natural habitat in the Ouyen-Walpeup area. During 2000 these excursions included carefully supervised tours along a track through the Mallee Research Station site so that members of the public could be informed about the population of Orange Sun-moths that occur there. However, to continue this educational event, the steering committee must now raise a public liability insurance fund of approximately $500.00 each year to cover the cost of possible accidents to about $10 million dollars. Because this festival is organized by a non profit community group, its continuation is now in jeopardy for the above-mentioned financial reason. As it is important that the wider community is educated about the Orange Sun-moth, it is recommended that the Department of Sustainability and Environment and/or Parks Victoria should help the steering committee of this festival to raise enough funds to meet the annual insurance cost. This recommendation is also made because local awareness of the Orange Sun-moth may lead to the discovery and subsequent conservation of more populations of this species on privately owned remnants of natural habitat on farms in the Walpeup area.

Synemon theresa (Cryptic Sun-moth)

Entomological consultants should survey areas where this species occurred historically, for surviving populations. These surveys would need to be carried out from mid-December to early January, during the adult flight period. Priority should be given to surveying the Castlemaine district for the reasons that are outlined above, under the heading ‘Decline of, and current threats to the Victorian sun-moths’.

The Department of Sustainability and Environment should contact relevant wildlife departments/authorities in South Australia so that efforts to locate and conserve this species can be co-ordinated throughout its former range.

Synemon collecta (Striated Sun-moth)

The Department of Sustainability and Environment should liaise with the land manager/s of the Shelley site, to ensure that the current management practices (of annually mowing/slashing the area) are maintained and that the site is not harrowed or ploughed.

Entomological consultants to survey the Shelley district and other areas where this species occurred historically for more populations. These surveys and other fieldwork on the species would need to be carried out from late December to mid-January, during the adult flight period.

Entomological consultants should try to find live females at the Shelley site and observe them for long enough to determine which species of larval food plants they seek for oviposition.

Botanical and entomological consultants should investigate the possibility of reintroducing this species to suitable sites at the historic localities where it has died out. However, reintroductions should not be attempted where threatening processes such as weed invasion or soil disturbance are likely to occur, or where the site is small and not compact (i.e. has a high ratio of perimeter to area).

Appropriate Department of Sustainability and Environment staff and/or consultant entomologists should annually monitor the occurrence of this species at the Shelley site, to obtain regular data on its population size and density. The accumulation of such data would create a retrospective reference that will enable a decline in the abundance and/or distribution of the Shelly population to be detected, before it is too late to implement other actions that would avert its eventual extinction.

Synemon plana (Golden Sun-moth)

A *Flora and Fauna Guarantee Act* (1988) Action Statement for the Golden Sun-moth was compiled by C. O'Dwyer, S. Hadden and A. Arnold in 1998. This document lists a number of recommendations for the conservation of this species under the headings 'Intended Management Action' and 'Other Desirable Management Action'. It is most important that those who are responsible for managing the Victorian sites where the Golden Sun-moth occurs should fully understand all of these recommendations so that they can be implemented when and where appropriate.

It is of utmost importance that an annual monitoring of introduced grasses and forbs at all of the Victorian sites where this species occurs is carried out by the organizations or groups who have control over these areas. If this is done regularly, it will be apparent when the encroachment of exotic weeds becomes, or is already a problem at any of these sites (as it is at the Salisbury site). Some weed control methods that could be trialled are as follows:
(1) Mowing or carefully controlled and monitored sheep grazing during the winter months, while live annual weeds are present in the ground flora but before the native perennial grasses have commenced flowering.
(2) Elimination of pure stands of exotic weeds by spraying them with a broad-spectrum herbicide such as 'Roundup'. This spraying should be carried out during winter or early spring before the majority of these plants form most of their viable seeds.
(3) Control of exotic forbs in existing areas of native perennial grasses by spot spraying with a selective broad leaf herbicide such as 'Fusilade'. This would need to be done during winter before the native perennial grasses commence their main growing and flowering period during spring. It would also need to be determined if selective broad leaf herbicides have a detrimental effect on the subterranean early stages of the Golden Sun-moth and/or other grassland invertebrates such as Grass Cicadas (*Cicadetta* and *Urabunana* spp.).
(4) Reduction of existing seed stocks of exotic weeds by using a carefully controlled annual patch-burning regime in the most heavily weed infested areas. Depending on the local climate of the site being burnt, this should be done at a time between mid December and early January, after the adult flight period of the Golden Sun-moth at the particular locality is over and before the season's total fire ban days start. At the southernmost localities where the species occurs this may not be possible, as it would probably still be on the wing when the local fire restrictions come into force. However, at sites such as Salisbury and Nhill, it is likely that the judicious use of pre fire ban season patch-burning as a weed control method would not adversely effect the Golden Sun-moth. See Chapter 4 of Part 1 for information on how two other species of sun-moths (*Synemon* spp.) and their perennial larval host plants respond to fire.

In 1993 the Nhill College commenced to rehabilitate approximately 5.2 hectares of degraded *Austrodanthonia* grassland that is a part of the college grounds. To date, several experimental techniques have been employed in different parts of this area to control exotic weeds. These have included burning, scalping of topsoil and spraying with herbicides as well as the removal of a plantation of non-indigenous Sugar Gums. Parts of this area have also been sown down with locally collected Bristly Wallaby-grass (*Austrodanthonia setacea*) seed. As a result of this work, Bristly Wallaby-grass now comprises approximately 50% of the overall ground cover of grasses and forbs in the area. It was also encouraging that during the adult flight periods of 1998, 1999 and 2000, small numbers of male Golden Sun-moths were seen patrolling the site (C. Crouch pers. comm. 2000). Although these males could have come from the nearby Belcher Street population, it was an indication that this section of the Nhill College grounds was progressively becoming suitable as a potential breeding area. It is recommended that the Department of Sustainability and Environment should contact the Nhill College to discuss the recent progress of this project and if necessary to offer assistance with management issues, by providing manpower and/or access to appropriate machinery. Perhaps the Department of Sustainability and Environment could also help the Nhill College to raise further funds for the continuation of this work.

It is likely that there may be a residual population of Golden Sun-moths along parts of the railway line between Salisbury and Nhill. The above-mentioned *Flora and Fauna Guarantee Act* Action Statement for the Golden Sun-moth states that this stretch of railway line has been managed in the past by burning. However, it is now being annually harrowed along a 3 m wide strip on each side of the lines as a precaution against sparks from the locomotives possibly starting a fire (C. Crouch pers. comm. 2006). While this management practice is obviously necessary, it is recommended that the Department of Sustainability and Environment should inform V/Line that the most appropriate way of managing the area on either side of the harrowed strip would be to annually slash it. It may also be necessary to occasionally burn this area at a suitable time of the year to reduce the seed bank and/or density of introduced grasses and forbs. As outlined above, it is important that any such burning is carried out after the adult flight period of the Golden Sun-moth has concluded. An integrated management plan of slashing/burning would be preferable to uniformly boom spraying the area with herbicide, as the latter management practice would kill the native perennial grasses (on which the Golden Sun-moth depends) as well as the exotic grasses and forbs.

Because the Belcher Street site (where the Golden Sun-moth occurs at Nhill) holds populations of two other threatened species, it is proposed that a carefully integrated approach be taken towards its management. This is described in detail in Chapter 9 of Part 3 of this work, below ‘Nhill Morph’, under the heading ‘Additional management actions required for each morph’.

Synemon selene **(Pale Sun-moth)**

Refer to Chapter 9 of Part 3 for the conservation and management of *Synemon selene* (Pale Sun-moth).

All species

The Department of Sustainability and Environment and/or Parks Victoria should produce educational pamphlets and posters relating to the Victorian sun-moths. Ideally, these should depict some of the threatened Victorian species and contain basic information about their conservation status, biology and distribution. They should also list people or organizations that members of the public can contact if new populations of any of the threatened species are found. A good example of this type of publicity for an endangered sun-moth is the pamphlet and poster on the Golden Sun-moth (*Synemon plana*) that has already been produced by the Zoological Parks and Gardens Board, Parks Victoria and BEAM – Mitchell Environment Group.

The creation of a web site dealing with Victorian sun-moths and their conservation could tap into the recent upsurge in the use of the Internet as an information source. This would be especially useful for individuals who require information rapidly, and do not have ready access to resources such as those provided by government departments and environmental groups.

The following points reiterate and emphasize ways in which the Department of Sustainability and Environment and/or Parks Victoria, or non-government conservation groups such as the Trust for Nature (Victoria) could contribute significantly to the aim of conserving the threatened species of Victorian sun-moths.

1) Reverse the threatening ecological processes that have caused the endangered species of Victorian Sun-moths to have such restricted distributions, or in one case caused a species to apparently become extinct within the state limits.

2) Identify and implement actions that would maintain wild populations of all of the extant species of Victorian sun-moths and if at all possible, stop the threatened species from edging closer to extinction.

3) Protect and conserve in perpetuity as many as possible of the currently utilized breeding sites of the threatened Victorian sun-moths. Enhance the ecological integrity of these breeding areas (by weed control etc.) and where possible increase the distribution and local abundance of larval food plants.

4) Carry out the necessary research on all of the Victorian sun-moths to gain a better understanding of their habitat requirements, biology and current distributions throughout Victoria.

5) If possible, establish additional populations of the threatened Victorian sun-moths in suitable areas of reserved habitat within their former ranges. Under some circumstances this could be expanded to include appropriately managed habitat remnants on private land. An example of this would be suitable private land that has been placed under a Trust for Nature (Victoria) conservation covenant.

6) In as many ways as possible, such as setting up an informative and illustrated web page and through publications in appropriate nature journals, increase the public's awareness of sun-moths and the values of conserving them.

Appendices

Appendix 1. Final draft of the *Flora and Fauna Guarantee Act* 1988 Action Statement for five of the threatened Victorian *Synemon* spp. This Action Statement was compiled by the author during 2000.

FLORA AND FAUNA GUARANTEE ACTION STATEMENT

Five threatened Victorian Sun-moths (*Synemon* species)

Synemon discalis **Strand, 1911 (Small Orange-spotted Sun-moth)**

Synemon jcaria **R. Felder, 1874 (Reddish-orange Sun-moth)**

Synemon nais **Klug, 1850 (Orange Sun-moth)**

Synemon theresa **Doubleday, 1846 (Cryptic Sun-moth)**

Synemon **sp. aff.** ***collecta*** **(Striated Sun-moth)**

Description and Distribution

General description of Sun-moths

The Sun-moths (family Castniidae) are considered to have a Gondwanan origin as they occur in the Neotropical, Australian and Oriental regions. The Australian species are all placed in the single genus *Synemon,* containing 20 described and 22 undescribed species (E. D. Edwards, pers. comm.).

Sun-moths are broad-winged, colourful, day-flying moths with clubbed antennae and relatively slender bodies. Their diurnal habits are so strong that if passing clouds block out the sunshine they will immediately settle and not take flight again (unless disturbed) until sunlight returns. They usually fly rapidly, within a metre of the ground and keep their wings in motion continuously. When Sun-moths rest for short periods they often raise and lower their wings rhythmically, showing their brightly coloured hindwings. However, when resting for longer periods the hindwings are concealed by cryptically coloured forewings that harmonize perfectly with the surrounding debris and soil surface crust. Unlike most moth families, the Sun-moths are unable to fold away their antennae when at rest.

Synemon discalis (Small Orange-spotted Sun-moth)

Description

A medium-sized sun-moth with a series of prominent bright orange spots on the black uppersides of the hindwing. Wingspan: about 3.1cm in males and 3.5 cm in females.

In the Big Desert, this species is on the wing concurrently with the superficially similar Orange-spotted Sun-moth (*Synemon parthenoides*) with which it can be easily confused. The Small Orange-spotted Sun-moth can be distinguished by its smaller size, narrower wings, paler wing undersides and bronzy-grey rather than blackish-grey upper forewings.

Note: E. D. Edwards has indicated that the *Synemon* species illustrated in Common (1990) as “*S.* ?*discalis*” is actually an undescribed species from Western Australia.

Distribution

Within Victoria this species is only known to occur at two localities:

(a) in the south-eastern corner of the Big Desert, occupying an area of about 2 ha on the western side of the Chinaman's Well Track, 0.6 km north-west of its junction with Netting Fence Road;
(b) 6 km north of Hattah on the Calder Highway. This record is based on a single female collected in October 1995.

Outside Victoria the Small Orange-spotted Sun-moth occurs in limited areas on the Yorke and Eyre Peninsulas in South Australia and at Mount Ragged and Norseman in Western Australia (E. D. Edwards pers. comm.). However, E. D. Edwards has indicated that the populations in Western Australia may belong to a closely allied but separate species.

Common (1990) states that *Synemon discalis* is "widely distributed in western Victoria and South Australia". However, this is an error as this species has a restricted distribution in South Australia and was not known to occur in western Victoria until 1995.

Synemon jcaria (Reddish-orange Sun-moth)

Description

A medium-sized species with a thicker body form and narrower forewings than other Victorian sun-moths. Wingspan: about 3.5 cm in males and 3.8 cm in females. This species has bright reddish-orange uppersides to the hindwings with two small, black central markings and black borders.

Distribution

In Victoria the Reddish-orange Sun-moth has been recorded at the Kiata Native Plants and Wildlife Reserve in the Wimmera and at several localities in the Big Desert. The Big Desert localities are as follows: (a) Nhill-Murrayville Road, 33 km and 43 km north of Yanac, near the western boundary of Wyperfeld National Park and the Big Desert State Forest respectively; and, (b) Milmed Track, 9.5 km, 14.6 km and 18.1 km west of its junction with Bullygall Road, Wyperfeld National Park. Recent survey work has determined that the populations in the Kiata Native Plants and Wildlife Reserve, and on the Milmed Track (9.5 km west of its junction with Bullygall Road) in the eastern Big Desert are extant. Beyond Victoria, this species is known to occur near Mount Hope in central New South Wales, at the southern end of the Yorke Peninsula and in the Barossa Valley in South Australia, and in Western Australia at Mount Ragged and the Darling Range (E. D. Edwards pers. comm.).

Synemon nais (Orange Sun-moth)

Description

This is the smallest Victorian sun-moth; its hindwings are orange with a blackish-brown inner section that surrounds an orange spot. Near their outer edges they have a row of small black spots that are surrounded by orange. Wingspan: about 2.7 cm in males and 3 cm in females.

Distribution

The Orange Sun-moth has a restricted distribution in Victoria where it is known to occur at three sites near Walpeup. It formerly occurred at Sea Lake. The Walpeup sites are as follows: (a) Walpeup Recreation Reserve, on the northern side of the sports oval; (b) an area of remnant habitat on the western side of the main entrance to the Mallee Research Station; and, (c) in a small Bushland Reserve on both sides of the Ouyen Highway, 2 km east-north-east of Walpeup. This species also occurs at Ceduna in South Australia and near Mundrabilla in the far south-east of Western Australia (E. D. Edwards pers. comm.). Common (1990) mentions Madura as another Western Australian locality where this species occurs.

Synemon theresa (Cryptic Sun Moth)

Description

A small indistinctly marked species. Males are generally brownish-black and females paler grey; both sexes have dull orange uppersides on the hindwings with a row of spots near their outer edges (brown in males, black in females). Wingspan: about 3.1 cm in males and 3.5 cm in females.

Distribution

This species has not been recorded in Victoria for approximately one hundred years. It occurred formerly at Castlemaine, Ararat and Beechworth. It also occurred formerly in South Australia near Adelaide and at Slapes Gully in the Mount Lofty Ranges and in the Clare Valley. The most recent South Australian record is from the Clare Valley where a single specimen was collected by N. B. Tindale during the early 1960's (E. D. Edwards. pers. comm.).

Synemon sp. aff. *collecta* (Striated Sun-moth)

Description

A medium-sized sun-moth with whitish striations and markings on the dark brown uppersides of the forewings. Females are marked more prominently. Wingspan: about 3.9 cm in males and 4.1 cm in females.

This taxon is very closely related to *Synemon collecta* and may prove to be conspecific with it. However, typical *Synemon collecta* is paler and occurs only in coastal and sub-coastal Queensland from Bowen to Inglewood and Warrick (E. D. Edwards, pers. comm.).

Distribution

There appears to be only one extant population of this species in Victoria. This population occurs near Shelley on the Murray Valley Highway approximately 35 km west of Corryong, occupying a small area (about 50 m wide by 300 m long) along the south-east side of the road. A few individuals have also been recorded at the airstrip to the south-west of Shelley. Historic Victorian records from Stawell, Hamilton and Beremboke (on the western side of the Brisbane Ranges) date from the early 1900s or earlier. The species has also been recorded from the Northern Tablelands of New South Wales, from Armidale to Barrington Tops (E. D. Edwards, pers. comm.). It is still occurs near Armidale (D. Britton, pers. comm.), where a population has recently been located.

Habitat

Synemon discalis (Small Orange-spotted Sun-moth)

(a) Big Desert site: Low lying, open heathland on greyish-white sands. The dominant plant species at the one Victorian site are as follows: *Gahnia lanigera* (Desert Saw-sedge), *Lepidosperma carphoides* (Black Rapier-sedge), *Lepidosperma viscidum* (Sticky Sword-sedge), *Triodia scariosa* (Porcupine Grass), *Dampiera rosmarinifolia* (Rosemary Dampiera) and *Kunzea pomifera* (Muntries). Although trees and shrubs are scarce at the site there are a few specimens of *Eucalyptus leptophylla* (Narrow-leaf Mallee) and *Leptospermum coriaceum* (Green Tea-tree) near its margin.

(b) Hattah site: An undulating mallee community on a reddish, sandy soil. The most abundant mallee species at the site are *Eucalyptus socialis* (Grey Mallee) and *Eucalyptus costata* (Yellow Mallee). Although the ground flora is dominated by *Triodia scariosa* (Porcupine Grass), the area also contains scattered occurrences of *Gahnia lanigera* (Desert Saw Sedge). Other plants that occur at the site include: *Lepidosperma viscidum* (Sticky Sword-sedge), *Westringia rigida* (Stiff Westringia), *Leptospermum coriaceum* (Green Tea-tree) and *Baeckea behrii* (Broom Baeckea).

Synemon jcaria (Reddish-orange Sun-moth)

(a) Kiata Native Plants and Wildlife Reserve: Mixed woodland on grey loamy soil. Dominant plant species at the main site where the Reddish-orange Sun-moth occurs are as follows: *Eucalyptus largiflorens* (Black Box), *Eucalyptus leucoxylon* (Yellow Gum), *Bursaria spinosa* (Sweet Bursaria) and *Lomandra effusa* (Scented Mat-rush).

(b) Big Desert Sites: Mallee-heath on pale, sandy soils and mallee in swales variously on loamy, grey soil and/or pale orange, gritty, clay. The single Big Desert breeding site that has been found to date is in the latter habitat; this site is dominated by the following plants: *Eucalyptus dumosa* (Dumosa Mallee), *Eucalyptus costata* (Yellow Mallee), *Baeckea behrii* (Broom Baeckea), *Melaleuca lanceolata* (Moonah), *Melaleuca uncinata* (Broom-Honey-myrtle), *Acacia calamifolia* (Wallowa) and *Lomandra effusa* (Scented Mat-rush).

Synemon nais (Orange Sun-moth)

The habitat of this species in the Walpeup district is a floristically diverse combination of open grassy areas interspersed with stands of trees and shrubs. The grassy areas are dominated by *Austrodanthonia setacea* (Bristly Wallaby-grass) and *Austrostipa* species (Spear-grasses). The more abundant tree and shrub species that occur are as follows: *Callitris gracilis* (Slender Cypress-pine), *Casuarina cristata* (Belah), *Alectryon oleifolius* (Cattle-bush), *Dodonaea viscosa* subsp. *angustissima* (Narrow-leaf Hop-bush), *Acacia hakeoides* (Hakea Wattle), *Pimelea microcephala* (Mallee Rice-flower), *Hakea leucoptera* (Silver Needlewood) and *Senna artemisioides* (Desert Cassia).

Synemon theresa (Cryptic Sun-moth)

As there are no extant populations of this species, its exact habitat requirements are unclear. The locality data on historic specimens indicate that it inhabited open, grassy woodland (probably dominated by eucalypts) on well-drained and possibly stony soils. The ground flora was probably dominated by *Austrodanthonia* species (Wallaby-grasses) and *Austrostipa* species (Spear-grasses).

Synemon sp. aff. *collecta* (Striated Sun-moth)

The natural habitat of this species is uncertain as the only known Victorian population occurs in a mowed firebreak along the margin of a pine plantation. It seems likely that the Striated Sun-moth would have originally inhabited open, grassy woodland and grassland habitats that were dominated by *Austrodanthonia* species. The firebreak at Shelley is dominated by *Austrodanthonia laevis* (Smooth Wallaby-grass) (E. D. Edwards, pers. comm.).

Life History and Ecology

General life history and ecology of sun-moths

As adults, sun-moths have relatively brief lives of approximately four to ten days (depending on the species). The adults of some sun-moths have reduced mouthparts and do not feed. These species rely on nutrients that are stored in their bodies during the larval stage to sustain them through their short adult lives.

Female sun-moths mate and commence oviposition shortly after emergence from their pupae as all of their eggs are fully matured during the pupal stage. They have long, retractable ovipositors that are used to deposit their eggs beneath the soil, at or near the base of their larval food plants. After hatching, the larvae tunnel to the food plants roots or rhizomes and commence feeding. Prior to pupation each larva constructs a vertical, silk-lined tunnel to just below the soil surface from which the empty pupal casing protrudes after the adult moth has emerged.

It is not known how long any of the Victorian sun-moths take to complete their life cycles. However, Common and Edwards (1981) found that *Synemon magnifica*, a species that occurs in New South Wales, takes two to three years to complete a generation. The known larval host plants of the eight species of

Victorian sun-moths are invariably monocotyledons and belong to the families Cyperaceae, Xanthorrhoeaceae, Poaceae and Juncaceae.

Synemon discalis (Small Orange-spotted Sun-moth)

At the Big Desert site this species is on the wing from late-October to mid-November, with the highest numbers being recorded in early November. In most instances the females were recorded ovipositing at the base of *Gahnia lanigera* (Desert Saw-sedge) plants but on a few occasions they have been observed ovipositing at the base of *Lepidosperma carphoides* (Black Rapier-sedge) plants. The rarity of large areas of *Gahnia lanigera* (Desert Saw-sedge) in the Wimmera-Mallee area may explain why the Small Orange-spotted Sun-moth appears to have such a restricted distribution in western Victoria. Although *Gahnia lanigera* is widespread in the Big Desert, it seems that the Small Orange-spotted Sun-moth requires fairly dense and extensive stands of this plant to maintain viable populations. At Port Lincoln in South Australia, E. D. Edwards found *S. discalis* probably utilizing ?two other species of small, unidentified sedges as larval food plants.

On the 17th of October 1998, just prior to the adult flight period, the site where this species occurs in the Big Desert was completely burnt. During the next three weeks several adults that had obviously emerged after the fire were observed flying around the area as if nothing had happened; it was noted however, that fewer individuals appeared throughout that flight period than during 1997. Throughout the 1999 flight period the adult population density at the site was similar to that observed in 1997. These observations seem to indicate that the subterranean early stages of this species and a life cycle that possibly takes 2 to 3 years to complete are both excellent adaptations to survive wildfire.

The date on the single Hattah specimen would seem to indicate the adult flight period is earlier near Hattah than in the southern Big Desert. It seems likely that the adults would be on the wing from early to late October.

Synemon jcaria (Reddish-orange Sun-moth)

It has been confirmed that the larval food plant of the Reddish-orange Sun-moth is *Lomandra effusa* (Scented Mat-rush). Unusually, instead of feeding on the roots of their larval food plant (like the larvae of most other Australian sun-moths) the larvae of this species feed internally on its rhizomes. The presence of larvae inside a plant is indicated by rhizomes with dead foliage amongst others that are healthy. This characteristic foliage dieback is caused by the feeding activities of the larvae, which eventually hollow out entire rhizomes.

Although the adults of this species have a very rapid flight the males are reasonably easy to observe as they often return to a favourite resting place. Females behave very differently and are usually difficult to locate. This species has a relatively long adult flight period that commences in late January and concludes in mid-March.

Synemon nais (Orange Sun-moth)

The adult flight period of the Orange Sun-moth is from mid-October to mid-November with the highest numbers appearing in early November. Although this species is very colourful its comparatively small size and rapid flight make it difficult to observe. It is not unusual for only two or three specimens to be seen during an entire day of searching at one of the known breeding sites, at the peak of the adult flight period. Although adult activity occurs throughout the day it is at its greatest from about 10 am to noon (Eastern Summer Time). The few observations that have been made of ovipositing females indicate that *Austrodanthonia setacea* (Bristly Wallaby-grass) and a small, unidentified species of *Austrostipa* (Spear-grass) may be the larval food plants of this species.

Synemon theresa (Cryptic Sun-moth)

Very little is known of the ecology of the Cryptic Sun-moth. On morphological grounds, E. D. Edwards (CSIRO Division of Entomology) has placed it in the temperate subgroup of the grass-feeding group of *Synemon* species. This affinity would suggest that the larval food plant/s of this species are probably *Austrodanthonia* (Wallaby-grass) species.

The label data on historic specimens held at the Museum of Victoria and information provided by E. D. Edwards indicates that the adult flight period of this species commences in mid-December and finishes in early January.

Synemon **sp. aff.** ***collecta*** **(Striated Sun-moth)**

Observations of this species at Shelley in Victoria and Armidale in New South Wales have found that the males are more easily located than females (G. E. Wurtz and D. Britton pers. comm. respectively). This is probably due to males flying above the grass as they search for freshly emerged, unmated females. Adult Striated Sun-moths are on the wing from late December to mid-January.

At Shelley, the larvae of this species probably feed on *Austrodanthonia laevis* (Smooth Wallaby-grass) as it is the dominant *Austrodanthonia* species at the site. It is likely that the larval food plants at the other historic Victorian sites would also have been *Austrodanthonia* (Wallaby-grass) species.

Conservation Status

Synemon discalis **(Small Orange-spotted Sun-moth)**

Listed as a threatened taxon under Schedule 2 of the *Flora and Fauna Guarantee Act* 1988.
Listed as critically endangered in the NRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon jcaria **(Reddish-orange Sun-moth)**

Listed as vulnerable in the NRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon nais **(Orange Sun-moth)**

Listed as a threatened taxon under Schedule 2 of the *Flora and Fauna Guarantee Act* 1988.
Listed as endangered in the NRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon theresa **(Cryptic Sun-moth)**

Listed as a threatened taxon under Schedule 2 of the *Flora and Fauna Guarantee Act* 1988.
Listed as extinct in the NRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Synemon **sp. aff.** ***collecta*** **(Striated Sun-moth)**

Listed as a threatened taxon under Schedule 2 of the *Flora and Fauna Guarantee Act* 1988.
Listed as critically endangered in the NRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Decline and Threats

Synemon discalis **(Small Orange-spotted Sun-moth)**

Historically, it appears that the Small Orange-spotted Sun-moth would have had a more extensive distribution along the southern edge of the Big Desert. The wholesale clearing of natural vegetation that took place after Europeans settled the area seems to have brought this species to the brink of extinction in Victoria, as a result of habitat loss. Despite surveys carried out during the past three years at other (more northerly) sites where Desert Saw-sedge occurs in the Big Desert, no more populations have been found. The unusually large area of (particularly) healthy Desert Saw-sedge inhabited around Chinaman's Well Track seems to distinguish this site from other potential sites.

A possible threat to the Big Desert population of the Small Orange-spotted Sun-moth is from firebreak construction along the Chinaman's Well Track. Disturbance of this type (i.e. soil movement) would kill a high percentage of the Desert Saw-sedge plants, resulting in serious damage to the population of Small Orange-spotted Sun-moths.

Although the Hattah site does not appear to be under threat (it is within the Hattah-Kulkyne National Park), the population of the Small Orange-spotted Sun-moth in the area cannot be regarded as secure, until the population's survival can be confirmed and its size assessed.

Synemon jcaria (Reddish-orange Sun-moth)

This species has probably suffered a significant decline in distribution as a result of habitat loss, since Europeans settled the Wimmera and Mallee. It seems likely that it would have inhabited many sites on the Wimmera Plain between the Big and Little Deserts.

Unlike other Victorian sun-moths, this species is probably vulnerable to local extinctions as a result of fire. Larvae feed and finally pupate inside the rhizomes of *Lomandra* and are not protected by being underground (it is likely that hollowed out rhizomes that contain larvae or pupae would be highly combustible). It appears that this species relies on a cyclic recolonisation of burnt areas for its survival.

As the known breeding sites of this species are limited, it seems that wildfire or inappropriate prescribed burning has the potential to seriously reduce its numbers. It is also possible that the only known Big Desert breeding site could be threatened by any firebreak construction along the southern side of the Milmed Track.

The breeding population at the Kiata Native Plants and Wildlife Reserve is subject to the following threats: soil disturbance and grazing of larval food plants by rabbits, invasion of the site by *Ehrharta calycina* (Perennial Veldt-grass), and/or damage to the larval food plants caused by the continued use of a vehicular track that runs through the site.

Synemon nais (Orange Sun-moth)

Clearing for agriculture appears to have reduced the Victorian distribution of this species to a few small sites near Walpeup. The historic records from the Sea Lake area suggest that it may have occurred more widely throughout the central Mallee in the past.

Parts of the largest breeding site, 2 km east-north-east of Walpeup (on the Ouyen Highway) are threatened by weed invasion, particularly *Avena fatua* (Wild Oat). During years of good rainfall it seems that *Avena* has the ability to colonize any areas that have been disturbed, for example disturbance and compaction by vehicle movements away from the road, including trail bikes. Such disturbance has degraded some of the restricted patches of perennial grasses required by the Orange Sun-moth. This disturbance has also broken the cryptogamic crust (of lichens and mosses) in places, further exacerbating the potential for weed invasion of the area generally.

Although the other two sites where this species occurs near Walpeup are in good (natural) condition they may be under the following threats in the future:
(a) inappropriate firebreak construction, leading to further habitat loss and/or weed invasion,
(b) change of land tenure and management practices at the Recreation Reserve site, causing alienation of habitat,
(c) weed establishment (especially Wild Oats) along the northern boundary of the Recreation Reserve site,
(d) clearing or modification of the Mallee Research Station site to use more land for agricultural research.

Synemon theresa (Cryptic Sun-moth)

Although the reason why this species seems to have died out is unclear, it can probably be attributed to the widespread loss of habitat as a result of clearing for agriculture. It is possible that undiscovered population/s of this species persist. As one of the historic occurrences of this species was at Castlemaine, it is of interest that a small population of the Golden Sun-moth (*Synemon plana*) was recently discovered at Fryerstown (J. Landy pers. comm.). This is an indication that the Cryptic Sun-moth may have also survived past disturbance from gold mining activities in the Castlemaine-Fryerstown district. The hilly terrain and stony soils of the area limit cultivation and thus have increased the likelihood of this species surviving.

Synemon sp. aff. *collecta* (Striated Sun-moth)

The Striated Sun-moth seems to prefer grassy habitats with a higher rainfall than most other Victorian sun-moths. This preference has probably lead to its loss in many parts of its former range, as it would have occupied areas that were preferentially cleared for agriculture by early European settlers. It is also possible that its grassy habitats were prone to colonization by many species of exotic grasses and broad-leafed weeds.

The most serious potential threat to the Shelley site would be from a change of management practices for fire control. Ploughing or harrowing would be deleterious to the Striated Sun-moth population and may cause its disappearance. The site may also be vulnerable to weed invasion in the medium term.

Existing Conservation Measures

Synemon discalis (Small Orange-spotted Sun-moth)

There are no existing conservation measures for this species in the Big Desert, while the Hattah site is within a National Park.

Synemon jcaria (Reddish-orange Sun-moth)

1.) The population of this species at Kiata is protected to some extent by being within the Kiata Native Plants and Wildlife Reserve.

2.) As the Big Desert breeding site (on the Milmed Track) is included in Wyperfeld National Park it is reasonably secure.

Synemon nais (Orange Sun-moth)

1.) Following the final recommendations of the Land Conservation Council, the area where this species occurs on the Ouyen Highway (2 km east-north-east of Walpeup) was designated as a Bushland Reserve.

2.) To date, the breeding site within the grounds of the Mallee Research Station has been retained as part of the Station’s shelterbelt system and has been fenced to exclude livestock.

Synemon theresa (Cryptic Sun-moth)

There are no existing conservation measures for this species as it is presumed extinct.

Synemon sp. aff. *collecta* (Striated Sun-moth)

The site where the Striated Sun-moth occurs at Shelley is slashed at least annually. This form of management may help to maintain the ecological conditions that the species requires.

Wider Conservation Issues

All species

Whilst Sun-moths are well adapted to survive in the Australian environment, they are vulnerable to any form of major soil disturbance. Accordingly, Sun-moths are generally indicators of sites with high conservation values such as high levels of biodiversity, the presence of other rare or threatened plants and animals, and largely intact communities.

Sun-moths with their bright colouration, diurnal habits and likely Gondwanan ancestry, are a charismatic and integral part of Victoria’s insect fauna. As a group they are well-suited to public education, with respect to raising a general awareness about the need to conserve native grassland, heathland and woodland habitats as well as the species that depend on them for their survival.

Conservation Objectives

Long term objectives

All species

1.) Maintain populations in the wild of all four extant sun-moth species included in this Action Statement.

2.) Conserve the existing breeding sites of these sun-moth species in perpetuity and if possible establish additional populations in suitable areas.

3.) Enhance the ecological integrity of these breeding areas and where possible increase the distribution and local abundance of larval food plants.

Objectives of this Action Statement

All species

1.) Reverse the threatening processes that have caused these Sun-moths to have such restricted Victorian distributions or in some cases brought them close to extinction.

2.) To identify necessary research on these sun-moths to gain a better understanding of their habitat requirements, biology and current distribution in Victoria.

3.) Increase public awareness of sun-moths and the values of conserving them.

4.) Identify steps that would stop the remaining sun-moths from approaching extinction in Victoria.

Intended Management Actions

Synemon discalis (Small Orange-spotted Sun-moth)

1.) Department of Natural Resources and Environment to ensure that no soil disturbance or other damage to the Chinaman's Well Track site occurs. It is imperative that the relevant regional Department of Natural Resources and Environment and Parks Victoria staff knows the whereabouts of this area so that it is not accidentally damaged.

2.) Entomological consultants to conduct surveys for other Victorian populations of this species. In the Big Desert these surveys should be carried out from late October to mid-November and concentrate on areas of the southern Big Desert where Desert Saw-sedge occurs. Suitable habitat in the Hattah-Kulkyne area should also be surveyed for this species during October (as it is likely that the adult flight period is some two weeks earlier in this area).

3.) Department of Natural Resources and Environment to investigate the possibility of extending the boundary of the Birdcage Flora and Fauna Reserve to 1 km west of its present western boundary along the Chinaman's Well Track. This would officially upgrade the conservation status of the Chinaman's Well Track site and possibly improve the chances of the Small Orange-spotted Sun-moth surviving in perpetuity.

Synemon jcaria (Reddish-orange Sun-moth)

1.) Department of Natural Resources and Environment to close the vehicular track that presently runs from the north-east corner to the south-west corner of the western section of the Kiata Native Plants and Wildlife Reserve (on the western side of the L. D. Argall Memorial Oval). The area that was formerly occupied by the track should then be planted out with *Lomandra effusa* (Scented Mat-rush) to extend the potential breeding area of the Reddish-orange Sun-moth in the Reserve. It is most important that the seeds and/or divisions that are used for this purpose are gathered from local (Kiata) populations of the plant.

2.) Department of Natural Resources and Environment and/or Parks Victoria to increase the level of routine vermin and weed control at the Kiata Native Plants and Wildlife Reserve. The main pest species to be controlled immediately are rabbits throughout the reserve, and *Ehrharta calycina* (Perennial Veldt-grass), around the perimeter of the main Sun-moth breeding site, on the western side of the Oval.

3.) Department of Natural Resources and Environment to inform regional Parks Victoria staff about the location of the Milmed Track breeding site in the eastern Big Desert to ensure that no damage to this area occurs from firebreak construction or other works along the southern side of the Milmed Track. The protected section of the Milmed Track should extend from about 5 to 20 km east of its junction with Bullygall Road.

4.) Consultant entomologists to carry out surveys for additional populations of this species. These surveys would need to be carried out from late January to mid-March (during the adult flight period) and should concentrate on areas of native vegetation in the Wimmera and Mallee that have not been recently burnt.

Synemon nais (Orange Sun-Moth)

1.) Department of Natural Resources and Environment to liaise with the Mallee Research Station to make sure that no unnecessary soil disturbance occurs at the Mallee Research Station site. Also, to determine if the fence around the area needs to be upgraded to exclude rabbits and hares.

2.) Department of Natural Resources and Environment to contact the management committee of the Walpeup Recreation Reserve to inform them of the Reserve's conservation significance and the need to prevent soil disturbance throughout the Reserve.

3.) Department of Natural Resources and Environment to protect the Bushland Reserve 2 km east-north-east of Walpeup from further unnecessary soil disturbance by:
   (a) preventing trail bike riding. Consideration should be given to fencing and signage,
   (b) liaising Vic Roads and V/Line to ensure minimal impact from routine maintenance of the Ouyen Highway and the railway line, both of which traverse the area.

4.) Consultant entomologists to survey areas of suitable habitat in the Walpeup, Sea Lake and Underbool areas for other populations of this species. These surveys would need to be carried out during the adult flight period from mid-October to mid-November.

5.) Department of Natural Resources and Environment and / or Parks Victoria to biannually monitor the abundance of exotic weeds and grasses at all three of the sun-moth sites near Walpeup. It is imperative that measures are taken to control these plants if they appear to be invading the areas of native perennial grasses at any of these sites.

Synemon theresa (Cryptic Sun-moth)

1.) Entomological consultants to survey areas where this species occurred historically, for surviving populations. These surveys would need to be carried out from mid-December to early January, during the adult flight period. Priority should be given to surveying the Castlemaine district for the reasons outlined under the heading "Decline and Threats".

2.) Department of Natural Resources and Environment to contact relevant wildlife departments/authorities in South Australia so that efforts to locate and conserve this species can be co-ordinated throughout its former range.

Synemon sp. aff. *collecta* (Striated Sun-moth)

1.) Department of Natural Resources and Environment to liaise with the land manager of the Shelley site, to ensure that the current management practices are maintained and that the site is not harrowed or ploughed.

2.) Entomological consultants to survey the Shelley district and other areas where this species historically occurred for other populations. These surveys and other fieldwork on the species would need to be carried out from late December to mid-January, during the adult flight period.

3.) Entomological consultants to find live females at the Shelley site and observe them for long enough to determine which species of larval food plants they seek for oviposition.

4.) Botanical and entomological consultants to investigate the possibility of reintroducing this species to suitable sites at the historic localities where it has died out.

5.) Appropriate Department of Natural Resources and Environment staff and/or consultant entomologists to biannually monitor the Shelley site for this species, to obtain regular data on its population size and density.

Other Desirable Actions

All species

Department of Natural Resources and Environment and/or Parks Victoria should produce educational pamphlets and posters relating to these and other Sun-moths. Ideally, these should depict some of the threatened Victorian species and contain basic information about their conservation status, biology and distribution. They should also list people or organizations that members of the public can contact if new populations of these threatened species are found. A good example of this type of publicity for a threatened sun-moth is the pamphlet and poster on the Golden Sun-moth (*Synemon plana*) that has recently been produced by the Zoological Parks and Gardens Board, Parks Victoria and BEAM – Mitchell Environment Group.

Contact People

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Geoffrey Allen (Department of Natural Resources and Environment, Mildura Office): management and land tenure (Mallee sites). Ph. 03 5022 4300.

Ian Hastings (Department of Natural Resources and Environment, Ballarat Office): management and land tenure (all sites in Dept. N. R. E. South West Region) Ph. 03 5333 6508.

Gary Deal (Mallee Research Station, Walpeup): management and land tenure (Mallee Research Station and Walpeup Recreation Reserve sites). Ph. 03 5091 7200.

E. D. (Ted) Edwards (CSIRO Division of Entomology, Canberra): taxonomy, biology, distribution and management (all sites). Ph. O2 6246 4001.

Fabian Douglas (Entomologist) taxonomy, biology, distribution and management (all sites). Ph. 03 5391 8228 or 03 5395 1443.

Ian Sluiter (Ogyris Ecological Research): botany (Mallee sites). Ph. 03 5025 6500.

Neil Marriott (Trust for Nature, Victoria): botany (all sites). Ph. 03 5356 2404.

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Compiled by: Fabian Douglas.

Date: 30 October 2000

Appendix 2. An unpublished report detailing the discovery (in 2005) of an occurrence of *Synemon discalis* (Small Orange-spotted Sun-moth) within the ‘study area’ of the proposed Long Term Containment Facility at Nowingi, Victoria. This report was prepared by the author in 2005 for the Victorian Department of Sustainability and Environment.

Results of a survey for occurrences of *Synemon discalis*, Lepidoptera: Castniidae (Small Orange-spotted Sun-moth), within the Hattah-Nowingi district, including the Long Term Containment Facility (LTCF) study area.

Survey conducted by Fabian Douglas & Joan Noelker on 12 & 13 October 2005.

Map datum used for GPS locations: WGS 84

Introduction.

The Small Orange-spotted Sun-moth (*Synemon discalis*) belongs to the family Castniidae. These are day flying Lepidoptera that resemble butterflies. However, despite their appearance they are not closely related to the butterflies. The world distribution of the sun-moths (in S.E. Asia, mainland Australia and Central and South America) has lead to the widespread conclusion that they have a Gondwanan origin of considerable antiquity.

The known distribution of the Small Orange-spotted Sun-moth is restricted to the southern Yorke and Eyre Peninsulas in South Australia and within Victoria, to one small site in the south-eastern Big Desert (discovered by the author in 1997) and the Calder Highway at 6 km. north of Hattah. The latter record is only represented by a single female specimen that was collected by Mr. Andrew Atkins during October 1995. Common (1990) says that *Synemon discalis* is ‘widely distributed in western Victoria and South Australia’, however, this statement is an error. As mentioned above, this species has a restricted distribution in South Australia and was not known to occur in western Victoria until 1995. While the species may also occur at a few localities in Western Australia, it appears that at least some of the Western Australian populations may belong to a closely allied species that is undescribed. Although the Small Orange-spotted Sun-moth is not yet listed under Schedule 2 of the Victorian *Flora and Fauna Guarantee Act* 1988, it is listed as critically endangered under the N. R. E. 1999 *Threatened Invertebrate Fauna in Victoria* list. It has also been recently nominated for listing as an endangered taxon under the Commonwealth Government’s *Environment Protection and Biodiversity Conservation Act* 1999.

There is very strong circumstantial evidence to indicate that within Victoria, the larvae of the Small Orange-spotted Sun-moth feed underground on the roots of *Gahnia lanigera*

(Desert Saw Sedge) Cyperaceae. At the Big Desert site the adults are on the wing from very late October to mid November. While the complete adult flight period of the occurrence of the species near Hattah is still uncertain, it appears that it is earlier than it is in the Big Desert, with the adults probably first emerging in very late September and persisting until mid October.

Survey method.

The surveys for occurrences of the Small Orange-spotted Sun-moth were carried out during the day, between 9.00 a. m. and 6.00 p. m. E.S.T. This work was conducted on October 12 and 13, 2005, during the suspected peak of the univoltine adult flight period. Special attention was given to surveying sites in the study area of the proposed Long Term Containment Facility near Nowingi, that contain occurrences of the putative larval host plant (Desert Saw Sedge). The area on the Calder Highway where Mr. A. Atkins had previously recorded the species in 1995 was also surveyed.

As the adults of this species have a rapid flight and usually settle infrequently, a butterfly net was used to capture one of the individuals that was observed in a given area to confirm its specific identity beyond doubt. However, it was considered most unlikely that there would be any possibility of confusing the target species with any other. This is because the only other species of sun-moth that is now known to occur in the Hattah area is the Reddish-orange Sun-moth (*Synemon jcaria*), a species that is considerably different in appearance from the Small Orange-spotted Sun-moth and flies at a different time of the year.

While the survey was in progress, other species of diurnal Lepidoptera that were encountered at each of the surveyed sites were also recorded. These records were kept so as to contribute additional information regarding the biodiversity of the surveyed areas. With all of the obtained records, WGS 84 map datum was used to pinpoint their precise GPS locations. To facilitate the speedy recognition of where the surveys were carried out, the distance and direction of the localities from the nearest town was also recorded.

Survey results.

12 October, 2005:

Calder Hwy. at 6 km. N. of Hattah;
54H 0615899 UTM 6158184 Elevation 47 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
Family Nymphalidae;
Vanessa kershawi, 2 ?females, medium wing wear (feeding at flowers of *Leptospermum coreaceum*).
Family Lycaenidae;
Nacaduba biocellata biocellata, 2 males & 1 female, medium wing wear.

Four sites in the Long Term Containment Facility (LTCF) Study Area, at approximately 1.1 to 1.4 km. W. of the Calder Hwy. (at approximately 9.9 km. N. of Hattah);

Site 1, 54H 0614086 UTM 6161585 Elevation 38 m.

Records of *Synemon discalis*:

None.

Other diurnal Lepidoptera recorded:

Family Pieridae;

Belenois java teutonia, 3 males of pale form, slight to medium wing wear (migrating W.N.W.).

Site 2, 54H 0614006 UTM 6161748 Elevation 48 m.

Records of *Synemon discalis*:

2 males, fresh to slight wing wear (one of these was captured and released, to confirm the specific identity of the occurrence beyond doubt).

Other diurnal Lepidoptera recorded:

Family Pieridae;

Belenois java teutonia, 2 males of pale form, slight to medium wing wear (migrating W.N.W.).

Site 3, 54H 0613970 UTM 6161498 Elevation 46 m.

Records of *Synemon discalis*:

None.

Other diurnal Lepidoptera recorded:

Family Nymphalidae;

Vanessa kershawi, 2 ?females, slight to medium wing wear (feeding at flowers of *Westringia rigida*).

Site 4, 54H 0613839 UTM 6161398 Elevation 42 m.

Records of *Synemon discalis*:

1 male, fresh.

Other diurnal Lepidoptera recorded:

Family Pieridae;

Belenois java teutonia, 5 males of pale form, slight to medium wing wear & 1 female of pale form, medium wing wear (all migrating W.N.W.).

Family Nymphalidae;

Vanessa kershawi, 1 ?female, medium wing wear.

Family Arctiidae;

Nyctemera amica, 1 male, slight wing wear.

Two sites along the W. boundary of the Long Term Containment Facility (LTCF) Study Area, at approximately 1.7 km. W. of the Calder Hwy. (at approximately 9.9 km. N. of Hattah);

Site 1, 54H 0613384 UTM 6161882 Elevation 54 m.

Records of *Synemon discalis*:

None.

Other diurnal Lepidoptera recorded:

Family Pieridae;

Belenois java teutonia, 5-6 males of pale form, slight to medium wing wear & 1 female of pale form, medium wing wear (all migrating W.N.W.).
Family Nymphalidae;
Vanessa kershawi, 1 ?male, worn & 2 ?females, medium wing wear.
Family Lycaenidae;
Candalides heathi heathi, 1 female, worn.
Site 2, 54H 0613489 UTM 6161509 Elevation 54 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
Family Lycaenidae;
Candalides heathi heathi, 1 female, fresh.

Site on S. boundary of the Long Term Containment Facility (LTCF) Study Area, at approximately 0.9 km. W. of the Calder Hwy. (at approximately 9.3 km. N. of Hattah);
54H 0614486 UTM 6160696 Elevation 61 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
Family Pieridae;
Belenois java teutonia, 4 males of pale form, slight wing wear to worn (migrating W.N.W. to W.).
Family Nymphalidae;
Vanessa kershawi, 2 ?males, medium wing wear to worn.
Family Lycaenidae;
Nacaduba biocellata biocellata, 1 female, medium wing wear.

Site on walking track to the N.N.W. of the southern entrance road to Hattah-Kulkyne National Park, at approximately 0.2 km. E. N. E. of the Murray Valley Hwy. (at approximately 4.5 km. E. of Hattah);
54H 0620640 UTM 6152843 Elevation 52 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
None.

13 October, 2005:

Calder Hwy. at 6 km. N. of Hattah;
54H 0615899 UTM 6158184 Elevation 47 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
None.

Six sites in the Long Term Containment Facility (LTCF) Study Area, at approximately 0.8 to 1.1 km. W. of the Calder Hwy. (at approximately 9.9 km. N. of Hattah);
Site 1, 54H 0614128 UTM 6161842 Elevation 50 m.
Records of *Synemon discalis*:
14 males & 2 females, fresh to slight wing wear.
Other diurnal Lepidoptera recorded:
Family Pieridae;
Belenois java teutonia, 5 males of pale form, slight to medium wing wear (migrating W.N.W.).
Family Nymphalidae;
Vanessa kershawi, 3 ?males, slight wing wear to worn & 1 ?female, slight wing wear.
Family Noctuidae;
Periscepta polysticta, 1 male, fresh.
Site 2, 54H 0614077 UTM 6161826 Elevation 44 m.
Records of *Synemon discalis*:
1 female, fresh (observed while ovipositing at the base of a *Gahnia lanigera* plant).
Other diurnal Lepidoptera recorded:
None.
Site 3, 54H 0614095 UTM 6161790 Elevation 51 m.
Records of *Synemon discalis*:
3 males, fresh to slight wing wear.
Other diurnal Lepidoptera recorded:
None.
Site 4, 54H 0614102 UTM 6161805 Elevation 52 m.
Records of *Synemon discalis*:
1 female, fresh.
Other diurnal Lepidoptera recorded:
Family Nymphalidae;
Vanessa kershawi, 1 ?female, slight wing wear.
Site 5, 54H 0614099 UTM 6161870 Elevation 49 m.
Records of *Synemon discalis*:
2 males, fresh to slight wing wear & 4 females, fresh to worn (one of the females was observed while ovipositing at the base of a *Gahnia lanigera* plant).
Other diurnal Lepidoptera recorded:
Family Pieridae;
Belenois java teutonia, 3 males of pale form, slight to medium wear (migrating W.N.W.).
Site 6, 54H 0614086 UTM 6161875 Elevation 48 m.
Records of *Synemon discalis*:
2 males & 2 females, fresh to slight wing wear.
Other diurnal Lepidoptera recorded:
Family Pieridae;
Belenois java teutonia, 2 males of pale form, slight to medium wing wear & 1 female of pale form, slight wing wear (all migrating W.N.W.).

Site on walking track to the N. N. W. of the southern entrance road to Hattah-Kulkyne National Park, at approximately 0.2 km. E. N. E. of the Murray Valley Hwy. (at approximately 4.5 km. E. of Hattah);
54H 0620640 UTM 6152843 Elevation 52 m.
Records of *Synemon discalis*:
None.
Other diurnal Lepidoptera recorded:
Family Pieridae;
Belenois java teutonia, 1 male of pale form, slight wing wear (migrating W.).

Discussion.

The discovery of a comparatively large occurrence of *Synemon discalis* and its suspected larval host plant within the proposed Long Term Containment Facility study area is highly significant for the following reasons:

As outlined in the introduction, there was only one extant population (in the S.E. Big Desert) and one single record (from 6 km. N. of Hattah) of *Synemon discalis* known from Victoria, prior to this survey being carried out. The discovery of another population of this species immediately strengthens the prospects for its successful conservation within the state. However, the greatest concentration of sun-moths was along the top of a sand-hill that was approximately 200 m. to the S. W. of the western boundary of the proposed L.T.C.F. 'footprint'. If the proposed L.T.C.F. is constructed, it seems likely that the resulting works would have a negative impact on the habitat of this occurrence of *Synemon discalis*. For example, it is unknown what effect the habitat disturbance and loss that will undoubtedly take place during the construction work would have on the ecological balance of the area and if this disturbance etc. would in turn cause the resident population of *Synemon discalis* to decline.

The observations of two females ovipositing at the base of *Gahnia lanigera* plants is a clear indication that as with the occurrence of *Synemon discalis* in the S.E. Big Desert, this is also very likely to be the larval host plant of the species in the Nowingi area. The repeated selection of this plant by ovipositing females at both of these (disjunct) Victorian localities may indicate that the Victorian populations represent a subspecies (or perhaps a separate species) that is distinct from the occurrences in South Australia. This is hypothesized because E. D. (Ted) Edwards of the CSIRO Division of Entomology found pupal casings of the Port Lincoln population protruding from the bases of two undetermined species of small sedges, while none were found to be associated with *Gahnia lanigera* that also occurs at the site. If it is determined through future research work that the South Australian occurrences of *Synemon discalis* are distinct from the Victorian populations, it becomes apparent that at least for the time being, both taxa would probably be best regarded as critically endangered due to their very limited distributions.

Despite a careful search of more than two hours on both sides of the Calder highway (at 6 km. N. of Hattah), no adults of the Small Orange-spotted Sun-moth or plants of Desert

Saw Sedge were located. The apparent absence of both of these species at this locality may be an indication that they have died out at the site or that the kilometre reading (to the N. of Hattah) of the original record was in error. At present, this complete lack of recent records from the Hattah site increases the need for the population in the Nowingi L.T.C.F. study area to be adequately protected, preferably within an extension to the Murray Sunset National Park. Further, the situation with extant occurrences of *Synemon discalis* being currently known from only two restricted areas in Victoria highlights the need for more survey work to be carried out in an attempt to locate additional populations of the species. The results of this work would allow for a better understanding to be gained of its true conservation status and management needs within Victoria.

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Part 3:

A Detailed Study of the Pale Sun-moth, *Synemon selene* Klug, 1850

Part 3

Chapter 1

Descriptions of the Six Morphs of the Pale Sun-moth (*Synemon selene* Klug, 1850)

Introduction

Although an approximately equal ratio of males to females of *Synemon selene* was collected in South Australia after the species was first discovered (?near Two Wells) during the mid 1800s, all of the historic specimens from Victoria are females. At the time they were collected this was simply thought to be a strange coincidence. However, when D. R. Crouch, the late O. F. Noelker and the author rediscovered this species at several Victorian localities between 1991 and 1997, it was also noted that males seemed to be absent from all of these populations. Despite protracted and careful searches on these (and many following) occasions, no males were ever collected or observed. For this reason it seemed that this species might be parthenogenetic in Victoria. The situation became especially interesting after 1991, when the author determined that five morphs or forms of this species occurred in Victoria, all of which differed in various ways from the historic, non-parthenogenetic South Australian specimens (that are referred to in this work as the ‘Two Wells Morph’).

Experimental work that has been carried out (by the author) on *S. selene* since 1997 has revealed that all of the known Victorian morphs of this species are indeed parthenogenetic. This has clearly indicated that these morphs would be unable to interbreed and would therefore be genetically isolated from each other. Moreover, it is highly significant that while four of the five Victorian morphs can be easily distinguished from one another visually, all five of the morphs exhibit slight variations (i.e. within a given morph). This seems to suggest that each one of these morphs contains a certain amount of genetic variability and may be continuing to evolve, possibly by accumulating minor mutations through time, in the absence of males. Refer to Chapter 3 of Part 3 for how it was determined beyond doubt that all five the Victorian morphs of the Pale sun-moth are parthenogenetic. These parthenogenetic morphs are alluded to throughout this work as the ‘Pale Morph’, ‘Terrick Terrick Morph’, ‘Nhill Morph’, ‘Narrow-winged Morph’ and ‘Dark Morph’.

Although the five parthenogenetic morphs of *S. selene* have not been scientifically described to date, it appears that all but the Terrick Terrick Morph are morphologically different enough from each other to warrant recognition as separate subspecies. The Terrick Terrick Morph is similar to the Pale Morph and is probably only a local form of the latter. For these reasons it was deemed appropriate to compile detailed and in some cases comparative descriptions of the wing surfaces of all six of the *S. selene* morphs. These descriptions and the following illustrations are intended to provide a reference point that would enable all of the morphs of the Pale Sun-moth to be readily distinguished from one another.

If any of the five parthenogenetic morphs of the Pale Sun-moth are ever formally described as distinct subspecies, it would be the non-parthenogenetic Two Wells Morph that would become the nominotypical subspecies, as this was the morph that was originally described by Klug in 1850. Ironically, it is likely that this morph is now extinct as a result of its grassland habitat being destroyed when the last areas of the Adelaide plains were cleared and ploughed for agriculture during the late 1940s.

General description of *Synemon selene* Klug, 1850, Pale Sun-moth

As its common name implies, the Pale Sun-moth is more lightly coloured than most of the other sun-moths that occur in Australia. It is one of the largest Victorian *Synemon* species with a wingspan that varies from about 3.5 cm to about 4.7 cm. The forewing uppersides are predominantly light brown or greyish-brown with small black and white markings and pale fawn or greyish-fawn striations, which follow the veins. The hindwing uppersides are yellowish-orange with blackish spots and markings and a silvery-grey basal area. On their undersides, the forewings and hindwings are shades of pale whitish-orange with a few blackish spots and markings. Due to its distinctive markings, comparatively pale colouration and relatively large size, this species cannot be easily confused with any of the other Australian *Synemon* species.

Descriptions of the six morphs of *Synemon selene*

Note on the following wingspan measurements and descriptions.

The cited wingspans of the six morphs of the Pale Sun-moth are measurements that were taken between the forewing apices of correctly set specimens (as seen in the accompanying illustrations).

The wing areas and wing veins that are cited in the following descriptions are illustrated on page 14 and explained in detail on pages 13 to 15 of ‘Butterflies of Australia’ by I. F. B. Common and D. F. Waterhouse (1981).

Pale Morph (parthenogenetic)

Wingspan.
From about 3.5 cm. to about 4.6 cm.
Forewing upperside.

Base to submedian area: brownish-fawn with a scattering of black scales between veins, from lower side of cell to inner margin. Submedian to postmedian area: light brown with the cell enclosing a suffused black spot at its outer end that is immediately followed by a roughly triangular, white postcellular marking. Also, between veins CuA1 and 1A+2A there is a series of three suffused white markings that are narrowly lined with black along their inner edges and are angled inwards from below outer end of cell to central inner margin. Postmedian to subterminal area: blackish-brown, interrupted between veins M3 and CuA1 by an influx of light brown, crossed by brownish-fawn lines along veins and enclosing a slightly inward curving, crescent shaped, white subapical marking. This white marking commences at the costa and tapers to a blunt point at vein M3. It is also crossed by fine brownish-fawn lines along the veins. Subterminal to terminal area: light brown with termen and outer ends of veins blackish. Scale fringe: brown.

Forewing underside.

Base to median area: whitish with a slight pale orange suffusion, shading to pale orange towards median area. Median to postmedian area: pale orange, enclosing an obscure, triangular creamy-orange marking at the outer end of the cell and a faintly indicated, creamy-orange band between veins M2 and 1A+2A. This band is immediately followed along its outer edge by an obscure whitish patch. Postmedian to subterminal area: pale orange, enclosing a suffused, postcellular patch of blackish scales that is immediately followed by a whitish subapical marking, crowned near its outer edge by a series of five small, black apical spots between the costa and vein M3. Apical and terminal area: narrowly whitish with a faint orange tinge and crossed by very fine black lines along outer ends of veins. Inner margin: dull white. Termen: very narrowly black. Scale fringe: brownish-fawn.

Hindwing upperside.

Base to submedian area: silvery-grey with a fawn tinge. Submedian to median area: greyish-black, becoming black towards outer edge and enclosing a pale yellowish-orange spot at the outer end of the cell. In some specimens there is also an additional small yellowish-orange marking just to the costal side of the cell spot. Median to subterminal area: yellowish-orange with three intrusions of black, which extends from the median area in the form of two blunt points along veins Rs and M3 and a fine point that follows vein 1A+2A. Subterminal to terminal area: yellowish-orange with a series of six partly coalesced, black subterminal spots that progressively become larger towards the tornus. In some specimens the subterminal spot between veins M3 and CuA1 is considerably reduced in size. Terminal area: yellowish-orange with the outer ends of veins followed by black lines. Costa: grey. Apex: black. Termen: narrowly black. Area between vein 1A+2A and inner margin: greyish-fawn at base, becoming pale yellowish-orange towards tornus. Tornus: pale yellowish-orange, narrowly edged black. Scale fringe: yellowish-fawn, becoming yellowish at apex and tornus.

Hindwing underside.

Base to submedian area: dull white with a slight creamy sheen. Costa: dull white. Submedian to postmedian area: dull white, tinged orange along veins, enclosing a faint blackish marking towards outer end of cell and a suffused, blackish v-shaped postcellular marking that is situated so that its centre points towards the termen, between veins M3 and CuA1. Postmedian to terminal area: pale whitish-orange, partly enclosing a series of four black apical spots and entirely enclosing two black subtornal spots. In some specimens these two groups of spots are united into a continuous subterminal row by the presence of a small black spot between veins M3 and CuA1. Apical and terminal area: whitish with an orange tinge and crossed by very fine black lines along outer ends of veins. Tornus: broadly pale whitish-orange, narrowly edged black along outer end of inner margin. Termen: very narrowly black. Scale fringe: whitish-fawn with a scattering of blackish scales.

Terrick Terrick Morph (parthenogenetic)

Wingspan.
From about 3.7 cm. to about 4.6 cm.
Forewing upperside.
Similar to Pale Morph except slightly paler, with all of the white markings a little more accentuated and slightly broader.
Forewing underside.
Similar to Pale Morph except slightly paler, with the blackish markings a little more suffused.
Hindwing upperside.
Similar to Pale Morph except slightly paler, with the row of subterminal black spots slightly larger.
Hindwing underside.
Similar to Pale Morph except slightly paler, with the black markings a little less distinct.

Nhill Morph (parthenogenetic)

Wingspan.
From about 4.4 cm. to about 4.7 cm.
Forewing upperside.
Differs from the Pale Morph in that the white markings are a little more restricted and the black marking near the outer end of the cell is reduced to almost nothing. The light brown interruption to the blackish-brown postmedian to subterminal area is larger and extends to the costa between the white marking at outer end of cell and close to the inner edge of the white subapical marking. Also, the blackish-brown postmedian to subterminal area is immediately followed along its outer edge by small, transverse whitish-fawn markings between the costa and vein M3 and again between veins CuA1 and 1A+2A. In addition to these differences, the entire wing is slightly darker while the scale fringe is paler, being brownish-fawn instead of brown. Also, the costa is more convex and the apex slightly more acute (pointed) than in the Pale Morph.
Forewing underside.
Similar to Pale Morph except all of the markings are a little more accentuated and the black apical spot nearest vein M3 is faintly highlighted with white around its outer edge. The scale fringe is also paler, being whitish with a fawn tinge at the apex and tornus.
Hindwing upperside.

Differs from the Pale Morph in the following ways. All of the yellowish-orange markings are darker and would be best described as light orange. The pale orange spot at outer end of cell is smaller and never has the additional small pale orange marking on its costal side. The blunt point of black that follows vein M3 is finer and longer and in some specimens reaches the series of black subterminal spots, thereby narrowly dividing the pale orange median to subterminal area in half. Unlike the Pale Morph, this pale orange area of the wing is also crossed by very fine blackish-brown lines along the other veins and has an obscure, whitish longitudinal marking between veins M1 and M2. In some specimens there is a similar whitish marking between veins M2 and M3. Other differences from the Pale Morph are that the series of subterminal black spots do not become larger towards the tornus and that the scale fringe is pale yellowish-orange with no fawn tinge.

Hindwing underside.

Similar to Pale Morph except that the whitish-orange postmedian to terminal area is marked with white between veins M1 and M3 and CuA1 and 1A+2A. The two black apical spots that are furthest away from the apex are obscurely edged whitish on their terminal sides and the subtornal black spots are much smaller and are narrowly crowned with white around their outer edges. Also, in some specimens the subtornal spot nearest the tornus is divided longitudinally to form two very small spots. Another difference is that the scale fringe is entirely whitish-fawn and is not scattered with blackish scales.

Narrow-winged Morph (parthenogenetic)

Wingspan.

From about 3.5 cm. to about 4.2 cm.

Forewing upperside.

Differs from the Pale Morph in being darker and having the subterminal to terminal area overlaid with grey scales, especially along its inner edge and also near the termen and apex. All of the white markings are smaller, with the white markings between veins CuA1 and 1A+2A all but obscured by an overlay of grey scales. The blackish-brown postmedian to subterminal area is not interrupted by an influx of brown between veins M3 and CuA1. However, it is replaced by greyish-brown between vein CuA1 and the inner margin. Also, the wing is slightly narrower, with the costa much more convex, the inner margin slightly concave instead of straight and the apex more acute. The scale fringe is greyish-brown instead of brown.

Forewing underside.

Varies from the Pale Morph in having the base to median area slightly suffused with blackish scales and having the creamy-orange markings and obscure whitish patch in the median to postmedian area overlaid with pale orange scales. The postcellular patch of blackish scales in the postmedian to subterminal area is more pronounced and the series of five black apical spots are larger than in the Pale Morph. There is also an additional series of three very faintly indicated blackish subterminal to subtornal spots between veins CuA1 and 1A+2A. Also, the inner margin is greyish-white instead of dull white.

Hindwing upperside.

Differs from the Pale Morph in having the base to submedian area dark grey, the yellowish-orange spot at the outer end of the cell much smaller and never having the small yellowish-orange marking near its costal side. The yellowish-orange median to subterminal area is much more restricted and is crossed by fine blackish lines along the veins. In some specimens the black intrusion along vein M3 narrowly extends outwards to meet the series of black subterminal spots, dividing the yellowish-orange median to postmedian area centrally. The series of black subterminal spots are larger, close to uniform in size, and are more strongly coalesced into a continuous band. Also, the subterminal spot between vein M3 and CuA1 is never reduced in size to the extent that it sometimes is in the Pale Morph. The considerably darker greyish-fawn basal area between vein 1A+2A and the inner margin is much more extensive and reaches toward the tornus so that only a very narrow transverse band of pale yellowish-orange remains at the tornus, just inside the black tornal edging. Though the scale fringe is similar to the Pale Morph, it is slightly darker and not so obviously yellowish at the tornus.

Hindwing underside.

Generally darker than the Pale Morph. The base to submedian area and the costa are greyish-white instead of dull white and all the black markings are more pronounced. The black subterminal spot between veins M3 and CuA1 is always present and in some specimens is only slightly smaller than the other subterminal black spots in the apical and subtornal areas.

Dark Morph (parthenogenetic)

Wingspan.

From about 4.1 cm. to about 4.7 cm.

Forewing upperside.

Similar to Pale Morph except more greyish, with all of the white markings much more restricted and the subapical white marking overlaid with a scattering of brownish scales. The light brown interruption to the blackish-brown postmedian to subterminal area (between veins M3 and CuA1) is more greyish and extends in a suffused manner to the costa, leaving an obscure blackish line along the inner edge of the white subapical marking. Also, the brownish subterminal to terminal area is heavily overlaid with greyish scales, especially along its inner edge and towards the termen. The scale fringe is also greyish-brown rather than brown.

Forewing underside.

Differs from the Pale Morph in that the pale orange outer extremity of the basal to median area is suffused with black scales. Also, the postcellular patch of black scales in the postmedian to subterminal area is much more extensive, while the series of black apical spots are slightly smaller and the scale fringe is a paler shade of brownish-fawn.

Hindwing upperside.

Darker than the Pale Morph, with all of the yellowish-orange markings smaller and paler. The pale yellowish-orange median to subterminal area is broadly divided into subapical and subtornal areas by a much more extensive intrusion of black along vein M3 that always reaches the subterminal black spots. These subterminal black spots are slightly larger than in the Pale Morph and are more strongly coalesced into a continuous band with the size of the spot between vein M3 and CuA1 only slightly reduced in some specimens. The pale yellowish-orange terminal area is not as clearly defined and is crossed by heavier black lines along the veins. With some specimens this terminal area is narrowly bordered with pale grey along its outer edge, between veins CuA1 and 1A+2A. In some instances the subterminal black spot nearest the tornus is also narrowly edged with pale grey along its outer edge. In addition to these differences, the black terminal edging is slightly suffused into the pale yellowish-orange of the terminal area and the scale fringe is darkened with a heavy scattering of blackish scales and does not become yellowish towards the apex. Also, the basal area of greyish-fawn between vein 1A+2A and the inner margin is much more extensive and almost reaches the tornus, all but obscuring the much paler yellowish-orange tornal area.

Hindwing underside.

Similar to Pale Morph except that the basal to submedian area is tinged greyish and the faint blackish marking at the outer end of the cell is even more obscure. The black v-shaped postcellular marking is much more extensive (especially towards the costa) and almost reaches the subterminal space between the apical and subtornal groups of black spots. Also, the small black apical spot nearest the apex is usually missing and there is never a small black subterminal spot between veins M3 and CuA1.

Two Wells Morph (non-parthenogenetic)

Male:

Wingspan.

From about 4.5 cm. to about 4.8 cm.

Forewing upperside.

Very similar to Dark Morph except slightly paler. Also, in the some specimens the white markings are even more restricted and are partially overlaid with greyish-brown scales.

Forewing underside.

Base to submedian area: greyish-brown with an increasingly heavy overlay of pale orange scales towards the base and with the outer end of the cell pale orange. Costa: narrowly whitish-orange. Submedian to postmedian area: pale orange, enclosing a large greyish-brown patch between the costa and vein CuA1, which is crossed by very fine, pale orange lines along the veins. Postmedian to subterminal area: pale orange, enclosing a series of four small, greyish-brown subapical spots. There is also an indistinct, greyish-brown subtornal marking between veins CuA1 and CuA2. Subterminal to terminal area: pale orange, crossed by fine, greyish lines along the veins. Termen: very narrowly greyish-orange. Scale fringe: pale greyish-orange with outer edge brown.

Hindwing upperside.

Similar to Dark Morph except paler, with the yellowish-orange areas sometimes considerably reduced in size. In specimens with restricted yellowish-orange markings, the yellowish-orange terminal area appears as a series of small, roughly rectangular, yellowish-orange terminal spots.

Hindwing underside.

Base to submedian area: light grey with a slight orange tinge, enclosing a pale orange spot at the outer end of the cell. Costa: narrowly light grey with an orange tinge. Inner margin: light grey, becoming pale orange towards tornus. Submedian to median area: greyish-brown. Median to postmedian area: greyish-brown, partly enclosing two small, semi-coalesced, pale orange subapical spots and two similarly coloured but slightly larger subtornal spots. Postmedian to subterminal area: crossed by narrow greyish lines that follow the veins and separate a series of five oval, brownish-grey subterminal spots. These spots are divided into an apical group of three and a tornal group of two by an indistinct influx of pale orange between veins M3 and CuA1. Subterminal to terminal area: pale orange, becoming grey towards apex and narrowly crossed by greyish-brown lines along the veins. Termen: very narrowly greyish-brown. Scale fringe: pale greyish-orange with a slight edging of dark brown towards the apex.

Female:

Wingspan.

From about 4.5 cm. to about 4.9 cm.

Forewing upperside.

Similar to Narrow-winged Morph except slightly darker in some specimens and usually with the all of the white markings a little larger and more distinct.

Forewing underside.

Similar to Narrow-winged Morph except slightly paler. Also, there are no faintly indicated, blackish subterminal to subtornal spots between veins CuA1 and 1A+2A.

Hindwing upperside.

Similar to Narrow-winged Morph except that the basal to submedian area is light grey instead of dark grey. In addition to this, all of the yellowish-orange markings are a little more extensive in most specimens. As with the Narrow-winged Morph, the yellowish-orange median to postmedian area is sometimes divided centrally by a narrow intrusion of black along vein M3.

Hindwing underside.

Similar to Narrow-winged Morph except slightly paler and without the black subterminal spot between veins M3 and CuA1.

Illustrations

The numbered scale bars in the following illustrations denote centimetres.

Unless otherwise stated the specimens of *Synemon selene* (Pale Sun-moth) that were used in the following illustrations are currently held in the F. Douglas (author's) collection.

Figure 1. Pale Morph (parthenogenetic). Photo: T. Crouch.

Left: 6.8 km south of Murtoa, Victoria (west side of Murtoa-Glenorchy Road, near the NE corner of Murtoa Golf Course). 24 Feb. 1991 D. R. Crouch.

Right: 'Kinipanial Grassland', 5.5 km ESE of Borung, Victoria (east side of Kurting-Boort Road at 2.1 km SSW of its junction with Borung-Hurstwood Road). 25 Feb. 1999 F. Douglas.

Figure 2. Terrick Terrick Morph (parthenogenetic). Photo: T. Crouch.

Left: 10 km NNE of Mitiamo, Victoria (private property on south side of the eastern extension of Regals Road at 1.3 km east of its junction with Mitiamo-Kow Swamp Road). 24 Feb. 1999 F. Douglas.

Right: Regal Point Road at 4.5 km east of Terrick Terrick State Park, Victoria. 21 Feb. 1994 O. F. Noelker. According to P. Forman (pers. comm. 1999) the correct locality data for this specimen (and two others that were collected on the same occasion) is 10 km NNE of Mitiamo, Vic. (private property on north side of Forbes Road at 2.9 km east of its junction with Mitiamo-Kow Swamp Road). See Chapter 6 of Part 3 for the author’s comments regarding the anomalous data of this specimen.

Figure 3. Nhill Morph (parthenogenetic). Photo: T. Crouch.

Left: Nhill Sun-moth Reserve at 1.4 km east of Nhill, Victoria (north side of Belcher Street at 500m east of its junction with Nhill-Netherby Road). 13 Feb. 2000 F. Douglas.

Right: data as for the preceding specimen, except collected on 20 Feb. 1999.

Figure 4. Narrow-winged Morph (parthenogenetic). Photo: T. Crouch.

Left: Pimpinio Golf Course at 0.3 km west of Pimpinio, Victoria (south side of Golf Course Road at 0.3 km west of its junction with the Western Highway). 22 Feb. 2004 F. Douglas.

Right: 4.5 km SSE of Jung, Victoria (private property at 300 m east of Flume Road at 2.8 km south of its junction with the Wimmera Highway). 12 Feb. 2000 F. Douglas.

Figure 5. Dark Morph (parthenogenetic). Photo: T. Crouch.

Left: Pimpinio Golf Course at 0.3 km west of Pimpinio, Victoria (south side of Golf Course Road at 0.3 km west of its junction with the Western Highway). 21 Feb. 1999 F. Douglas.

Left: 4.3 km SE of Dimboola, Victoria (private property on south side of Old Minyip Road at 0.3 km east of its junction with the Western Highway). 18 Feb. 1998 F. Douglas.

Figure 6. Pale examples of the Two Wells Morph (non-parthenogenetic).

Left: male. 3 miles north of Two Wells, South Australia (34.32S. 138.31E.). 4 Mar. 1948 N. B. Tindale. A.N.I.C. database no. 8375 (one of thirteen male specimens with this database no.). Specimen currently held in the Australian National Insect Collection (CSIRO Division of Entomology).

Right: female. Data as for male except A.N.I.C. database no. 8372 (one of eleven female specimens with this database no.). Specimen currently held in the Australian National Insect Collection (CSIRO Division of Entomology).

Figure 7. Dark examples of the Two Wells Morph (non-parthenogenetic).

Left: male. Two Wells, South Australia (34.35S. 138.31E.). 4 Mar. 1948 F. M. Angel. A.N.I.C. database no. 8373 (one of five male specimens with this database no.). Specimen currently held in the Australian National Insect Collection (CSIRO Division of Entomology).

Right: female. Data as for male except specimen collected on 4 Mar. 1937 and A.N.I.C. database no. 8371 (one of four female specimens with this database no.). Specimen currently held in the Australian National Insect Collection (CSIRO Division of Entomology).

Part 3

Chapter 2

Distribution and Conservation Status of the Pale Sun-moth Morphs

Introduction

To date, the Pale Sun-moth has only been recorded in South Australia and Victoria. It was first described as *Synemon selene* by J. C. F. Klug in 1850. Subsequently, C. Swinhoe described the same species as *Synemon adelaida* in 1892. It is likely that both of these descriptions were of specimens from the Adelaide Plains (?Two Wells area), 30 km north of Adelaide, South Australia, where it appears that the species is now extinct as a result of clearing for agriculture. The only other South Australian locality where this species has been collected is Lyndoch, in the southern Barossa Valley, 42.5 km NNE of Adelaide. This record is represented by a single historic female specimen that appears to belong to the parthenogenetic Pale Morph. It is also possible that another historic female specimen of the Pale Morph was collected in South Australia. However, the data label on this specimen is ambiguous and confusing as it reads 'Murray River near Vic. - S. A. border'.

Within Victoria the Pale Sun-moth was collected historically (from the late 1800s to the early-mid 1900s) at Murtoa, Kewell, Rapanyup and Nhill. Following this, it was thought to be also extinct in Victoria (due to habitat loss) until it was rediscovered by the late O. F. (Frank) Noelker and the author during 1991. This discovery was made at the Brynterion Flora and Fauna Reserve, 4.9 km ENE of Lubeck. After this initial discovery, the species was found at several more localities in the Wimmera area and at some sites on the Victorian Riverine Plain, near Borung and Mitiamo. For a more detailed account of the nomenclature and collection history of the Pale Sun-moth, see Part 3, Chapter 6.

Before south-eastern Australia was settled by Europeans it seems likely that the Pale Sun-moth would have had a much wider occurrence on the grassy plains of Victoria and South Australia. However, the widespread alienation of grassy habitats that followed this event has undoubtedly caused a dramatic reduction in the distribution of this species. It is now regarded as endangered in Victoria, with three of the Victorian morphs listed as endangered and two listed as critically endangered in the unpublished 1999 *Threatened Invertebrate Fauna in Victoria* list (former Dept. of Natural Resources and Environment 1999).

Simplified locality names for the Pale Sun-moth sites

To avoid the unnecessary duplication of information in this work, simplified names for the following localities will be used throughout the other chapters of Part 3. These names (in bold type and bracketed) follow each locality that is listed below.

Distribution of the Pale Sun-moth

Two Wells Morph

No extant occurrences known. Not recorded or collected since 4 March 1948.

Formerly known to occur at approximately 4 km north of Two Wells, 30 km north of Adelaide, South Australia (ANIC database). **(Two Wells site.)**

It is possible though, that some of the early specimens of this morph that are simply labeled 'Adelaide' (ANIC database), may have been collected at other sites on the Adelaide Plains.

Pale Morph

Four extant populations are known in Victoria. Three of these occur in the Wimmera area and one is situated near Borung, which is situated between Boort and Wedderburn. The precise localities are as follows:

1) Private property, 4.5 km SSE of Jung. AMG 237433, 300 m east of Flume Road, 2.8 km south of its junction with the Wimmera Highway. At this locality the pale morph occurs sympatrically with the Narrow-winged Morph and the Dark Morph. **(Jung site.)**

2) Private property, 7.3 km SSE of Murtoa. AMG 347402, 0.4 km south of Hopefields Road, 2.7 km east of its junction with Murtoa-Glenorchy Road. At this locality the pale morph occurs sympatrically with the Dark Morph. **(Murtoa site.)**

3) Brynterion Flora and Fauna Reserve, 4.9 km ENE of Lubeck. AMG 430336, Brynterion Road, 2.9 km NNE of its junction with Lubeck Road. **(Brynterion site.)**

4) 'Kinipanial Grassland', land owned by Trust for Nature (Victoria), 5.5 km ESE of Borung. AMG 515769, east side of Kurting-Boort Road, 2.1 km SSW of its junction with Borung-Hurstwood Road. **(Borung site.)**

Also recorded at the following sites in the Wimmera during 1991, but not since:

1) Barrabool Flora and Fauna Reserve, 8.4 km south of Murtoa. AMG 312376, 0.4 km west of Barrabool Road, 4 km south of its junction with Murtoa-Glenorchy Road. **(Barrabool site.)**

2) Western verge of Murtoa-Glenorchy Road, 6.8 km south of Murtoa. AMG 330393, Near the NE corner of Murtoa Golf Course. **(Murtoa-Glenorchy Road site.)**

Historic records, prior to 1940:

1) Murtoa, Victoria (Museum of Victoria data).

2) Rupanyup, Victoria (ANIC database).

3) Kewell, Victoria (Museum of Victoria data).

4) Western District, Victoria (Museum of Victoria data).

5) Lyndoch, 42.5 km NNE of Adelaide, South Australia (ANIC database). Only one (?parthenogenetic) female specimen known from this locality that seems to belong to this morph.

6) Murray River near South Australian-Victorian Border (?Renmark Area), (ANIC database). This record is also represented by a single (?parthenogenetic) female specimen that appears to belong to this morph.

Terrick Terrick Morph

Known to occur at three localities in Victoria, near Mitiamo. These are as follows:

1) Mitiamo Golf Course, 3.5 km NNW of Mitiamo. AMG 501922, west side of northern continuation of Eaglehawk-Mitiamo Road, 0.5 km north of its west junction with J. Leech’s Road. **(Mitiamo site.)**

2) Private property, 10 km NNE of Mitiamo. AMG 556981, south side of eastern extension of Regals Road, 1.3 km east of its junction with Mitiamo-Kow Swamp Road. **(Regals Road site.)**

3) Private property, 10 km NE of Mitiamo. AMG 573969, north side of Forbes Road, 2.9 km east of its junction with Mitiamo-Kow Swamp Road. **(Forbes Road site.)**

Nhill Morph

Only known to occur at one site near Nhill, in the Wimmera area of Victoria. This is as follows:

Land owned by the Hindmarsh Shire Council + private property, 1.4 km east of Nhill. AMG 596787, Nhill Sun-moth Reserve on north side of Belcher Street, 500m east of its junction with Nhill-Netherby Road. At this locality the Nhill Morph occurs sympatrically with the Golden Sun-moth, *Synemon plana*. **(Nhill site.)**

Historic records, prior to 1940:

1) Nhill, Victoria (Museum of Victoria data).

Narrow-winged Morph

Known to occur at the three following sites in the Victorian Wimmera area:

1) Private property, 4.3 km SE of Dimboola. AMG 969631, south side of Old Minyip Road, 0.3 km east of its junction with Western Highway. At this locality the Narrow-winged Morph occurs sympatrically with the Dark Morph. **(Dimboola site.)**

2) Pimpinio Golf Course, 0.3 km west of Pimpinio. AMG 997499, south side of Golf Course Road, 0.3 km west of Pimpinio. At this locality the Narrow-winged Morph occurs sympatrically with the Dark Morph. **(Pimpinio site.)**

3) Private property, 4.5 km SSE of Jung. See distribution of extant populations of Pale Morph, site 1, for the precise location of this site. At this locality the Narrow-winged Morph occurs sympatrically with the Pale Morph and the Dark Morph. **(Jung site.)**

Dark Morph

Extant populations of this morph are known to occur at the five following Victorian sites in the Wimmera area:

1) Private property, 4.3 km SE of Dimboola. See distribution of Narrow-winged Morph, site 1, for the precise location of this site. At this locality the Dark Morph occurs sympatrically with the Narrow-winged Morph. **(Dimboola site.)**

2) Pimpinio Golf Course. See distribution of Narrow-winged Morph, site 2, for the precise location of this site. At this locality the Dark Morph occurs sympatrically with the Narrow-winged Morph. **(Pimpinio site.)**

3) Private property, 4.5 km SSE of Jung. See distribution of extant populations of Pale Morph, site 1, for the precise location of this site. At this locality the Dark Morph occurs sympatrically with the Pale Morph and the Narrow-winged Morph. **(Jung site.)**

4) Private property, 7.3 km SSE of Murtoa. See distribution of extant populations of Pale Morph, site 2, for the precise location of this site. At this locality the Dark Morph occurs sympatrically with the Pale Morph. **(Murtoa site.)**

5) Private property, 5.5 km east by north of Wail. AMG 042599. 0.3 km west of Geodetic Road, 0.8 km south of its junction with Wail East Road. **(Wail site.)**

Also recorded at the following site in the Wimmera during 1965, but not since:

1) 10 km east of Dimboola, Victoria (N. T. Starick pers. comm.).

Historic records, prior to 1940:

1) Murtoa, Victoria (Museum of Victoria data).

Conservation status of the Pale Sun-moth

Two Wells Morph

Not officially listed (as extinct or critically endangered) by the South Australian Department of Environment and Heritage (Peter Copley pers. comm., National Parks & Wildlife Service, S. A., 2002).

Thought to be extinct (E. D. [Ted] Edwards pers. comm., CSIRO Division of Entomology, 1990).

Pale Morph

Listed (under *Synemon* sp. aff. *selene*) as regionally and nationally endangered by Douglas (1993).

Listed (under *Synemon selene*) as endangered in Victoria by Venn (1993).

Listed as endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Terrick Terrick Morph

Listed as endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Nhill Morph

Listed as critically endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Narrow-winged Morph

Listed as critically endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

Dark Morph

Listed (under *Synemon* sp. aff. *selene*) as regionally and nationally endangered by Douglas (1993).

Listed (under *Synemon selene*) as endangered in Victoria by Venn (1993).

Listed as endangered in the unpublished DNRE 1999 *Threatened Invertebrate Fauna in Victoria* list.

All Victorian morphs

To date none of the five Victorian morphs of the Pale Sun-moth have been listed under the (Victorian) *Flora and Fauna Guarantee Act* 1988.

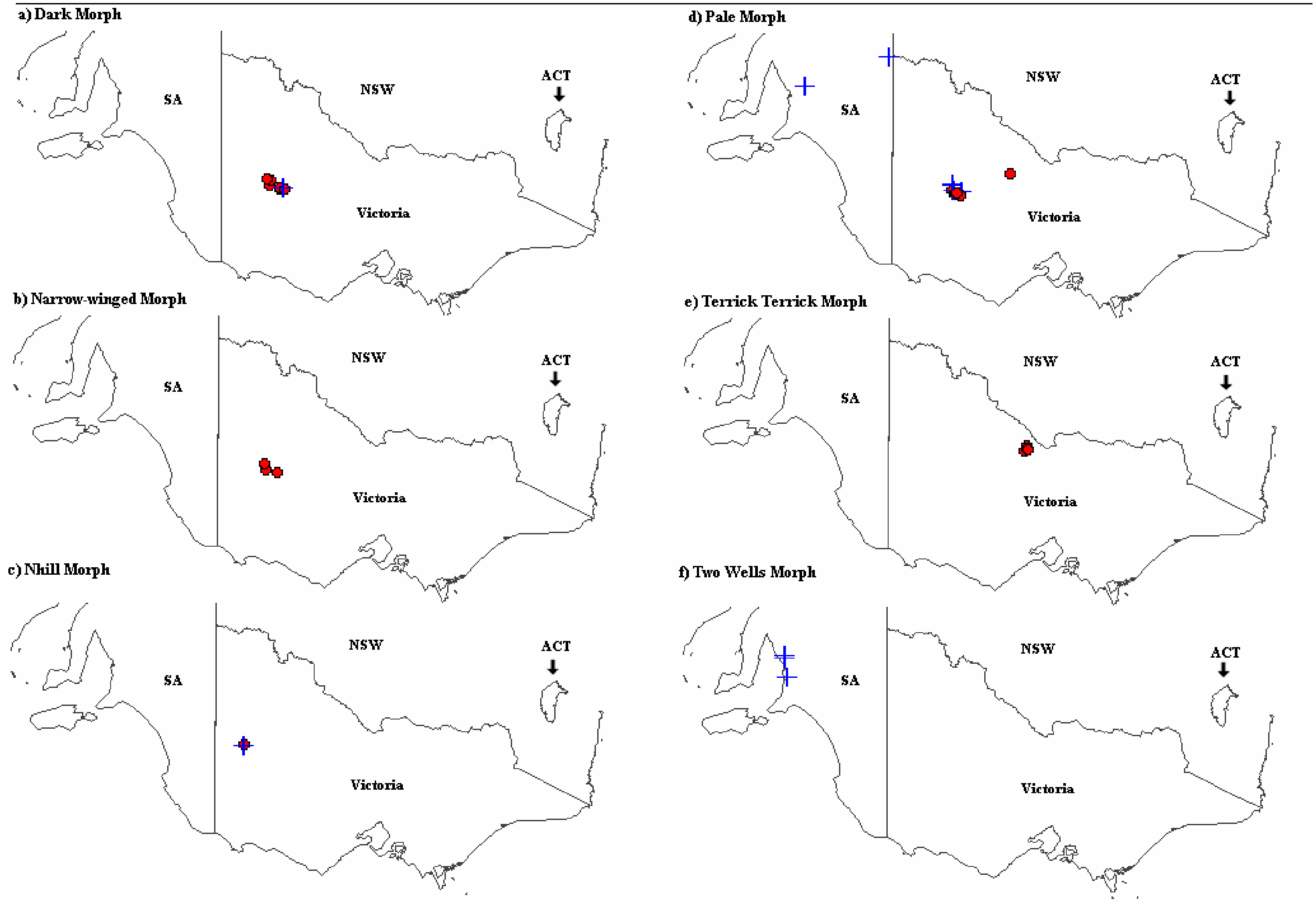
Discussion

In the author’s opinion, it would be appropriate to regard the entire parthenogenetic morph complex of the Pale Sun-moth as critically endangered. The term ‘critically endangered’ is used by the Flora and Fauna Directorate (of the Victorian Department of Sustainability and Environment) to define taxa or species that are ‘facing an extremely high risk of extinction in the wild in the immediate future’. Observations that have been made by the author during the past fifteen years clearly indicate that all of the Victorian morphs/populations of the Pale Sun-moth easily fit into this category. Refer to Part 3, Chapter 9 for detailed information on/and recommendations re the conservation and management of all of the Victorian parthenogenetic morphs of the Pale Sun-moth.

Appendices

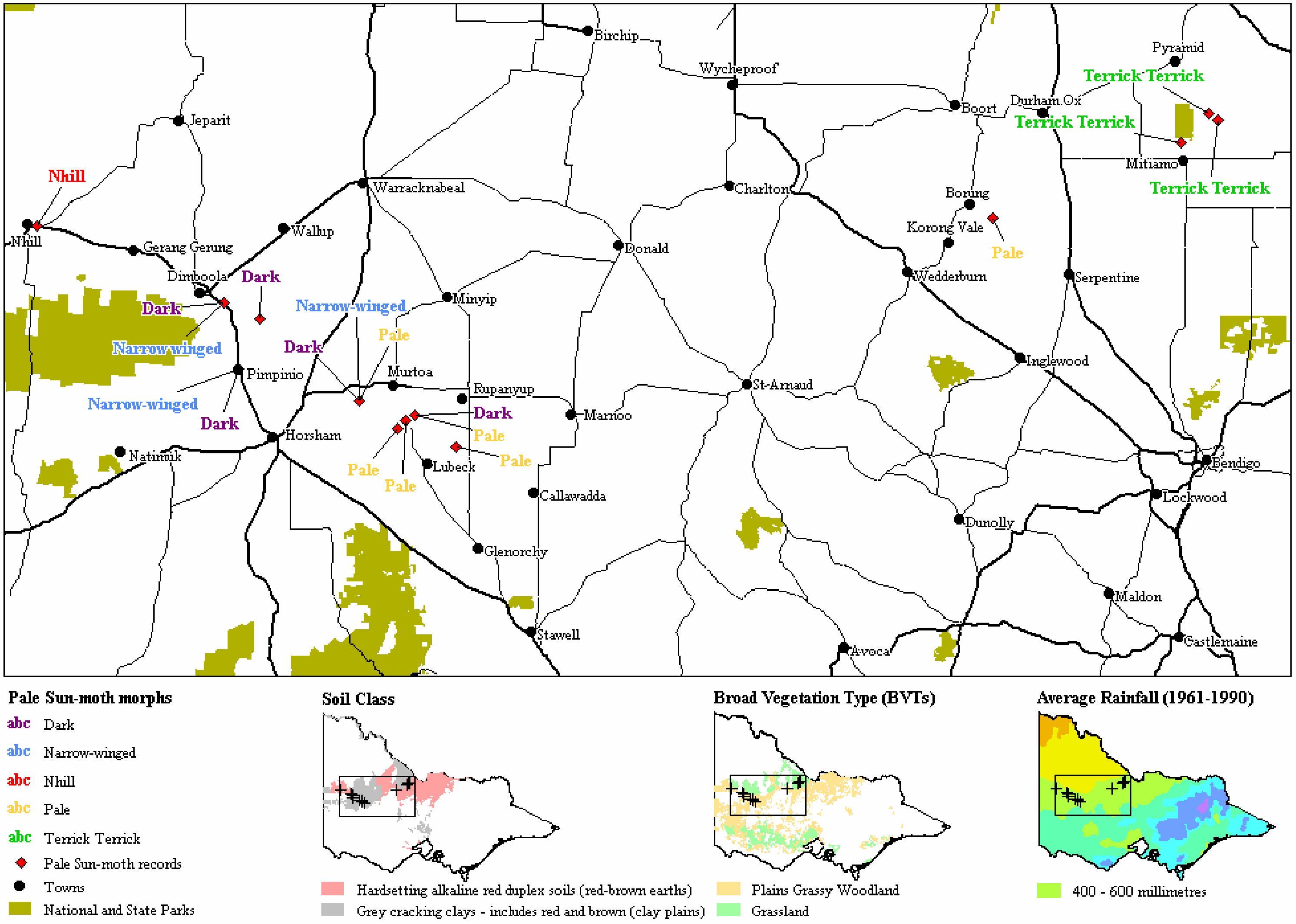
Appendix 1. Distribution map of historic and extant records of *Synemon selene* (prepared by B. Baker, based on information provided by the author).

Records of the Pale Sun-moth (*Synemon selene* Klug, 1850)



Appendix 2. Distribution map of extant records of Synemon selene, since 1990 (prepared by B. Baker, based on information provided by the author).

Records of the Pale Sun-moth (*Synemon selene* Klug, 1850) since 1990



Part 3

Chapter 3

Are the Victorian Morphs of the Pale Sun-moth Parthenogenetic?

Introduction

Parthenogenesis is defined as a form of asexual reproduction, i.e. the reproduction of an individual from a female gamete without fertilization by a male gamete (Lawrence, 1998). Asexual reproduction is rare in the animal kingdom and only occurs in about one in one thousand animal taxa (White, 1978). It is a puzzle to biologists why sexual reproduction is so successful in comparison with parthenogenesis. It is also a puzzle as to the conditions that are required for parthenogenesis to be successful when it does occur (M. Kearney pers. comm. 2003). Within the Lepidoptera, parthenogenetic reproduction is known in the family Psychidae (case moths) and more rarely in the families Pyralidae (pyralid moths) and Pieridae (pierid butterflies, i.e. the whites and yellows) (Common, 1979). In an earlier publication, Common (1966) mentions that *Zermizinga indocilisaria*, an Australian geometer moth (family Geometridae), is capable of reproducing parthenogenetically in some circumstances. As parthenogenesis may not be readily apparent, it could also exist in other Lepidoptera that have not been well studied to date.

In 1991 it was first suspected that the Victorian populations of the Pale Sun-moth, *Synemon selene* might be parthenogenetic (E. D. Edwards pers. comm., pers. obs.). The reasons for this were that while there were many historic female specimens from Victoria, it appeared that a Victorian male of this species had never been collected. This was apparently not a result of substantial difficulties in detecting or catching males. As evidence, there were approximately equal numbers of historic male and female specimens from a population that formerly occurred near Two Wells in South Australia. Many of these specimens from Two Wells are now held in the Australian National Insect Collection (CSIRO Division of Entomology). Finally, when three extant Victorian populations were discovered (during February 1991) no males were recorded or collected. This situation was surprising because it is the males of *Synemon* spp. that are the most frequently observed or captured, as they continuously fly around open areas of suitable habitat, while searching for virgin females. The likelihood of the original hypothesis being correct was increased when it was found that males seemed to be absent in populations of the species that were subsequently discovered between 1993 and 2002. A detailed account of the above-mentioned discoveries of the extant Victorian populations of *S. selene* is given in Chapter 6 of Part 3.

The strong possibility that the Victorian populations of *Synemon selene* could be parthenogenetic prompted the author to conduct a series of experiments between 1997 and 2004, to determine whether this was the case. In these experiments, cohorts of unfertilised ova were removed directly from the ovaries of fifteen Victorian *S. selene* females. From two to five specimens of the 'Pale', 'Terrick Terrick', 'Nhill', 'Narrow-winged' and 'Dark' morphs were represented in the experiments because it was strongly suspected that all five of the Victorian morphs of the Pale Sun-moth were breeding parthenogenetically.

Cohorts of unfertilised ova were also removed from the ovaries of the following non-parthenogenetic *Synemon* species: one female each of *S. plana* (Golden Sun-moth), *S. nais* (Orange Sun-moth) and *S. discalis* (Small Orange-spotted Sun-moth) and three females of *S. parthenoides* (Orange-spotted Sun-moth). The four non-parthenogenetic *Synemon* species were included in the experiments to discover whether any larvae would hatch from their unfertilised ova. This was to determine whether the randomly selected females of these sexually reproducing species would have been capable of reproducing parthenogenetically in the absence of males.

It was anticipated that the results of these experiments would be conclusive because the ova of ditrysian Lepidoptera, which include the family Castniidae, are not fertilised by spermatozoa while they are still within the ovaries. Before the ova can be fertilised they must leave the ovaries and pass through the oviduct. It is only after this has taken place that fertilization occurs in the vagina, just before the ova are laid (Common, 1990). Therefore, it was apparent that if the ova of *Synemon* spp. were removed directly from the ovaries of females, these ova would not have been fertilised by exposure to any spermatozoa. More detailed descriptions of the fertilization of the ova of ditrysian Lepidoptera are available in Common (1990), Scoble (1992) and Braby (2000).

Materials and methods

Unless otherwise stated in the accompanying appendices to this chapter, the specimens that were selected for the experiments were individuals that had recently emerged from their pupae. The recently emerged condition of these females was clearly indicated by minimal or no wing wear. The females of all *Synemon* species appear to emerge from their pupae in a fully gravid condition, i.e. with all of their ova completely developed and ready to be laid. This would enable them to commence oviposition without unnecessary delay and would probably minimize the impact that potential predators could have on their populations. Such freshly emerged specimens were chosen for some of the dissections because they would still be carrying most or all of their ova. This not only provided a comparatively high number of ova from these dissections for the experiments but also gave some indication of the fecundity of the dissected taxa. However, several females of *Synemon selene,* which were showing a medium to advanced stage of wing wear, were also dissected. These dissections were undertaken to determine how many ova were still being carried within the ovaries of older *S. selene* females. In addition, the single female of *S. nais* that was chosen for dissection was exhibiting a medium stage of wing wear. A freshly emerged and therefore fully gravid specimen of this species was not selected for the experiments because *S. nais* is very rare within Victoria, both in terms of distribution and abundance.

Prior to dissection, live specimens were immobilized by being chilled in the refrigerator for at least 24 hours. Following this, they were killed immediately by carefully applying (squirting) a small amount of Helmar 'Dustaway'TM to the head. This rapidly freezes the contacted tissue (head) without affecting the remainder of the specimen. Helmar 'Dustaway'TM is an ozone friendly aerosol spray product that is normally used for blowing dust out of scientific equipment or cleaning camera lenses. After being prepared in this way, each specimen was dissected immediately. The author devised the following procedure that was used for the extraction of ova from *Synemon* species, to minimize unnecessary damage to the donor specimens. Firstly, the specimen was pinned vertically through the thorax with a number 3 'Asta'TM stainless steel entomological pin. The pin was then pushed into a 4 cm thick block of polystyrene foam so that the ventral surface of the pinned specimen came into contact with the foam. Two more of the same pins were used to ease the wings outwards, away from their normally folded position above the abdomen. After this, the pins were carefully inserted into the foam, in such a way as to hold the wings clear of the abdomen without damaging them. Next, the abdomen was removed by cutting with a scalpel across its junction with the thorax. The detached abdomen was picked up with a pair of soft 'featherlight' entomological forceps and placed onto a piece of 'Clingwrap'TM plastic. It was then positioned so that its dorsal surface was orientated upwards. Immediately after this, the contents of the abdomen (including the ovaries) were squeezed out by applying gentle pressure to its dorsal surface with my index finger. As pressure was applied, the ovaries appeared at the anterior end of the abdomen as a soft yellowish mass of tissue.

After the ovaries had been completely squeezed from the abdomen, any connective tissue was severed with a scalpel. Following this, the ovaries were lifted with a camel-hair brush and placed into a Petri dish of clean water. They were then held with the forceps and gently shaken in the water until the eight individual ovarioles were separated out and clearly visible. After this, each ovariole was held with the forceps while enough pressure was applied to it with the camel-hair brush to break it into sections. Following this, each semi-transparent section of the ovariole was held at one end with the forceps while the camelhair brush was used to push the ova out of the opposite end (one at a time) into the surrounding water. Each time a few loose ova had accumulated they were picked up with the camel-hair brush and placed on a sheet of absorbent paper to dry. After they had completely dried, each batch of ova was placed in a small jar. Each jar was labeled with the following information: species and, if applicable, morph of the specimen from which the ova were dissected, dissection date, number of ova in the container and the date and locality of donor specimen capture. The jars were then stored at room temperature and placed where they would be out of direct sunlight at all times. A small hole was pierced in the lid of each jar for ventilation and a wad of slightly moistened 'Kleenex'TM tissue was placed with the batches of ova to protect them from desiccation.

Immediately after a dissection had been completed, each donor specimen was pinned into a setting board and set in the standard way. After the setting process was finished, the emptied abdomen was carefully glued back onto the posterior end of the metathorax of the specimen with Selley's 'Aquadhere'TM and held in the correct position with several crossed pins. Approximately three weeks later, after the specimens had completely dried, they were removed from the setting boards. A printed data label corresponding to the information that was recorded with the relevant cohort of ova was then attached to the pin beneath each of the voucher specimens. The required materials and correct methods of pinning and setting Lepidoptera are described on pages 601 to 605 of 'Butterflies of Australia' by Common & Waterhouse (1981).

Results

Embryogenesis commenced within 21 % of the ova that were extracted from ovaries of the five Victorian morphs of *Synemon selene* (Table 3.1), with larvae hatching successfully from 5 % of the ova, after incubation periods ranging from 24 to 93 days. Embryogenesis did not commence in any of the cohorts of ova that were removed from the ovaries of *S. plana*, *S. nais, S. parthenoides* and *S. discalis*.

Table 3.1. Summarised results of the determination of parthenogenesis experiments on the Victorian morphs of *Synemon selene* and four other *Synemon* species

Species / morph	Total number of specimens	Total number of ova extracted	Total number of fertile ova	Total number of larvae hatched
***Synemon selene*, Pale Morph**	**4**	**222**	**34**	**2**
***Synemon selene*, Terrick Terrick Morph**	**2**	**98**	**27**	**21**
***Synemon selene*, Nhill Morph**	**4**	**119**	**5**	**4**
***Synemon selene*, Narrow-winged Morph**	**2**	**254**	**3**	**2**
***Synemon selene*, Dark Morph**	**5**	**503**	**179**	**26**
Synemon plana	**1**	**110**	**0**	**-**
Synemon nais	**1**	**31**	**0**	**-**
Synemon parthenoides	**3**	**248**	**0**	**-**
Synemon discalis	**1**	**64**	**0**	**-**

Ova that are alluded to as 'fertile' in this table, the following discussion and in the two appendices to this chapter are those in which embryogenesis occurred. The use of the term in these instances is not intended to imply that the 'fertile' ova of the Victorian morphs of *Synemon selene* were fertilised by exposure to spermatozoa. See Appendix A to this chapter for the specimen collection data and detailed results of the experiments that are summarised in Table 3.1.

Discussion

The ova of the ditrysian Lepidoptera (which include the family Castniidae) are not fertilised by spermatozoa until they reach the vagina, after they leave the ovaries. Therefore, the preceding results of the experiments have demonstrated beyond doubt that all five of the Victorian morphs of *Synemon selene* are able to reproduce parthenogenetically. These results have also provided much stronger evidence to imply that all of the known populations of these Victorian morphs of *S. selene* are entirely parthenogenetic. This seems to be especially likely when the complete absence of any male specimens (or records of males) of *S. selene* from Victoria is taken into consideration. Further, it appears that the total infertility of the cohort of five ova from 'specimen (1)' of the Pale Morph (see Appendix A to this chapter) could be attributed to the small number of ova in the cohort rather than to the particular female being non-parthenogenetic. This hypothesis is borne out by the relatively low fertility levels of some of the larger cohorts of ova from the other *S. selene* females that were included in the experiments.

However, the complete sterility of the comparatively large cohorts of ova that were removed from the ovaries of *Synemon discalis, S. parthenoides, S. plana* and *S. nais* has shown that these species are probably unable to reproduce parthenogenetically by default, i.e. in the absence of males of their respective species. It appears that the ova of the tested females of these species would have required fertilization by spermatozoa before embryonic development could commence. It also suggests that the parthenogenetic reproduction in *Synemon selene* may be unique within the genus *Synemon* or perhaps the entire family Castniidae. Because of the necessarily small samples though, it does not constitute proof of this and does not rule out the possibility that some parthenogenetic females/populations may occasionally arise in these and/or other *Synemon* species. However, to the author's knowledge, parthenogenesis has not been discovered or suspected to date in any other species within the family Castniidae. If an extant population of the non-parthenogenetic morph of *S. selene* is ever located, it would be worthwhile to conduct the same experimentation on its ova, in order to determine whether it could reproduce in the absence of males. A comparison between the chromosomes and DNA of this morph and one or more of the parthenogenetic morphs of the species would also be an important and potentially rewarding area of study. Perhaps a comparative study of this nature would engender an understanding of how and/or why the Victorian morphs of *S. selene* originally became parthenogenetic.

The environmental and/or genetic circumstances that caused *S. selene* to become parthenogenetic in Victoria are not understood. However, the broad geographic range of its remnant populations suggest that the species was a very successful one, in terms of distribution and abundance, until most of its habitat was cleared and alienated after European settlement (pers. obs. 1991-2004). Moreover, it seems that parthenogenetic reproduction could be advantageous to a threatened species in some respects. Potential reasons for this are as follows:

(1) Every individual can reproduce without any delay caused by the need for fertilisation, thereby reducing the risk of being taken by predators before reproduction is commenced.

(2) The need to find a mate is negated, so it would only require one individual to continue the existence of the species, or to found a new population.

(3) Males, which are incapable of dispersing ova, do not utilise approximately fifty percent of the potentially limited environmental resources.

(4) Existing populations, no matter how small and isolated, would not be subjected to the genetic problems (e.g. the manifestation of detrimental or lethal recessive genes) that are often associated with inbreeding in small populations of sexually reproducing taxa.

While the reason for the low fertility levels of many of the tested cohorts of *Synemon selene* ova is uncertain, it may have been brought about by the dissection process and/or the artificial conditions under which the ova were incubated. It is possible that during the normal oviposition process there is a cue or trigger that would usually cause cell division to commence in a higher percentage of ova from the parthenogenetic morphs of *S. selene* than the test results indicated in most cases. This is suspected because it is unlikely that a *Synemon* species with such a low level of fecundity would be able to survive in the wild, i.e. to be able to withstand the losses to predators, pathogens and other factors that normally occurs in insect populations.

Despite this, it is most unlikely that the complete sterility of all the dissected-out cohorts of ova from the four non-parthenogenetic *Synemon* species was caused by the same reasons and/or conditions that may have brought about the low fertility rate of the parthenogenetic *S. selene* ova. This conclusion is drawn because 55 larvae hatched successfully out of 61 ova that were laid naturally by two captive females of *S. parthenoides*. These two cohorts of naturally laid ova were incubated under similar conditions to all of the other cohorts of dissected-out ova from the non-parthenogenetic *Synemon* species and the parthenogenetic morphs of *S. selene*. This was to ensure that the results (i.e. potential fertility rates) of these additional cohorts of ova were not altered from the results of the original experiments by differing environmental factors. The detailed data for these ‘control’ experiments are documented in Appendix B to this chapter.

Two to three weeks after their extraction, the fertile ova of *Synemon selene* could be easily distinguished from those that were infertile by a gradual colour change from creamy-yellow to pink. This colour change was brought about by the increasing pigmentation of the developing larvae, which were clearly visible through the semitransparent chorions of the ova. Although the naturally laid fertile ova of *S. parthenoides* were not as obvious as those of *S. selene*, they could also be distinguished from those that were infertile by a progressive but slight colour change, from creamy-white to pale creamy-yellow. As larval development progressed, they were also indicated by a very subtle but gradually increasing brownish-amber coloured pigmentation of the larval head capsule, which (as with the ova of *S. selene*) could be seen through the semitransparent chorions of the ova, at the end nearest the micropyle. In both *S. selene* and *S. parthenoides*, these indicating features of the fertile ova were most obvious for approximately one week before the larvae hatched.

In most instances, only a small percentage of larvae hatched from the fertile ova of the parthenogenetic morphs of *S. selene*. However, it seems likely that this low rate of hatching success was caused by difficulties in determining and replicating the natural environmental conditions into which the normally subterranean ova would be laid. It was found that there was an extremely fine balance between too much moisture in the containers, which seemed to render the ova to be vulnerable to attack by a blackish mould or not enough moisture, which caused the ova to desiccate. A fungicide or mould deterrent was not added to the containers because it was thought that such compounds might kill the developing larvae. It also seemed that fluctuating humidity levels within the containers could have brought about the staggered hatching dates of the larvae that did eventually hatch. This is suggested because many of the fully developed larvae that were clearly alive and were found to be able to move around inside the ova failed to hatch. In some cases the larvae of specimen 3 of the Pale Morph actually commenced to chew escape holes through the chorions of the ova but died before the hatching process was completed. Perhaps a toughening of the chorions was caused by the ova being exposed to more unstable or possibly drier than the natural (soil) conditions, resulting in the failure of these fully formed *S. selene* larvae to hatch successfully.

Miller (1986) experienced similar difficulties with the fertile ova of some of the Neotropical Castniidae. Her comments on this subject are as follows: ‘During the course of attempting to rear some species, it was determined that additional moisture was necessary in the rearing containers to prevent further desiccation of the egg chorion and aid it in remaining pliable so that the first instar larva could hatch. However, it is difficult to maintain a natural balance between optimum conditions and one in which mould would flourish. Under such conditions, only about one-half to two-thirds of the eggs finally hatched, approximately 10-14 days after deposition’.

Finally, the dissections have revealed that the females of *S. selene* that showed an advanced stage of wing wear were carrying few or no ova in their ovaries. This is consistent with the hypothesis that the short-lived adults of this species oviposit rapidly to reduce the overall effect that predators could otherwise have on their population levels.

Appendices

Appendix 1. The following data are the detailed results of a series of experiments that were undertaken by the author between 1997 and 2004, to determine whether the five Victorian morphs of the Pale Sun-moth are parthenogenetic. These data are immediately followed by the detailed results of a series of similar 'control' experiments on four non-parthenogenetic *Synemon* species. Unless otherwise stated in the following text, the specimens that were included in all of the experiments were in a fresh (recently emerged condition) when collected.

***Synemon selene*, Pale Morph (Pale Sun-moth).**
All four specimens were collected at the same locality, at 7.3 km SSE of Murtoa, Victoria (0.4 km south of Hopefields Road at 2.7 km east of its junction with the Murtoa-Glenorchy Road).
Specimen (1) showing medium wing wear, collected on 19 February 1999.
Specimen dissected on 22 February 1999, 5 ova yielded.
Number of fertile ova: 0.
Specimen (2) collected on 23 February 1999.
Specimen dissected on 1 March 1999, 103 ova yielded.
Number of fertile ova: 10.
Number of larvae that hatched successfully: 0.
Specimen (3) showing medium wing wear, collected on 24 February 2000.
Specimen dissected on 26 February 2000, 44 ova yielded.
Number of fertile ova: 21.
Number of larvae that hatched successfully: 0.
Specimen (4) collected on 22 February 2001.
Specimen dissected on 24 February 2001, 70 ova yielded.
Number of fertile ova: 3.
Number of larvae that hatched successfully: 2.
Dates that these larvae hatched:
1 larva hatched on 18 April 2001.
1 larva hatched on 20 April 2001.

***Synemon selene*, Terrick Terrick Morph (Pale Sun-moth).**
Both specimens were collected at the same locality, at 10 km NNE of Mitiamo, Victoria (eastern end of Regal's Road at 3.5 km east of the eastern boundary of Terrick Terrick National Park).
Specimen (1) collected on 2 March 1997.
Specimen dissected on 5 March 1997, 74 ova yielded.
Number of fertile ova: 25.
Number of larvae that hatched successfully: 21.
Dates that these larvae hatched:
1 larva hatched on 29 March 1997.
2 larvae hatched on 31 March 1997.

2 larvae hatched on 1 April 1997.
1 larva hatched on 6 April 1997.
6 larvae hatched on 8 April 1997.
2 larvae hatched on 12 April 1997.
2 larvae hatched on 13 April 1997.
1 larva hatched on 14 April 1997.
1 larva hatched on 17 April 1997.
1 larva hatched on 14 May 1997.
1 larva hatched on 19 May 1997.
1 larva hatched on 6 June 1997.
Specimen (2) showing medium wing wear, collected on 24 February 1999.
Specimen dissected on 1 March 1999, 24 ova yielded.
Number of fertile ova: 2.
Number of larvae that hatched successfully: 0.

***Synemon selene*, Nhill Morph (Pale Sun-moth).**

All four specimens were collected at the same locality, at 1.4 km east of Nhill, Victoria (0.1 km north of Belcher Street at 0.5 km east of its junction with the Nhill-Netherby Road).
Specimen (1) showing an advanced stage of wing wear, collected on 25 February 2000.
Specimen dissected on 26 February 2000, 6 ova yielded.
Number of fertile ova: 1.
Number of larvae that hatched successfully: 0.
Specimens (2 & 3) both showing an advanced stage of wing wear, collected on 25 February 2000.
Specimens (2 & 3) dissected on 26 February 2000, both yielding 0 ova.
Specimen (4) collected on 19 February 2001.
Specimen dissected on 24 February 2001, 113 ova yielded.
Number of fertile ova: 4.
Number of larvae that hatched successfully: 4.
Dates that these larvae hatched:
1 larva hatched on 16 April 2001.
3 larvae hatched on 17 April 2001.

***Synemon selene*, Narrow-winged Morph (Pale Sun-moth).**

Both specimens were collected at the same locality, at 0.3 km west of Pimpinio, Victoria (Pimpinio Golf Course).
Specimen (1) showing slight wing wear, collected on 22 February 2004.
Specimen dissected on 14 March 2004, 115 ova yielded.
Number of fertile ova: 1.
Number of larvae that hatched successfully: 1.
Date that this larva hatched: 24 April 2004.
Specimen (2) collected on 25 February 2004.
Specimen dissected on 13 March 2004, 139 ova yielded.
Number of fertile ova: 2.
Number of larvae that hatched successfully: 1.

Date that this larva hatched: 18 April 2004.

***Synemon selene*, Dark Morph (Pale Sun-moth).**

The following four specimens were collected at the same locality, at 0.3 km west of Pimpinio, Victoria (Pimpinio Golf Course).
Specimen (1) collected on 15 February 1999.
Specimen dissected on 22 February 1999, 117 ova yielded.
Number of fertile ova: 76.
Number of larvae that hatched successfully: 1.
Date that this larva hatched: 6 April 1999.
Specimen (2) collected on 19 February 1999.
Specimen dissected on 1 March 1999, 92 ova yielded.
Number of fertile ova: 43.
Number of larvae that hatched successfully: 1.
Date that this larva hatched: 22 April 1999.
Specimen (3) showing medium wing wear, collected on 24 February 2000.
Specimen dissected on 26 February 2000, 83 ova yielded.
Number of fertile ova: 17.
Number of larvae that hatched successfully: 10.
Dates that these larvae hatched:
5 larvae hatched on 5 April 2000.
5 larvae hatched on 6 April 2000.
Specimen (4) collected on 22 February 2001.
Specimen dissected on 24 February 2001, 120 ova yielded.
Number of fertile ova: 6.
Number of larvae that hatched successfully: 6.
Dates that these larvae hatched:
3 larvae hatched on 3 April 2001.
3 larvae hatched on 4 April 2001.
Specimen (5) collected at 4.3 km SE of Dimboola, Victoria (south side of Old Minyip Road at 0.3 km east of its junction with the Western Highway), on 19 February 1999.
Specimen dissected on 1 March 1999, 91 ova yielded.
Number of fertile ova: 37.
Number of larvae that hatched successfully: 10.
Dates that these larvae hatched:
2 larvae hatched on 21 April 1999.
3 larvae hatched on 22 April 1999.
3 larvae hatched on 27 April 1999.
2 larvae hatched on 30 April 1999.

***Synemon plana* (Golden Sun-moth).**

Specimen collected at 1.4 km east of Nhill, Victoria (0.2 km north of Belcher Street at 0.5 km east of its junction with the Nhill-Netherby Road), on 11 November 1999.
Specimen dissected on 14 November 1999, 110 ova yielded.
Number of fertile ova: 0.

***Synemon nais* (Orange Sun-moth).**
Specimen showing medium wing wear, collected at 2 km ENE of Walpeup, Victoria (at 0.3 km south of the Ouyen Highway), on 28 October 1999.
Specimen dissected on 30 October 1999, 31 ova yielded.
Number of fertile ova: 0.

***Synemon parthenoides* (Orange-spotted Sun-moth).**
All three specimens were collected at the same locality, in the SE Big Desert at 28 km WSW of Rainbow, Victoria (Chinaman's Well Track at 0.6 km NW of its junction with the Netting Fence Road).
Specimen (1) collected on 9 November 1998.
Specimen dissected on 13 November 1998, 82 ova yielded.
Number of fertile ova: 0.
Specimen (2) collected on 9 November 1998.
Specimen dissected on 13 November 1998, 87 ova yielded.
Number of fertile ova: 0.
Specimen (3) collected on 12 November 1999.
Specimen dissected on 14 November 1999, 79 ova yielded.
Number of fertile ova: 0.

***Synemon discalis* (Small Orange-spotted Sun-moth).**
Specimen collected in the SE Big Desert at 28 km WSW of Rainbow, Victoria (Chinaman's Well Track at 0.6 km NW of its junction with the Netting Fence Road), on 31 October 1999.
Specimen dissected on 3 November 1999, 64 ova yielded.
Number of fertile ova: 0.

Appendix 2. Detailed results of the additional ‘control’ experiments on two cohorts of ova that were laid naturally by two females of *Synemon parthenoides*, one of the non-parthenogenetic *Synemon* species that was included in the (previously documented) determination of parthenogenesis experiments. These naturally laid ova were incubated under similar conditions to those that were dissected-out of the ovaries of all the *Synemon* species that were included in the determination of parthenogenesis experiments. The following results have demonstrated that the complete sterility of the dissected-out cohorts of ova from the four non-parthenogenetic *Synemon* species was unlikely to have been brought about by the artificial conditions under which their ova were incubated.

Synemon parthenoides **(Orange-spotted Sun-moth).**

Both specimens were collected at the same locality as the three specimens of the same species that were included in the determination of parthenogenesis experiments, i.e. in the SE Big Desert at 28 km WSW of Rainbow, Victoria.

Specimen (1) showing slight wing wear, collected on 21 November 2003.
Specimen died by 1 December 2003 after laying 38 ova.
Number of fertile ova: 32.
Number of larvae that hatched successfully: 32.
Dates that these larvae hatched:
6 larvae hatched by 18 December 2003.
21 more larvae had hatched by 21 December 2003.
5 remaining larvae had hatched by 24 December 2003.
Specimen (2) showing medium wing wear, collected on 21 November 2003.
Specimen died by 1 December 2003 after laying 23 ova.
Number of fertile ova: 23.
Number of larvae that hatched successfully: 23.
Dates that these larvae hatched:
9 larvae had hatched by 18 December 2003.
11 more larvae had hatched by 21 December 2003.
3 remaining larvae had hatched by 24 December 2003.

Part 3

Chapter 4

Would the Parthenogenetic Morphs of the Pale Sun-moth be Capable of Non-parthenogenetic Reproduction?

Introduction

Confirmation that the Victorian morphs of the Pale Sun-moth are parthenogenetic has raised the following questions: would these parthenogenetic morphs be mechanically capable of mating? Or alternatively, has the bursa copulatrix become non-functional in these morphs? To answer these questions the genitalia of the (parthenogenetic) Pale, Nhill and Dark Morphs were dissected out and mounted on glass slides for microscopic examination. These specimens were also compared with a mounted specimen of the female genitalia of the non-parthenogenetic Two Wells Morph from South Australia. All of these specimens are now held in the Australian National Insect Collection (CSIRO Division of Entomology). Due to a scarcity of available specimens, the Terrick Terrick Morph and Narrow-winged Morph were not included in this dissection work.

Materials and methods

Mr. E. D. Edwards prepared all of the slides that were used in this work at the CSIRO Division of Entomology. The required materials and methods for mounting the genitalia of Lepidoptera on microscope slides are documented on pages 480 to 481 of ‘Moths of Australia’ by I. F. B. Common (1990). The illustrations for this chapter were drawn in freehand by the author. All of these diagrams were originally drawn at twelve times life size. Firstly, the genitalia were softly sketched to the correct proportions with a graphite HB pencil. As this work progressed, any corrections or alterations were made by removing the necessary sections with a soft eraser, before re-sketching them. Finally, each diagram was drawn in with a ‘Unipin’TM 0.1 black ink pen. After the ink had thoroughly dried, the excess pencil work was rubbed away with the soft eraser.

Results

All three of the parthenogenetic morphs that were dissected appeared to have fully functional genitalia. Apart from what seemed to be the remains of a broken spermatophore in the corpus bursae of the non-parthenogenetic Two Wells Morph (see the first of the following illustrations), there was no significant difference between the genitalia of this morph and the parthenogenetic Victorian morphs that were examined (see the second to fourth of the following illustrations). The differences that are apparent in these illustrations are largely an artifact of the way that the soft parts of each specimen were arranged on the glass slides and are not indicative of a significant amount of variation in the genitalic structure of the specimens.

Discussion

The absence of spermatophores in the genitalic specimens from the parthenogenetic morphs is a clear indication that none of the ‘donor’ individuals had mated prior to being captured. This adds credence to the conclusion that these morphs are parthenogenetic, as evidenced by the cohorts of larvae that hatched from batches of their unfertilized ova (see the preceding chapter). Under normal circumstances, the females of non-parthenogenetic *Synemon* spp. are quickly located and mated with by patrolling males, soon after they emerge. It is therefore highly likely that had they been non-parthenogenetic, the individuals of the three Victorian morphs from which these genitalic specimens were extracted, would have already mated and been carrying complete or perhaps broken spermatophores.

A possible explanation for the examined genitalia of the parthenogenetic morphs being seemingly fully developed could be that since these taxa have become parthenogenetic, there have been no selective pressures for them to lose the potential to copulate successfully. The apparently fully functional nature of the genitalia of these parthenogenetic morphs of the Pale Sun-moth raises a few interesting, though hypothetical, questions. These are as follows:

(1) Would any of the parthenogenetic morphs have been capable of reproducing normally if males of the (?now extinct) non-parthenogenetic Two Wells Morph had been introduced to their populations?

(2) Or, have the parthenogenetic morphs changed genetically (i.e. in the number of chromosomes they carry) so that it now impossible for these females to reproduce non-parthenogenetically?

(3) Have the purely parthenogenetic populations of this species lost the normal behavioral and/or biochemical characteristics that would trigger the mating responses of males?

(4) If the males of the non-parthenogenetic Two Wells Morph had been successfully crossbred with one or more of the parthenogenetic morphs, would the parthenogenetic females have been able to produce male offspring?

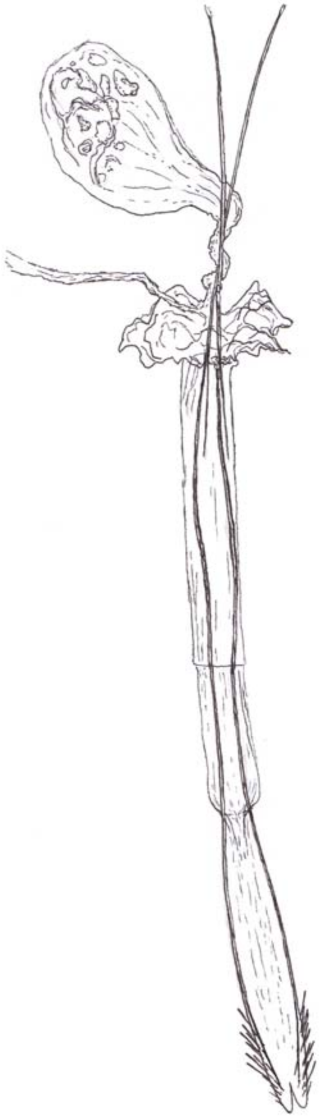
(5) Would some (or all) of the non-parthenogenetic females of the Two Wells Morph have been able to reproduce parthenogenetically in the absence of males?

(6) If this was the case, did the Victorian populations become entirely parthenogenetic because the species became especially rare at some time in the past, possibly due to unsuitable ecological conditions?

Unfortunately, it appears that these questions cannot be answered unless an extant non-parthenogenetic population of the Pale Sun-moth is rediscovered. It is certainly a great tragedy for Australia's wider conservation values and also for science that the habitat of the non-parthenogenetic Two Wells Morph was destroyed before the parthenogenetic state of the Victorian morphs of this species was fully realised, as a consequence of this work.

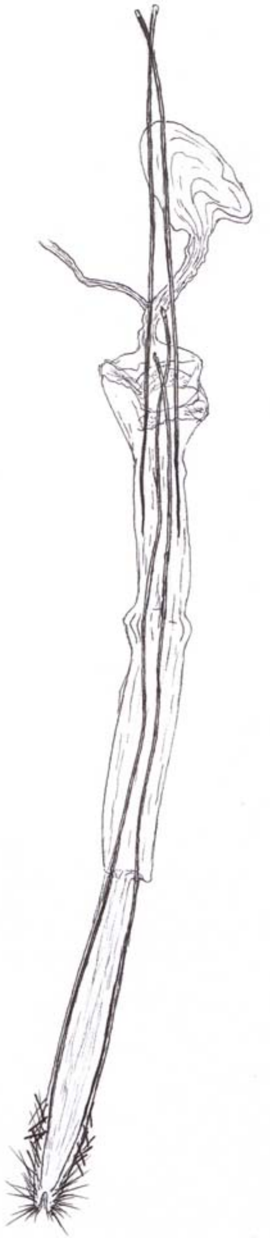
Illustrations

Figure 1. Ovipositor and bursa copulatrix of the non-parthenogenetic Two Wells Morph of *Synemon selene* (Pale Sun-moth). Note the fragments of what may be a broken spermatophore in the corpus bursae of this specimen. Approx. 7 times life size.



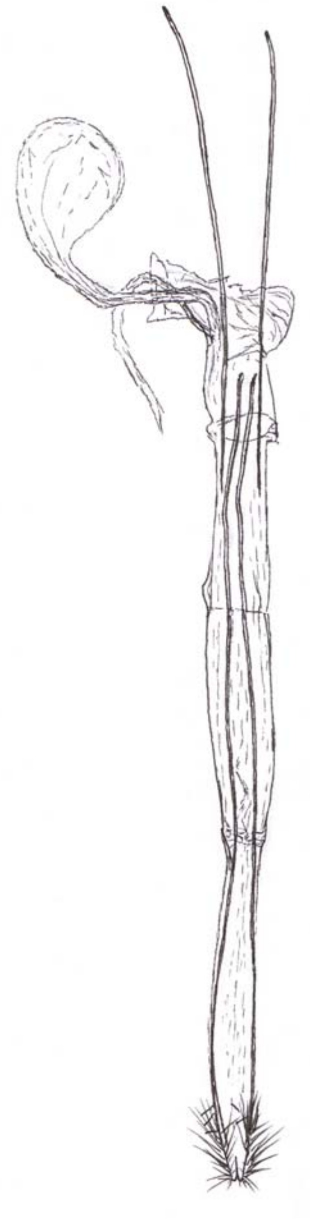
Collection data: Australian National Insect Collection. Castniidae number 11890 female, *Synemon selene* Klug. Two Wells, South Australia. No date but specimen probably collected during the 1940s. F. M. Angel. Via L. E. Couchman collection. Slide prepared by E. D. Edwards, 1997. Illustration by F. Douglas, 2000.

Figure 2. Ovipositor and bursa copulatrix of the parthenogenetic Pale Morph of *Synemon selene* (Pale Sun-moth). Approx. 7.5 times life size.



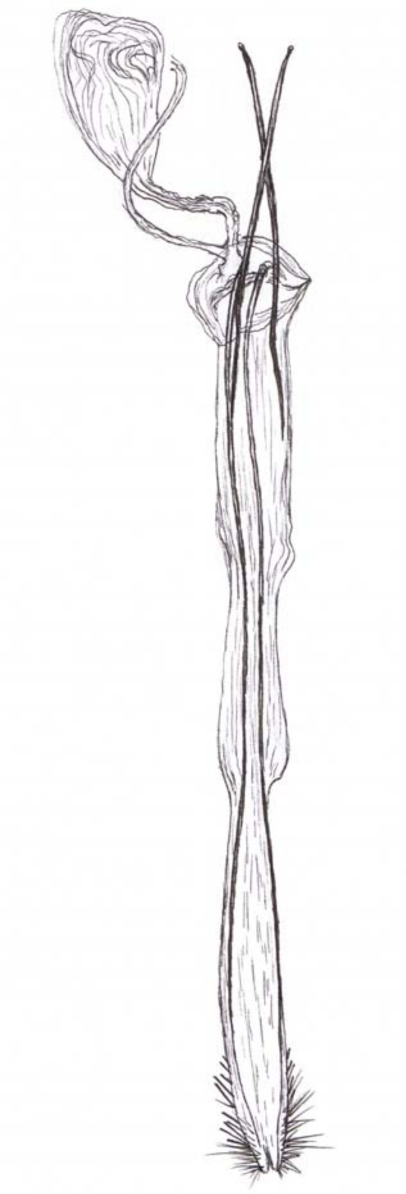
Collection data: Australian national Insect Collection. Castniidae number 16560 female, *Synemon selene* Klug. Flume Rd. 2.8 km. S. of Wimmera Hwy. 4.5 km. S. S. E. of Jung, Vic. 12 Feb. 2000. F. Douglas & J. Noelker. Slide prepared by E. D. Edwards, 2000. Illustration by F. Douglas, 2000.

Figure 3. Ovipositor and bursa copulatrix of the parthenogenetic Nhill Morph of *Synemon selene* (Pale Sun-moth). Approx. 7 times life size.



Collection data: Australian National Insect Collection. Castniidae number 16558 female, *Synemon selene* Klug. Belcher St. at 0.5 km. E. of Nhill-Netherby Rd. Nhill, Vic. 13 Feb. 2000. F. Douglas & J. Noelker. Slide prepared by E. D. Edwards, 2000. Illustration by F. Douglas, 2000.

Figure 4. Ovipositor and bursa copulatrix of the parthenogenetic Dark Morph of *Synemon selene* (Pale Sun-moth). Approx. 7 times life size.



Collection data: Australian National Insect Collection. Castniidae number 16559 female, *Synemon selene* Klug. Pimpinio Golf Course at 0.3km. W. of Pimpinio, Victoria. 21 Feb. 1998. F. Douglas. Slide prepared by E. D. Edwards, 2000. Illustration by F. Douglas, 2000.

Part 3

Chapter 5

The Extent of Genetic Variability Between and Within the Parthenogenetic Morphs of the Pale Sun-moth

Introduction

Four of the five parthenogenetic morphs of *Synemon selene* are morphologically distinct enough to be easily distinguished, but their levels of genetic divergence, if any, are unknown. Minor variations in size and/or markings in all five of these morphs also suggest that there may be genetic variability within each. To test for possible genetic variability within and between morphs, tissue samples were collected from one to four individuals of all of the (parthenogenetic) morphs for analysis, based on the Cytochrome Oxidase Subunit One (*COI*) mitochondrial gene. Quantifying the levels of genetic variability within and between the five parthenogenetic morphs may have implications for prioritizing actions towards their conservation.

The following text documents the results of preliminary work towards the publication of a co-authored paper (in prep. by Dr A. Kallies, Dr M. F. Braby, Dr D. Hilton and the author) on the phylogeny and adult morphology of the Castniidae.

Materials and methods

Taxon sampling.

In addition to the five parthenogenetic morphs of *S. selene*, 1515 bp of *COI* of seven species of *Synemon* and eight species from two families of more distantly related ditrysian Lepidoptera were included. The taxa from the other two families included two species of Sesiidae (clearwing moths: *Ichneumenoptera chrysophanes* and a *Melittia* sp.) and six species of Brachodidae (little bear moths: two *Brachodes* spp. and four *Miscera* spp.). Both families are now considered to be related to the Castniidae, with all three families belonging to the superfamily Sesioidea (Edwards *et al*. 1999). The Sesiidae, which comprise a well defined and distinct monophyletic group, were chosen as the outgroup in all phylogenetic analyses.

The phylogeny of the Brachodidae and their systematic position is not so well established (Edwards *et al*. 1999). However, this family may prove to be the sister group of the Castniidae (A. Kallies pers. comm. 2005) and was therefore included as a distant ingroup in the analysis, mainly to confirm the monophyly of the *Synemon* spp./Castniidae.

Collection of specimens.

Because of the high conservation status of the five Victorian morphs of *Synemon selene*, the following method was devised to collect tissue samples for DNA sequencing that did not necessitate killing of the sampled individuals. Firstly, the individual to be sampled was caught in a large (61 cm diameter) butterfly net, by carefully placing the net over the specimen so that the net's rim was pressed onto the ground. The specimen was then gently manoeuvred so that it commenced to walk up the inside of the net bag. The utmost care was always taken to accurately identify the morph from which the tissue sample was to be collected. The rim of the net was then raised and one mid leg and one hind leg (on the opposite side) were removed with sterilized forceps. The legs were removed by grasping each one consecutively with the forceps, upon which the individual would usually flutter to an extent that caused the leg to detach easily without it being necessary to hold or restrain the specimen. After each leg was removed it was immediately placed into a vial of 100% ethanol. The specimen was then released without delay. Subsequent observations of the sampled individuals indicated that removal of the legs did not adversely effect their ability to fly, walk or oviposit.

The morphs, localities and numbers of individuals from which tissue samples of *Synemon selene* were collected are as follows: Narrow-winged Morph: ex-Dimboola site (1) and ex-Pimpinio site (1); Dark Morph: ex-Dimboola site (2) and ex-Murtoa site (1); Nhill Morph: ex-Nhill site (3); Pale Morph: ex-Jung site (1), ex-Murtoa site (1) and ex-Borung site (2) and Terrick Terrick Morph: ex-Forbes Road site (1).

Tissue samples of the Sesiidae, Brachodidae and the other species of Castniidae were collected by Dr A. Kallies and /or Dr D. Hilton and were also preserved in 100% ethanol.

Molecular techniques.

Protocols for extraction of genomic DNA (carried out by Mrs. A. Hilton) follow Aljanabi & Martinez (1997). Amplification of *COI* gene fragments (PCR), purification of the PCR product, cycle sequence reactions and sequencing of all samples follows Kallies (2003) as per Weller *et al*. (1994) and/or Brown *et al*. (1999). Alignment and editing of the sequences was carried out (by Dr A. Kallies) with the program 'DNA Star*'.

The primer sequences (with relative positions of the primers in the in the *COI* gene bracketed) and the PCR conditions that were used are as follows:

Primer sequences:
COI-4fwd (-50 - -25): 5'- TAC AAT TTA TCG CCT AAA CTT CAG CC - 3'
COI-8fwd (685 - 707): 5'- CAA CAT TTA TTT TGA TTT TTT GG - 3'
COI-9rev (715 - 740): 5'- CCT GGT AAA ATT AAA ATG TAA ACT TC - 3'
COI-12rev (1534 - 1558): 5'- CAC ATA TAT TCT GCC ATA TTA GAA - 3'

PCR conditions: an initial step of 95°C for 5 min, then 35 cycles of 95°C for 30 s, 55°C for 35 s, 72°C for 1 min and a final extension period of 72°C for 10 min.

Phylogenetic analysis.

The methods (‘PAUP*’ version 4.0b10) used (by Dr M. F. Braby) to construct the phylogenetic (neighbourhood joining [NJ] and maximum parsimony [MP]) trees follow Braby *et al*. (2005).

Results

Of the 1515 bp sequenced for *COI* there were 16 sites (1.06%) that were parsimony-informative within the *Synemon selene* data set. Of the remaining characters, 3 were variable but parsimony-uninformative and 1496 were constant. Of the 16 parsimony informative characters, 12 were in third codon positions, 4 were in first positions and none were in second positions. While 14 of the character changes involved transitions, the remaining 2 were transversions (A↔T).

The two different methods of phylogenetic analysis have given similar results (Figures 1 and 2). The Australian genus *Synemon* of the family Castniidae was recovered as a monophyletic group with high support (Bootstrap: 100% NJ and 99% MP). Although there was strong support for the sister relationship between *Synemon discalis* and *S. parthenoides* (Bootstrap: NJ 99% and MP 93%), relationships between the remaining six species of *Synemon*, including *S. selene*, were unresolved. However, the monophyly of the five parthenogenetic morphs of *S. selene* was strongly supported (Bootstrap: 100% NJ and MP).

Within *Synemon selene*, three major clades were recovered. These are the Narrow-winged Morph (Bootstrap: 100% NJ and 83% MP), the Dark Morph (Bootstrap: 100% NJ and 97% MP) and the Nhill Morph + Pale Morph + Terrick Terrick Morph (Bootstrap: 100% NJ and 95% MP). Relationships between these three clades were unresolved, although both of the analyses suggest that the Narrow-winged Morph is the sister group to the other two clades. There was negligible phylogenetic structure within each of these clades.

Table 5.1 shows the level of genetic divergence within *Synemon selene*. Levels of divergence between the Narrow-winged Morph, Dark Morph and the clade containing the Nhill Morph + Pale Morph + Terrick Terrick Morph were 0.59% - 0.79% (9 - 12 bp) for *COI*. Within morphs there were only minor levels of divergence, ranging from 0% - 0.13% (0 - 2 bp).

Table 5.1. Uncorrected pairwise distance within *Synemon selene*, expressed as the number of characters (nucleotides) for *COI* (1515 bp)

	Morph / locality	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Narrow-winged Morph – Dimboola	–												
2	Narrow-winged Morph – Pimpinio	**0**	–											
3	Dark Morph – Dimboola	9	9	–										
4	Dark Morph – Dimboola	10	10	**1**	–									
5	Dark Morph – Murtoa	9	9	**0**	**1**	–								
6	Nhill Morph – Nhill	10	10	9	10	9	–							
7	Nhill Morph – Nhill	10	10	9	10	9	**0**	–						
8	Nhill Morph – Nhill	11	11	10	11	10	**1**	**1**	–					
9	Pale Morph – Jung	11	11	10	11	10	1	1	2	–				
10	Pale Morph – Murtoa	11	11	10	11	10	1	1	2	**0**	–			
11	Pale Morph – Borung	11	11	10	11	10	1	1	2	**2**	**2**	–		
12	Pale Morph – Borung	11	11	10	11	10	1	1	2	**2**	**2**	**0**	–	
13	Terrick Terrick Morph – Forbes Road	12	12	11	12	11	2	2	3	3	3	1	1	–

Numbers in bold type denote divergence levels within morphs.

Discussion

The 0.59% - 0.79% divergence levels (within 1515 bp of *COI*) between the Narrow-winged Morph, Dark Morph and the Nhill Morph + Pale Morph + Terrick Terrick Morph clade suggests that these major taxonomic entities (clades) may have evolved independently through time from a once widespread non-parthenogenetic common ancestor, that was probably similar to the (?now extinct) non-parthenogenetic Two Wells Morph. It is extraordinary that *Synemon selene* has formed five separate parthenogenetic morphs in Victoria, particularly when it was found that some of them occur sympatrically at three Victorian sites, near Pimpinio, Jung and Murtoa. Perhaps these parthenogenetic morphs expanded their distributions after their non-parthenogenetic common ancestor became extinct in Victoria, as a result of successful competition from one or more of the parthenogenetic morphs and/or widespread ecological changes. The historic occurrence of the only known (?relict) non-parthenogenetic morph of *S. selene*, near Two Wells in South Australia, at the western extremity of the known distribution of this species, adds some credence to this hypothesis. However, an alternative could be that some or all of the five Victorian morphs are the progeny of individual mutant females that appeared within an ancestral population that had already become entirely parthenogenetic. When it is considered that Quek *et al*. (2004) proposed that the mitochondrial DNA of insects mutates at a rate of approximately 1.5% per million years, it becomes apparent that the three major clades within the parthenogenetic morphs of *S. selene* are probably about 390,000 to 530,000 years old (i.e. that the radiation of their [?parthenogenetic] crown group occurred 390 to 530 thousand years ago). This is a clear indication that the parthenogenetic state of these (Victorian) morphs is not a response of the species to the widespread fragmentation and loss of its habitat that has occurred since European settlement.

The data resulting from the sequencing of 1515 bp of *COI* of thirteen Victorian specimens of *Synemon selene* have also demonstrated that there are genetic differences between some of the (parthenogenetic) individuals within a given morph of the species. This suggests that these parthenogenetic morphs of *S. selene* may have continued to evolve in isolation from each other after they had become parthenogenetic, possibly by accumulating minor mutations, even in the absence of males and sexual reproduction. This is supported by the pairwise divergence levels (within 1515 bp of *COI*) of 0.7% that were found to occur in the samples of three specimens each of the Dark Morph and the Nhill Morph and 0.13% in the sample of four specimens of the Pale Morph. It could also explain the small amount of morphological variation, in size, colouration and markings that occurs within the individuals of a given morph. The extent of this variation is about the same as usually occurs in a particular population of a non-parthenogenetic species of *Synemon*, such as *S. parthenoides* (Orange-spotted Sun-moth) or *S. plana* (Golden Sun-moth), (pers. obs. 1998 to 2005). Perhaps a progressive accumulation of favorable mutations within these parthenogenetic morphs may provide them with sufficient genetic plasticity to adapt to changing environmental conditions through time.

However, as mutations are uncommon in most species, it appears that at a given point in time the majority of the parthenogenetic females of *S. selene* would be genetically identical to their mothers because they cannot inherit any genes from a male parent. Although this scenario is likely, the hypothesis could only be resolved by a series of genetic comparisons between some randomly selected parthenogenetic females of *S. selene* and their respective cohorts of progeny. To do this it would be necessary to raise cohorts of larvae, which were bred from females that were subsequently preserved in alcohol, so that the genetic similarity of both parent and progeny could be assessed and compared. Unfortunately, it is likely that only very small first instar larvae would be available for work of this nature. This is because the larvae of the grass-feeding group of *Synemon* species (which include *S. selene*) are notoriously difficult to rear in captivity, with no larvae having ever been kept alive for long enough to reach their second instar (pers. obs. 1991 to 2003, C. O'Dwyer pers. comm. 2006).

It seems that *Synemon selene* may be one of the more recently evolved or 'derived' species of *Synemon*. This is hypothesized because of its derived morphological and biological characters, i.e. that it is one of the *Synemon* species that has a reduced haustellum and has consequently lost the ability to feed as an adult and also that its Victorian populations have diverged into five parthenogenetic morphs. These derived characters are an indication that this species has undergone a considerable amount of evolutionary change since it radiated from the common ancestor that it shares with the other species of *Synemon*.

Illustrations

Figure 1. Neighbour joining (NJ) tree (phylogram) for *Synemon* (Castniidae) based on 1515 bp *COI*. Parthenogenetic morphs of *S. selene* are indicated to right of tree. Bootstrap values (600 full heuristic search replicates) are shown below branches for nodes with $\geq$ 50% support. *Melittia* sp. and *Ichneumenoptera chrysophanes* (Sesioidea) are outgroup taxa.

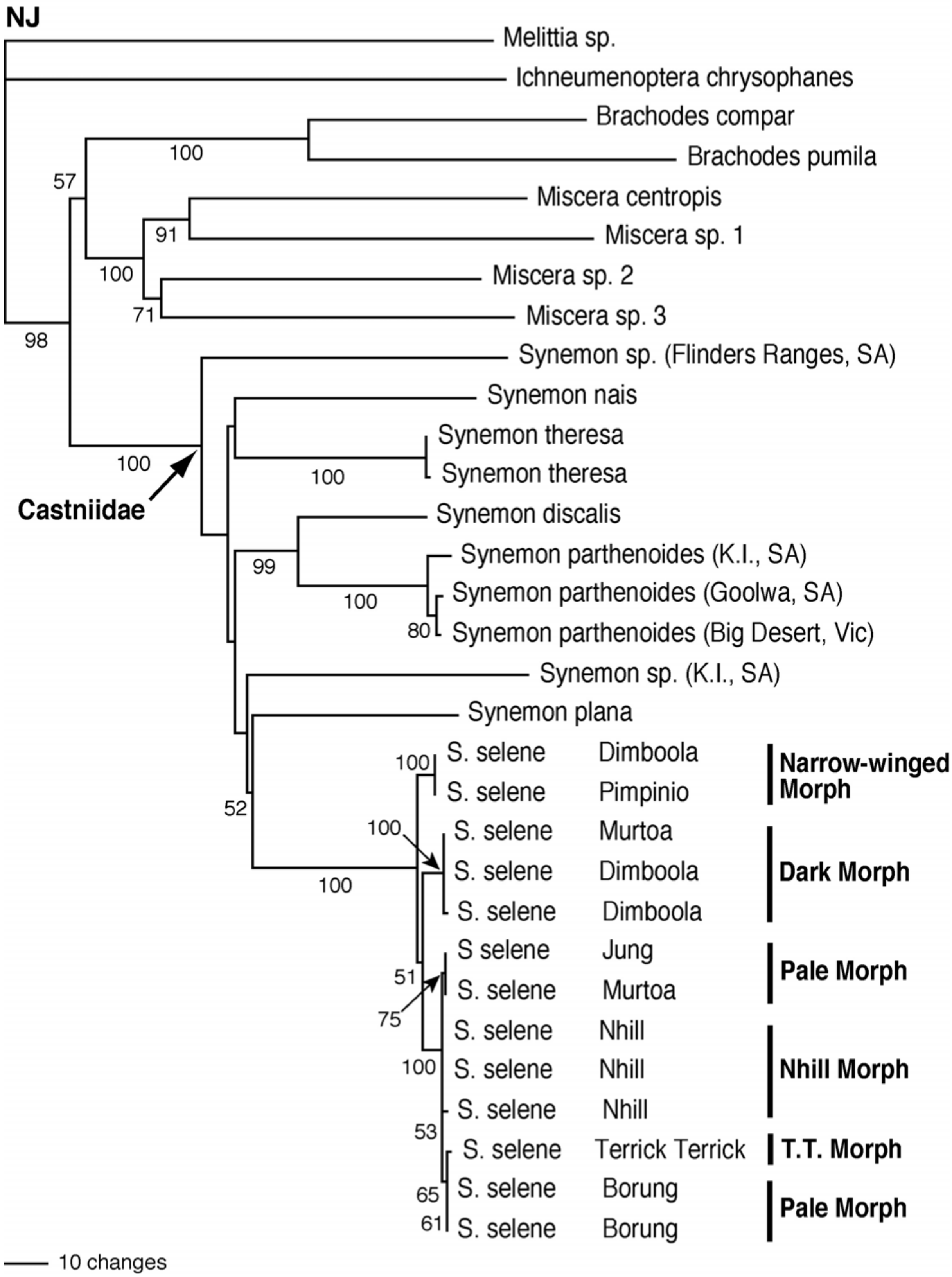
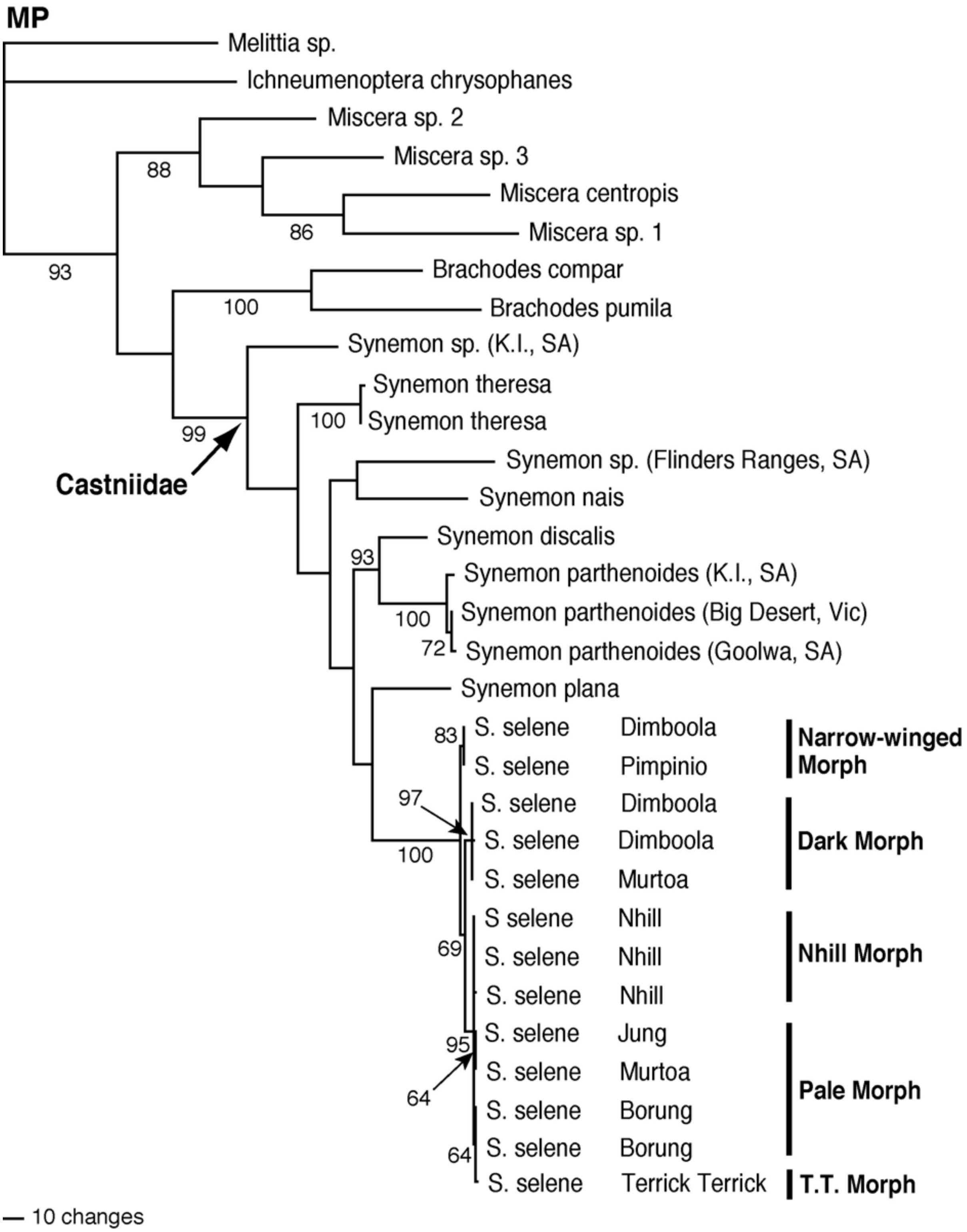

NJ
Melittia sp.
Ichneumenoptera chrysophanes
Brachodes compar
Brachodes pumila
100
57
Miscera centropis
Miscera sp. 1
91
100
Miscera sp. 2
Miscera sp. 3
71
98
Synemon sp. (Flinders Ranges, SA)
Synemon nais
Synemon theresa
Synemon theresa
100
100
Castniidae
Synemon discalis
Synemon parthenoides (K.I., SA)
99
Synemon parthenoides (Goolwa, SA)
100
80
Synemon parthenoides (Big Desert, Vic)
Synemon sp. (K.I., SA)
Synemon plana
100
S. selene Dimboola
S. selene Pimpinio
Narrow-winged Morph
52
100
S. selene Murtoa
S. selene Dimboola
S. selene Dimboola
Dark Morph
100
S selene Jung
S. selene Murtoa
Pale Morph
51
75
S. selene Nhill
100
S. selene Nhill
S. selene Nhill
Nhill Morph
53
S. selene Terrick Terrick
T.T. Morph
65
S. selene Borung
61
S. selene Borung
Pale Morph
10 changes

Figure 2. Single maximum parsimonious (MP) tree (phylogram) for *Synemon* (Castniidae) based on 1515 bp *COI* (395 informative characters; length = 1509, consistency index = 0.488, retention index = 0.599). Parthenogenetic morphs of *S. selene* are indicated to right of tree. Bootstrap values (1000 full heuristic search replicates) are shown below branches for nodes with ≥ 50% support. *Melittia* sp. and *Ichneumenoptera chrysophanes* (Sesioidea) are outgroup taxa.


MP
Melittia sp.
Ichneumenoptera chrysophanes
Miscera sp. 2
Miscera sp. 3
Miscera centropis
Miscera sp. 1
Brachodes compar
Brachodes pumila
Synemon sp. (K.I., SA)
Synemon theresa
Synemon theresa
Synemon sp. (Flinders Ranges, SA)
Synemon nais
Synemon discalis
Synemon parthenoides (K.I., SA)
Synemon parthenoides (Big Desert, Vic)
Synemon parthenoides (Goolwa, SA)
Synemon plana
S. selene Dimboola
S. selene Pimpinio
S. selene Dimboola
S. selene Dimboola
S. selene Murtoa
S selene Nhill
S. selene Nhill
S. selene Nhill
S. selene Jung
S. selene Murtoa
S. selene Borung
S. selene Borung
S. selene Terrick Terrick
Narrow-winged Morph
Dark Morph
Nhill Morph
Pale Morph
T.T. Morph
Castniidae
93
88
86
100
99
100
93
100
72
83
97
100
69
95
64
64
10 changes

Appendix

Appendix 1. Uncorrected pairwise distances for all sequences (1515bp) for *COI*.

2	*Ichneumenoptera chrysophanes*	0.152958	–								
3	*Miscera centropis*	0.1580113	0.171951	–							
4	*Brachodes compar*	0.1613303	0.1653617	0.1419142	–						
5	*Miscera* sp. 2	0.1553702	0.1620348	0.1128713	0.1379538	–					
6	*Miscera* sp. 3	0.1476579	0.1613513	0.1170699	0.1408519	0.1038603	–				
7	*Miscera* sp. 1	0.1579828	0.1765732	0.1141914	0.149835	0.1214521	0.1236979	–			
8	*Brachodes pumila*	0.1672766	0.1807011	0.1544554	0.0990099	0.1537954	0.1646486	0.1716172	–		
9	*Synemon discalis*	0.1388953	0.1415277	0.1306931	0.1346535	0.1141914	0.1216518	0.1478548	0.1452145	–	
10	*Synemon* sp. (F.R., SA)	0.1553119	0.1597175	0.1349335	0.147733	0.1256458	0.1369642	0.1435927	0.1618081	0.0842349	–
11	*Synemon* sp. (K.I., SA)	0.1468467	0.1486176	0.1338501	0.1339454	0.1265833	0.1238995	0.1431377	0.1593373	0.0719892	0.098878
12	*Synemon nais*	0.1529525	0.1500967	0.1329349	0.1428332	0.1335893	0.1321877	0.1402193	0.1521003	0.0720588	0.0888268
13	*S. parthenoides* (Goolwa, SA)	0.1455007	0.1348629	0.1267327	0.1372937	0.1181518	0.1170081	0.1412541	0.1485149	0.0422442	0.0855645
14	*S. parthenoides* (K.I., SA)	0.1494656	0.1361931	0.1293729	0.1359736	0.1174918	0.1189924	0.1452145	0.1485149	0.0429043	0.085558
15	*S. parthenoides* (Big Desert, Vic)	0.1454981	0.1348641	0.1273927	0.1359736	0.1181518	0.117672	0.1419142	0.1478548	0.0422442	0.0855683
16	*Synemon plana*	0.1355587	0.1521292	0.1326733	0.1425743	0.1240924	0.1223242	0.1465347	0.149835	0.0587459	0.0882289
17	*Synemon theresa*	0.1368989	0.1487926	0.1227755	0.1247651	0.1207952	0.1203228	0.1419237	0.1373097	0.0594117	0.0835236
18	*Synemon theresa*	0.1375421	0.1487904	0.1247525	0.1247525	0.1214521	0.1222825	0.1425743	0.1386139	0.060066	0.0841775
19	*S. selene* Dimboola 'Narrow'	0.1401817	0.1428123	0.1260726	0.1392739	0.1207921	0.1282492	0.1346535	0.1531353	0.0594059	0.0848866
20	*S. selene* Pimpinio 'Narrow'	0.1401817	0.1428123	0.1260726	0.1392739	0.1207921	0.1282492	0.1346535	0.1531353	0.0594059	0.0848866
21	*S. selene* Dimboola 'Dark'	0.142822	0.1454646	0.1267327	0.1412541	0.1214521	0.1322186	0.1372937	0.1518152	0.0627063	0.0875574
22	*S. selene* Dimboola 'Dark'	0.1434844	0.1461292	0.1273927	0.1419142	0.1221122	0.1328786	0.1379538	0.1524753	0.0633663	0.0882277
23	*S. selene* Murtoa 'Dark'	0.1428256	0.1454689	0.1267361	0.1412541	0.1214556	0.1322262	0.1372971	0.1518152	0.0627063	0.0875493
24	*S. selene* Nhill 'Nhill'	0.1441426	0.1467923	0.1267327	0.1379538	0.1194719	0.128913	0.1359736	0.1531353	0.0620462	0.0835485
25	*S. selene* Nhill 'Nhill'	0.1441426	0.1467923	0.1267327	0.1379538	0.1194719	0.128913	0.1359736	0.1531353	0.0620462	0.0835485
26	*S. selene* Nhill 'Nhill'	0.144805	0.1474568	0.1273927	0.1386139	0.120132	0.1295731	0.1366337	0.1537954	0.0627063	0.0842188
27	*S. selene* Jung 'Pale'	0.1441426	0.1474553	0.1267327	0.1379538	0.1194719	0.1289147	0.1359736	0.1531353	0.0620462	0.0835507
28	*S. selene* Murtoa 'Pale'	0.1441426	0.1474553	0.1267327	0.1379538	0.1194719	0.1289147	0.1359736	0.1531353	0.0620462	0.0835507
29	*S. selene* Borung 'Pale'	0.144883	0.147537	0.127447	0.1386964	0.1201925	0.129649	0.1366957	0.1538855	0.0627438	0.0842508
30	*S. selene* Borung 'Pale'	0.144805	0.1474568	0.1273927	0.1386139	0.120132	0.1295731	0.1366337	0.1537954	0.0627063	0.0842188
31	*S. selene* Terrick Terrick 'T.T.'	0.1441449	0.1481199	0.1280528	0.1379538	0.1207921	0.1302359	0.1359736	0.1531353	0.0633663	0.0848877

	Taxon name	11	12	13	14	15	16	17	18	19	20
1	*Melittia* sp.										
2	*Ichneumenoptera chrysophanes*										
3	*Miscera centropis*										
4	*Brachodes compar*										
5	*Miscera* sp. 2										
6	*Miscera* sp. 3										
7	*Miscera* sp. 1										
8	*Brachodes pumila*										
9	*Synemon discalis*										
10	*Synemon* sp. (F.R., SA)										
11	*Synemon* sp. (K.I., SA)	–									
12	*Synemon nais*	0.0912509	–								
13	*S. parthenoides* (Goolwa, SA)	0.0852867	0.0727096	–							
14	*S. parthenoides* (K.I., SA)	0.0866127	0.074694	0.0059406	–						
15	*S. parthenoides* (Big Desert, Vic)	0.0852899	0.0727115	0.0013201	0.0046205	–					
16	*Synemon plana*	0.0773162	0.0786822	0.0646865	0.0666667	0.0646865	–				
17	*Synemon theresa*	0.0733195	0.066795	0.0607275	0.0620477	0.0607275	0.0653583	–			
18	*Synemon theresa*	0.0739646	0.0674433	0.0607261	0.0620462	0.0607261	0.0660066	0.0006601	–		
19	*S. selene* Dimboola 'Narrow'	0.0733159	0.0687729	0.0607261	0.0627063	0.0607261	0.060066	0.062715	0.0633663	–	
20	*S. selene* Pimpinio 'Narrow'	0.0733159	0.0687729	0.0607261	0.0627063	0.0607261	0.060066	0.062715	0.0633663	0	–
21	*S. selene* Dimboola 'Dark'	0.0759787	0.07076	0.0653465	0.0673267	0.0653465	0.0607261	0.0660182	0.0666667	0.0059406	0.0059406
22	*S. selene* Dimboola 'Dark'	0.0766464	0.0714201	0.0660066	0.0679868	0.0660066	0.0613861	0.0666811	0.0673267	0.0066007	0.0066007
23	*S. selene* Murtoa 'Dark'	0.0759795	0.0707573	0.0653465	0.0673267	0.0653465	0.0607261	0.0660182	0.0666667	0.0059406	0.0059406
24	*S. selene* Nhill 'Nhill'	0.0733136	0.0707611	0.0633663	0.0646865	0.0633663	0.0613861	0.0640351	0.0646865	0.0066007	0.0066007
25	*S. selene* Nhill 'Nhill'	0.0733136	0.0707611	0.0633663	0.0646865	0.0633663	0.0613861	0.0640351	0.0646865	0.0066007	0.0066007
26	*S. selene* Nhill 'Nhill'	0.0739814	0.0714211	0.0640264	0.0653465	0.0640264	0.0620462	0.064698	0.0653465	0.0072607	0.0072607
27	*S. selene* Jung 'Pale'	0.0739794	0.0707628	0.0640264	0.0653465	0.0640264	0.0613861	0.0646952	0.0653465	0.0072607	0.0072607
28	*S. selene* Murtoa 'Pale'	0.0739794	0.0707628	0.0640264	0.0653465	0.0640264	0.0613861	0.0646952	0.0653465	0.0072607	0.0072607
29	*S. selene* Borung 'Pale'	0.0740184	0.0714543	0.0640601	0.0653791	0.0640602	0.0620777	0.0647247	0.0653732	0.0072621	0.0072621
30	*S. selene* Borung 'Pale'	0.0739814	0.0714211	0.0640264	0.0653465	0.0640264	0.0620462	0.064698	0.0653465	0.0072607	0.0072607
31	*S. selene* Terrick Terrick 'T.T.'	0.0746472	0.072084	0.0646865	0.0660066	0.0646865	0.0627063	0.0653581	0.0660066	0.0079208	0.0079208

	Taxon name	21	22	23	24	25	26	
1	*Melittia* sp.							
2	*Ichneumenoptera chrysophanes*							
3	*Miscera centropis*							
4	*Brachodes compar*							
5	*Miscera* sp. 2							
6	*Miscera* sp. 3							
7	*Miscera* sp. 1							
8	*Brachodes pumila*							
9	*Synemon discalis*							
10	*Synemon* sp. (F.R., SA)							
11	*Synemon* sp. (K.I., SA)							
12	*Synemon nais*							
13	*S. parthenoides* (Goolwa, SA)							
14	*S. parthenoides* (K.I., SA)							
15	*S. parthenoides* (Big Desert, Vic)							
16	*Synemon plana*							
17	*Synemon theresa*							
18	*Synemon theresa*							
19	*S. selene* Dimboola 'Narrow'							
20	*S. selene* Pimpinio 'Narrow'							
21	*S. selene* Dimboola 'Dark'	_						
22	*S. selene* Dimboola 'Dark'	0.0006601	_					
23	*S. selene* Murtoa 'Dark'	0	0.0006601	_				
24	*S. selene* Nhill 'Nhill'	0.0059406	0.0066007	0.0059406	_			
25	*S. selene* Nhill 'Nhill'	0.0059406	0.0066007	0.0059406	0	_		
26	*S. selene* Nhill 'Nhill'	0.0066007	0.0072607	0.0066007	0.0006601	0.0006601	_	
27	*S. selene* Jung 'Pale'	0.0066007	0.0072607	0.0066007	0.0006601	0.0006601	0.0013201	
28	*S. selene* Murtoa 'Pale'	0.0066007	0.0072607	0.0066007	0.0006601	0.0006601	0.0013201	0
29	*S. selene* Borung 'Pale'	0.0066034	0.0072648	0.0066034	0.0006601	0.0006601	0.0013215	0.001
30	*S. selene* Borung 'Pale'	0.0066007	0.0072607	0.0066007	0.0006601	0.0006601	0.0013201	0.001
31	*S. selene* Terrick Terrick 'T.T.'	0.0072607	0.0079208	0.0072607	0.0013201	0.0013201	0.0019802	0.001

Part 3

Chapter 6

The Nomenclature and History of the Pale Sun-moth

Introduction

The following documentation of the nomenclature and history of *Synemon selene* was derived from many sources, some of which were anecdotal. For this reason, it is possible that some of the historic events that have taken place could have been inadvertently omitted, or some minor inaccuracies may have been included. However, the following anecdotes are portrayed as accurately as possible, and it is hoped that the following chapter will provide a reasonably complete account of these aspects of *S. selene* (the Pale Sun-moth).

Two Wells Morph

It appears that the first specimens of this morph were collected by Dr H. H. Behr during the mid 1800s (E. D. Edwards pers. comm. 2000). It was ?four of these specimens (two males and two females) that were selected as the syntypes of *Synemon selene* by Dr J. C. F. Klug, a German lepidopterist who described this species in 1850. Following this, more specimens were obtained by Colonel C. Swinhoe, who being unaware that the same taxon had already been described, described the species again during 1892 as *Synemon adelaida*. The syntype specimens of *S. selene* are now held the Berlin Museum while the syntypes of its junior synonym (*S. adelaida*) are held in the Oxford University Museum (Hope Dept.). Although two of the likely syntypes of *S. selene* and ?all of the syntypes of *S. adelaida* bear the locality data ‘Adelaide’, it is possible that they were collected to the north of Adelaide, in the Two Wells area of the Adelaide plains (in southern South Australia).

Between 1904 and 1948, Mr. Frank M. Angel and Mr. Norman B. Tindale collected a number of male and female specimens of this morph in the Two Wells area, with the most recent specimens dated 4 March 1948. After this, it seems that the Two Wells Morph became extinct as a result of the widespread ploughing and alteration of its grassland habitat for agriculture. It appears that many of the specimens that were collected by F. M. Angel and N. B. Tindale were ultimately lodged in the South Australian Museum and the Australian National Insect Collection (CSIRO Division of Entomology). To the author’s knowledge there are no specimens of the Two Wells Morph in the Museum of Victoria’s collection of Castniidae.

The late Mr. O. F. (Frank) Noelker and the author carried out a search for extant populations of this morph in the Two Wells area during late February 1993. Following this, Mrs. J. T. Noelker and the author undertook two further surveys for the Two Wells Morph in the same area, during late February 1998 and early March 2004. On all three of these field trips, the results of the searches were negative. It certainly does appear that this morph of the Pale Sun-moth may be extinct, as the alteration of the southern Adelaide Plains area for farming activities seems to have left little natural habitat where it could survive.

Pale Morph

So far as can be determined, in 1884, Mr. James A. Kershaw and a (?Mr.) W. Kershaw collected the earliest specimens of the Pale Morph at Kewell and Murtoa respectively, in the Wimmera area of western Victoria. However, it is possible that this morph was actually discovered first by a member of the Hill family (?James Hill senior) who also collected it at Kewell in the late 1800s. To the author's knowledge the earliest specimen that was probably collected by James Hill senior (at Kewell) is dated April 1887. However, another member of the Hill family may have collected this specimen because its data label bears the name 'Hill, J.' as its collector. Also, in the South Australian Museum, there is an old specimen (collected by O. B. Lower) that is simply labeled 'Lyndoch' (a South Australian locality) and another old specimen (that may have been collected on the Blandowski expedition, circa 1856 to 1857) that is labeled 'Murray River near Vic. S. A. border'. There is also an old specimen in the Museum of Victoria that is labeled 'Western District' (Victoria). Unfortunately, the data labels on all three of these specimens do not include the dates when they were collected, so it would be difficult to determine if any of them predate the specimens that were collected by J. A. Kershaw and W. Kershaw in 1884.

From available specimen data, it seems that a (?Mr.) 'J. H. Hill', a (?Mr.) 'J. R. Hill' and a 'Mrs. Hill' continued to collect specimens of the Pale Morph from the Kewell and Murtoa districts until about 1931. Curiously, Mrs. Valerie Read and Mr. Brian Newell (who are descendants of James Hill junior) have both stated that they were unaware that either of the two Hill brothers had middle names. However, Mrs. V. Read said that 'J. H. Hill' was probably James Hill junior and 'J. R. Hill' was likely to be his younger brother Joseph Hill. Messrs. James Hill junior and Joseph Hill were sons of James Hill senior. The (undated) 'Kewell' specimens that bear the name 'Mrs. Hill' were probably collected by the wife of James Hill senior, as the Hill family first settled in the Kewell district after they immigrated to the Wimmera area from St. Albans, England in 1854.

Many of the 'Hill' specimens are now held in the collection of Castniidae at the Museum of Victoria. Additional specimens of the Pale Morph were also collected at Kewell in 1936 and Murtoa in 1939. The data labels of the 1936 specimens bear the name 'Newell' while the data labels of those that were collected in 1939 bear the name 'E. Newell'. Although the initial 'E.' does not precede the name 'Newell' on the data labels of the earlier specimens, it is likely that both the 1936 and 1939 'Newell' specimens were collected by Mrs. Elsie Newell, who was the fourth daughter of James Hill junior (V. Read pers. comm. 2006).

Of special interest is a letter (dated 16 October 1927) that was sent to Mr. James Hill (?junior) by Mr. Norman B. Tindale, an eminent lepidopterist and anthropologist who was based at the South Australian Museum during the time when members of the Hill family were actively collecting specimens of the Pale Morph of the Pale Sun-moth. It is significant that N. B. Tindale wrote the following sentences in this letter to 'James Hill esq.': 'We have a long series of females of a yellow winged *Synemon*, which has been long, but wrongly, called *Synemon laeta* but have never seen a male. I understand that you are the fortunate captor of many of the examples in collections. Have you ever seen a male associated with them? It may be of quite a different colour to the female'. It seems that there is little doubt that N. B. Tindale is actually referring to the Pale Morph of *Synemon selene* (the Pale Sun-moth) here. However, it is strange that, although he mentions that the taxon had been wrongly referred to as *Synemon laeta* for a long time, he does not mention *Synemon selene* by name. Nor does he mention that at his time of writing, it was known that there was a (then extant) population (of the non-parthenogenetic Two Wells Morph) of this species in South Australia, from which male specimens had already been collected. An explanation for his omission of this information could be that, although he probably knew about the South Australian population of *Synemon selene*, he thought that the Victorian specimens belonged to a separate species. Further, although N. B. Tindale had noticed that there were no male specimens of this 'yellow winged *Synemon*' from Victoria, it appears that he did not suspect that the specimens in question could have been collected from a parthenogenetic population. The original of this letter was kindly loaned to the author in 1998 by the late Mr. Keith V. Hateley (see Appendix 4 of this chapter for a reproduction of this historic letter.)

An early specimen of the Pale Morph from Rupanyup, Victoria, dated 28 January 1900 does not bear the name of its collector. However, it was most likely to have been collected by Mr. David Goudie (E. D. Edwards pers. comm. 2006). According to E. D. Edwards (pers. comm. 2006), this specimen was probably deposited in the L. Gooding collection or the A. J. Turner collection before it was finally lodged in the G. Lyell collection. It is now held in the Australian National Insect Collection (CSIRO Division of Entomology). To the author's knowledge, there are no other records of *Synemon selene* from the Rupanyup area.

Between 1939 and 1991 this morph was not recorded or collected. By the late 1980s it was thought that it might be extinct because much of its former habitat had been cleared and then regularly ploughed for cropping purposes (E. D. Edwards pers. comm. 1990).

By 1990 it was apparent that several of the Australian sun-moths (*Synemon* spp.) were becoming increasingly rare and restricted in their distributions as a result of their habitats being altered for agriculture. As well as this, about twenty of the *Synemon* species were still undescribed and some had not been seen alive for many years. For these reasons the CSIRO Division of Entomology commenced a major review of the Australian Castniidae in 1991. This project was (and still is) being co-ordinated by Mr. E. D. (Ted) Edwards, who is a leading authority on this family. Prior to the initial funding being obtained to carry out this work, Ted wrote to many entomologists throughout Australia and the rest of the world, requesting specimen loans of any Australian Castniidae, to clarify the taxonomy and past and present distributions of as many species as possible. During 1990 he wrote to the author (who was then based at Rainbow) to inquire about any sun-moths that had been observed or collected in north-western Victoria. The correspondence that followed included a letter in which the author was informed about *Synemon selene*, 'a large pale species' of sun-moth that had been collected historically in the Wimmera area of western Victoria, but not since the late 1930s.

It was this information about the (?former) existence of Pale Sun-moth that led to the Pale Morph of this species being rediscovered on 17 February 1991, by the late Mr. O. F. (Frank) Noelker and the author. This population was found in the Brynterion State Forest at 4.9 km ENE of Lubeck. After this initial discovery, Mr. Damien R. Crouch and the author located two more populations of the Pale Morph in the Barrabool area (at 6.8 km and 8.4 km south of Murtoa) on 24 February 1991. On all of these occasions, a considerable effort was made to find the males of this species. This was because Ted had explained in his correspondence that, although the males of *Synemon selene* were known from South Australia, no males had ever been collected in Victoria. For this reason it was noted with great interest that no males were observed by any of us in the areas where the females were flying. This seemed to be especially strange because with other species of sun-moths it is the males that are usually more conspicuous as they fly rapidly around open areas while searching for freshly emerged and unmated females. It was just after these observations were made that the author sent a letter to Mr. E. D. (Ted) Edwards, in which it was suggested that *Synemon selene* might be parthenogenetic in Victoria. A reply was soon received in which Ted agreed that, based on the very strong circumstantial evidence, this seemed to be the case.

The voucher specimens that were collected during the above mentioned rediscovery of *Synemon selene* in Victoria are now held in the following insect collections: the Australian National Insect Collection (CSIRO Division of Entomology), the Museum of Victoria, the F. Douglas (author's) collection and the M. F. Braby collection. All of the 1991 voucher specimens that were collected in the Brynterion State Forest bear data labels (that were hand written by the author) in which the name 'Brynterion' is miss-spelt as 'Bryterion'. This spelling error was repeated from Edition 1 of the Country Fire Authority's Region 17 Map Directory (1986). More specimens of the Pale Morph were collected during February 1992, when Mr. E. D. Edwards visited the 'Brynterion site' in company with the late Dr Ebbe S. Nielsen. All of these specimens are now held in the Australian National Insect Collection. These specimens also bear data labels in which the name 'Brynterion' is miss-spelt 'Bryterion' (possibly for the same reason as the original series of 1991 voucher specimens).

In 1992 the author was provided with funding by the (then) Department of Conservation and Natural Resources for the production of a report on the conservation status, distribution and habitat requirements of diurnal Lepidoptera in central and western

Victoria. These aspects of the family Castniidae were covered in Part 1 of this work, which included a recommended conservation strategy for each species, including the Pale Morph of the Pale Sun-moth. This report was completed in January 1993. Later in 1993, part one of a recovery plan for threatened diurnal Lepidoptera in north-western Victoria was compiled by David R. Venn, under funding provided by the (former) Australian Nature Conservation Agency. In this recovery plan, Venn (1993) largely reiterated the recommendations that were made by Douglas (1993) for the conservation of the Pale Morph. After this, the Brynterion and Barrabool State Forests were designated as flora and fauna reserves. The recommendations that were made in the above mentioned reports may have had some influence on these decisions being made.

During 1995 the Department of Conservation and Natural Resources provided further funding for the author to carry out surveys in north-western Victoria for unknown populations of several species of threatened diurnal Lepidoptera, including the Pale Sun-moth. It was while this survey work was being undertaken that the late Mr. O. F. (Frank) Noelker and the author discovered an additional population of the Pale Morph on 2 March 1996. The precise locality were this population was located is on private land at 7.3 km SSE of Murtoa, Victoria (on the south side of Hopefields Road at 2.7 km east of the Murtoa-Glenorchy Road). A single voucher specimen was collected on this occasion. This specimen was subsequently lodged at the Museum of Victoria.

While further research work on the Pale Sun-moth was being undertaken by Mrs. Joan T. Noelker and the author on 17 February 1997, it was found that the Pale Morph also occurs at the ‘Jung site’ (at 4.5 km SSE of Jung, Vic.). This is where a population of the Dark Morph had already been discovered in 1993 but was thought to have become extinct after a large portion of the area was ploughed up for cropping purposes during 1995.

In February 1996 another population of the Pale Morph was discovered on the Wishart’s ‘Kinipanyal’ grassland property at 5.5 km ESE of Borung in central Victoria. This population was found by Dr Susan Hadden who at the time was working on grassland ecology as a PhD student at the University of Ballarat. An article, which documented this discovery, was published in the 1996-97 summer edition of ‘Outdoors’, the quarterly magazine of the (then) Department of Natural Resources and Environment. However, although the Pale Morph of *Synemon selene* is correctly illustrated in this article, it does not inform the reader as to which species of *Synemon* had actually been discovered, and simply refers to the taxon as ‘an endangered sun-moth’. The illustration that was used for the article in ‘Outdoors’ was copied from ‘The Conservation Status and Habitat Requirements of Diurnal Lepidoptera in Central and Western Victoria’ (1993), the above-mentioned unpublished report (by the author) that was commissioned by the former Department of Conservation and Natural Resources. It was only through subsequent communications with Dr S. Hadden as well as a personal visit to the site on 27 February 1999, that the author was able to determine (beyond doubt) that it was indeed an occurrence of the Pale Morph of *S. selene* that had been discovered. Due to its extreme conservation values, the land where this population is situated was purchased in 1999 by the Trust for Nature (Victoria) and will now be managed in perpetuity as the ‘Kinipanyal Grassland’ reserve.

Terrick Terrick Morph

The late Mr. O. F. (Frank) Noelker was apparently the first to discover and collect this morph. Although this discovery was made on 21 February 1994, the locality data that were given to the author for the three specimens that were collected at this time are confusing. These locality data are as follows: Regal Point Road at 4.5 km east of Terrick Terrick State Park, Victoria. The apparent inaccuracy of these data was not realised until Mrs. Joan T. Noelker and the author attempted to revisit this site on 2 March 1997. On this occasion, Edition 1 of the Country Fire Authority's Region 20 Rural Directory (1990) was used in our attempt to find the precise locality. However, the nearest name to Regal Point Road that we could find in the area was Regal's Road, which also runs east from what is now the Terrick Terrick National Park. One other problem was that Regal's Road became a private driveway at 3.5 km east of the Terrick Terrick National Park, so we were unable to progress beyond this point. As this was the closest approximation that could be found to the above mentioned locality data and the habitat appeared to be suitable, the area in question was searched for the Terrick Terrick Morph, resulting in 2 individuals being found. For this reason it was thought that this might have been the site where the original discovery was made.

However, in 1999 a conversation between the author and Dr Paul Forman (who was the conservation manager of Trust for Nature, [Victoria] in 1994) revealed that the site where this morph was originally discovered by Mr. O. F. Noelker was actually on the north side of Forbes Road at 2.9 km E. of its junction with the Mitiamo-Kow Swamp Road. The area in question is 4.8 km east of the Terrick Terrick National Park and is approximately 10 km NE of Mitiamo. Apparently, Dr. P. Forman had accompanied Mr. O. F. Noelker on 21 February 1994, when the three specimens in question were collected. One of these voucher specimens is now held in each of the following collections: F. Douglas collection (author's collection), the Museum of Victoria and the Australian National Insect Collection (CSIRO Division of Entomology). It is a pity that this anomaly with the data of these specimens is now beyond explanation, because the late Mr. O. F. Noelker was usually meticulous to the last detail when recording scientific data for insect specimens.

On 1 March 1998 Mrs. Joan T. Noelker and the author captured a single specimen of this morph in the grounds of the Mitiamo Golf Course, at 3.5 km NNW of Mitiamo. This specimen is currently held in the author's reference collection. To date (1 April 2006), this record has not been duplicated.

As indicated by Dr P. Forman, the site on Forbes Road (at 10 km NE of Mitiamo) was surveyed by Mrs. Joan T. Noelker and the author for the (alleged) population of the Terrick Terrick Morph on 27 February 2004. During this visit to the area, nine individuals of the Terrick Terrick morph were recorded. Therefore, it seems that the information that Dr P. Forman had provided was correct, as to the whereabouts of the locality where Mr. O. F. Noelker originally discovered this morph in 1994.

Nhill Morph

It is likely that this morph was first collected at Nhill, Victoria by the Rev. J. R. Fiddian in 1902. This assumption is based on a single specimen that was presented to the Museum of Victoria on 31 July 1932 by Mr. George Lyell. The author noticed this specimen in 1997, while data were being extracted from the Museum of Victoria's collection of Castniidae. Subsequent study of the morphological characters of this unique 'Nhill' specimen revealed that it belonged to an as yet unrecognized morph of the Pale Sun-moth. Because of this, Mrs. Joan T. Noelker and the author surveyed the nearest remnant of native grassland to Nhill (on the northern side of Belcher Street at 1.4 km east of Nhill) for this morph, on 16 February 1999. On this occasion three specimens were recorded. Since the Nhill Morph was rediscovered, a very small quantity of voucher specimens have been collected. While one of these is now held in the Australian National Insect Collection (CSIRO Division of Entomology) the remainder have been retained in author's reference collection of Castniidae. However, after the preparation of this work is concluded (in the year 2006), at least one of these voucher specimens will be lodged in the Museum of Victoria.

The discovery of the Nhill Morph of the Pale Sun-moth at the Belcher Street site was highly significant because Mrs. Joan T. Noelker and the author had also discovered a large population of the Golden Sun-moth (*Synemon plana*) in the same area, during the previous November. These two discoveries made the Belcher Street site the only known locality to hold sympatric occurrences of these two endangered species of Sun-moths as well as the only known area to hold a population of this particular (Nhill) morph of the Pale Sun-moth. For these reasons, the Hindmarsh Shire Council and the relevant Department of Sustainability and Environment staff were informed about the extreme conservation values of this grassland remnant. This information was also conveyed to the regional officer of the Trust for Nature (Victoria) Mr. Neil Marriott and to local naturalist Mr. Clive R. Crouch. Following this, a series of meetings was held at the shire offices in Nhill so that a co-ordinated attempt could be made to convert the site into a small flora and fauna reserve. Applications were then made to the Trust for Nature (Victoria) and the R. E. Ross Trust for funding to purchase the necessary land (from several owners) so that the proposed reserve could be established. Both of these applications were successful and the Shire of Lowan is now in the final stages of acquiring this land, with the majority of the blocks being already purchased (by 30 November 2006). The Nhill Sun-moth Reserve was officially opened on 18 November 2004 by Mr. John Landy, the former Governor of Victoria. For a more detailed account of how the Nhill Sun-moth Reserve was established see Appendix 2 to Chapter 9 of Part 3 of this work.

Narrow-winged Morph

The Narrow-winged Morph was discovered on 18 February 1998, when Mrs. Joan T. Noelker and the author captured the first known specimen. This was collected at the 'Jung site' (at 4.5 km SSE of Jung, Victoria) where this morph is now known to occur sympatrically with extant populations of the Pale Morph and the Dark Morph. After the specimen in question had been set so that its morphological features could be examined and comparisons made between it and specimens of the other five Pale Sun-moth morphs, it became obvious that it most closely resembled the females of the non-parthenogenetic, South Australian Two Wells Morph.

Following this, Mrs. J. T. Noelker and the author caught a second specimen of the Narrow-winged Morph at the ‘Jung site’ on 12 February 2000. Although the two ‘Jung’ specimens that are alluded to above are currently held in the author’s reference collection, one of them will ultimately be lodged in the Australian National Insect Collection (CSIRO Division of Entomology) during the year 2007.

It was especially significant that two specimens of the Narrow-winged Morph were collected at the ‘Jung site’ because its presence there caused it to become the only known locality where three morphs of the Pale Sun-moth occur sympatrically. Because it has now been determined that the Narrow-winged Morph is also parthenogenetic, it is extraordinary that this population of the species contains three separate parthenogenetic morphs that are genetically isolated from one another and are therefore incapable of interbreeding.

A second population of the Narrow-winged Morph was discovered by the author on 21 February 1998, with the first specimen being (inadvertently) collected when a population of the Dark Morph was discovered at the Pimpinio Golf Course (at 0.3 km east of Pimpinio, Victoria). On this occasion a small series of reference/voucher specimens of the Dark Morph was collected and it wasn’t until the following day when these specimens were being set, that it was noticed that one of them belonged to the Narrow-winged Morph.

Curiously, only one more individual of this morph was observed (but not captured) at the Pimpinio Golf Course during a number of visits to the area in the following adult flight periods of 1999, 2000 and 2001. However, in 2002 two more were recorded and in 2004 it was found that there was a concentration of the Narrow-winged Morph in a discrete area along the western half of southern boundary of the Golf Course, with the highest concentration of individuals near its SW corner. In this area it all but replaced the Dark Morph, which is distributed fairly evenly throughout the rest of the Golf Course. This same very localised distribution of the Narrow-winged Morph within the same area of the Golf Course was also noted during the subsequent adult flight period of 2005.

On 27 February 2005 Mrs. J. T. Noelker and the author captured a single individual of the Narrow-winged Morph at the ‘Dimboola site’ (at 4.3 km SE of Dimboola, Victoria). This was surprising because only the Dark Morph had been recorded at this locality on all of the previous visits. This individual was released after one of its hind legs was carefully removed and placed into ethanol for future DNA analysis.

The discovery of the Narrow-winged Morph of the Pale Sun-moth raised some interesting questions that still remain to be answered. Firstly, why has it only been recorded at three localities where other morphs of the Pale Sun-moth occur? With each one of the other morphs, there is at least one locality where it seems to occur without any others. Secondly, why does this morph so closely resemble the non-parthenogenetic Two Wells Morph? And finally, is this morph on the verge of extinction because the areas that were occupied by its main populations have already been cleared and ploughed for agriculture?

Dark Morph

The earliest known specimen of the Dark Morph is (probably) one that was collected at approximately 10 km. east of Dimboola, Victoria, during 1965 by Mr. Noel T. Starick, who was living on a nearby farm at the time. However, it was not until this specimen was shown to Mr. E. D. (Ted) Edwards and the author during October 1997 that the existence of this record (and specimen) was known to the wider entomological community. At this time Noel very kindly donated the specimen in question to the Australian National Insect Collection (CSIRO Division of Entomology).

After the ?initial record and discovery of the Dark Morph in 1965, no more specimens were collected until a population was located by the late Mr. O. F. Noelker and the author on 4 March 1993, at 4.5 km SSE of Jung, Victoria. On this occasion three voucher specimens were collected. Of these, one was lodged in the Museum of Victoria, one in the Australian National Insect Collection and one is still held in the author's reference collection. In 1995 most of the private land where this population was situated was ploughed for agriculture (despite the former Department of Conservation and Natural Resources being notified as to its whereabouts) and it was presumed that this morph might be extinct. However, new hopes for its survival were held when Mr. Noel Starick brought his 'Dimboola' specimen to the Australian Insect Collection in 1997. It was knowledge of this 'Dimboola' specimen that led to the discovery (by Mrs. J. T. Noelker and the author) that a population was still extant near Dimboola, with several adults being observed, some of which were collected as voucher specimens. The rediscovery of this occurrence took place on 18 February 1998, on private land at 4.3 km SE of Dimboola, at approx. 7.5 km to the WSW of where the original specimen was collected Mr. Noel Starick.

Later on the same day (18 February 1998) Mrs. Joan T. Noelker and the author also visited the above-mentioned 'Jung site' (at 4.5 km SSE of Jung) where one worn individual of the Dark Morph was located. During most of the subsequent years a few more individuals of this morph were observed at this site, so it now seems that a small population has survived within the remaining area of uncultivated grassland. Following the rediscovery of the Dark Morph at the 'Jung site' the author discovered another much larger occurrence on 21 February 1998, at 0.3 km east of Pimpinio, Victoria (on the Pimpinio Golf Course). This discovery was highly significant because the Pimpinio Golf Course now holds the largest known populations of the Dark Morph and the Narrow-winged Morph and as such, probably offers the best prospect and potential for their long-term conservation.

On 19 February 1999, Mrs. Joan T. Noelker and the author recorded a single individual of the Dark Morph at the ‘Murtoa site’ (at 7.3 km SSE of Murtoa). As with the ‘Jung site’ a few more individuals were also recorded at this site during the adult flight periods of subsequent years. The discovery of the Dark Morph at the ‘Jung site’ was of special interest because it is the furthest south that this morph has been recorded to date (27 Feb. 2006) and it occurs sympatrically with the Pale Morph at this locality.

In early 2002, Mr. Clive R. Crouch noticed what appeared to be suitable habitat for *Synemon selene* surrounding the residence of Mr. and Mrs. Graham and Maree Goods, at 5.5 km E by N of Wail, Victoria. As a result of this observation, a survey of the area by Mr. Clive R. Crouch, Mrs. Joan T. Noelker and the author was arranged for 19 February 2002. This visit resulted in the discovery of another occurrence of the Dark Morph, with the majority of the seven-plus adults and all four of the pupal exuviae that were located being concentrated in a remnant area of open grassy woodland immediately to the south of the Goods’ homestead.

Finally, on 15 August 2003, Mr. Peter Marriott brought to the author’s attention another historic specimen of the Dark Morph in the ‘acquisition material’ of the Museum of Victoria’s collection of Castniidae. This specimen bears a data label reading ‘Murtoa, Vic. 21/2/1927 J. H.’. As this specimen predates the above mentioned ‘Dimboola’ specimen, it now seems likely that it was actually a member of the Hill family (probably James Hill junior) who collected the earliest known specimen of the Dark Morph.

All Victorian morphs of the Pale Sun-moth

In 1999 Mr. Garry Backhouse compiled a list of threatened invertebrates of Victoria for the (then) Department of Natural Resources and Environment. Consultations with the author during this process resulted in the five Victorian morphs of *Synemon selene* being listed in the unpublished ‘DNRE 1999. *Threatened Invertebrate Fauna in Victoria*’ list, under the following categories: Critically endangered; Nhill Morph and Narrow-winged Morph. Endangered; Pale Morph, Terrick Terrick Morph and Dark Morph.

After this, in the year 2000, the Department of Natural Resources and Environment commissioned the author to compile a *Flora and Fauna Guarantee Act* 1988 Action Statement for all of the Victorian morphs of *Synemon selene*. This work was completed on 26 September 2000 and covered such topics as the present distribution, current conservation status, habitat requirements and long-term management of the species in Victoria. The final draft of this Action Statement is included in this work as Appendix 1 to Chapter 9 of Part 3.

Illustration

Figure 1. Male and female syntype specimens of *Synemon selene* Klug, 1850 (males at top of figure). These specimens were photographed at the Australian National Insect Collection (CSIRO Division of Entomology) while on loan from the Berlin Museum, Germany. About 1.6 times life size.

Appendices

Appendix 1. Description of *Synemon selene* published by Dr J. C. F. Klug in 1850 (with additional hand-written notes by Mr. E. D. [Ted] Edwards).

Klug J. C. F (1850) Abh. K Akad. Wiss. Berl. 1848 p249 fig 3.4.

2) ~~Synemon Selene~~ n. sp.

Fig. 3. 4.

S. corpore fusco, subtus albido, abdomine supra griseo; alis anticis fusco-griseis, medio late fuscis, ante apicem fusco-maculatis, fascia maculari transversa interrupta ante medium lunulaque media albis; posticis fuscis, luteo-trifasciatis; omnibus subtus albido-testaceis, fusco-maculatis. Mas. Fem.

Noch etwas größer als *S. Sophia*, die Länge des Männchen 9½ Linien, des Weibchen mit dem hervorstehenden Legestachel 12 Linien, die Breite bei ausgespannten Flügeln 20½ bis 21 Linien. Diese Art unterscheidet sich leicht von der vorhergehenden durch den grauen Hinterleib, die mattere graubräunliche Grundfarbe der Vorderflügel und die dunkelbraunen großen länglichen Flecke auf denselben zwischen der Mitte und dem Außenrande, so wie durch die ganz verschiedene Stellung der weißen Binde, die in der Mitte so abgebrochen ist, daß die untere Hälfte mehr nach innen tritt und den Mondfleck an der Spitze der Discoidalzelle, wogegen die hinteren Flügel in fast übereinstimmender Weise aus Flecken zusammengesetzte Binden haben, die jedoch von weniger lebhafter Farbe sind. Die Färbung der unteren Seite der Flügel ist gelblichweiß und nur die Umgebung der schwarzen Flecken röthlichgelb. Die Fühler sind schwarz und weiß geringelt, auch ist die Fühlerkolbe unten zum Theil weiß.

166/5

Cast

'6107'

'Selene
Kl *
Adelaide

✓

Appendix 2. Translation of Dr J. F. C. Klug’s description of *Synemon selene* (by Dr Axel Kallies).

2) *Synemon selene* n. sp.
Fig. 3, 4.

…. [Latin description]
Even bigger than *S. sophia*, length of male 9.5 lines, of females including the protruding ovipositor 12 lines; with spread wings 20.5 to 21 lines wide. This species differs readily from the previous by the grey abdomen, the duller grey-brown coloration of the forewings and the dark brown big elongate markings between the centre and the termen on the same [forewings]. It can also be distinguished by the very different position of the white band on the forewing, which is broken in the middle so that the lower half is closer to the base while the moon-shaped spot is at the tip of the discoidal cell. The hindwings show bands composed of spots almost like [sophia] but of less bright coloration. The color of the underside of the wings is yellowish-white, only around the spots reddish yellow. The antennae are black and white ringed; the club is partly white underneath.

Appendix 3. Description of *Synemon adelaida* (syn. S. *selene*) published by Colonel C. Swinhoe in 1892 (with additional hand-written notes by Mr. E. D. [Ted] Edwards).

1892

Swinhoe, [redacted], Cat. east. and Aust. Lepid. Heterocera 1: 154

Synemon Doubl.

CASTNIID.

711. Synemon adelaida : n. sp. Pl. VII. f. 10.

♂ ♀ Frons, top of head, and thin ring behind the eyes whitish, body and fore-wings greyish brown, lower part of abdomen paler. Fore-wings with whitish veins, a whitish spot at end of cell, a transverse band of three similar spots below it between the veins, a discal incomplete similar band, disjointed in the centre, and in the two male specimens an indistinct sub-marginal similar band. Hind-wings dark blackish brown, with reddish ochreous macular bands, discal and submarginal, and a similarly coloured large spot at the end of the cell, the spot and bands of spots larger in the female than in the males. Underside, fore-wings bright ochreous red with a large blackish suffused basal patch, and a large blackish discal patch, veins near the margin marked with black, marginal line black, cilia grey, interlined and tipped with black; hind-wings as above, marginal line and cilia as in fore-wings, both wings below in the female are of a greyish colour suffused in parts with ochreous, fore-wings with the blackish patches as in the male, hind-wings with a large blackish discal patch and a submarginal band of smaller blackish spots, marginal line of both wings black, cilia interlined.

Expanse of wings $1\frac{6}{10}$ inches.

a. Adelaide (type ♂ ♀). b. Adelaide.

NB Swinhoe had 3 specimens
a. Type ♂, ♀ b. male.
The type ♂, ♀ are the syntypes (no lectotype, there no holotype)
the spec. b is not known as syntype.

CAST. ✓

274

10. Synemon adelaida, Swinh.

syntype ♂ Oxford. (3 syntypes all ♂)

not so.

"Adelaide"

" A "

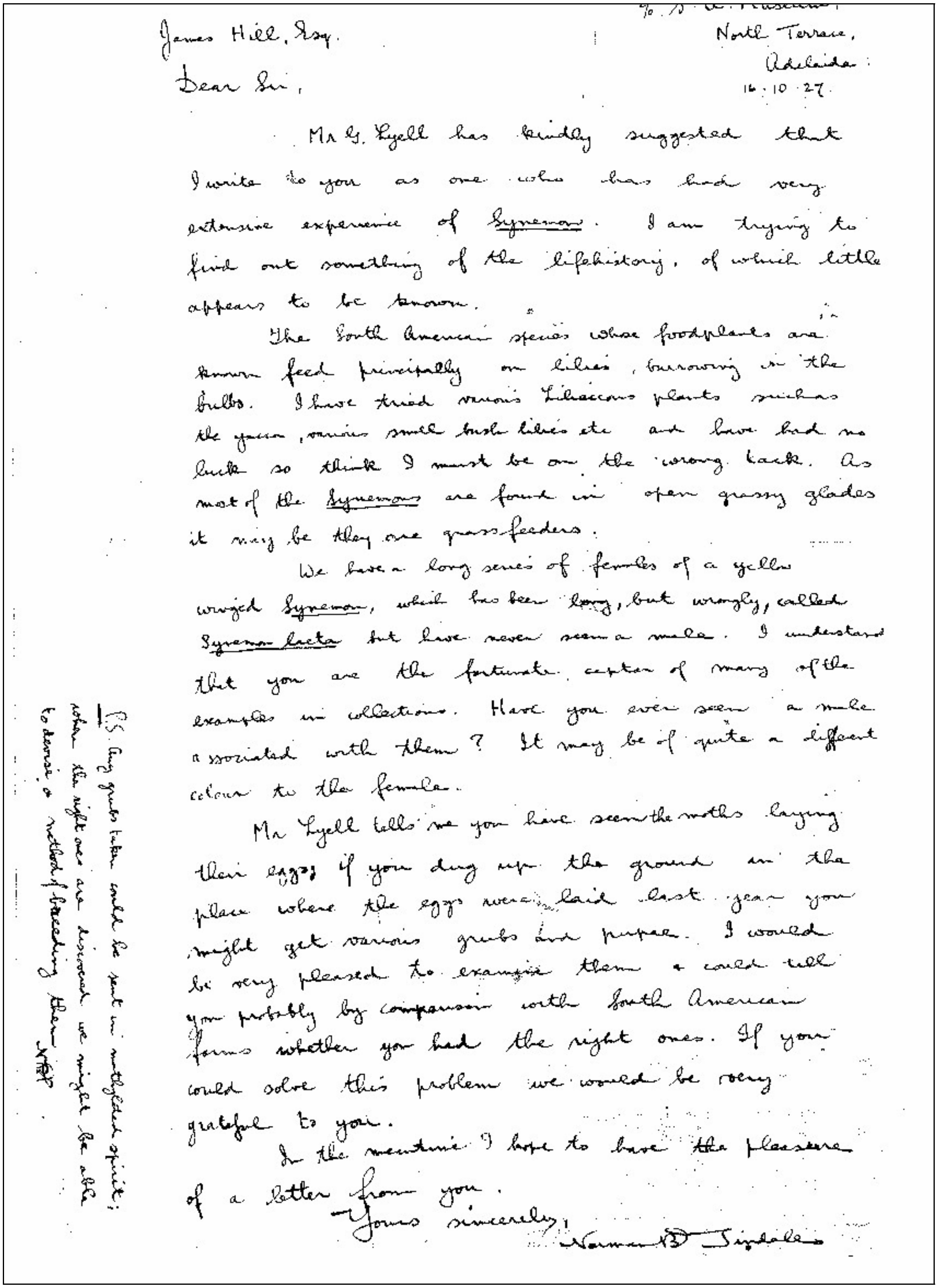
" Synemon adelaida Swinhoe ♂ type " Syn.

" 711 "

" Type Lep No. 274 1/3 Synemon adelaida ♂/♀ Swinhoe. Hope Dept Oxford "

F.E. 142/15

Appendix 4. Letter to Mr. James Hill (?Junior) from Mr. Norman B. Tindale, ?re the parthenogenetic Pale Morph of *Synemon selene*.



℅ S. A. Museum,
North Terrace,
Adelaide.
16.10.27.

James Hill, Esq.

Dear Sir,

Mr G. Lyell has kindly suggested that I write to you as one who has had very extensive experience of *Synemon*. I am trying to find out something of the lifehistory, of which little appears to be known.

The South American species whose foodplants are known feed principally on lilies, burrowing in the bulbs. I have tried various Liliaceous plants such as the yucca, various small bush lilies etc and have had no luck so think I must be on the wrong track. As most of the *Synemons* are found in open grassy glades it may be they are grass feeders.

We have a long series of females of a yellow winged *Synemon*, which has been long, but wrongly, called *Synemon laeta* but have never seen a male. I understand that you are the fortunate captor of many of the examples in collections. Have you ever seen a male associated with them? It may be of quite a different colour to the female.

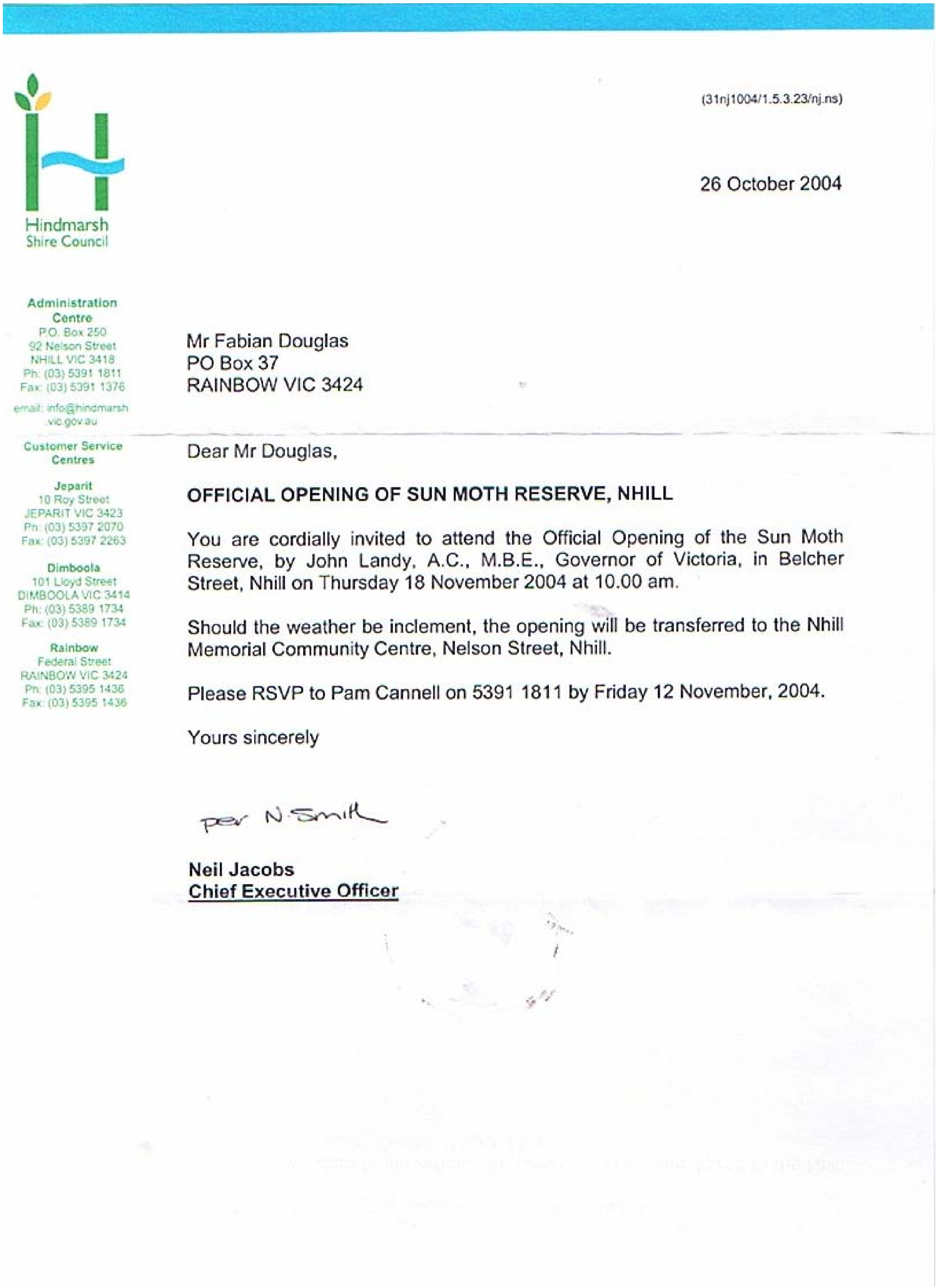
Mr Lyell tells me you have seen the moths laying their eggs; if you dug up the ground in the place where the eggs were laid last year you might get various grubs and pupae. I would be very pleased to examine them & could tell you probably by comparison with South American forms whether you had the right ones. If you could solve this problem we would be very grateful to you.

In the meantime I hope to have the pleasure of a letter from you.

Yours sincerely,
Norman B Tindale

P.S. Any grubs taken could be sent in methylated spirit; when the right ones are discovered we might be able to devise a method of breeding them NBT

Appendix 5. The author's invitation to attend the Official Opening of the Nhill Sun-moth Reserve.



Hindmarsh
Shire Council

Administration Centre
P.O. Box 250
92 Nelson Street
NHILL VIC 3418
Ph: (03) 5391 1811
Fax: (03) 5391 1376
email: info@hindmarsh.vic.gov.au

Customer Service Centres

Jeparit
10 Roy Street
JEPARIT VIC 3423
Ph: (03) 5397 2070
Fax: (03) 5397 2263

Dimboola
101 Lloyd Street
DIMBOOLA VIC 3414
Ph: (03) 5389 1734
Fax: (03) 5389 1734

Rainbow
Federal Street
RAINBOW VIC 3424
Ph: (03) 5395 1436
Fax: (03) 5395 1436

(31nj1004/1.5.3.23/nj.ns)

26 October 2004

Mr Fabian Douglas
PO Box 37
RAINBOW VIC 3424

Dear Mr Douglas,

OFFICIAL OPENING OF SUN MOTH RESERVE, NHILL

You are cordially invited to attend the Official Opening of the Sun Moth Reserve, by John Landy, A.C., M.B.E., Governor of Victoria, in Belcher Street, Nhill on Thursday 18 November 2004 at 10.00 am.

Should the weather be inclement, the opening will be transferred to the Nhill Memorial Community Centre, Nelson Street, Nhill.

Please RSVP to Pam Cannell on 5391 1811 by Friday 12 November, 2004.

Yours sincerely

per N.Smith

Neil Jacobs
Chief Executive Officer

Part 3

Chapter 7

Habitats of the Pale Sun-moth

Introduction

It was deemed that an appropriate way to characterise the habitats that are occupied by the Pale Sun-moth was to document their vascular plant flora, avian fauna, soil types and average annual rainfall. Only the vascular plants were surveyed for this purpose because in most cases they are not so seasonal in their appearance as non-vascular plants and they are usually easier to identify. Birds were selected as the faunal element to document because, as a group, they are the most easily observed, being mostly diurnal, relatively active and often noisy. Also, in most cases they are readily identifiable from field observations, and therefore do not require capture. Further, a number of avian species have fairly precise habitat requirements. This renders such taxa to be good indicators of habitat type and overall habitat integrity.

As a number of uncommon plant species were located at the sites where the Pale Sun-moth occurs (pers. obs. 1991 to 2005, N. Marriott pers. comm. 1999 to 2006), it is clearly evident that the areas in question have very wide biodiversity conservation values. It is also significant that several of the ‘woodland birds’ that were recorded in the course of this work are species that are considered to be in a state of decline throughout south-eastern Australia (Robinson 1993, Robinson & Traill 1996).

Methodology

Vascular plant and bird species were recorded at nine of the eleven sites in central and western Victoria where extant populations of the Pale Sun-moth are known to occur. These taxa are listed below. The following lists, though not comprehensive, are intended to provide a sufficient amount of information to outline the ecological similarities and differences between these areas. The bracketed abbreviations that follow each listed species are used respectively to indicate the sites where it was recorded and its abundance at a given site. All of the following observations were made between March 1997 and March 2001.

Explanation of abbreviations that are used to denote the occurrence of a given species at a particular site.

1) A = All sites.

2) Bo = Borung.

3) Br = Brynterion F. & F. R.

4) D = Dimboola.

5) J = Jung.

6) Mi = Mitiamo.

7) Mu = Murtoa.

8) N = Nhill.

9) P = Pimpinio.

10) R = Regals Road.

For the precise location of the nine sites that are listed above, refer to Chapter 2 of Part 3, ‘Distribution and Conservation Status of the Pale Sun-moth’.

Explanation of abbreviations that are used to indicate the abundance of a given species at a particular site.

A) 1 = 1 to 5 individuals recorded.

B) 2 = 6 to 10 individuals recorded.

C) 3 = 11 to 20 individuals recorded.

D) 4 = 21 to 40 individuals recorded.

E) 5 = over 40 individuals recorded.

Each species that is listed as threatened in accordance with Section 10 of the Victorian *Flora and Fauna Guarantee Act* 1988 is indicated by its scientific name being underlined and each introduced species is indicated by an asterisk before its scientific name.

Information on the average annual rainfall and soil types of the Pale Sun-moth sites was obtained from the Bureau of Meteorology in 2001 and a soil profile map compiled by Mr. Brock Baker in 2003 respectively, with added personal observations that were made from 1991 to 2005. For a reproduction of the above-mentioned map, see Appendix 1 to Chapter 2 of Part 3 (‘Distribution and Conservation Status of the Pale Sun-moth’).

Results

Tables 7.1 and 7.2 respectively show the (recorded) occurrence and abundance of plant and bird species at nine of the eleven known Pale Sun-moth sites in Victoria.

Table 7.1. Plant species recorded at all but two of the Victorian sites that are known to hold extant occurrences of the Pale Sun-moth

The taxonomy, nomenclature and common names that are used in this table follow the Victorian Department of Sustainability and Environment's 2004 version of the Flora Information System. In a few cases, the common names are followed by an alternative common name that is bracketed. This has been done where the common names that are used in the DSE (2004) Flora Information System differ from those that appear in certain publications and are also widely applied to the species in question.

PHYLUM FILICOPHYTA (FERNS):

Family Marsileaceae: nardoos;

1) ***Marsilea*** ?***drummondii***, Common Nardoo, (D 3, P 3).

PHYLUM CONIFEROPHYTA (CONIFERS):

Family Cupressaceae: cypresses and allies;

2) ***Callitris glaucophylla***, White Cypress-pine, (Mi 5).

PHYLUM MAGNOLIOPHYTA (ANGIOSPERMS OR FLOWERING PLANTS):

CLASS LILIOPSIDA (MONOCOTS):

Family Juncaceae: rushes;

3) ***Carex inversa***, Knob (Common) Sedge, (J 4).

4) ***Juncus flavidus***, Gold (Yellow) Rush, (J 1).

Family Poaceae: grasses;

5) ****Aira*** sp. Hair-grass, (Bo 5).

6) ***Aristida behriana***, Brush Wire-grass, (N 2).

7) ***Austrodanthonia auriculata***, Lobed Wallaby-grass, (Bo 3).

8) ***Austrodanthonia caespitosa***, Common Wallaby-grass, (Bo 5, N 4).

9) ***Austrodanthonia carphoides***, Short Wallaby-grass, (Bo 2).

10) ***Austrodanthonia duttoniana***, Brown-back Wallaby-grass, (Bo 2).

11) ***Austrodanthonia eriantha***, Hill Wallaby-grass, (Bo 3).

12) ***Austrodanthonia setacea***, Bristly Wallaby-grass, (A 5).

13) ***Austrostipa aristiglumis***, Plump (Plains) Spear-grass, (Bo 2).

14) ***Austrostipa bigeniculata***, Kneed (Yanganbil) Spear-grass, (?D 1, J 4, ?P 2).

15) ***Austrostipa blackii***, Crested Spear-grass, (Bo 2).

16) ***Austrostipa gibosa***, Spurred Spear-grass, (Bo 5, J 5).

17) ***Austrostipa puberula***, Fine-hairy Spear-grass, (J 5).

18) ***Austrostipa scabra***, Rough Spear-grass, (Bo 4, ?D 5, J 5, ?N 5, ?P 5).

19) ****Avena fatua***, Wild Oat, (Bo 5, D 5, N 5, P 5).

20) ****Bromus hordaceus*** (?subspecies ***hordaceus***), Soft (Silky) Brome, (Bo 5).

21) ****Bromus diandrus***, Great Brome, (N 5, P 5).

22) ***Chloris truncata***, Windmill Grass, (Mu 2, P 2).

23) ****Ehrharta calycina***, Perennial Veldt-grass, (P 2).

24) ***Elymus scaber***, Common Wheat-grass, (J 4).

25) ****Hordeum leporinum***, Barley Grass, (N 5, P 5).

26) ***Lachnagrostis aemula***, Leafy Blown Grass, (Bo 4, P 1).

27) ****Lolium perenne***, Perennial Rye-grass, (Bo 5, D 5, J 5, Mu 5, P 5).

28) ****Vulpia myuros***, Rat’s-tail Fescue, (Mu 5).

29) ***Whalleya proluta***, Rigid Panic, (J 2).

Family Liliaceae: lilies;

30) ***Arthropodium fimbriatum***, Nodding Chocolate-lily, (Bo 3, D 3, P 2).

31) ***Arthropodium minus***, Small Vanilla-lily, (Bo 3).

32) ***Dianella revoluta***, Black-anther Flax-lily, (P 1).

Family Lomandraceae (Xanthorrhoeaceae): mat-rushes;

33) ***Lomandra*** sp. Mat-rush, (P 3).

Family Iridaceae: irises and allies;

34) ****Moraea setifolia***, Thread Iris, (P 5).

35) ****Romulea rosea***, Onion Grass, (N 5, P 5).

CLASS MAGNOLIOPSIDA (DICOTS):

Family Casuarinaceae: she-oaks;

36) <u>***Allocasuarina luehmannii***</u>, Buloke, (Bo 2, D 5, J 5, Mi 2, Mu 4, P 5, R 1).

Family Loranthaceae: mistletoes;

37) ***Amyema linophylla***, Buloke Mistletoe, (P 5).

38) ***Amyema miquelii***, Box Mistletoe, (Br 2).

39) ***Lysiana exocarpi***, Harlequin Mistletoe, (Mu 4, P 5).

40) ***Lysiana exocarpi***, yellow flowered form, Yellow Harlequin Mistletoe, (Mu 1).

Family Chenopodiaceae: saltbushes and allies;

41) ***Atriplex leptopcarpa***, Slender-fruit (Narrow-fruited) Saltbush, (J 1).

42) ***Atriplex semibaccata***, Berry Saltbush, (J 4, N 1, P 2).

43) ***Chenopodium desertorum***, Frosted Goosefoot, (J 3).

44) ***Einadia nutans***, Nodding Saltbush, (J 2, P 5).

45) ***Enchylaena tomentosa***, Ruby Saltbush, (J 1, P 4).

46) ***Maireana decalvans***, Black Cotton-bush, (J 2, P 1).

47) ***Maireana enchylaenoides***, Wingless Bluebush, (J 4, Mu 2, N 2, P 1).

48) ***Maireana excavata***, Bottle Bluebush, (D 3, P 4).

49) ***Maireana pentagona***, Hairy Bluebush (Slender Fissure-weed), (J 4, Mu 2, P 1).

50) ***Maireana rohrlachii***, Rohrlach's Bluebush, (J 3, N 5, P 3).

51) ***Salsola tragus***, Prickly Saltwort, (N 5, P 2).

52) ***Sclerolaena dicantha***, Grey Copperburr (Horned Bassia), (J 2).

53) ***Sclerolaena napiformis***, Turnip Copperburr (Turnip Bassia), (Mu 5).

Family Pittosporaceae: pittosporums and allies;

54) ***Bursaria spinosa***, Sweet Bursaria, (D 5, P 1).

55) ***Pittosporum angustifolium***, Weeping Pittosporum, (J 1).

Family Mimosaceae: wattles and allies;

56) ***Acacia acinacea***, Gold-dust Wattle, (P 1).

57) ***Acacia oswaldii***, Umbrella Wattle, (J 1, R 1).

Family Fabaceae: peas, clovers and allies;

58) ***Eutaxia microphylla*** (shrub form), Common (Small-leaved) Eutaxia, (J 2).

59) ***Eutaxia microphylla*** var. ***diffusa***, Spreading Eutaxia, (J 1).

60) ***Swainsona procumbens***, Broughton Pea, (J 1, Mu 1, P 2).

61) ****Trifolium angustifolium***, Narrow-leaf Clover, (D 3, P 5).

62) ****Trifolium arvense***, Hare's-foot Clover, (N 5).

63) ****Trifolium campestre***, Hop Clover, (D 3, P 4).

Family Haloragaceae: raspworts;

64) ***Haloragis aspera***, Rough Raspwort, (J 2).

65) ***Haloragis glauca***, Bluish Raspwort, (J 2).

66) ***Haloragis heterophylla***, Varied Raspwort, (J 2).

Family Polygonaceae: docks and allies;

67) ***Muehlenbeckia florulenta***. Tangled Lignum, (D 1).

68) ***Rumex dumosus***, Wiry Dock, (N 1).

Family Oxalidaceae: wood-sorrels and soursobs;

69) ***Oxalis perennans***, Grassland Wood-sorrel, (D 3, Mu 2, N 1, P 2).

70) *****Oxalis pes-caprae***, Soursob, (P 5).

Family Malvaceae: mallows, hollyhocks and allies;

71) ***Sida corrugata***, Variable Sida, (Bo 4, D 3, J 5, Mi 3, Mu 4, P 4).

Family Myrtaceae: gums, bottlebrushes, tea-trees, paperbarks and allies;

72) ***Eucalyptus behriana***, Bull Mallee, (Br 1).

73) ***Eucalyptus camaldulensis***, River Red-gum, (R 5 along abutting water course).

74) ***Eucalyptus largiflorens***, Black Box, (D 4, J 5).

75) ***Eucalyptus leucoxylon***, Yellow Gum, (D 1, Mi 1).

Family Amaranthaceae: mulla mullas, celosias and allies;

76) ***Ptilotus erubescens***, Hairy Tails, (Bo 1, P 1).

77) ***Ptilotus exaltatus***, Pink Mulla Mulla (Lamb Tails), (D 2, Bo 3, P 5).

78) ***Ptilotus macrocephalus***, Feather Heads, (Bo 2, J 1, Mu 1, P 5).

79) ***Ptilotus spathulatus***, Pussy Tails, (Bo 2, D 3, P 1).

Family Apiaceae: blue devil, prickfoot and allies;

80) ***Eryngium ovinum***, Blue Devil, (J 5, P 5).

Family Convolvulaceae: bindweeds and morning glories;

81) ***Convolvulus erubescens***, Pink Bindweed, (D 3, J 2, P 1).

82) ***Convolvulus remotus***, Grassy Bindweed, (D 1, Mu 1, P 1).

Family Lamiaceae: salvias, germanders and allies;

83) ****Marrubinum vulgare***, Horehound, (D 1).

84) ****Salvia verbenaca***, Wild Sage, (D 5, N 5, P 5 along abutting roadside verge).

85) ***Teucrium racemosum***, Grey Germander, (J 3, P 1).

Family Solanaceae: nightshades, kangaroo apples, tomatoes, potatoes and allies;

86) ****Lycium ferocissimum***, African Box-thorn, (D 4, Mi 1, P 1).

87) ***Solanum esuriale***, Quena, (J 4, Mu 5).

Family Goodeniaceae: goodenias and allies;

88) ***Goodenia glauca***, Pale Goodenia, (J 5).

89) ***Goodenia pinnatifida***, Cut-leaf Goodenia, (D 3, N 1, ?P 2).

90) ***Goodenia pusilliflora***, Small-flower (Small-leaf) Goodenia, (Bo 3).

91) ***Lobelia concolor***, Poison Pratia, (J 3).

92) ***Velleia paradoxa***, Spur Velleia, (P 5).

Family Campanulaceae: Australian bluebells, campanulas and allies;

93) ***Wahenbergia*** ?***gracilis***, Sprawling Bluebell, (Bo 5).

94) ***Wahlenbergia luteola***, Bronze (Yellowish) Bluebell, (Bo 4, D 3, J 3, P 2).

95) ***Wahlenbergia*** ?***stricta***, Tall Bluebell, (Bo 2, P 1).

Family Stackhousiaceae: stackhousias;

96) ***Stackhousia monogyna***, Creamy Stackhousia (Creamy Candles), (P 5).

Family Asteraceae: daisies, sunflowers, everlastings, thistles and allies;

97) ****Arctotheca calendula***, Cape Weed, (D 3, P 3).

98) ***Brachyscome*** ?***basaltica***, Woodland Swamp Daisy, (J 5).

99) ***Brachyscome*** ?***dentata***, Lobed-seed Daisy, (D 2, P 2).

100) ***Brachyscome*** sp. small, mauve tinged white flowers, (P 1).

101) ***Calocephalus citreus***, Lemon Beauty-heads, (Bo 2, J 2, P 4).

102) ***Calotis anthemoides***, Cut-leaf (Chamomile) Burr-daisy, (Bo 5, P 4).

103) ***Chrysocephalum apiculatum*** s. l., Common Everlasting, (J 2).

104) ***Chrysocephalum semipapposum***, Clustered Everlasting, (P 1).

105) *****Gazania*** ?***rigens***, Gazania (African Daisy), (N 5).

106) *****Lactuca serriola***, Prickly Lettuce (Compass Plant), (D 1, P 1).

107) ***Leiocarpa panaetioides***, Woolly Buttons, (J 1, P 1).

108) ***Leptorhynchos squamatus***, Scaly Buttons, (Bo 4).

109) ***Leptorhynchos tetrachaetus***, Beauty Buttons, (Bo 5).

110) ***Minuria leptophylla***, Minnie Daisy, (?D 3, J 1, ?P 1).

111) ***Pycnosorus globosus***, Drumsticks, (J 3).

112) ***Rhodanthe corymbiflora***, Paper Sunray, (D 3, J 5).

113) ***Triptilodiscus pygmaeus***, Common Sunray, (Bo 4).

114) ***Vittadinia cuneata***, Fuzzy (Common) New Holland Daisy, (D 5, P 5).

115) ***Vittadinia pterochaeta***, Winged (Rough) New Holland Daisy, (J 2).

116) *****Xanthium spinosum***, Bathurst Burr, (R 2).

Family Brassicaceae: cabbages, turnips, radishes, cresses and allies;

117) *****Lepidium africanum***, Common Peppercress, (D 3, N 2, P 2).

Family Euphorbiaceae: spurges and allies;

118) ***Chamaesyce drummondii***, Flat Spurge (Caustic Weed), (J 4, Mu 2).

Table 7.2. Bird species recorded at all but two of the Victorian sites that are known to hold extant occurrences of the Pale Sun-moth

The taxonomic arrangement, nomenclature and common names that are used in this table follow Christidis & Boles (1994).

ORDER ANSERIFORMES:

Family Anatidae: swans, geese and ducks;

1) ***Chenonetta jubata***, Australian Wood Duck, (Mu 1).

ORDER CICONIIFORMES:

Family Ardeidae: herons;

2) ***Egretta novaehollandiae***, White-faced Heron, (Bo 1, J 1).

Family Threskiornithidae: ibises and spoonbills;

3) ***Threskiornis spinicollis***, Straw-necked Ibis, (N 1).

ORDER FALCONIFORMES:

Family Accipitridae: eagles, goshawks and kites;

4) ***Milvus migrans***, Black Kite, (N 1).

5) ***Accipiter cirrhocephalus***, Collared Sparrowhawk, (P 1).

6) ***Aquila audax***, Wedge-tailed Eagle, (Br 1, Mi 1, R 1).

7) ***Hieraaetus morphnoides***, Little Eagle, (R 1).

Family Falconidae: falcons and kestrels;

8) ***Falco berigora***, Brown Falcon, (Bo 1, J 1, P 1, R 1).

9) ***Falco cenchroides***, Nankeen Kestrel, (Bo 1).

ORDER COLUMBIFORMES:

Family Columbidae: pigeons and doves;

10) ***Ocyphaps lophotes***, Crested Pigeon, (J 1, N 1).

11) ***Geopelia striata***, Peaceful Dove, (R 1).

ORDER PSITTACIFORMES:

Family Cacatuidae: cockatoos and cockatiel;

12) ***Cacatua roseicapilla***, Galah, (Bo 5, J 3, Mi 3, Mu 2, N 5, P 5, R 1).

13) ***Cacatua tenuirostris***, Long-billed Corella, (J 5, N 5).

14) ***Cacatua galerita***, Sulphur-crested Cockatoo, (Br 1).

15) ***Nymphicus hollandicus***, Cockatiel, (Bo 2, J 1).

Family Psittacidae: parrots and lorikeets;

16) ***Glossopsitta concinna***, Musk Lorikeet, (J 1, P 5).

17) ***Glossopsitta porphyrocephala***, Purple-crowned Lorikeet, (P 3).

18) ***Platycercus eximius***, Eastern Rosella, (Br 1, J 3, Mu 1, P 1).

19) ***Northiella haematogaster***, Blue Bonnet, (J 2).

20) ***Psephotus haematonotus***, Red-rumped Parrot, (Bo 1, D 3, J 5, Mi 3, Mu 1, R 4).

ORDER STRIGIFORMES:

Family Strigidae: owls;

21) ***Ninox novaeseelandiae***, Southern Boobook, (Bo 1, Br 1).

ORDER CORACIIFORMES:

Family Halcyonidae: kookaburras and kingfishers;

22) ***Dacelo novaeguineae***, Laughing Kookaburra, (J 1).

ORDER PASSERIFORMES:

Family Climacteridae: Australian treecreepers;

23) ***Climacteris picumnus***, Brown Treecreeper, (J 4).

Family Pardalotidae: pardalotes, greygones, scrubwrens and thornbills;

24) ***Pardalotus striatus***, Striated Pardalote, (J 1).

25) ***Acanthiza reguloides***, Buff-rumped Thornbill, (J 1).

26) ***Acanthiza chrysorrhoa***, Yellow-rumped Thornbill, (Bo 1, D 1, J 3, Mu 1, P 5).

27) ***Aphelocephala leucopsis***, Southern Whiteface, (J 1).

Family Meliphagidae: honeyeaters;

28) ***Anthochaera carunculata***, Red Wattlebird, (N 1, P 1).

29) ***Entomyzon cyanotus***, Blue-faced Honeyeater, (Br 1).

30) ***Manorina flavigula***, Yellow-throated Miner, (D 1, N 1).

31) ***Lichenostomus penicillatus***, White-plumed Honeyeater, (D 1).

32) ***Phylidonyris novaehollandiae***, New Holland Honeyeater, (Mu 1).

33) ***Phylidonyris albifrons***, White-fronted Honeyeater, (P 2).

34) ***Phylidonyris melanops***, Tawny-crowned Honeyeater, (Br 1).

Family Petroicidae: Australian robins;

35) ***Microeca leucophaea***, Jacky Winter, (J 1, Mi 1).

36) ***Petroica goodenovii***, Red-capped Robin, (D 1, Mi 1, P 1).

37) ***Melanodryas cucullata***, Hooded Robin, (J 2).

Family Neosittidae: sittellas;

38) ***Daphoenositta chrysoptera***, Varied Sittella, (D 3, P 3).

Family Pachycephalidae: whistlers and shrike-thrushes;

39) ***Colluricincla harmonica***, Grey Shrike-thrush, (Br 1, Mi 1).

Family Dicruridae: monarchs, fantails and flycatchers;

40) ***Myiagra inquieta***, Restless Flycatcher, (J 1, Mi 1, R 1).

41) ***Grallina cyanoleuca***, Magpie-lark, (Br 1, R 1).

42) ***Rhipidura leucophrys***, Willie Wagtail, (Bo 1, Br 1, D 1, J 2, P 1, R 1).

Family Campephagidae: cuckoo-shrikes and trillers;

43) ***Coracina novaehollandiae***, Black-faced Cuckoo-shrike, (Bo 1).

Family Artamidae: woodswallows, butcher-birds, Australian magpie and currawongs;

44) ***Artamus superciliosus***, White-browed Woodswallow, (D 2, J 2).

45) ***Artamus cyanopterus***, Dusky Woodswallow, (P 1).

46) ***Gymnorhina tibicen***, Australian Magpie, (Bo 2, Br 1, J 2, Mi 3, Mu 2, N 1, P 3, R 1).

Family Corvidae: crows and ravens;

47) ***Corvus coronoides***, Australian Raven, (J 5, P 1, R 2).

48) ***Corvus mellori***, Little Raven, (J 2).

Family Corcoracidae: white-winged chough and apostlebird;

49) ***Corcorax melanorhamphos***, White-winged Chough, (J 1, R 3).

Family Motacilidae: pipits;

50) ***Anthus novaeseelandiae***, Richard’s Pipit, (R 1).

Family Passeridae: sparrows and grass finches;

51) ****Passer domesticus***, House Sparrow, (Bo 2, P 1).

52) ***Stagonopleura guttata***, Diamond Firetail, (D 1, J 1).

Family Fringillidae: finches;

53) ****Carduelis carduelis***, European Goldfinch, (P 5).

Family Hirundinidae: swallows and martins;

54) ***Hirundo neoxena***, Welcome Swallow, (Bo 3, N 5, R 3).

55) ***Hirundo nigricans***, Tree Martin, (J 1, Mu 3).

Family Sturnidae: starlings;

56) ****Sturnus vulgaris***, Common Starling, (J 1).

Discussion

The flora of vascular plants at the various localities where the Pale Sun-moth occurs is mainly composed of native perennial grasses such as species of *Austrodanthonia* (Wallaby-grasses) and *Austrostipa* (Spear-grasses). It is also characterised by a great diversity of other grassland plants. Some of the species that occur at most (or all) of the Pale Sun-moth sites are as follows: *Sida corrugata* (Variable Sida), *Convolvulus erubescens* (Pink Bindweed), *Eryngium ovinum* (Blue Devil), *Ptilotus exaltatus* (Pink Mulla Mulla), *Ptilotus macrocephalus* (Feather Heads), *Swainsona procumbens* (Broughton Pea), *Wahlenbergia luteola* (Bronze Bluebell), *Calocephalus citreus* (Lemon Beauty-heads), *Oxalis perennans* (Grassland Wood-sorrel), *Maireana decalvans* (Black Cotton-bush), *Teucrium racemosum* (Grey Germander) and *Atriplex semibaccata* (Berry Saltbush). Notably, although various species of small to large shrubs, from one to three (or more) m. high are often present at the Pale Sun-moth sites, they are never in sufficient quantity to contribute significantly to the overall habitat profile.

It appears that the most important habitat requirements for the Pale Sun-moth are that the ground flora is dominated by *Austrodanthonia setacea* (Bristly Wallaby-grass) and that the sward is relatively short and open. There is strong evidence to suggest that to remain in optimum condition, the habitat of the Pale Sun-moth needs to be grazed (preferably by kangaroos or sheep) or annually mown. This issue is discussed and illustrated in Chapter 9 of Part 3, 'Conservation and Management of the Six Pale Sun-moth Morphs'. The dominant tree species at most of the sites where the species occurs are *Allocasuarina luehmannii* (Buloke), *Eucalyptus largiflorens* (Black Box) and to a lesser extent *Eucalyptus leucoxylon* (Yellow Gum). However, it seems that when the tree canopy cover of a given area exceeds about 50% (i.e. so that it would be technically classed as forest), the habitat becomes unfavorable for the Pale Sun-moth (pers. obs. 1997 to 2005).

At the eleven known sites in Victoria with extant occurrences of the Pale Sun-moth, the mean annual rainfall from Jan. 1995 to Jan. 2001 ranged from about 409 mm (at the Wail and Dimboola sites) to about 451 mm (at the Pimpinio site), (Bureau of Meteorology pers. comm. 2001). The mean annual rainfall during the same period of time at the eight remaining sites was approximately as follows: Borung site: 430 mm, Mitiamo, Regals Road and Forbes Road sites: 432 mm, Brynterion and Murtoa sites: 423 mm, Jung site: 421 mm and Nhill site: 416 mm (Bureau of Meteorology pers. comm. 2001). The climate of all eleven of the Victorian Pale Sun-moth breeding areas would best be classed as typically 'Mediterranean' because it has hot, dry summers and cool, wet winters which include some frosts.

In summary, the habitat of the Pale Sun-moth varies from grassland to open forest with a grassy understory, on hard-setting, alkaline, reddish or greyish cracking clay or clayey-loam duplex soils, (pers. obs. 1991-2005, B. Baker pers. comm. 2003). The topography of these areas varies from plains that are almost level to a gently undulating terrain, at approximate elevations between 100 m and 150 m above sea level.

Part 3

Chapter 8

Biology of the Pale Sun-moth

Introduction

To date, very little has been published on the biology of the Pale Sun-moth. The following biological information on this species is entirely based on work that has been carried out by the author, since extant occurrences were rediscovered 1991. Some publications on this subject that the author is aware of are as follows: Douglas (2000, 2004 and 2005) and Maron *et al*. (2005).

Adult biology

Adult female behaviour (parthenogenetic morphs).

The adults of the Pale Sun-moth are strictly diurnal and unless disturbed will only fly while the sun is shining. During periods of sunshine, they seek open areas that are dominated by numerous small plants of Bristly Wallaby-grass (*Austrodanthonia setacea*), where they spend a great deal of time probing small cracks in the ground with their long retractable ovipositors. When an individual finds a suitable oviposition site it deposits one or sometimes more eggs at a depth of about 1.5 cm. After oviposition is completed at a given site, the ovipositor is withdrawn from the soil and flight is resumed, or in some instances the individual walks rapidly while continuing to probe the ground for another oviposition site. During this probing activity the wings are usually raised and lowered rhythmically and held so that the brightly coloured hindwings are partly exposed. However, when this species rests for long periods of time, such as during periods of cool and/or cloudy weather, the cryptically patterned forewings are folded roof-wise over the body so that the brightly coloured hindwings are concealed from potential predators. Distances between chosen oviposition sites can vary from as little as a few centimetres to fifteen metres or more.

The flight of the Pale Sun-moth is typical of the genus *Synemon*, and is rapid and direct. It is powered by continuous wing beats (at a rate of approximately eight per second) and is not interspersed with periods of gliding. During periods of excessively hot and still weather with a shade temperature of (or above) 40 degrees Celsius, it was found that the adults of this species do not seek shade as many other families of Lepidoptera do. Instead of this they rest in a vertical position on standing grass stems with their heads orientated upwards. In most instances these resting sites are about 20 to 30 cm above the ground. By doing this it seems that they can avoid some of the radiant heat from the ground and also minimize the surface area of their bodies that is directly exposed to the sun, while it is at its zenith during the hottest part of the day.

Possible adult male behaviour.

If an extant non-parthenogenetic population of Pale Sun-moths is ever found, it is likely that the males would behave in a similar way to the males of the Striated Sun-moth (*Synemon collecta*). The reason why this is suspected is that both of these species belong to the 'grass' group within the genus *Synemon* and both species have females that are not semi-flightless. It seems that the semi-flightless females of the Golden Sun-moth (*Synemon plana*) cause the males of this species to completely ignore each other as they fly over grass while searching for receptive females. In most instances, mate-seeking males of the Striated Sun-moth will briefly investigate other conspecific males as they pass by and not ignore each other as the males of the Golden Sun-moth do (E. D. Edwards pers. comm. 2000).

As with all of the other species of *Synemon* that occur in Victoria, the males of the Striated Sun-moth mainly fly during periods of sunshine and have a rapid and fairly direct flight. While searching for virgin females, they will sometimes patrol open grassy areas by flying in a series of large circles (D. Britton pers. comm. 2000). In most instances they fly at a height that just allows them to clear the grass stems by approximately 15 cm (G. E. Wurtz pers. comm. 2000).

Adult life-span and fecundity.

As with the Golden Sun-moth, the adults of this species have a very poorly developed haustellum (proboscis) and do not feed. They rely on nutrients stored in their bodies during the larval stage to sustain them throughout their adult lives and only live for approximately three to five days (pers. obs. 1997 to 2004). It seems that this relatively brief period of time is long enough for them to lay all of their eggs, which are fully developed at emergence and usually number from about 70 to about 120 (pers. obs. 1997 to 2004).

Adult flight period.

In the author's experience, the adult flight period of the Victorian Pale Sun-moth morphs commences in mid February and concludes in early March. However, there are several historic Victorian specimens in the Australian National Insect Collection and two old specimens held in the Museum of Victoria that bear data labels stating that they were collected during other months. These are as follows: October (one specimen of the Dark Morph and three specimens of the Pale Morph), November (one specimen of the Pale Morph), December (one specimen of the Pale Morph), January (five specimens of the Pale Morph) and April (one specimen of the Pale Morph).

It seems that these unusual early records could be erroneous because most of the known Victorian breeding sites of this species have been carefully searched (by J. T. Noelker and the author) during all of the above mentioned months without any adults being located. However, it is also possible that some adult Pale Sun-moths may have emerged outside their normal flight season in the past because the species would probably have been more abundant in earlier times, before most of its habitat was cleared.

Although there are many historic specimens of the Two Wells Morph in the Australian National Insect Collection, their data labels only bear three collection dates. These are February 1904 (day of capture not recorded), 4 March 1937, and the 4 March 1948. However, this limited amount of available information indicates that the adult flight period of the Two Wells Morph probably coincided with the main adult flight period of the Victorian morphs of the species.

Predation of adults.

Although the impact of predators on the Pale Sun-moth is uncertain, there is some anecdotal information. On one occasion at the Brynterion site (near Lubeck), a Willy Wagtail (*Rhipidura leucophrys*) was observed as it caught and ate a passing Pale Sun-moth, after attempting to catch several others. Further, on two separate occasions at the Pimpinio site, a Red-capped Robin (*Petroica goodenovii*) successfully captured and subsequently ate a Pale Sun-moth that was in the process of ovipositing. In one of these instances, the sun-moth managed to escape after it was initially caught, but possibly due to injury, was soon recaptured. Both of these Red-capped Robins removed the wings of their prey before the remainder of the sun-moth was eaten.

It is also possible that Australian Magpies (*Gymnorhina tibicen*) prey on adults of the Pale Sun-moth as they rest on the ground during periods of cool and/or cloudy weather. Other species of hawking and gleaning insectivorous birds would also be expected to prey on the Pale Sun-moth. As well as this, it is likely that ovipositing females are vulnerable to being attacked by terrestrial predators such as various species of diurnal reptiles and ground dwelling spiders.

Biology of the early stages

Incubation time of ova.

The incubation period for the eggs of this species is inconsistent and can take from 24 to 93 days. However, it was found that the majority of fertile eggs hatch after 53 days of incubation time. Refer to Chapter 3 of Part 3 for some more precise data on the incubation times of some cohorts of Pale Sun-moth ova that were dissected out of the ovaries of all five of the Victorian parthenogenetic morphs.

Larval host plant/s.

Although it has not yet been confirmed beyond doubt, there is strong circumstantial evidence to suggest that the roots of Bristly Wallaby-grass (*Austrodanthonia setacea*) are

the main larval food of all the morphs of the Pale Sun-moth. This evidence is based on the results of identifying florets from a random sample of ten *Austrodanthonia* seed heads that were collected from separate plants at nine sites, where one or more Pale Sun-moths had previously been observed ovipositing. These *Austrodanthonia* specimens were only collected from within a 1 m by 1 m quadrat that was placed over the actual oviposition sites. The results of this work have shown that Bristly Wallaby-grass (*A. setacea*) was present at all of the sites and was the most abundant *Austrodanthonia* species within all but one of the sampled areas. While Common Wallaby-grass (*A. caespitosa*) was the dominant *Austrodanthonia* species at this site, it was absent from another site, and was only a minor component of the remaining seven sites. The precise species compositions of these *Austrodanthonia* samples (that were collected at nine of the eleven localities where extant populations of the Pale Sun-moth are known to occur) are as follows:
(1) Nhill site (where the Nhill Morph occurs): eight *A. setacea* and two *A. caespitosa*.
(2) Dimboola site (where the Narrow-winged Morph and Dark Morph occur): eight *A. setacea* and two *A. caespitosa*.
(3) Pimpinio site (where the Narrow-winged Morph and Dark Morph occur): all *A. setacea*.
(4) Jung site (where the Pale Morph, Narrow-winged Morph and Dark Morph occur): nine *A. setacea* and one *A. caespitosa*.
(5) Murtoa site (where the Pale Morph and Dark Morph occur): all *A. setacea*.
(6) Brynterion site (where the Pale Morph occurs): six *A. setacea* and four *A. caespitosa*.
(7) Borung site (where the Pale Morph occurs): nine *A. setacea* and one *A. caespitosa*.
(8) Mitiamo site (where only one specimen of the Terrick Terrick Morph was ever located): four *A. setacea* and six *A. caespitosa*.
(9) Regals Road site (where the Terrick Terrick Morph occurs): seven *A. setacea* and three *A. caespitosa*.

However, there is conclusive evidence that the Pale Sun-moth may occasionally utilise Rough Spear-grass (*Austrostipa scabra*) as a larval host plant. This is based on the discovery of two pupal casings of *Synemon selene* (at the Nhill site) that were protruding from the soil against and at 1 cm away from the bases of mature plants of *A. scabra*. In these instances, the closest *Austrodanthonia* sp. were small plants of *A. setacea* that were respectively 1 m and 85 cm away from the two emergence sites. Both of these observations were made on 21 February 2004.

Larval behaviour.

After hatching it is likely that the larvae tunnel through the soil until they find the roots of a nearby Bristly Wallaby-grass plant so that feeding can commence. It is likely that each larva feeds slowly and as it grows, may use the roots of several adjacent tussocks of Bristly Wallaby-grass for feeding. This is suspected because individual plants do not usually die off within a breeding area. When each larva approaches maturity, it constructs a more or less vertical tunnel from just below the soil surface to about 20 cm deep. It is here that pupation finally occurs.

The restricted areas of suitable habitat that are available to the Victorian morphs of the Pale Sun-moth resulted in the author being reluctant to dig up pupal galleries of this species. However, one recently vacated pupal gallery of the Terrick Terrick Morph was carefully exhumed at the Regals Road site on 2 March 1997. This was done after the pupal casing that was protruding from it was removed and kept as a specimen. It was found that this gallery was 20 cm deep, roughly vertical and was not connected to any horizontal tunnels that led to the roots of nearby grasses. The cast head capsule and attached larval skin (from the final instar of the larva) were found at the bottom of this pupal gallery. These findings are an indication that prior to pupation, the larvae of the Pale Sun-moth may close off and possibly fill in any of their former feeding tunnels that joined the pupal gallery. They would probably do this so that various predators (such as ants) would be less likely to locate them during their larval to pupal ecdysis, when they would be especially vulnerable.

Pupal behaviour.

The pupa is probably able to move up or down its pupal gallery at will. This is suspected because the pupal exuviae have a succession of narrow, transverse ridges on their abdominal segments that are heavily sclerotized and finely serrated (?as an aid to traction in the pupal gallery). Although live pupae of the Pale Sun-moth have not been found to date, it is likely that the abdomen is also very flexible and can be moved in a series of rhythmic undulations to achieve pupal mobility. This is based on observations that have been made on live pupae of the Reddish-orange Sun-moth (*Synemon jcaria*), which have a similar morphology to the pupae of the Pale sun-moth and are able to move in this fashion.

Prior to eclosion the pupa must move to the top of the pupal gallery where it appears that it ruptures a thin seal of soil (?and larval silk) before it positions itself in such a way that the adult can emerge without obstruction. After emergence, the empty pupal casing is left with its head, thorax and first few abdominal segments protruding from the ground. Recent observations have indicated that this species may only breed successfully in completely open areas as all of the sites where pupal exuviae have been found were invariably away from the canopy cover of trees.

Duration of life cycle.

It is likely that the life cycle of the Pale Sun-moth would take two to three years to complete. This assumption is based on work that was carried out by Common & Edwards (1981), who confirmed that a congeneric species (*Synemon magnifica*) that is approximately the same size as *S. selene*, requires a similar length of time to complete its life cycle.

Illustrations

Figure 1. Empty pupal casing of *Synemon selene*, protruding from its pupal gallery. It is uncertain whether this is a pupal casing of the Pale Morph or the Dark Morph of the species as both of these morphs occur sympatrically where this photograph was taken. About 3 times life size.

Murtoa site: Private property, 7.3 km SSE of Murtoa, Victoria, (0.4 km south of Hopefields Road, 2.7 km east of its junction with Murtoa-Glenorchy Road). 22 February 2001.

Figure 2. Recently emerged adult (female) of the Nhill Morph of *Synemon selene*, at rest amongst dried foliage of grasses and forbs. About 2.5 times life size.

Nhill site: Nhill Sun-moth Reserve at 1.4 km east of Nhill, Victoria (north side of Belcher Street at 500m east of its junction with Nhill-Netherby Road). 19 February 2001.

Figure 3. Muture plant of *Austrodanthonia setacea* (Bristly Wallaby-grass), probably the most frequently utilised larval host plant of *Synemon selene*. About 0.3 times life size.

Nhill site: Nhill Sun-moth Reserve at 1.4 km east of Nhill, Victoria (north side of Belcher Street at 500m east of its junction with Nhill-Netherby Road). 16 November 2003.

Figure 4. Muture plant of *Austrostipa scabra* (Rough Spear-grass), a possible (alternative) larval host plant of *Synemon selene*. About 0.3 times life size.

Nhill site: Nhill Sun-moth Reserve at 1.4 km east of Nhill, Victoria (north side of Belcher Street at 500m east of its junction with Nhill-Netherby Road). 16 November 2003.

Appendices

Appendix 1. Final draft of the *Flora and Fauna Guarantee Act* 1988 Action Statement for the five Victorian morphs of *Synemon selene* (Pale Sun-moth). This Action Statement was compiled by the author during 2000.

FLORA AND FAUNA GUARANTEE ACTION STATEMENT

Pale Sun-moth, *Synemon selene* Klug, 1850

Pale, Terrick Terrick, Nhill, Narrow-winged and Dark Morphs

Description, Distribution, Taxonomy and Morphology

General description and distribution of sun-moths

The Sun-moths (family Castniidae) are considered to have a Gondwanan origin as they occur in the Neotropical, Australian and Oriental regions. The Australian species are all placed in the genus *Synemon*, containing 20 described and 22 undescribed species (E. D. Edwards, pers. comm.).

Sun-moths are broad-winged, colourful, day-flying moths with clubbed antennae and relatively slender bodies. Their diurnal habits are so strong that if passing clouds block out the sunshine they will immediately settle and not take flight again (unless disturbed) until sunlight returns. They usually fly rapidly, within a metre of the ground and keep their wings in motion continuously. When Sun-moths rest for short periods they often raise and lower their wings rhythmically, showing their brightly coloured hindwings. However, when resting for longer periods the hindwings are concealed by cryptically coloured forewings that harmonize perfectly with the surrounding debris and soil surface crust. Unlike most moth families, the Sun-moths are unable to fold away their antennae when at rest.

Wider distribution, taxonomy and morphology of the Pale Sun-Moth

To date the Pale Sun-moth has only been recorded from South Australia and Victoria. It was first described as *Synemon selene* by Klug in 1850, probably based on specimens from the Two Wells area in South Australia where it now appears to be extinct as a result of clearing for agriculture. The only other South Australian locality for this species is an old specimen from Lyndoch. Another old specimen was collected from the “Murray River near the Victorian – South Australian border”. Within Victoria the Pale Sun-moth was historically known from Murtoa, Kewell, Rupanyup and Nhill. The species was thought to be extinct in Victoria (due to habitat loss) until its rediscovery in 1991 at the Brynterion Flora and Fauna Reserve, near Lubeck. The species has since been found at several localities in the Wimmera and at sites on the Victorian Riverine Plain, near Borung and Mitiamo. All of the Victorian specimens are females, and males have not been located at any Victorian site. Historic specimens clearly show that the South Australian population at Two Wells was normal, with an approximately equal ratio of males to females. Further work has since revealed that all of the extant Victorian populations are either parthenogenetic or appear to be so, based on very strong circumstantial evidence. Parthenogenesis effectively genetically isolates each morph from the others.

Although it seems that four of the five Victorian morphs are significantly different enough from each other to warrant subspecific recognition they have not been scientifically described to date. The Terrick Terrick Morph only varies in small details from the Pale Morph.

General description of the Pale Sun-moth

As its common name implies, the Pale Sun-moth is more lightly coloured than most of the other Sun-moths that occur in Australia. It is one of the largest Victorian species with a wingspan that varies from about 3.5 cm to about 4.7 cm. The forewing uppersides are predominantly light brown or greyish-brown with small black and white markings and pale fawn or greyish-fawn striations that follow the veins. The hindwing uppersides are yellowish-orange with blackish spots and markings and a silvery-grey basal area. Both the forewings and hindwings are shades of pale whitish-orange beneath with a few blackish spots and markings. More detailed descriptions of the five parthenogenetic morphs of this species are provided in an Attachment.

Pale Morph

Description

See general description of the Pale Sun-moth above. Wingspan: From about 3.5 cm to about 4.6 cm.

Distribution

Populations are known from three sites in the Wimmera and one site near Borung, which is between Boort and Wedderburn. These are:

1. Private property 4.5 km south-south-east of Jung. AMG 237433. At this locality the pale morph occurs sympatrically with the narrow winged morph and the dark morph.
2. Private property 7.3 km south-south-east of Murtoa. AMG 347402. At this locality the pale morph occurs sympatrically with the dark morph.
3. Brynterion Flora and Fauna Reserve 4.9 km east-north-east of Lubeck. AMG430336.
4. “Kinipanial Grassland”, land owned by Trust for Nature (Victoria), 5.5 km east-south-east of Borung, on the east side of Kurting-Boort Road. AMG 515769.

Also recorded at the following sites in the Wimmera during 1991, but not since:

A. Barrabool Flora and Fauna Reserve 8.4 km south of Murtoa. AMG312376.
B. Western verge of Murtoa-Glenorchy Road 6.8km south of Murtoa, near the north-east corner of the Murtoa Golf Course. AMG 330393.

Terrick Terrick Morph

Description

Very similar to, but slightly paler than the Pale Morph. Wingspan: 3.7cm to 4.6cm.

Distribution

Known to occur at three localities near Mitiamo:

1. Mitiamo Golf Course 3.5 km north-north-west of Mitiamo. AMG 501922.
2. Private property 10 km north-north-east of Mitiamo. AMG 556981.
3. Private property 10 km north-east of Mitiamo. AMG 573969.

Nhill Morph

Description

Similar to the Pale morph but orange markings on the hindwings are brighter and less extensive. Wingspan: From about 4.4 cm to about 4.7 cm.

Distribution

Only known to occur at one site near Nhill, in the Wimmera:

Private property 1.4 km east of Nhill, on the north side of Belcher Street 500m east of its junction with Nhill-Netherby Road. AMG 596787. At this locality the Nhill morph occurs sympatrically with the Wimmera form of the Golden Sun-moth, *Synemon plana*.

Narrow-winged Morph

Description

This is the smallest of the Pale Sun-moth morphs, with narrower wings and generally intermediate in colouration between the Pale and Dark morphs. Wingspan: 3.5 cm to 4.2 cm.

Distribution

Only known to occur at two sites in the Wimmera:

1. Pimpinio Golf Course. AMG 997499. At this locality the narrow winged morph occurs sympatrically with the dark morph.
2. Private property 4.5 km south-south-east of Jung (see pale morph, site 1, for location of this site). At this locality the narrow winged morph occurs sympatrically with the pale morph and the dark morph.

Dark Morph

Description

Similar to the Pale Morph but with more restricted white markings on the forewings and less yellowish-orange on the hindwings. Wingspan: From about 4.1 cm to 4.7 cm.

Distribution

Known to occur at the following four sites in the Wimmera area:

1. Private property 4.3 km south-east of Dimboola. AMG 969631.
2. Pimpinio Golf Course. See distribution of narrow winged morph, site 1, for location of this site). At this locality the dark morph occurs sympatrically with the narrow winged morph.
3. Private property 4.5 km south-south-east of Jung. See distribution of pale morph, site 1, for location of this site). At this locality the dark morph occurs sympatrically with the pale morph and the narrow winged morph.
4. Private property 7.3 km south-south-east of Murtoa. See distribution of pale morph, site 2, for location of this site). At this locality the dark morph occurs sympatrically with the pale morph.

Habitat

All morphs

The habitat of the Pale Sun-moth varies from grassland to very open grassy woodland on heavy, reddish or greyish loamy soils. The most important requirement for this species appears to be a ground flora dominated by *Austrodanthonia setacea* (Bristly Wallaby-grass) that is relatively short and open. The dominant tree species at most of the sites where the species occurs are *Allocasuarina luehmannii* (Buloke), *Eucalyptus largiflorens* (Black Box) and less commonly *Eucalyptus leucoxylon* (Yellow Gum). At all sites tree cover is sparse.

Pale Sun-moths occur in diverse grassland communities frequently containing the following plant species: *Sida corrugata* (Variable Sida), *Convolvulus erubescens* (Pink Bindweed), *Eryngium ovinum* (Blue Devil), *Ptilotus exaltatus* (Lamb-tails), *Ptilotus macrocephalus* (feather-heads), *Swainsona procumbens* (Broughton Pea), *Wahlenbergia luteola* (Yellowish Bluebell), *Calocephalus citreus* (Lemon Beauty-heads), *Oxalis perennans* (Grassland Wood-sorrel), *Maireana decalvans* (Black Cottonbush), *Teucrium racemosum* (Grey Germander) and *Atriplex semibaccata* (Berry Saltbush).

Life History and Ecology

All morphs

The adults of the Pale Sun-moth are strictly diurnal and unless disturbed will only fly while the sun is shining. During periods of sunshine, these moths seek open areas that are dominated by numerous small plants of *Austrodanthonia setacea* (Bristly Wallaby-grass), where they spend a great deal of time probing small cracks in the ground with their long retractable ovipositors seeking suitable sites for egg laying. Distances between chosen oviposition sites can vary from as little as a few centimetres to fifteen meters or more.

Adults of this species have a poorly developed proboscis and do not feed. They rely on nutrients stored in their bodies during the larval stage to sustain them throughout their adult lives and only live for approximately five days, just long enough to lay their eggs which are fully developed at emergence and usually number about 80. The adult flight period of the Pale Sun-moth commences in early February and concludes in early March.

There is strong circumstantial evidence to indicate that the roots of *Austrodanthonia setacea* (Bristly Wallaby-grass) are the larval food of the Pale Sun-moth. After hatching it is likely that the larvae tunnel through the soil until they find the roots of a nearby Bristly Wallaby-grass plant so that feeding can commence. As it grows the larvae may use the roots of several tussocks of Bristly Wallaby-grass for feeding, as individual grass plants do not usually die within a breeding area. As the larvae approach maturity, they construct more or less vertical tunnels from just below the soil surface to about 20 cm deep for pupation. Recent observations have indicated that this species may only breed successfully in completely open areas as all of the sites where pupal remains have been found are invariably away from the tree cover.

It seems likely that the life cycle of the Pale Sun-moth probably takes two to three years to complete based on the investigations of Common and Edwards (1981) into *Synemon magnifica*.

Conservation Status

Pale Morph

Listed as endangered in the 1999 *Threatened Invertebrate Fauna in Victoria* list.

Terrick Terrick Morph

Listed as endangered in the 1999 *Threatened Invertebrate Fauna in Victoria* list.

Nhill Morph

Listed as critically endangered in the 1999 *Threatened Invertebrate Fauna in Victoria* list. Recently nominated for listing as a critically endangered taxon under the federal *Environment Protection and Biodiversity Conservation Act* 2000.

Narrow-winged Morph

Listed as critically endangered in the 1999 *Threatened Invertebrate Fauna in Victoria* list.

Dark Morph

Listed as endangered in the 1999 *Threatened Invertebrate Fauna in Victoria* list.

Decline and Threats

All morphs

Prior to European settlement, it is likely that the Pale Sun-moth would have had a much wider distribution on the grassy plains of north-central and western Victoria. These areas were converted to agricultural land soon after settlement, with ploughing and cropping destroying many areas where the Pale Sun-moth would have occurred. Observations made during the past few years indicate that the Pale Sun-moth's habitat requires regular grazing. When grazing is removed from sites where the species occurs, its numbers show a marked decline. This seems to be due to the accumulation of dead plant material in the absence of grazing, and/or taller grasses outcompeting Bristly Wallaby-grass (*Austrodanthonia setacea*).

Annual mowing may maintain the ecological conditions that the Pale Sun-moth requires in the short-term, based on the relatively large populations that persist at ungrazed sites such the Pimpinio Golf Course which has mown fairways and the Belcher Street site at Nhill that is mown each December for fire control.

The Pale Sun-moth does not survive on cultivated farmland nor thrive in the various reserves throughout its former range that are not grazed. Its survival to the present has only occurred in a few regularly grazed areas of privately owned native grassland or open grassy woodland that have never been ploughed.

Wider Conservation Issues

Sites where the Pale Sun-moth occurs usually hold populations of other rare and/or threatened plants and animals. Other species of conservation significance have been found at eleven of the twelve sites where the various morphs occur. For example, the Belcher Street site at Nhill where the Nhill Morph occurs also holds populations of three other endangered species: Golden Sun-moth (*Synemon plana*), Nhill Zitter (*Cicadetta* sp. aff. *waterhousei*) and Rohrlach's Bluebush (*Maireana rohrlachii*).

Existing Conservation Measures

Pale Morph

1.) Brynterion and Barrabool sites are within Flora and Fauna Reserves.
2.) The "Kinipanial Grassland" site (near Borung) was recently purchased by the Trust for Nature (Victoria). A community-based management committee for the area has now been formed.
3.) The Trust for Nature (Victoria) is in the final stages of purchasing an additional area of 220 hectares of native perennial grassland, 1 km east of the "Kinipanial Grassland" site. It is possible that this morph may also occur there because 40 hectares of this land has never been cultivated (P. Foreman pers. comm.).

Terrick Terrick Morph

The Trust for Nature (Victoria) and the Department of Natural Resources and Environment are negotiating the purchase of a grassland site where this morph occurs (10 km north-east of Mitiamo).

Nhill Morph

1.) The Hindmarsh Shire Council and West Wimmera Tree Group have successfully applied for a grant from the Grassy Ecosystems Grants Program to establish a Flora and Fauna Reserve at the Nhill site.

2.) Trust for Nature (Victoria) and Hindmarsh Shire Council are currently negotiating to purchase blocks at the Nhill site for inclusion in the proposed flora and fauna reserve
3.) The Hindmarsh Shire Council is negotiating a land swap to obtain some of the blocks of land at the Nhill site.
4.) Five privately owned blocks on the north-west side of the Nhill site have been placed under Trust for Nature (Victoria) covenants
5.) Weed control has been undertaken at the Nhill site. To date this work has been carried out on a voluntary basis and has mainly concentrated on the spot spraying (with Roundup) of *Gazania* ?*splendens* (African Daisy) which has started to invade the area from the southern verge of Belcher Street and nearby gardens.

Narrow-winged Morph

There are no existing conservation measures for this critically endangered morph.

Dark Morph

There are no existing conservation measures for this endangered morph.

Conservation Objectives

Long term objectives

All morphs

1.) Conserve and maintain wild populations of all of the Victorian parthenogenetic morphs of the Pale Sun-moth.
2.) Increase knowledge of the biology and ecology of the Pale Sum-moth so that its habitat requirements are clearly understood.
3.) Encourage studies to be undertaken on the genetics of all of the parthenogenetic morphs of the Pale Sun-moth and also, if an extant population is rediscovered, the “non parthenogenetic” morph.
4.) Establish a recovery team containing representatives of relevant organizations and interested individuals to co-ordinate long-term conservation strategies for the Pale Sun-moth.
5.) Increase awareness within the scientific community and the general public of the uniqueness of the Pale Sun-moth.

Objectives of this Action Statement

All morphs

1.) Halt, and if possible reverse, the threatening ecological processes that have caused the Victorian parthenogenetic morphs of the Pale Sun-moth to become endangered.
2.) Implement actions that will lead to the long-term conservation and appropriate management of the remaining sites where the Pale Sun-moth occurs.
3.) Clarify the differences between the five parthenogenetic morphs of the Pale Sun-moth and the values of conserving each morph as a distinct taxonomic entity.
4.) Maintain and, if possible, improve the ecological condition of the sites in Victoria where the Pale Sun-moth still occurs (see the activities listed below).

Intended Management Actions

Special note

If all of the parthenogenetic morphs of the Pale Sun-moth are to be protected and managed successfully, there is a need to prioritize the importance of sites where this species occurs. Given the conservation status, known distribution and local population density of each morph is taken into consideration, the following priority ranking of sites is suggested:

Very high priority:
1.) Jung site (Pale Morph, site 1).
2.) Site 10 km north-north-east of Mitiamo (Terrick Terrick Morph, site 2).
3.) Nhill site (Nhill Morph, site 1).
4.) Pimpinio site (Narrow-winged Morph, site 1).

High priority:
1.) Murtoa site (Pale Morph, site 2).
2.) Borung site (Pale Morph, site 4).
3.) Site 10 km north-east of Mitiamo (Terrick Terrick Morph, site 3).
4.) Dimboola site (Dark Morph, site 1).

Medium priority:
1.) Brynterion site (Pale Morph, site 3).
2.) Mitiamo Golf Course site (Terrick Terrick Morph, site 1).

Low priority:
1.) Barrabool site (Pale Morph, site A).
2.) Murtoa-Glenorchy Road site (Pale Morph, site B).

All morphs

To effectively conserve the five parthenogenetic morphs of the Pale Sun-moth, the following actions should be undertaken:

1. Contact all owners of Pale Sun-moth breeding sites on private land to ensure that these sites are not ploughed or harrowed.
2. Approach all owners of Pale Sun-moth breeding sites on private land to place the sites under appropriate Trust for Nature covenants or Land for Wildlife agreements.
3. Ensure that current grazing and mowing regimes at Pale Sun-moth breeding sites are maintained where appropriate.
4. Annually monitor all sites for the encroachment of exotic grasses and weeds and if necessary implement control measures.
5. Collect and maintain records of the abundance of the Pale Sun-moth at all of the known Victorian sites at 3 year intervals.
6. Consultant entomologists and/or appropriate Department of Natural Resources and Environment staff carry out surveys for additional populations of the Pale Sun-moth. Because the Nhill Morph and the Narrow-winged Morph are the most threatened of the five Victorian morphs, surveys should give priority to locating more occurrences of these taxa. These surveys should concentrate on regularly grazed or annually mown remnants of native perennial grassland that are relatively weed-free and have never been ploughed or harrowed.
7. Document the flora and fauna occurring at Pale Sun-moth breeding sites to identify the ecological requirements of the five morphs as well as determine if populations of other vulnerable or endangered taxa are present.

Specific management actions required for the five morphs

Pale Morph

Consultant entomologists and/or appropriate Trust for Nature (Victoria) staff to determine if this morph is breeding within an area of native perennial grassland (near Borung) that the Trust for Nature is in the process of purchasing. This area will eventually become a disjunct portion of the Trust for Nature owned "Kinipanial Grassland" Borung site, which supports a population of the Pale Morph.

Terrick Terrick Morph

1. Consultant entomologists and/or appropriate Department of Natural Resources and Environment staff to conduct surveys to determine if populations of this morph occur in the Terrick Terrick National Park (especially in the former Davies property).
2. Department of Natural Resources and Environment, in association with Parks Victoria, to ensure management of an appropriate section of the Terrick Terrick National Park to create and/or maintain a suitable area of habitat for this morph.

Nhill Morph

Trust for Nature (Victoria) to form a community-based management committee for the Nhill site.

Narrow-winged Morph

Department of Natural Resources and Environment to inform relevant officers of the Pimpinio Golf Club that while mowing is beneficial, it would be seriously detrimental to the Pimpinio population of this morph (and the Dark Morph) to apply fertilizer to the fairways or to aerate the soil in these areas.

Dark Morph

Department of Natural Resources and Environment to liaise with the owner/s of the Dimboola site to arrange for the removal of African Boxthorn (*Lycium ferocissimum*) plants that occur throughout the area.

Other Desirable Actions

All morphs

1.) Department of Natural Resources and Environment and/or other relevant organizations to produce an educational pamphlet and poster depicting the Pale Sun-moth and its habitat. These should also give basic information on the biology and habitat requirements of the species and provide a list of people to be contacted if a population is found.

2.) The collection of specimens of the Pale Sun-moth for scientific studies should be strictly controlled. Permit conditions should include how the specimens are to be preserved to maximize the potential use of each specimen. With the critically endangered Nhill and Narrow-winged Morphs only one specimen should be taken for this purpose each year, until the desired number of specimens has been preserved.

3.) Investigate the purchase and rehabilitation of an area of degraded land that would have been within the former range of the Pale Sun-moth. A suitable area in the Wimmera with heavy, loamy soil could be replanted with a wide range of native grassland species (including areas dominated by grazed or mown Bristly Wallaby-grass). The four morphs of the Pale Sun-moth that occur in the Wimmera area could be introduced to the one site as the parthenogenetic nature of these morphs would mean that they would be incapable of interbreeding.

4.) Further studies of larval feeding and other aspects of the life cycle should be undertaken for all morphs.

Contact People

Brian Hamilton (leaseholder of Murtoa site): management (Murtoa site). Ph. 03 5385 2237.

Christine Solly (owner of land adjacent to Pimpinio site): land tenure and management (Pimpinio site). Ph. 03 5384 2332.

Clive Crouch (Nhill College): land tenure, management and community involvement (Nhill site). Ph. wk. 03 5391 2111.

Dale Tonkinson (Arthur Rylah Institute for Environmental Research, Heidelberg): plant and general ecology and management (all sites). Ph. wk. 03 9450 8733.

David Fletcher (owner of Murtoa site) land tenure and management (Murtoa site). Ph. mobile 04 2933 5706.

David Venn (Department of Natural Resources and Environment, Horsham): land tenure and management (Wimmera sites). Ph. 03 5381 1255.

E. D. (Ted) Edwards (CSIRO Division of Entomology, Canberra): taxonomy, biology, distribution and management (all sites). Ph. wk. 02 6246 4001 hm. 02 6251 4503.

Fabian Douglas (Entomologist): taxonomy, biology, distribution and management (all sites) and land tenure (Nhill site). Ph. wk. 03 5391 8228 hm. 03 5395 1443.

Ian Hastings (Dept. of Natural Resources and Environment, Ballarat): land tenure and management (Wimmera sites). Ph. wk. 03 5333 6508.

Jack and Jean Wishart (previous owners of Borung site): management (Borung site). Ph. hm. 03 5494 7205.

James Veitch (Hindmarsh Shire Council): land tenure and community involvement (Nhill site). Ph. wk. 03 5391 1418.

Neil Jacobs (Hindmarsh Shire Council): land tenure (Nhill site). Ph. wk. 03 5391 1811.

Neil Marriott (Trust for Nature, Victoria): botany (all sites) and land tenure Nhill and Jung sites). Ph. mobile 04 0817 7989.

Paul Foreman (Trust for Nature, Victoria): botany (all sites) and land tenure and management (Nhill and Borung sites, also Mitiamo site - 10 km north-east of Mitiamo). Ph. wk. 03 9670 9933.

References

1.) **Common, I. F. B. and Edwards, E. D. 1981**. The life history and early stages of *Synemon magnifica* Strand (Lepidoptera: Castniidae). *J. Aust. Ent. Soc.* 20: 295-302.

2.) **Common, I. F. B. and Waterhouse, D. F. 1981**. *Butterflies of Australia*. Angus and Robertson Publishers, Sydney.

Compiled by: Fabian Douglas.

Date: 26 September 2000

Appendix 2. Final draft of a paper (by the author) that was published in the *Journal of Insect Conservation*, 8 (2-3): 221-228, during 2004. This pertains to the establishment and management of the Nhill Sun-moth Reserve, for the conservation of a sympatric occurrence of the Nhill Morph of the Pale Sun-moth (*Synemon selene*) and the golden Sun-moth (*S. plana*).

Part 3

Chapter 9

Conservation and Management of the Six Pale Sun-moth Morphs

Introduction

Prior to European settlement, it seems likely that the Pale Sun-moth would have had a much wider distribution on the grassy plains of central and western Victoria and southern South Australia. As this type of habitat was also premium land for agricultural purposes, it was widely taken up for farming (in preference to many other habitat types) soon after these parts of south-eastern Australia were settled. The subsequent ploughing of most of these grasslands for pasture improvement or cropping purposes has undoubtedly destroyed the ecological integrity of many areas where the Pale Sun-moth would have occurred in the past (pers. obs. 1991 to 2005).

However, from 1997 to 2005, observations by the author on the biology of the Pale Sun-moth have repeatedly shown that it requires its habitat to be regularly grazed. When grazing animals are removed from sites where the species occurs, its numbers show a marked decline. It is likely that this is due to two main factors. The first of these is that the dead plant material that accumulates on the ground after grazing ceases, compromises the open nature of its habitat. This makes it difficult for Pale Sun-moths to find safe oviposition and basking sites, as successful attacks by terrestrial predators, such as small diurnal reptiles and tunnel dwelling spiders, are much more likely to occur in a sheltered microhabitat where rapid escape routes are impeded. In addition to this, predators of this type are more confident to strike in a situation where they are less likely to be taken by larger predators, e.g. Laughing Kookaburras (*Dacelo novaeguineae*) and Nankeen Kestrels (*Falco cenchroides*).

The second factor is that Bristly Wallaby-grass (*Austrodanthonia setacea*) appears to be susceptible to competition from taller grasses when grazing animals are removed from a site where it dominates the ground flora. It is likely that this perennial grass is the main larval host plant of the Pale Sun-moth. Thus, it seems that the Pale Sun-moth is dependant on its habitat being grazed, or perhaps periodically burnt, to maintain favorable conditions for Bristly Wallaby-grass to proliferate. It also appears that an annual mowing regime will maintain the ecological conditions that the Pale Sun-moth requires. This is substantiated by the relatively high population levels of the species that persist at ungrazed sites such the Pimpinio site, which being a Golf Course, has mown fairways, and the Nhill site, which is mown each December for fire control.

These ecological requirements place the Pale Sun-moth in a precarious position, as it does not survive on cultivated farmland or thrive in the various reserves throughout its former range that are not grazed or annually mown. It is now apparent that one of the most important mainstays for its survival to the present time has been a few regularly grazed areas of privately owned native grassland and grassy open forest that have never been ploughed or harrowed. This was clearly demonstrated on 27 February 2004, at the Forbes Road site, where nine individuals of the Terrick Terrick Morph were located within a 50 m by 50 m area during one and half hours of searching time. On this occasion and in previous years when the Forbes Road site was visited, it was noted that it had been regularly grazed by sheep, to such an extent that the ground flora was consistently very open and dominated by Bristly Wallaby-grass. Throughout most of the searched area the Bristly Wallaby-grass was approximately 5 cm to 10 cm high. On the same occasion a 50 m by 50 m area of an adjacent ungrazed paddock was also searched for one and a half hours with no individuals of *Synemon selene* being located. Apart from the absence of any obvious signs of recent grazing pressure in the latter area, there was no apparent difference (in soil type or topography) between the two search sites. However, although the latter area was also dominated by Bristly Wallaby-grass it had become very overgrown and dense, with an average sward height of 35 cm.

While the only known occurrence of the Nhill Morph, and three of the six known (extant) occurrences of the Pale Morph are protected to some extent by being in reserves, the Terrick Terrick Morph, Narrow-winged Morph and Dark Morph are only known from occurrences on privately owned land. It is noteworthy that there are no known occurrences of any of the Pale Sun-moth morphs within Victorian national parks.

Wider conservation Issues

It has now become apparent that the sites where sun-moths occur usually hold populations of other vulnerable and/or endangered plants and animals (pers. obs. 1998 to 2006). The Pale Sun-moth is no exception to this trend, as other species of conservation significance have been found at eleven of the thirteen sites where the five Victorian parthenogenetic morphs occur. For example, the Nhill site at Belcher Street, where the Nhill Morph occurs, also holds populations of two other threatened species. These are the Golden Sun-moth (*Synemon plana*) and a very localised grass cicada that is now known as the Nhill Zitter (*Cicadetta* sp. aff. *waterhousei*, ?*kewelensis*).

So far as known, the extraordinary genetics of the Pale Sun-moth (with its possibly extinct non-parthenogenetic population and five extant parthenogenetic morphs) are unique within the family Castniidae. It is highly likely that this species would be of special interest to geneticists, because it is most unusual for a species to evolve into several parthenogenetic taxa that morphologically distinct from one another. This is especially so because some of these parthenogenetic morphs occur sympatrically at three sites in the Wimmera area. In short, the five extant morphs of the Pale Sun-moth represent a complex of three separate genetic clades that must be conserved in its entirety as a most significant part of Australia’s biodiversity. It is also possible that a complete understanding of the genetics (including the karyology) of parthenogenesis in the Pale Sun-moth may permit advances in certain areas of farming. For instance, imagine the economic gains for the dairying and egg production industries if there was an option available to reproduce high quality stock without the added cost of purchasing semen for artificial insemination or especially, of maintaining male animals on the farm.

Existing conservation measures for the Pale Sun-moth

Two Wells Morph

As this morph is already presumed to be extinct there are no existing measures for its conservation.

Pale Morph

The occurrences at the Brynterion and Barrabool sites are afforded some protection by being within Brynterion and Barrabool Flora and Fauna Reserves respectively. However, the current grazing regime at both of these reserves, by small populations of Western Grey Kangaroos (*Macropus fuliginosus*), is insufficient to maintain a microhabitat that is optimum for the Pale Sun-moth, for the reasons that are discussed above and illustrated below.

The Borung (‘Kinipanial Grassland’) site was purchased in 1999 by the Trust for Nature (Victoria). A community-based management committee for the area has now been formed.

In 2001, the Trust for Nature (Victoria) also purchased an additional 220 hectares of native perennial grassland, 1 km east of the Borung site. It is possible that this morph may also occur there because 40 hectares of this land have never been cultivated (P. Foreman pers. comm. 2000).

Terrick Terrick Morph

In 2000 the Trust for Nature (Victoria) and the (then) Department of Natural Resources and Environment were negotiating the purchase of the Forbes Road site, where this morph occurs (10 km north-east of Mitiamo). However, as at 14 November 2006, this land is still under private ownership (D. Marshall pers. comm. 2006). Therefore, there are no existing conservation measures for this endangered morph.

Nhill Morph

In 1999/2000 the Hindmarsh Shire Council and West Wimmera Tree Group successfully applied for three separate grants from the Trust for Nature (Victoria), the R. E. Ross Trust and the Worldwide Fund for Nature (Grassy Ecosystems Grants Program) to establish a flora and fauna reserve at the Belcher Street site (at Nhill). After the Hindmarsh Shire Council provided additional funding for land title transfers and legal costs, the former Governor of Victoria, Mr. John Landy, officially opened this reserve on 18 November 2004. It is now known as the Nhill Sun-moth Reserve.

In 2002, two hectares of privately owned land that abuts the north-west side of the Nhill site was placed under a Trust for Nature (Victoria) covenant.

Narrow-winged Morph

There are no existing conservation measures for this critically endangered morph.

Dark Morph

There are no existing conservation measures for this endangered morph.

Recommended management strategies for the Pale Sun-moth morphs

All extant morphs

To effectively conserve the five parthenogenetic morphs of the Pale Sun-moth, the following actions should be undertaken:

1) Contact all owners of Pale Sun-moth breeding sites on private land to ensure that these sites are not fertilised, ploughed or harrowed.

2) Approach all owners of Pale Sun-moth breeding sites on private land to place the sites under appropriate Trust for Nature covenants or Land for Wildlife agreements.

3) Ensure that current grazing and/or mowing regimes at Pale Sun-moth breeding sites are maintained and where appropriate, restore past grazing regimes at sites that have become overgrown.

4) Take measures to limit the potential drift into Pale Sun-moth breeding sites of pesticides and herbicides used on adjoining agricultural properties.

5) Annually monitor all sites for the persistence and continued health of Bristly Wallaby-grass (*Austrodanthonia setacea*) as well as encroachment by exotic grasses and forbs. If necessary, implement weed control measures.

6) Collect and maintain records of the abundance of the Pale Sun-moth at all of the known Victorian breeding sites, at one-year intervals (if possible).

7) Document the flora and fauna occurring at Pale Sun-moth breeding sites to further clarify the ecological requirements of the five morphs, as well as determine if populations of other vulnerable or endangered taxa are present. See Chapter 7 of Part 3 for a description of the habitat of the Pale Sun-moth.

8) Employ consultant entomologists and/or appropriate staff from the Department of Sustainability and Environment or Parks Victoria to carry out surveys for additional populations of the Pale Sun-moth. Because the Nhill Morph and the Narrow-winged Morph are the most threatened of the five Victorian morphs, surveys should give priority to locating more occurrences of these taxa. These surveys should concentrate on regularly grazed or annually mown remnants of native perennial grassland that are relatively weed-free and have never been ploughed or harrowed.

Additional management actions required for each morph

Two Wells Morph

This morph is presumed to be extinct. The necessary actions for its possible recovery and subsequent conservation are as follows:

1) The South Australian Department of Environment and Heritage would need to liaise with other government departments (such as the National Parks and Wildlife Service) as well as relevant community groups, to encourage, co-ordinate and provide funding for surveys to be undertaken to determine if this taxon is still extant. These surveys would have to be undertaken from mid February to mid March and concentrate on any remaining areas of native perennial grasslands on the Adelaide Plains that are dominated by wallaby-grasses (*Austrodanthonia* spp.), especially Bristly Wallaby-grass (*A. setacea*).

2) If an occurrence of this taxon is rediscovered it would be imperative that it is adequately protected under appropriate legislation (e.g. listed as critically endangered under the federal *Environment Protection and Biodiversity Conservation Act* 2000).

3) After this is done, a similar management strategy (as for the Victorian morphs) would need to be developed, to ensure that the population does not become extinct.

Pale Morph

Consultant entomologists and/or appropriate Trust for Nature (Victoria) staff should determine if this morph is breeding within an area of native perennial grassland (1 km east of the Borung site) that the Trust for Nature purchased in 2001. This area is now a disjunct portion of the Trust for Nature (Victoria) owned ‘Kinipanial Grassland’, i.e. the Borung site, which is already known to contain an occurrence of the Pale Morph.

Terrick Terrick Morph

Consultant entomologists and/or appropriate Department of Sustainability and Environment staff should conduct surveys to determine if populations of this morph occur in the Terrick Terrick National Park, especially within the extensive area of grassland that was formerly the Davies property.

Department of Sustainability and Environment, in association with Parks Victoria, should manage an appropriate section of the Terrick Terrick National Park in such a way that it would create and/or maintain a suitable area of habitat for this morph.

Nhill Morph

Because the Nhill Morph is only known to occur at one locality, it must be regarded as one of the most threatened of the six Pale Sun-moth morphs. However, as the area where it occurs also contains populations of two other endangered species, an integrated approach towards its management must be taken. The close proximity of the Nhill Sun-moth Reserve to a built up area also raises concerns about an adequate fire prevention regime for the Nhill site. For these reasons it is imperative that the greatest care should be taken to carefully implement the following the list of recommendations:

1) To maintain the ecological conditions that the Pale Sun-moth requires, most of the Nhill site will need to be high-mown annually, to a height of approximately 10 cm. The best time of the year for this to be done would be in mid December. The reasons for this are as follows: (a) By mid December the adult flight periods of the Golden Sun-moth (*Synemon plana*) and the Nhill Zitter (*Cicadetta* sp. aff. *waterhousei*) have concluded. (b) From late October to late November the females of the Nhill Zitter oviposit into standing green stems of Spear-grasses (*Austrostipa* spp.) and other grasses. Delaying the annual mowing of the area until mid December would allow enough time for the Nhill Zitter to complete its oviposition. (c) Mowing the area in mid December would not interfere with the adult flight period of the Pale Sun-moth, which is on the wing from early February to early March. (d) Another advantage of mowing the area at this time of the year is that it would give the native perennial grasses a chance to produce a large quantity of ripe (viable) seed.

2) As the incubation period of the ova of the Nhill Zitter is still unknown, it is important that some areas within the Nhill site that contain Spear-grasses are left unmown. The positions of these unmown sites should be chosen so that they also contain some plants of an uncommon chenopod, Rohrlach’s Bluebush (*Maireana rohrlachii*), which has a patchy occurrence in the area. This would ensure that some of the Nhill Zitter ova would have sufficient time to hatch successfully and also that the unmown Rohrlach’s Bluebush

plants would be able to reach maturity and produce seed. These unmown sites would probably need to be rotated to new areas every few years, to prevent a build up of dead grasses that may ultimately preclude the continuation of healthy plant growth.

3) Because the western boundary of the Nhill site abuts a built up area, it may be necessary to annually mow a 4 m wide firebreak around the perimeter of the proposed reserve before the rest of it is mowed in mid December. The best time of the year to do this firebreak mowing would be in mid October, just before the onset of the fire season and the adult flight periods of the Golden Sun-moth and the Nhill Zitter.

4) Since 1999, voluntary spot spraying (with 'Roundup'TM) of African Daisy (*Gazania ?rigens*) and Wild Sage (*Salvia verbenaca*) has been annually carried out at the Nhill site. It is imperative that this control regime is continued as these two exotic perennial plants are capable of rapidly colonizing large areas and if left unchecked would eventually pose a threat to the ecological stability of the area. A further problem with the African Daisy is that fresh seed is continuously blown into the reserve from the southern verge of Belcher Street and nearby gardens. For this reason, it is strongly recommended that the occurrence of the plant along Belcher Street should also be sprayed with 'Roundup'TM.

5) To control exotic annual grasses such as Great Brome Grass (*Bromus diandrus*) and Wild Oats (*Avena fatua*) at the Nhill site, it may be necessary to closely mow the areas where these grasses are abundant, in late winter or early spring, before they have set seed. Two alternative control methods for these species that could also be trialled from late winter to early spring are as follows: (a) Burn out any pure stands of exotic grasses with a flame-thrower. (b) Have the whole of the Nhill Sun-moth Reserve grazed by sheep for a brief period. However, the impact of sheep grazing on the occurrences of Rohrlach's Bluebush in the area would need to be carefully observed, so that there would be no delay in removing the animals if the need arose.

6) A consultant entomologist should visit the Nhill site at least twice annually, in mid November and again in mid February, to obtain records on the abundance from year to year of the Golden Sun-moth, Nhill Zitter and Pale Sun-moth. The accumulation of such data would enable any declines or increases in the population levels of these threatened species to be detected.

Narrow-winged Morph

The Narrow-winged morph is especially rare in terms of distribution and abundance. For this reason it is especially important that the Dimboola, Pimpinio and Jung sites are protected under appropriate legislation and managed in accordance with the guidelines that are listed above under the heading 'All Victorian Morphs'.

The Department of Sustainability and Environment should inform relevant officers of the Pimpinio Golf Club that, while mowing is beneficial, it would be seriously detrimental to the Pimpinio population of this morph (and the Dark Morph) to apply fertilizers to the fairways or to aerate the soil throughout these areas.

Dark Morph

The Department of Sustainability and Environment should liaise with the private owner/s of the Dimboola site to arrange for the removal of African Boxthorn (*Lycium ferocissimum*) plants that occur throughout the area. The implementation of this action would also benefit the occurrence of the Narrow-winged Morph at this site.

Illustrations

Figure 1. Optimal habitat of the Pale Sun-moth on private land at the Jung site, where populations of the Pale Morph, Narrow-winged Morph and Dark Morph occur sympatrically. This photograph was taken in February 1998 after sheep had grazed the area for many years. The habitat was (and still is) very open and has a ground cover that is dominated by short plants of Bristly Wallaby-grass (*Austrodanthonia setacea*).

Figure 2. The habitat of the Pale Morph and Dark Morph on private land at the Murtoa site. Once again it appears that regular (and sometimes heavy) sheep grazing at this locality has maintained the ecological conditions that the Pale Sun-moth requires. Although this photograph was taken during February 1998, this site is still in a similar condition.

Figure 3. Habitat of the Pale Morph on private land abutting the Murtoa-Glenorchy Road site (near the north-east corner of Murtoa Golf Course). When this photograph was taken in February 1998, this area of habitat was in the process of becoming unsuitable for the Pale Sun-moth because sheep had not grazed it for approximately three years. Note the tall sward of dried Wallaby-grasses (*Austrodanthonia* spp.) and abundance of regenerating eucalypts. It is likely that as the young eucalypts mature, they will eventually change this habitat to woodland with a partly or completely closed canopy.

Figure 4. Western boundary of an experimental exclusion plot in habitat of the Pale Morph at the Borung site. This exclusion plot was built in 1994 during studies on the ecology of grassland remnants (Hadden 1998). The photograph, taken during February 1999, clearly shows that an area of optimal Pale Sun-moth habitat had become completely unsuitable for this species in the absence of sheep grazing for five years. The right side of the photograph shows a part of the area that was enclosed inside the exclusion plot. This contained dense stands of Spear-grasses (*Austrostipa* spp.) and other tall grasses. These grasses had totally out competed the shorter Bristly Wallaby-grass (*Austrodanthonia setacea*) that was widespread and abundant outside the fenced off area.

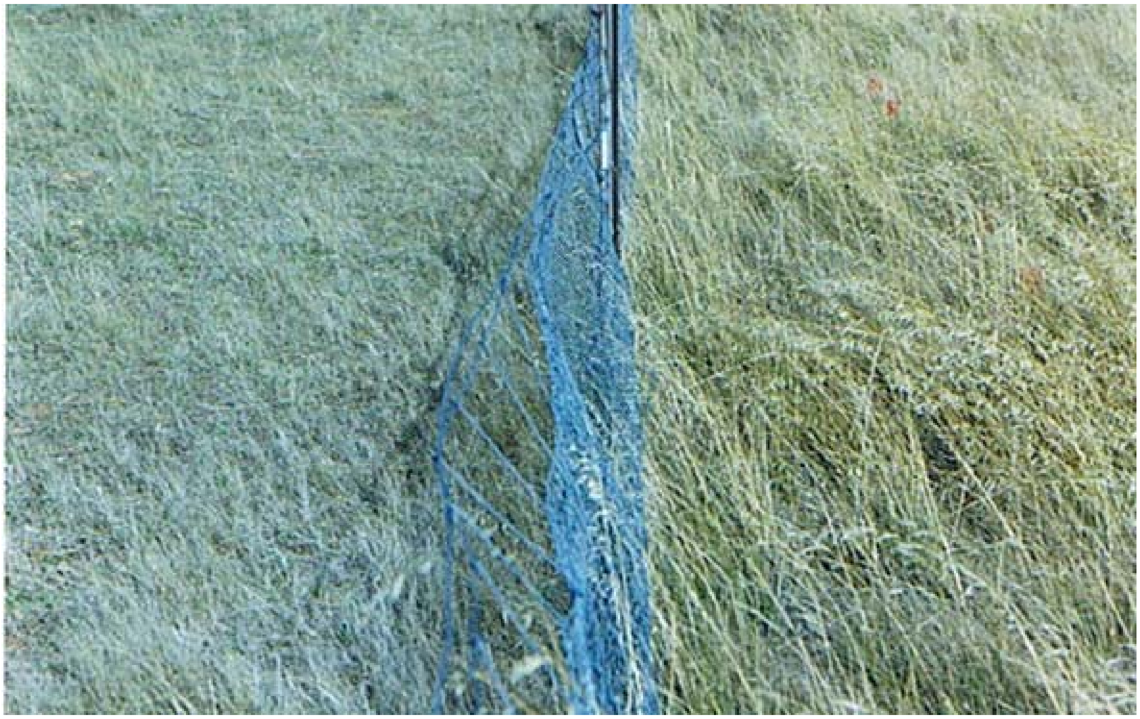


Figure 5. A close up study of the completely unsuitable habitat for the Pale Sun-moth that had become established inside the exclusion plot at the Borung site, after sheep had been excluded for five years. This photograph was also taken during February 1999. It is significant that Bristly Wallaby-grass (*Austrodanthonia setacea*), the most likely larval host plant of the Pale Sun-moth, could not be found inside the exclusion plot.

Figure 6. A close up study of the optimal habitat of the Pale Morph at the Borung site. Although this photograph was taken during February 1999 (near the end of summer) it can be clearly seen that the Bristly Wallaby-grass (*Austrodanthonia setacea*) plants are carrying green foliage and are in a healthy condition, as a result of having been grazed by sheep during the previous twelve months. In this more open habitat the Pale Sun-moth has easy access to the ground for oviposition and is not obstructed from being able to rapidly escape from terrestrial predators such as wolf spiders and small diurnal reptiles.

Figure 7. The Nhill site in February 2000, after it had been mown during the previous December for fire control purposes. It seems that the annual mowing of the Nhill site has had a similar effect on its ground flora to sheep grazing at most of the other sites where the Pale Sun-moth occurs. This in an indication that annually mowing the Nhill site in December/January has inadvertently maintained the habitat of the Nhill Morph in a suitable condition for its survival to the present time.

Figure 8. Suitably grazed habitat of the Terrick Terrick Morph on private land at the Forbes Road site. This photograph was taken on 27 February 2004, before nine individuals of this morph were located within a 50 m by 50 m area of the site during one and a half hours of searching time.

Figure 9. Appearance of unsuitable habitat for *Synemon selene* in a privately owned ungrazed paddock adjacent to the Forbes Road site. This photograph was also taken on 27 February 2004, just after a 50 m by 50 m area of the paddock was searched for a period of one and a half hours, without any individuals of the Pale Sun-moth being located.

A dedicated reserve for conservation of two species of *Synemon* (Lepidoptera: Castniidae) in Australia.

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Abstract

Introductory notes on the family Castniidae are followed by some general information on the Pale Sun-moth, *Synemon selene* Klug, 1850 and the Golden Sun-moth, *Synemon plana* Walker, 1854. An account is given of the discovery of an extant population of the Nhill Morph of *S. selene*. The remainder of this work documents steps that have been taken to establish a 4.5 hectare reserve at Nhill in western Victoria, to meet the urgent conservation needs of this taxon and a sympatrically occurring population of *S. plana*. Some management issues that concern these two grassland-dependent *Synemon* species at Nhill are also discussed.

Introduction

The Castniidae are thought to have a Gondwanan origin (Hall & Holloway, 1998). They are well represented by the subfamily Castniinae in Central and South America, where approximately 81 species are assigned to 32 genera (Lamas, 1995) and in mainland Australia by 44 species, 22 of which are undescribed (E. D. Edwards, pers. comm. 2004). All of the Australian species are currently placed in the genus *Synemon* Doubleday, 1846. A small but distinctive subfamily of five congeneric species, the Tascininae, occurs in southeast Asia (Fukuda, 2000). Although the Castniidae strongly resemble butterflies they are considered to be allied to the Sesiidae (Clear-wing Moths), Brachodidae (Little Bear Moths) and Cossidae (Wood Moths), (Edwards *et al*. 1998).

Adult castniids are noted for their diurnal habits, clubbed antennae and broad wings. In many species both surfaces of the hindwings and the forewing under side are brightly coloured, while the forewing upper sides are cryptically or disruptively patterned. When at rest many species hold their wings in a roof-wise position above the abdomen, with the inner margins of the forewings touching or slightly overlapping. It appears that they adopt this characteristic resting position so that the conspicuous hindwing coloration is concealed from predators by the forewing upper sides. In earlier times, castniids were commonly known as Connecting-link Moths or Butterfly Moths, but in Australia are now referred to universally as Sun-moths.

The known larvae of Castniidae feed on monocotyledonous plants belonging to several families. These include the Cyperaceae, Poaceae, Bromiliaceae, Xanthorrhoeaceae (= Lomandraceae) and Orchidaceae (Edwards *et al*. 1998). The larvae of some species feed internally on the rhizomes, pseudobulbs or other parts of their respective host plants while larvae of others tunnel through the soil and feed on their roots. Pupation occurs within the final larval gallery and the pupal exuviae are usually left protruding from the ground or host plant tissues after eclosion (pers. obs. 1993 – 2004).

It seems likely that many of the castniids are now threatened with extinction. There is little doubt that the widespread deforestation that has occurred in Central and South America and southeast Asia in recent years would have resulted in the distributions of many species becoming fragmented, with vulnerable and isolated populations being restricted to remnants of their respective habitats. At present it would be difficult to establish an adequate reserve system for the threatened castniids in these regions because the larval host plant associations of many of the Neotropical species and all of the southeast Asian species are still unknown. At least, a partial solution to this problem would be to ensure that as great a cross section of primary habitat types as possible are well represented in the national parks and nature reserves of the countries where castniids occur.

Several of the Australian castniids have suffered a drastic reduction in their distributions, as a result of habitat loss since European settlement. The subsequent clearing or modification of vast areas of native grasslands, woodlands and heathlands across the country's temperate and subtropical biomes has caused this scenario. One species (the Cryptic Sun-moth, *S. theresa* Doubleday, 1846) is now believed to be extinct. In particular, agricultural practice that involves repeated ploughing or cultivation of the soil has been especially destructive to the grass feeding *Synemon* spp. in southern Australia. Soil cultivation not only destroys the subterranean early stages of these species but also kills the native perennial grasses that are their larval host plants. Although some of the threatened Australian castniids are now listed for protection under government legislation, there is still an urgent need to properly conserve and manage their remaining habitats if they are to be saved from becoming extinct in the medium to long-term.

In southern Australia the grass-feeding *Synemon* spp. have an important role to play as flagship species for indicating high levels of biodiversity within the endangered grassland communities where they occur. For example, the author has determined that all of the Victorian localities where *S. selene* occurs are comparatively species rich and also contain populations of other threatened animals and plants. Moreover, it has been noted that these localities represent very important remnants of once widespread but now endangered grassland ecosystems. This paper considers some steps that have been taken toward the conservation of two of these flagship castniid species in southeastern Australia.

The Pale Sun-moth, *Synemon selene*

Within the Australian castniid fauna, the Pale Sun-moth, *Synemon selene* is of special interest. As its common name implies, this is an unusually pale species. It has a wingspan of about 3.5 to 4.7 cm and is attractively patterned in shades of pale yellowish-orange, brownish-fawn, grey, black and white. The known historical distribution of this species ranges from near Two Wells on the Adelaide plains in South Australia, eastwards to near Borung and Mitiamo in the central plains area of Victoria. *S. selene* is now restricted to a few circumscribed habitat remnants, most of which are in the Wimmera region of western Victoria.

The habitat of *S. selene* is native grassland and grassy woodland that is dominated by Wallaby Grasses, *Austrodanthonia* spp. and to a lesser extent Spear Grasses, *Austrostipa* spp. (both Poaceae). The larvae of *S. selene* live in underground tunnels below these perennial grasses and although it remains to be confirmed, are likely to feed on the roots of *Austrodanthonia* spp. The adult flight period of this species commences in mid February and concludes in early March (pers. obs. 1991 – 2004).

Experimental work carried out by the author (unpublished) has already demonstrated that all Victorian populations of this species are parthenogenetic. Curiously, while an approximately equal sex ratio of historic specimens were collected from near Two Wells in South Australia, a male of *S. selene* has never been collected from anywhere in Victoria. Unfortunately, widespread agricultural use of its habitat (native perennial grasslands) in the Two Wells area seems to have caused extinction of the localised sexual population. Within the Castniidae parthenogenesis is not known to occur in any other species.

Another unusual aspect of *S. selene* is that within the Victorian parthenogenetic populations, five distinct subspecies or morphs have evolved. In the Wimmera area of western Victoria, there are two localities where two of these morphs coexist, and one locality where three morphs occur sympatrically. Due to being parthenogenetic, the morphs are genetically isolated from each other at these sites and cannot interbreed. It is also evident that all of the parthenogenetic morphs may be continuing to evolve (? by accumulating small mutations through time) in the absence of males. Minor variations of colour and markings often occur between the individuals of a given morph.

Until these morphs have been formally described and named, they have been given convenient vernacular names by the author. These are either derived from the localities where they occur or are based on their morphological characteristics. The names are as follows: Pale Morph, Terrick Terrick Morph, Nhill Morph, Narrow-winged Morph and Dark Morph. Due to habitat loss since European settlement, all of these morphs of *S. selene* are endangered, with the Narrow-winged Morph and Nhill Morph being critically endangered (Dept. of Natural Resources & Environment, 1999, pers. obs. 1991-2004).

The Golden Sun-moth, *Synemon plana*

When the genus *Synemon* is considered as a whole, it becomes apparent that *S. plana* is another very unusual species. It is the only member of the genus that has semi-flightless females and exhibits pronounced sexual dimorphism. Although the forewing upper sides of both sexes are dark brown with delicate greyish-white markings, it is here that the resemblance ends. The males have dark bronzy-brown hindwing upper sides with a few indistinct blackish spots, while the females have the hindwing upper sides bright yellowish-orange with a few small black spots. The wingspans of the sexes also differ and measure about 3.5 cm for males and 3 cm for females.

The life history of this species is very similar to *S. selene*. The larvae tunnel through the soil and are also thought to feed on the roots of Wallaby Grasses, *Austrodanthonia* spp. (O'Dwyer & Attiwill, 2000). Depending on where a given population of this species occurs, its adult flight period can vary considerably. Throughout the cooler parts of its distribution it can range between the following extremes: early November to mid December and late November to early January (E. D. Edwards, pers. comm. 2004). In warmer regions such as the Wimmera area in western Victoria, the adults first appear in late October and fly until mid to late November (pers. obs. 1989 - 2003).

S. plana has a mate location strategy that seems to be unique within the Castniidae. The males fly rapidly around breeding areas at height of about one metre above the ground. When a patrolling male passes over an unmated female, the female signals to the male by exposing her brightly coloured hind wings in a series of rhythmic flaps. The male then lands beside or near the female before mating takes place (pers. obs. 1999). With other species of Castniidae it is usual for the males to pursue and then court virgin females in flight, before courting pairs land to commence copulation (pers. obs. 1987 – 2004).

It seems that since European settlement, *S. plana* has also become locally extinct in many districts as a result of its grassland habitat being converted to agricultural land. Historic records indicate that it once occurred widely in the perennial grasslands of southeastern Australia. Its former distribution ranged from near Bathurst and Yass in New South Wales, through the Australian Capital Territory, southern New South Wales and Victoria to as far west as Bordertown in South Australia (E. D. Edwards, pers. comm. 2004). The species is now restricted to several comparatively small areas in New South Wales, the Australian Capital Territory and Victoria. *S. plana* is listed as a threatened species in Schedule 2 of the Victorian *Flora and Fauna Guarantee Act* 1988. It has also been listed as endangered under the New South Wales *Threatened Species Conservation Act* 1995 and the Australian Capital Territory *Nature Conservation Act* 1980 (O'Dwyer *et al*. 2000).

Rediscovery of the Nhill Morph of *Synemon selene*

While the author was extracting data from historic specimens of *S. selene* at the Museum of Victoria, a morphologically distinctive specimen was noticed which bore a data label reading 'Nhill, 1902 J. R. F.' and a second label reading 'G. Lyell collection, presented

31 July 1932'. The museum's records revealed that the collector of this unique specimen was a Rev. J. R. Fiddian (K. Walker, pers. comm.). As the author already knew that a dense population of *S. plana* occurred near Nhill (a township in western Victoria) the relevant area was surveyed for *S. selene* on 16 February 1999. On this occasion J. T. Noelker and the author located 3 individuals of the 'Nhill Morph'.

The discovery of an extant population of this morph rendered the Nhill site to be doubly significant and in urgent need of a long-term conservation strategy. This was due to it now being the only known locality where *S. selene* (represented by the only known population of the Nhill Morph) and *S. plana* occurred sympatrically. It seemed that both of the *Synemon* spp. had survived in the area because it had never been ploughed or artificially fertilized. This was due to the unusual history of the land, which had only been used for grazing purposes since European settlement. In a predominantly wheat growing district such as Nhill, it was extraordinary that it had not been cultivated and utilized for cropping at some time in the past.

Creation of the Nhill Sun-moth Reserve

Initially it seemed that it would be very difficult to establish a sun-moth reserve at Nhill. One major problem that had to be overcome was that the land in question (of 4.5 hectares) had already been subdivided into 21 allotments which had been sold to 10 separate owners. To further complicate matters, it was discovered that within a year, one of these land owners planned to build a large machinery shed in the area, while another was intending to build his retirement home there and convert the remainder of his land into a cultivated garden. It seemed likely that this development would seriously compromise the ecological integrity of the remaining allotments and would cause the populations of *S. selene* and *S. plana* to become fragmented, possibly to the extent that they would not be viable for more than a few more years.

However, after the situation had been explained to the local shire council, it was agreed that the area could be rezoned as a reserve, if the current owners could be persuaded to either sell or exchange their blocks of land. Funds for land purchase were obtained from the Trust for Nature (Victoria) (Au$43,000.00), with an additional Au$13,000.00 from the R. E. Ross Trust. Subsequently, the Hindmarsh Shire Council, the local government authority responsible for the Nhill region, agreed to provide Au$8,580.00 to cover the land title transfers and legal costs. Fortunately, some of the owners had not paid their property rates for a protracted period so the Hindmarsh Shire Council was able to rescind the titles of their allotments after due warning had been given. By late 2003, the Hindmarsh Shire Council had acquired all but 5 of the blocks and the Nhill Sun-moth Reserve was officially recognized. Official recognition of the reserve by the shire council was also extended to the interim management committee that was formed in 2000. Further, as a part of their regional planning scheme, the shire council placed the reserve under an environmental overlay, to protect it from any form of development and/or human activities that would lead to degradation of the habitat.

In 2000 the Worldwide Fund for Nature provided the Hindmarsh Shire Council with a grant of Au$14,200.00. These funds are being used for the construction of an information shelter, a 40 m long tourist boardwalk, fencing around the reserve's boundaries, and appropriate signage. By early 2004, management committee members and volunteers from the Victorian Green Corps (under the auspice of Greening Australia Victoria) had completed much of this work. At present the committee of management is planning to hold the official opening of the Nhill Sun-moth Reserve in November 2004, during the flight period of *S. plana*.

Management issues

Although there is still much to be learned about the biology of *S. selene* and *S. plana*, the unique sympatric occurrence of the two species within the reserve dictated that an integrated approach had to be taken towards their long-term management. After careful evaluation of what was known about the habits of the two species, a draft management plan was written for the reserve in 2001. This was revised and finalized in 2003 and is now used as a reference for management of the reserve by the Hindmarsh Shire Council and the reserve's management committee. Some of the management issues and proposed management actions that have been taken into consideration are as follows:

Observations of the biology of *S. selene* have indicated that it requires its habitat to be annually mown or grazed to be able to maintain maximum population levels. When this is not done its habitat tends to become overgrown with annual introduced grasses such as Great Brome Grass, *Bromus diandrus* and Wild Oats, *Avena barbata* (both Poaceae). Another effect of nil grazing/mowing is that the taller Spear Grasses, *Austrostipa* spp. tend to increase in abundance while the shorter Wallaby Grasses, *Austrodanthonia* spp. slowly disappear. This scenario applies particularly to Bristly Wallaby Grass, *A. setacea*, which, although not confirmed beyond doubt, is the most likely larval host plant of *S. selene* and S. *plana* at Nhill. It was also considered to be highly significant that O'Dwyer & Attiwill (1999, 2000) determined that populations of *S. plana* were only present within remnants of native grassland that contained more than 40% cover of *Austrodanthonia* spp.

For the reasons that are outlined above, it is proposed that periodic or 'pulse' sheep grazing will be used during winter to control introduced grasses and perpetuate the ecological conditions that seem to cause *A. setacea* to proliferate. However, as sheep may select certain highly palatable native grasses and forbs over other less palatable species, the overall impact of grazing on the native ground flora will be carefully monitored. By late winter all sheep will be removed from the reserve because the native grasses commence to grow foliage during early spring, before they flower and produce their seeds in late spring.

To date, most of the area that is now occupied by the reserve has been mown annually, at a height of approximately 6 to 8 cm. It seems that this management practice has suited *S. selene* and *S. plana* because their population levels are relatively high within the reserve. It is also a clear indication that an annual mowing regime will be another management option that can be used if certain species of native plants become less abundant as a result of sheep grazing in winter, or the native grasses become a fire hazard by early summer. The most appropriate time of the year to carry out annual mowing in the reserve would be in mid December. The reasons for this are that the adult flight period of *S. plana* has concluded by this time of the year and the adults of *S. selene* do not begin to emerge until mid February. As well as this, the seeds of the native perennial grasses have ripened and largely fallen by mid December but the main fire danger period of mid summer has not begun.

Patch burning will also be trialled as a method of controlling the invasion of introduced annual grasses into parts of the reserve, because it has already been determined that both *S. selene* and *S. plana* can withstand their habitat at Nhill being burnt. It seems that controlled burning (outside the adult flight periods of the *Synemon* spp.) may help to reduce the seed residue of introduced grasses, in areas of the reserve where they are most abundant.

Another perplexing management issue within the reserve is periodic and often widespread disturbance to the crytogamic soil surface crust by a native cockatoo, the Long-billed Corella, *Cacatua tenuirostris* (Psittaciformes: Psittacidae). This usually occurs during the drier months of the year when these birds visit the reserve in large numbers to dig up and eat the bulbs of two species of introduced monocotyledons, namely Onion Grass, *Romulea rosea* and Thread Iris, *Gynandriris setifolia* (both Iridaceae). Although the birds are helping to control these small but invasive weeds, the damage they do while digging for them offsets any potential benefit to the reserve as a whole. Remarkably, it seems that at least some of the adults of *S. selene* are able to emerge through the disturbed soil, although it has been observed that when the levels of disturbance are high, some of the freshly emerged individuals have lost most of their thoracic scales. It appears that this is due to these adults having to struggle through the 1 to 3 cm thick layer of small, loose soil clods that would cover their pupal tunnels in the disturbed areas. *S. plana* is largely exempt from this problem because it emerges earlier in the spring/summer season than *S. selene*, before most of the disturbance by Long-billed Corellas takes place.

Since 1999, annual records have been kept on the abundance of *S. selene* and *S. plana* at the reserve. The management committee will continue this yearly collection of data indefinitely, to enable a decline or an increase in the numbers of either species to be detected. To date, the population levels of both species have remained fairly stable from year to year, with about ten to fifteen *S. selene* and one hundred and fifty to two hundred *S. plana* being observed annually. It seems that the comparatively low numbers of *S. selene* are not unusual for the species. This has been indicated by the similarly low population densities of the other four Victorian morphs of *S. selene* (at other localities), which have been recorded by the author since the rediscovery of extant populations in 1991.

Further comments

The successful establishment of the Nhill Sun-moth Reserve represents a pioneering step in Australian sun-moth conservation, and also has wider significance in the development of practical invertebrate conservation in Australia, as one of few reserves designated specifically for insects. However, it is of concern to the author that several restricted and equally important populations of endangered *Synemon* species are still threatened with extinction in Victoria. The threats to these populations vary from area to area and include habitat degradation due to excessive weed invasion in existing reserves and vulnerable occurrences on privately owned properties, which are not protected under appropriate conservation covenants.

Only one of the eight species of *Synemon* that occur in Victoria is regarded as being secure (Douglas, 1993). Of the remaining species, one is listed as vulnerable, three as endangered (with one of these having two critically endangered morphs), two as critically endangered and one is presumed to be extinct (Dept. of Natural Resources & Environment, 1999). When one considers that the family Castniidae is believed to have a Gondwanan origin, it becomes apparent that it represents a very old and integral part of the Australian fauna. The unique nature of these moths further emphasizes the need for a rapid response by conservation bodies to protect and manage populations in order to arrest decline. The current conservation status of the family as a whole in Victoria reflects very poorly on the present level of expertise under which the habitats of the threatened Victorian species are being conserved and managed.

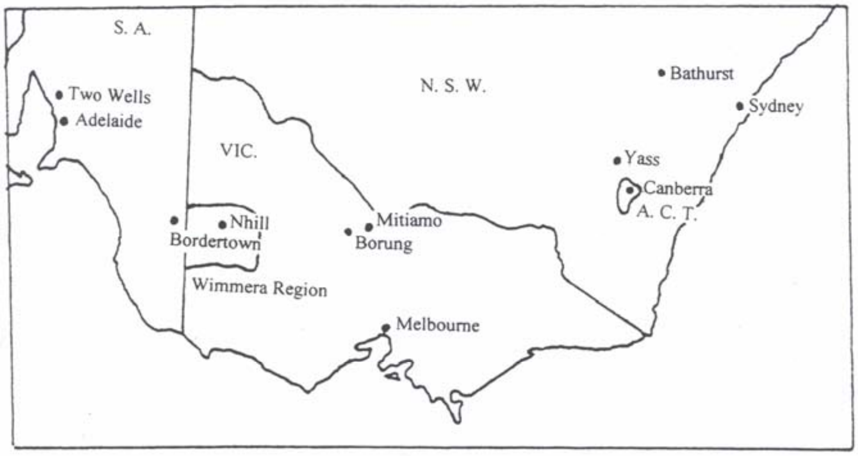
Illustrations

Parthenogenetic Nhill Morph of the Pale Sun-moth, *Synemon selene*.

Golden Sun-moth, *Synemon plana* (female).

Habitat of *Synemon selene* & *S. plana*, with a plant of *Austrodanthonia setacea* in the foreground.

Locality map



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