ARCHIVAL RECORD

REFERENCE No. 31

Hnatiuk, S 2008d
golden sun moth Newsletter no. 4
Friends of Grasslands
16 December 2008
Canberra

GSM NEWSLETTER no. 4

16 December 2008

A REMINDER THAT THE DEADLINE FOR GETTING YOUR RECORD SHEETS AND PUPAL CASES TO ANETT IS THE FIRST WEEK OF JANUARY.
(The deadline has slipped from the original one of 31 December as Anett will be away then.)

There are four options for handing in your records and samples:

1. **Deliver them to Anett at Room 51, Level C, Building 3 at UC – contact her to confirm time and place for delivery before dropping them off. See campus map on page 3 of this newsletter for the location of Building 3.**

2. **Let Anett know that you would like her to pick them up from you. Those of you who have already been in touch to request a pick up should contact Anett to arrange this.**

3. **If you have only record sheets, mail them to her.**

4. **If you can't get your records and pupal cases to her by the first week in January because she is away, contact Sarah Hnatiuk on hnatiuk1@cyberone.com.au, 6251 2228 or 0424 263 565 for alternative arrangements.**

Anett's contact details are:
(Please note she will not be at UC from 20 December to 3 January.)

Institute for Applied Ecology, University of Canberra, ACT 2601
Phone 6201 2937 or 0401 233 801
Email Anett.Richter@canberra.edu.au

Thanks to those of you who have already indicated their preferences for how they will get their records to Anett.

WE WOULD LIKE SOME FEEDBACK FROM YOU ABOUT YOUR EXPERIENCES WITH SUN MOTH COUNTING.

Please find attached to this newsletter a questionnaire covering different aspects of the sun moth project. It is also attached to this email as a stand alone document. If you could find time to fill it in, it would greatly help us improve and refine the procedures we have been trialling this season. Please return your questionnaire to Sarah at hnatiuk1@cyberone.com.au.

And if you have any funny or interesting sun moth counting stories, please share them with us.

SOME COMMENTS ABOUT SUN MOTH COUNTING

Many people have said when commenting on the progress they are making with their counts, that they **would appreciate better weather** on days when they are available to go out and count. However, despite the unfavourable conditions, **most people have completed two moth and pupal case counts**. With only two more to do, the counts should be finished by the end of the year, though it may take longer to get all the vegetation surveys done. **While quite a number of moths were seen at ACT sites in the warm weather in early November, fewer seem to be flying now**.

Several people report having seen **no moths or pupal cases** and are not hopeful of seeing any. The sites that they are monitoring include Umbagong Park near Kippax, Kaleen horse paddocks, the Pinnacle in Hawker, and Campbell near CSIRO's headquarters.

The horses in the horse paddock present some interesting challenges – there is one particularly curious Shetland pony that chews on the bamboo pegs and picks up and chews the neatly laid out stakes marking the metre square plots AND he won't go away. Having been given a whack on his backside to encourage his departure, he stuck even more tenaciously to the action.

Ian Clark writes about Gundaroo Common: *What I have noted **is the lack of moths compared with last season**. Very few are been flushed out as I walk from plot to plot and most are males. There have been correspondingly few pupal cases not only in the plots but in a general search to try to find some. This is in great contrast to the dozens that I found as road kill in previous years. I am, however, able to announce that the mossies are the worst for years.*

There is also some good news. Michael Mulvaney has seen quite a number of moths over a wide area as he roamed through grassy places from the Yarralumla Woolshed to the golf course, north and south of the Cotter Road in the Dudley and Guilfoyle Street areas, and east of Novar Street, south of Alexandrina Drive.

A REMINDER ABOUT THE PHOTO COMPETITION. Please send Anett your photos of moths, people, plants, animals, and anything else that caught your attention while sun moth counting.

PAST NEWSLETTERS ARE NOW ONLINE at http://aerg.canberra.edu.au/teams/osborne/moth-count/?page_id=28.

SUN MOTH MONITORING WRAP UP. We are planning a gathering in the early part of next year for moth counters and other interested people. We would like to let you know some of the preliminary results from analysing the data, including the feedback you provide us with about the project; discuss ways of improving how we do things; and above all thank you for your participation.

Arscott House
Aikman Drive
New Ressies (I-N)
Old Ressies (A-H)
International House
College House
21
University Village
Pantowora Street
Ginninderra Drive
to Dickson
Allawoona Street
University Drive Nth
University Drive Sth
Cooinda Street
Bimbimbie
Bimbimbie Street
Childhood Centre
Kirinari Street
UC Innovation Centre
Haydon Drive
to City
College Street
to Belconnen Town Centre
N
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B
1
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15
16
17
18
19
20
22
23
Parking
Sports fields
Bus stops
The Hub

Feedback Form

1. Personal information

1.1 Name ______________________________ **1.2 Sex** ☐ male ☐ female

1.3 Age ☐ < 30 ☐ 30-45 ☐ 46-60 ☐ > 60 **1.4 Profession**_______________

1.5 Are you a member of … ?

☐ Friends of Grasslands
☐ Governmental agency
☐ University
☐ Other community group: ____________________
☐ No membership

1.6 How did you find out about the Sun Moth Count program?

☐ Friends of Grasslands Newsletter
☐ Internet
☐ Personal communication
☐ Public events (e.g. Presentation)
☐ Others____________________

2. Workshop

2.1 Did you attend a Sun Moth Count workshop?

☐ 01.11.2008 ☐ 05.11.2008 ☐ 08.11.2008 ☐ No, I didn't.

2.2 If yes, please indicate your opinions about the workshop:

	☹☹	☹	😐	☺	☺☺
1. I obtained information about identification of the moths and pupal cases.					
2. I learned something about the Golden Sun Moth biology and ecology and native grasslands in the ACT.					
3. I gained an understanding about the importance of this monitoring program.					
4. I gained information about the proposed methods within the GSM monitoring.					
5. I found the information presented interesting, relevant & understandable.					

☹☹ = Strongly Disagree ☹ = Disagree 😐 = Neutral ☺ = Agree ☺☺ = Strongly Agree

2.3 How might the workshop be improved? Let us know.

2.4 Did you attend a Sun Moth Count training session?

☐ 01.11.2008 ☐ 08.11.2008 ☐ 15.11.2008 ☐ 16.11.2008 ☐ No, I didn't.

2.5 If yes, please indicate your opinions about the training session:

	☹☹	☹	😐	☺	☺☺
1. The instructions about the monitoring techniques were clear and understandable.					
2. After the training session I felt confident to conduct the moth counts.					
3. After the training session I felt confident to conduct the pupal case counts.					
4. After the training session I felt confident to conduct the vegetation survey.					

2.6 How might the training sessions be improved? Let us know.

3. Fieldwork

3.1 Please indicate your experience during the field work:

	☹☹	☹	😐	☺	☺☺
1. The prepared map was helpful.					
2. I set up the permanent plots without problems.					
3. At each visit I found the plots again easily.					
4. It was simple to count the moths.					
5. I found pupal cases without difficulty.					
6. The time I needed for establishing the plots was acceptable.					
7. The time I needed to determine the vegetation was acceptable.					
8. The time I needed to count the moths (each visit) was acceptable.					

3.2 Comments or suggestions that would improve the field procedure:

3.3 Please indicate your experience with the recording sheets:

	☹☹	☹	😐	☺	☺☺
1. Recording sheets for pupal case counts and flying adults were easy to follow.					
2. Recording sheet for vegetation survey was easy to follow.					
3. Recording sheet for habitat quality assessment was easy to follow.					

3.4 Comments or suggestions that would improve the recording sheets:

3.5 Please indicate your experience with the monitoring kit:

	☹☹	☹	😐	☺	☺☺
1. It was helpful having the monitoring kit.					
2. Bamboo sticks worked well in order to permanently mark the plots.					
3. The provided recording sheets were applicable in the field.					

3.6 Comments or suggestions that would improve the monitoring kit:

4. Website & Online Newsletter

4.1 Please indicate your experiences with the website/online Newsletter:

	☹☹	☹	😐	☺	☺☺
1. The webpage was easy to find on the internet.					
2. The webpage is simple to use.					
3. The information on the webpage is helpful.					
4. The webpage adequately represents the project.					
5. The design of the webpage is appropriate.					
6. I have visited the website often.					
7. I always felt informed and updated about the project progress because I received and read the newsletters circulated via email.					
8. I have regularly access to internet.					

4.2 Comments or suggestions that would improve the website and online communication through Newsletter:

5. Further involvements

5.1 Please indicate your interest in the future:

	☹☹	☹	😐	☺	☺☺
1. I would like to be involved in the GSM project in the future.					
2. I feel that I have significantly contributed to the conservation of an endangered insect species and natural temperate grassland conservation.					
3. I really enjoyed the Golden Sun Moth monitoring.					
4. In kind help was accessible and available throughout the project.					

5.2 General comments or suggestions for further project improvements:

5.3 I have had experience with conservation and protection of endangered species in the past.

☐ Yes

☐ No

5.4 It was the first time I had heard about the endangered Golden Sun Moth.

☐ Yes

☐ No

5.5 It was my first time volunteering in environmental conservation.

☐ Yes

☐ No

5.6 Would you like to be notified about the Sun Moth Count program in the future?

☐ Yes

☐ No

We highly appreciated your contribution to this study. Thank you very much. Please send form to:

Anett.Richter@canberra.edu.au or ring me (0401233801) to pick it up.

ARCHIVAL RECORD

REFERENCE No. 32

Hnatiuk, S 2009a
golden sun moth Newsletter no. 5
Friends of Grasslands
13 January 2009
Canberra

GSM NEWSLETTER no. 5

13 January 2009

THE FINAL EVENT FOR THIS SEASON'S SUN MOTH COUNT IS A WRAP-UP of the project**,** to be held on Saturday, 14 February at CSIRO's Discovery Centre, Clunies Ross Street, Black Mountain, from 2pm – 4.45pm.

We would like to:

- let you know some of the preliminary results from analysing the data, including the feedback you have provided us with about the project;
- discuss with you ways of improving how we do things; and
- above all thank you for your participation.

Please invite friends, family and anyone else who you think might be interested. Afternoon tea will be provided. For catering purposes, please let Sarah know if you are coming: phone 6251 2228 or email sarah.hnatiuk@fog.org.au.

HAVE YOU GIVEN YOUR RECORD SHEETS AND PUPAL CASES TO ANETT?

If not, please get in touch with her NOW to arrange when to bring them to her or for her to pick them up from you

DO YOU NEED HELP WITH YOUR VEGETATION SURVEY?

Contact Anett by phone 6201 2937 or 0401 233 801 or email Anett.Richter@canberra.edu.au

ALSO A REMINDER TO FILL IN THE FEEDBACK FORM if you haven 't already done so and return it to sarah.hnatiuk@fog.org.au. It is attached to the email sent with this newsletter.

AND PLEASE SEND YOUR PHOTOS FOR THE PHOTO COMPETITION TO ANETT: your photos of moths, people, plants, animals, and anything else that caught your attention while sun moth counting. The award for the best photo, a copy of *Butterflies of Australia*, will be presented at the Wrap Up afternoon.

INFORMATION ABOUT THE SUN MOTH COUNT PROJECT is available:

- at the website: http://aerg.canberra.edu.au/teams/osborne/moth-count/; and
- in a poster prepared by Anett for display at the current Snakes Alive exhibition at the Botanic Gardens, not included with this newsletter as it is large (1,213KB). Let Sarah know if you would like it and she will forward it to you (sarah.hnatiuk@fog.org.au)

Photos by Anett Richter
Newsletter compiled by S. Hnatiuk

ARCHIVAL RECORD
REFERENCE No. 33

Hnatiuk, S 2009b
golden sun moth Newsletter no. 6
Friends of Grasslands
23 February 2009
Canberra

GSM NEWSLETTER no. 6

23 February 2009

CASH FOR YOU! Friends of Grasslands have received a grant from the Federal Government's Volunteer Grants Program that helps volunteers with some of the expenses incurred when volunteering. We are therefore able to provide some money to those of you who have not yet received any to cover some of the costs of traveling by car (or motor bike) to and from Golden Sun Moth events. If you would like to make a claim, please let me know (hnatiuk1@cyberone.com.au). For payment to be made to you, I need the details that will enable us to make an electronic transfer to your account (account name, BSB and account number) or postal address to send you a cheque. We'd prefer to pay you by electronic transfer.

GOLDEN SUN MOTH PROJECT FOR CLEAN UP AUSTRALIA DAY

We have registered with the Clean Up Australia Day campaign to clean up the rubbish that has blown into a sun moth grassland from surrounding building sites in Franklin and Harrison.

When: Sunday, 1 March from 10am – 12 noon

Where Grassland in the south east corner of Franklin . Access from Flemington Road (NOT Sandford Road as indicated in the Clean Up Australia Day's web site). Look on the west side of the road between Lysaght Street and Nullabor Avenue for Anett's blue Holden station wagon with balloons attached.

What to bring and wear: Gardening gloves, long pants, sturdy shoes, hat and something to drink – FOG will provide some goodies for morning tea at 10am.

Check before you come to the clean up: Log on to our page on Clean Up Australia Day's website at http://events.cleanup.org.au/?fog to check on any change to the arrangements. You can get into the page with user name fog, password FOG. **Or** contact Anett Richter on 0401 233 801.

COPIES OF GRASSLAND FLORA AVAILABLE FOR MOTH COUNTERS. Mary Appleby and Rod Pietsch have offered a copy of *Grassland Flora: A Field Guide for the Southern Tablelands* to each sun moth counter. The flora is a great book for helping you to become familiar with the local flora. If you would like one, please let me know (hnatiuk1@cyberone.com.au) and give me your postal address. And very many thanks to Mary, Rod and the Golden Sun Moth research project of the NSW Department of Environment and Climate Change for their support.

WRAP-UP WORKSHOP, 14 FEBRUARY 2009

About 30 people attended the workshop at CSIRO's Discovery Centre. Anett provided an overview of the preliminary results from her analysis of the data we collected. More details are in her power point presentation that is being sent out with the same email as this newsletter.

Anett's presentation was followed by a discussion among the people present about their experiences with the project and their suggestions for improving our approach in future monitoring. Some of the issues raised included:

- Why are we collecting the data? How will it be used?
- The length of time required to carry out the vegetation survey and the detail of the data to be collected. Many suggestions were made for improving the vegetation survey. For example, would photos of plots be useful? Could details of fewer plant species be recorded?
- The timing of data collection. Should there be a minimum time between moth and pupal case counts? Is it alright to spread the vegetation survey out over as long as six weeks?
- How were sites selected for monitoring?
- Are 12 plots enough to assess the presence of moths?

Anett addressed some of these points in her presentation when she outlined the Coordinating Group's thoughts on future monitoring. She also noted that the ACT Government is most interested in the outcome of our project and is seeking funding so that it can be continued in future.

We also heard from Ted Edwards about the discovery in the ACT this summer of a very small population of a sun moth species new to this area. *Synemon collecta* is known from sites in Queensland, NSW and Victoria and, unlike the Golden Sun Moth, is not an endangered species. He described its appearance and reassured us that we are unlikely to mix it up with the Golden Sun Moth when monitoring as it is extremely rare in the ACT.

Compiled by S. Hnatiuk
Photos by A. Richter

ARCHIVAL RECORD

REFERENCE No. 34

Hnatiuk, S 2009c
golden sun moth Newsletter no. 7
Friends of Grasslands
10 November 2009
Canberra

GSM NEWSLETTER no. 7

10 November 2009

UPDATE ON GOLDEN SUN MOTH MONITORING IN THE ACT AND REGION. As some of you have been asking about what is happening with Golden Sun Moth monitoring, we (the GSM Coordinating Group of Anett Richter, Geoff Robertson, Will Osborne and Sarah Hnatiuk) thought we would provide you with this brief update.

REPORT ON LAST SUMMER'S MONITORING. A 53-page report on the results of the monitoring is in the final stages of production for WWF which funded the project. The report covers:

- The recruitment and training of volunteers, and an assessment, including a self assessment, of their efforts,
- The methods used in the survey,
- What was learnt about the ecology of the moth,
- Recommendations for further monitoring, and
- Recommendations for improved management of sites where the moth occurs hat will assist in the moth's conservation.

We will send a pdf copy of the report to all the volunteers who contributed to the survey. We also plan to produce hard copies. **Please let Sarah (hnatiuk1@cyberone.com.au) know if you would like a hard copy as soon as possible and no later than Friday, 20 November, and provide her with your postal address.**

FUTURE GOLDEN SUN MOTH MONITORING
Will GSM monitoring continue? The results of last season's monitoring produced valuable results. The ACT Government in particular sees them as providing information that is useful in advancing understanding of the moth's distribution, biology and management. It would welcome continued GSM monitoring and is interested in being involved in planning with Friends of Grasslands for this to happen. In addition, many of last season's volunteers have indicated that they would like to monitor again.
New procedures. You may remember from Anett's presentation at the 'Wrap Up' session held last February that our experience with the monitoring procedures used had convinced us that they should be modified, including making part of the process simpler. We have started discussing the details of the new procedures with relevant experts but progress has been hampered by the absence overseas of a number of the more significant people we would like to consult. As a result we are sadly not ready to trial the new procedures for the start of this season's GSM flying. However …

We would be delighted if you would let us know of any sightings of GSM (and failures to sight GSM) you make this summer. Send any information to Sarah (hnatiuk1@cyberone.com.au; 6251 2228; 0424 263 565; or 13 Ellis Place, Cook, ACT 2614). Any information you accumulate would be welcome, either from the same sites as you visited last year or from grasslands, or parts of large grasslands, you have not visited before. In contrast to what you did last year, we would encourage you to wander far and wide.

If you feel particularly energetic and enthusiastic, you might make four visits over the next four weeks and record:

- date;
- start and finish times of visit;
- location - a map/Google image showing area covered would be very helpful in the case of large grasslands;
- numbers of moths seen in 20 minutes walking (0, 1-5, 6-20, 21-50, 51-100, >100);
- if moths are not evenly distributed across the site, where the greatest concentrations are;
- comments on vegetation - if you are able (is wallaby grass or Chilean needle grass present? Is the area grazed, mowed? Are there intertussock spaces);
- any threats to GSM; and
- any other comments you would like to make.

Any information will be gratefully received.

MOTHS ARE ALREADY FLYING!! Will Osborne reports that he saw six GSM flying today in Latham.

Compiled by S. Hnatiuk
Photos by A. Richter

ARCHIVAL RECORD

REFERENCE No. 35

Hnatiuk, S 2009d
golden sun moth Newsletter no. 8
Friends of Grasslands
27 November 2009
Canberra

GSM NEWSLETTER no. 8

27 November 2009

HAVE YOU SEEN ANY GOLDEN SUN MOTHS FLYING?

From all reports, it is a bumper year for Golden Sun Moths and a chance to observe how widespread and numerous they are.

PLEASE KEEP YOUR OBSERVATIONS COMING IN TO ME, HOWEVER SMALL THEY MAY SEEM.

Sarah Hnatiuk (**hnatiuk1@cyberone.com.au**,
6251 2228, or 13 Ellis Place, Cook, ACT 2614

Here are some of the reports we have received from the most recent back to the first ones from 9 November. **You can see how numbers are building!**

25/11/09 from Julian Robinson. 'There are 'lots' at the park bounded by Ebden, Herbert, Duffy and Hassall Sts in Ainslie. Also many in small patches, mostly the unmown footpaths, in Cowper St between Limestone and Bonney/Foveaux St. … While I was on the footpath of … Cowper I saw two moths get skittled by cars, and one eaten by a Yellow-rumped Thornbill.'

20 November 2009 from Murray Evans. 'I was out at the airport yesterday with Alison Rowell doing sun moth counts and there were thousands at one area (large grassland SE of runways). Alison believes this is the largest population in the ACT. We frequently counted in excess of 200 moths per 100 m walked ... Lots of females, mating and females scurrying through the grass with trains of 3 or 4 males following. And yes, it was hot. The moths were flying early - peak was about 10.30 - 11.30, with noticeably less moths flying by about 12.30. This is a bumper year and new sightings are turning up in roundabouts, median strips and leases over much of the central/northern ACT.'

19 November 2009 from Will Osborne. **'**I was at Woden property (Jerrabomberra West) today … and did some sun moth counts... Temperature was 38 o C there were sun moths … over the entire paddock as I stayed on for two hours and did a comparison of walking around slowly with stopping to do ten half minute circle counts … walking is a great way to see how widely distributed the moths are and would provide information on area of occupation at a site. Lots of pupal cases sticking out of the ground as well.'

‘I have also continued my weekly counts at Dudley St and York Park and there are very large numbers flying there now.’

9 November from Alison Rowell. ‘There were ‘a few flying at Dudley Street ... Also a female on the median strip on the eastern extension of Sydney Avenue in Barton.’
And from Will Osborne: ‘6 moths flying in Latham’.

SO WHAT IS HAPPENING IN YOUR NECK OF THE WOODS?

HOW ABOUT RETURNING TO THE SITE YOU MONITORED LAST YEAR AND SEE WHAT IS HAPPENING THERE.

OR GO SOMEWHERE NEW.

THERE MAY EVEN BE MOTHS WHERE NONE WHERE FOUND BEFORE.

Compiled by S. Hnatiuk
Photos by A. Richter

ARCHIVAL RECORD

REFERENCE No. 36

Mulvaney, M 2012
Golden Sun Moth (golden sun moth) ACT
Strategic Conservation Management Plan
Prepared for the Flora and Fauna Committee
Conservation Planning and Research
ACT Government, Canberra

Will Osborne

ACT Government

Golden Sun Moth (GSM)
ACT Strategic Conservation Management Plan

Prepared for:

the ACT Flora and Fauna Committee

Author:

Dr Michael Mulvaney
(Senior Planner – Conservation Planning and Research)

2012/01
November 2012

Conservation Planning and Research | Policy Division | Environment and Sustainable Development Directorate

Golden Sun Moth (GSM) ACT Strategic Conservation Management Plan

Prepared for the Flora and Fauna Committee

by Dr Michael Mulvaney (Senior Planner – Conservation Planning and Research)

November 2012

A.Richter

R. Zollinger

Female and male golden sun moth

Introduction

The golden sun moth (*Synemon plana)* is a medium-sized day-flying moth with green eyes, clubbed antennae and no functional mouthparts. They have a wingspan of about 3 - 3.5 cm and a tapered abdomen with males being slightly larger than females. The sexes can be distinguished by their wing colours with only the females having the characteristic golden hind wings (NSW Office of Environment and Heritage 2012).

At the time of European settlement the golden sun moth was widespread across south-eastern Australia and showed a close correlation with the distribution of native grasslands in which wallaby grasses (*Austrodanthonia spp.)* were at least a dominant species (O'Dwyer and Attiwilli 1999). Its distribution extended from Bathurst in NSW, through the Southern Tablelands and Central Victoria and into South Australia. It was once relatively continuous across its range but pasture improvement and land clearing has now greatly reduced and fragmented its distribution. Today less than one per cent of the estimated two million hectares of native temperate grasslands remains, and weeds have invaded much of these remnant grasslands (NSW Office of Environment and Heriatge 2012). The golden sun moth is now known from about 220 sites across Australia (100 in Victoria, 48 in NSW and 73 in the ACT - Brown and Tolsma 2010, Brown et al 2011, DSE 2010 and DEWHA 2009a). Most of the remaining sites are less than 5 hectares, with fewer than 20 moths observed in each area at a particular time. The total remaining habitat area is estimated to be about 15,000 hectares (mainly on the Victoria Volcanic Plains) (DSE 2011).

The golden sun moth is listed as *Critically Endangered* under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Victorian Government has proposed that, given that the known habitat area at the time of initial listing was about 1,000ha and this is now up to 15,000 ha, there may be grounds for the Commonwealth conservation status of the moth to be downgraded from critically endangered to endangered (DSE 2011).

On 15 April 1996 the moth was declared "Endangered" under the Australian Capital Territory *Nature Conservation Act 1980.* In accordance with the declaration, an Action Plan (No. 7) was produced in 1998. This Plan was updated in 2005 as part of the *ACT Lowland Native Grassland Strategy - Action Plan No 28.*

Since 2005 and particularly during the spring/early summers of 2010 and 2011 there has been considerable survey effort undertaken as part of planning, development and conservation management processes. ACT's native vegetation communities, including those of the grasslands, are currently, and for the first time, being mapped. The ACT Flora and Fauna Committee decided that revision of the grassland Action Plan should wait until the vegetation community mapping had been completed. However they also determined that in the interim a strategic conservation plan should be produced for the golden sun moth. The conservation plan should;

- incorporate all the latest distributional and ecological knowledge;
- enable development or conservation considerations of a particular site to be put in the context of the total ACT population and all other known sites; and
- provide strategic guidance as to how ACT's golden sun moth population may remain viable over the long term.

The first part of this plan collates current knowledge in relation to the known and potential distribution of golden sun moth across the ACT, the genetic relationships and connectivity between different populations and the threats the moth faces.

The second part of this plan examines this information, prioritises habitat sites and details strategic actions aimed at maintaining a long term presence of golden sun moth in the ACT.

Part 1 – The current situation of golden sun moth in the ACT

1. Known habitat

The current known extent of GSM habitat in the ACT was determined through consulting all survey reports undertaken for the moth, and unpublished data held by the Conservation Planning and Research Unit. The reports consulted are provided in the reference list. In 1996, GSM was known from 16 sites within the ACT with a total habitat area of around 700 hectares (Action Plan No 7). By 2005 GSM was known from 27 sites with a total habitat area of around 1150 hectares (Action Plan 28). Today GSM is known from 73 sites within the ACT with a total habitat area of around 1800 hectares (see Figure 1). This equates to about 12% of the known national habitat and about a third of the known sites (DSE 2011). Appendix 1 provides details on each of the habitat sites.

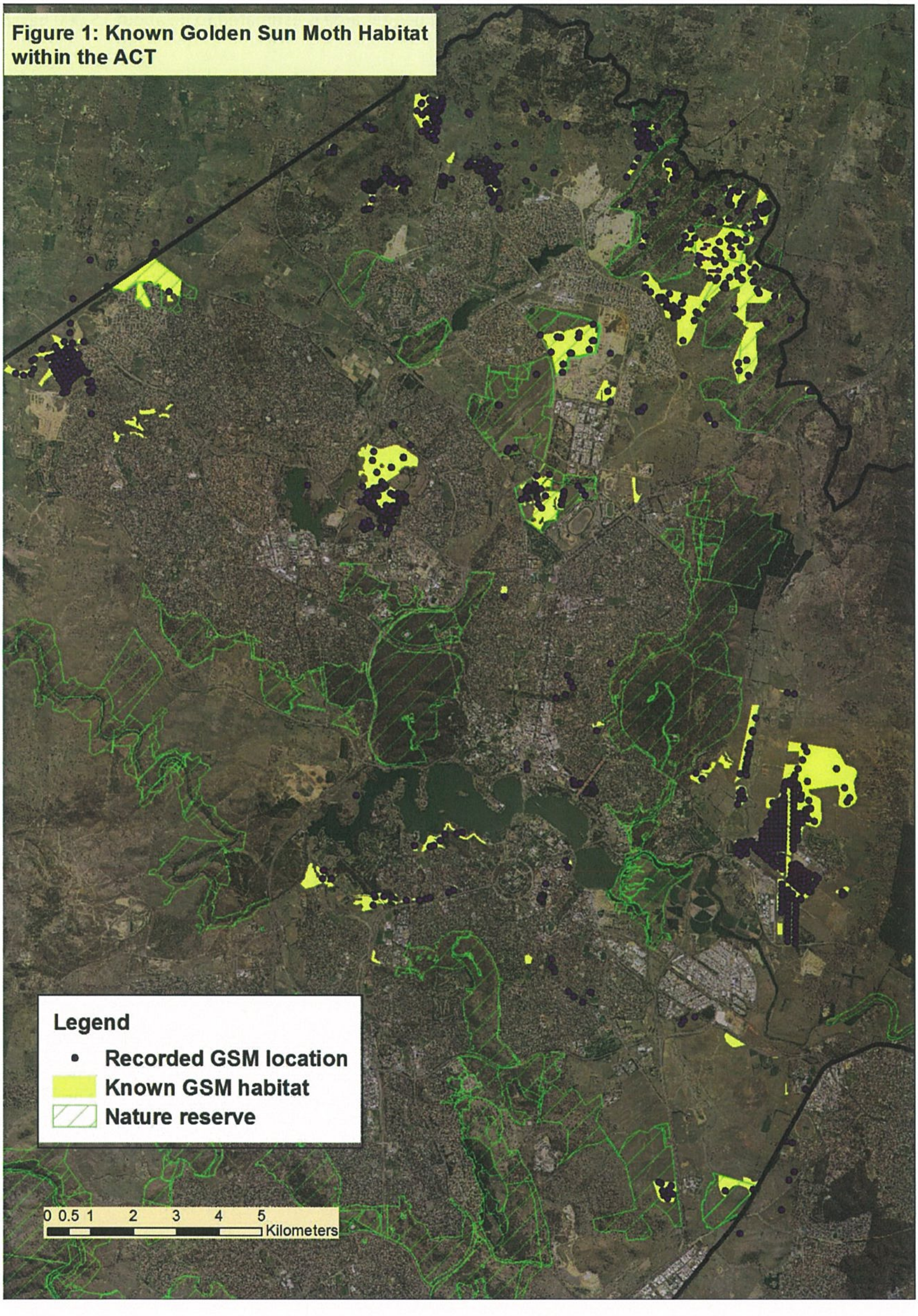
Figure 1: Known Golden Sun Moth Habitat within the ACT
Legend
Recorded GSM location
Known GSM habitat
Nature reserve
0 0.5 1 2 3 4 5
Kilometers

It is estimated that there was about 20,000 hectares of natural temperate grassland in the ACT prior to European settlement (Benson and Wyse Jackson 1994). Most of this grassland, together with neighbouring open woodland areas would probably have once been GSM habitat. Thus about 5-10% of the original habitat remains. There are around 2100 ha of natural temperate grassland remaining in the ACT, though not all is known to be golden sun moth habitat.

Most of the recently recognised habitat occurs within Gungahlin. Four former sites (Forde North, Harrison, the Sri Lankan Embassy site and Ngunawall) have recently been cleared, while Clarke (1999) presumes that the moth has become locally extinct at three sites (CSIRO Headquarters- Campbell, Yarramundi and Lake Ginninderra).

Of the 73 remaining sites, only three provide a habitat area of greater than 100 ha. A further six have a habitat area of between 50 – 100 hectares. Fifty-one of the sites are less than 5 hectares, with nineteen of these being less than one hectare. The largest extant site is Goorooyarroo- Throsby – Mulligans Flat which contains 440 ha of continuous habitat, the smallest is a 0.055 ha nature strip area on Cowper Street, Ainslie. The mean area of the 73 sites is 22.5 ha while the median size is 2.8 ha.

In Action Plans 7 and 28, GSM sites were identified according to land management. For example, the contiguous Lawson habitat was divided into two sites the Commonwealth owned Belconnen Naval Transmission Station and the Territory owned South Lawson. The 73 sites identified in this paper are all areas of contiguous habitat. In identifying a particular habitat area the approach of DEWHA (2009a) and DSE (2011) was adopted. That is, because of the moth's poor flying ability, populations separated by distances of greater than 200 metres can be considered effectively isolated. Sites separated by major barriers such as housing or roads wider than two lanes, were also considered isolated. Some of the identified sites, such as some of those within the Jerrabomberra valley are connected by what appears to be suitable grassland habitat, but to date no moths have been observed between a few scattered observation points and the distances between areas in which moths have been sighted is beyond 200m. Further survey may fill in gaps and expand the extent of occupied habitat.

GSM has been recorded at many small sites, which appear to have been isolated for at least a number of decades. Though demonstrating an ability to survive over time on very small sites, populations at such sites are prone to extinction from stochastic events (Clarke and Dear 1998). The poor mobility of the species means that it would be unlikely to naturally recolonise following extinction at a particular site (Clarke and Whyte 2002). Although in the ACT there is no correlation between size of habitat and the maximum number of moths recorded in any one season (see Figure 2), larger habitat areas are likely to contain greater variation in suitable habitat and more viable populations. DEWHA (2009b) consider that sites of less than 0.25ha are unlikely to contribute to the overall ecological health of the species. On 16 April 2010 the Commonwealth Minister approved prescriptions for GSM, which if complied with allow clearing of GSM habitat in the Greater Melbourne area. The prescriptions require retention of any GSM habitat in excess of 100ha (DSE 2011). In ranking the conservation importance of NSW sites, Clarke and Dear (1998) utilised the size of the site and the extent and density of *Danthonia* coverage.

Retaining the larger habitat areas in the ACT is a desired conservation outcome. There are nine sites with a habitat area of greater than 50 ha. A list of sites together with their size and other information is provided at Appendix 1.

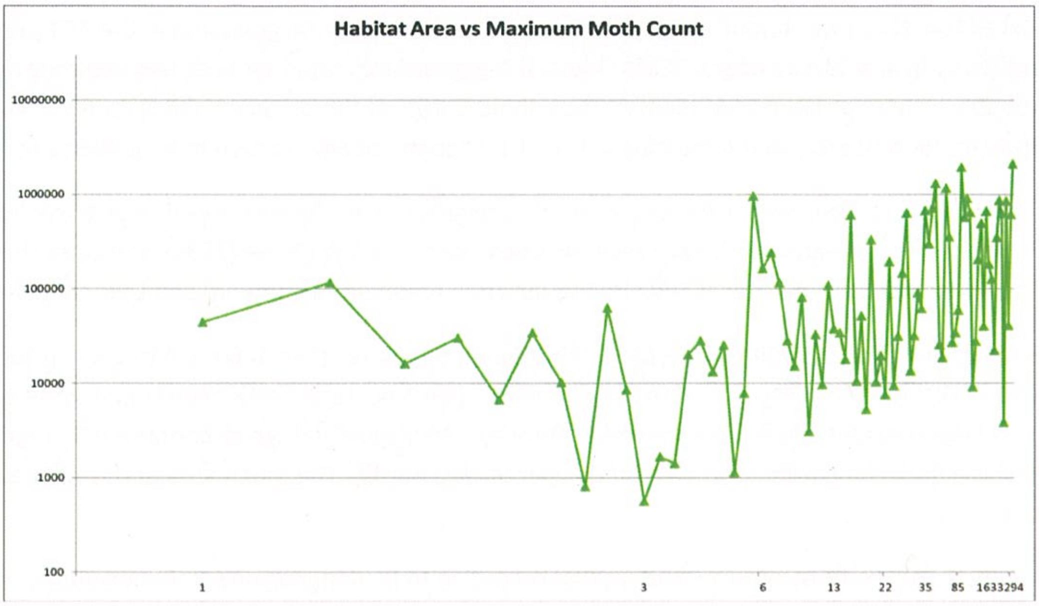

Figure 2: Habitat area (m sq) against maximum number of moths counted at site.

2. Numbers of moths at individual sites

Estimating the population size at individual habitat sites is problematic. Individual moths live only for a few days while populations emerge over an extended period of six to eight weeks. The rate and timing of emergence differs from day to day and from year to year and is highly influenced by climatic conditions. Within a flight season there is fairly continuous adult emergence and rapid turnover of individuals (Gibson and New 2006). The rapid individual turnover makes capture and release studies difficult and only an emergence cohort is sampled at any particular time (Cook and Edwards 1994). In addition only male moths are readily observed. Direct counts on any single occasion, however accurate, can at best reflect one emergence cohort of males, and most individuals in the population will not be observed on any single date. It is unknown how long moth larvae may exist, 2-3 years has been suggested, so that it is possible that the total number of moths observed in a flight season may simply be one annual cohort of a larger resident population (Gibson and New 2006).

The difficulties presented by the considerable variation in moth activity within and between seasons, are further complicated by moth counting across the ACT locations not being conducted in a uniform manner. The numbers estimated at a site may be based on comprehensive and repeated transects counts, derived from a one-off meander or circle counts from points, while those from the well studied York Park reflect figures derived from capture and release studies. Apart from York Park, no other areas have been surveyed on every suitable emergence day during a flight season. Most of the ACT locations only have moth count records from one or two years. Of these some yearly records reflect one count while others are derived from multiple counts. Since 2009, surveys conducted for or seeking Commonwealth and/or ACT Government approval have had to meet survey guidelines, which specify the conditions under which survey must occur and that survey must occur over at least four suitable days at approximately weekly interval (DEWHA 2009b).

Pupal cases, which are half emerged from the soil, can last for at least three weeks and as they are not subject to the vagaries of weather may provide a better means of gauging population density. In 2008, 50 community volunteers collected 650 pupal cases from 11 grassland areas. There was only a 2% rate of mis-identification of pupal cases, so it is likely that counting pupal cases will become a valuable tool for monitoring local populations. Comparative data is scarce at present, while the relationship between the total population of adults that have emerged by a given date and the accumulated total number of pupal cases that can be found is not known and requires further research. Pupal cases are also likely to be difficult to time in areas of high grass cover (Richter et al 2012).

Edwards (1994) emphasises great caution in the interpretation of moth counts. Nevertheless useful comparisons can be made between those habitats at which relatively large numbers have been observed and those where very few moths have been seen. The greater the number of counts and the more seasons over which counts have occurred, the greater the reliance that can be put on the figures representing a true reflection of the relative population size present at a habitat location.

Richter et al (2009) categorised sites according to the total number of moths recorded on the highest of 2 – 4 days of counting across 28 sites surveyed in 2008. Categories employed were:

Table 1: Site Moth Population Comparison (after Richter et al 2009).

Size of Maximum Count	Population size description
>150	Very large
51 – 150	Large
21 - 50	Medium
<21	Small

Hogg (2010c) proposed a classification for making comparisons between counts derived from standing rotational counts, whole site fixed time counts, transect counts and meandering or structured traverses. Hogg proposed four levels of GSM activity. A site has zero activity if no flying males are detected during a minimum of four reconnaissance surveys under suitable conditions.

Table 2: Comparison of Activity Level (Hogg 2010c)

Activity Level	Standing rotational count (30 second rotation)	Standing fixed whole site counts (1 minute)	Walked Transects	Meandering or Structured traverses
High	10 or more per rotation	20 or more per minute	40 or more per 100m of transect	20 or more per minute
Moderate	3-5 per rotation	5-10 per minute	10 to 20 per 100m of transect	5 to 10 per minute
Low	1 or less per rotation	2 or less per minute	4 or less per 100 m of transect	2 or less per minute

Moth survey data for the ACT has been collated, and sites compared according to the Richter et al (2009) method of utilising maximum day count. However whereas Richter et al. were making comparisons within the 2008 season, the ' ACT records span many seasons. Where data exists the activity level of each site as classified under the Hogg (2010c) system is also noted (see Appendix 1). Maximum day count was utilised as the variability between years makes mean values of differing years very hard to interpret, most sites only had a few counts and a maximum count is more likely to reflect a count undertaken under good emergence conditions. Both male and female observations were included in counts, but they are nearly all male. Based on an analysis of pupal cases, male moths are twice as numerous as females. Thus counts at best reflect two thirds of moths active on a particular day (Richter 2012.

Sites with three or more year's data in the same category are considered to have reliable population data. Sites with two year's data in the same category were considered neither reliable or unreliable, while sites with only one year's data are considered to have unreliable data. Of the 73 ACT sites, reliable data has only been collected from nine. West Macgregor –Jaramlee, York Park, north and south Lawson and the South – East Majura Valley (Canberra Airport) are the only sites where large or very large populations have been regularly recorded. Small populations have been consistently recorded at Umbagong Park and Gungaderra Nature Reserve.

The relative size of maximum moth counts for all sites is shown in Figure 3. Across the 73 sites, there are 11 sites that support very large populations. Maximum daily population counts for a site range from 1 moth to 5347. The mean number is 155 and the median count is 13. Forty-two sites (58%) have only had small populations observed on them, 13 (18%) of sites have had a moderate moth count and seven (10%) have had a large number of moths on at least one occasion. The total of maximum counts from all sites in the ACT is 14, 818. Richter et. al (2009) found a 60:40 ratio of male to female moths. Thus a rough estimate of the total ACT population is around 25,000 moths.

The majority of the ACT moths appear to occur at a few sites. Eighty-four percent of the total maximum moth count is recorded from less than 10% of the total number of sites. A list of sites together with the maximum moth count at each is provided at Appendix 1.

3. Habitat Connections

As indicated in Figure 3, there are a few grassland/open woodland areas in which no GSM has been recorded but which lie between other known locations. Given the survey difficulties and the lack of repeatability at most sites, it is possible that moths do in fact utilise this intervening area, or potentially these areas could be restored to become suitable GSM habitat.

Key potential habitat restoration or linkage areas include:

- The grassland area between Dunlop and West Macgregor-Jamalee
- The grasslands that link Cookanella, Harman and East Jerrabomberra sites
- Apparently unoccupied grassland on Crace nature reserve; and
- Potentially, the rough on the Royal Canberra Golf Club extension area, that connects the Curtin- Dudley Street population to that of Lady Denman Drive and the Yarralumla Woolshed;.

There are also tenuous connections, largely along open space reserves, between many of the smaller habitat areas, which could also provide a future habitat link. Recent development at Casey and proposed development at Moncrieff, Jacka and Taylor has or will sever potential links between the large Gungahlin populations.

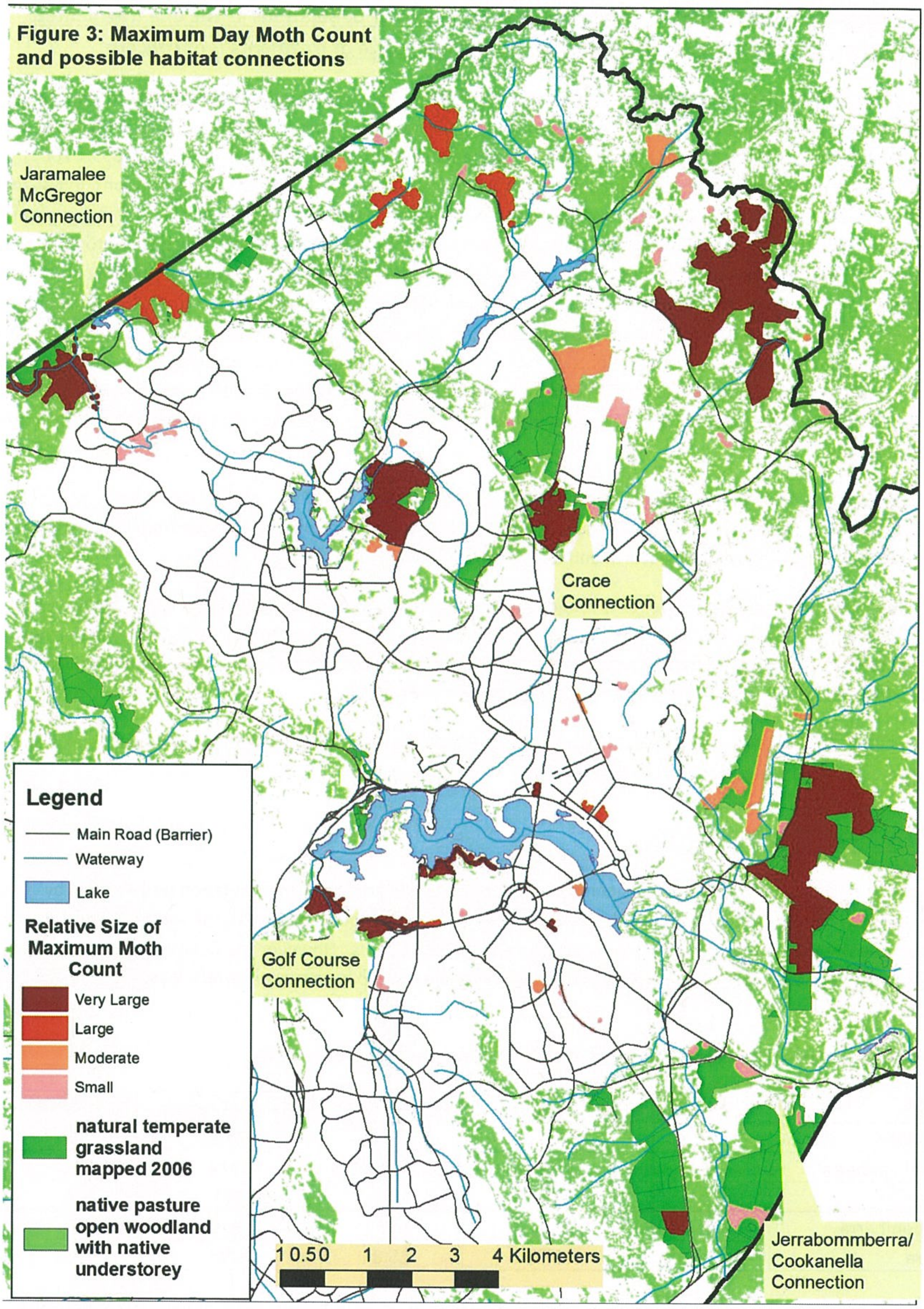
Figure 3: Maximum Day Moth Count and possible habitat connections
Jaramalee McGregor Connection
Crace Connection
Golf Course Connection
Jerrabommberra/ Cookanella Connection
Legend
Main Road (Barrier)
Waterway
Lake
Relative Size of Maximum Moth Count
Very Large
Large
Moderate
Small
natural temperate grassland mapped 2006
native pasture open woodland with native understorey
1 0.5 0 1 2 3 4 Kilometers

4. Genetic studies suggest that it is appropriate to treat all ACT populations as the one fragmented population – but that any further reduction in population size of fragments is of concern.

Genetic diversity is crucial to the short term viability of individuals and populations and to longer term evolutionary potential. Thus the conservation of genetic diversity (allelic richness) and variation (heterozygosity) within populations is a key conservation goal (Clark and O'Dwyer 1998). Clark and O'Dwyer (1998 + 2000) and Clarke (1999 + 2001) surveyed the genetic diversity and variation amongst and between ACT, NSW and Victorian populations. Initial analysis of the genetic diversity of moths from 20 sites across the moth's range revealed five genetically distinct groups of GSM populations which correspond closely with geographic location. The Victorian populations were found to be the most distinctive. ACT populations fell into three distinct clusters, one in the northern ACT/NSW border region, one north of Lake Burley Griffin and the other south of the Lake. In addition ACT populations were found to contain less genetic diversity on average than either Victorian or NSW populations. This low level of variability was postulated as resulting from recent fragmentation and population bottlenecks (drastic reduction in effective population size), with insufficient time for recovery of variability. The loss of genetic diversity in the ACT populations is seen as being caused by the loss of rare alleles distributed across small populations being lost through chance sampling event during mating (Clark and O'Dwyer 1998).

Subsequent analysis from 46 populations placed all ACT populations into one distinct population cluster and found that genetic distances between populations were low (Clarke 2001). Nevertheless the populations from the northern ACT/NSW border (Dunlop, Mulligans North and Ginninderra Rd -NSW) still clustered together.

Overall, the majority of genetic difference is found within rather than among ACT populations. Genetically all ACT moths can be regarded as belonging to the one population, with the possible exception of sites near the northern ACT/NSW border. The major genetic issue appears to be the tendency for loss of allelic diversity and relatively high level of non-random mating due to relatively low population sizes (Clarke 1999).

The key actions to conserve the genetic diversity of ACT's GSM population is to maintain or enhance the existing population sizes and maintain or restore habitat links.

5. Distribution within ACT's Valleys

Gunghalin contains 45% of ACT's golden sun moth habitat but only 9% of the GSM population (as recorded by maximum moth counts). In terms of number of sites, habitat area and moths supported, the Jerrabomberra Valley appears to be the least important of the five valleys in which GSM occurs. However the Commonwealth land in Jerrabomberra is perhaps the last large high potential habitat area yet to be surveyed, which if surveyed may change the figures.

Table 3: Distribution of GSM sites, habitat and moth numbers amongst ACT's valleys

District	No of sites	Habitat area (ha)	%of habitat	Max no of moths	% of moths
Belconnen	9	355	19.7	3083	27
Central Canberra	25	110	6.1	1484	13
Gungahlin	32	812	45.0	991	9
Jerrabomberra	7	60	3.3	502	4
Majura	5	466	25.8	5444	47

Much of the habitat at Gungahlin is woodland and this may explain why the 812 hectares of habitat in Gungahlin, supports less moths than habitat elsewhere which generally consists of grasslands.

In Table 4 grassland habitat is identified as those sites which predominately occur within the area modelled to have supported grassland in 1750. Sites that just lie outside this modelled grassland area, were considered to be open woodland, while sites containing woodland or secondary grassland away from the modelled grassland area where considered to be woodland sites.

Table 4: Vegetation type Vs Moth density

Vegetation Type	No of Sites	Habitat Area	Total max moth number	Male Mths/ha
Grassland	39	1,028	10,100	9.82
Open woodland	12	122	673	5.52
Woodland	22	1028	731	0.71

As detailed in the Table 4 grassland sites on average support a much higher (over ten times) density of moths than woodland habitats.

It is also relevant that the long term future of woodland sites is uncertain, as moths tend to occur in formerly cleared or partly cleared woodland and that natural regeneration of woodland, and the shading of understorey that will result, may have an adverse impact on the moth. Thus management of woodland reserves containing golden sun moth may be problematic, with moth conservation potentially conflicting with other conservation goals such as enhanced small bird habitat or increased plant diversity.

6. Extent of potential habitat in the ACT

The Draft National Recovery Plan (NSW Office of Environment and Heritage 2012) infers that GSM prefer native grasslands or derived grasslands in which *Austrodanthonia* is a common element. GSM are also considered to mainly occur on slightly sloping sites (at 3° or less) and that are exposed to full sun. Slight slopes with a northerly aspect are considered to be particularly favoured. These site characteristics and known ACT GSM habitat are examined in order to assess the potential extent of GSM habitat in the ACT.

6.1 Dietary requirements and *Austrodanthonia* occurrence

Adult GSM lack functional mouthparts. Therefore species feeding behaviour is restricted to the larvae stages. Until recently understanding of the diet was based on the assumption that the finding of pupal cases within grass tussocks of wallaby grass (*Danthonia)* and Spear grass (*Austrostipa),* indicated that the larvae were feeding on these grasses (Richter et al 2011). O'Dwyer and Attiwill (1999) studied 14 known sites of GSM, including eight in the ACT, and found that all sites had a greater than 40% cover of *Austrodanthonia* and had soils low in Phosphorus. Subsequent surveys have found moths in habitat with less than 10% *Austrodanthonia* cover (Brown and Tolsma 2010, Brown et al 2011, Gibson 2006). Precise cover rates are not available for all the ACT sites, but many have less than 40% *Austrodanthonia* coverage. Although GSM can exist in areas with low *Austrodanthonia* cover, within the ACT sites at which relatively large numbers of GSM have been recorded do tend to have a large *Austrodanthonia* cover. Of the nine sites at which over 200 moths have been recorded on a single day, *Austrodanthonia* is a dominant species, with a high percentage cover at eight of the sites. The only exception is West Macgregor where a large population is associated with Chilean Needle grass. Gibson (2006) also found that the highest densities of GSM on Craigieburn grassland reserve (Victoria) were in areas with high *Austrodanthonia* cover, while Brown et al (2012) found a positive relationship between the cover of wallaby grasses and the number of GSM sighted amongst 46 sites surveyed across the Victorian Volcanic Plains.

Richter et al (2011) collected GSM larvae from ACT and Victorian sites and undertook molecular and stable isotope analyses to determine the diet composition. The study found that GSM feeds on wallaby grasses (*Austrodanthonia species),* spear grasses (*Austrostip*a species), and Chilean needlegrass (*Nasella neesiana).* These are all C3 species. GSM avoids C4 grasses including kangaroo grass (*Themeda australis),* hairy panic (*Panicum effusum),* redleg grass (*Bothrichloa macra)* and African lovegrass (*Eragrostis curvula).* It is possible that GSM feeds on other C3 grasses, not present at the particular collection sites. Larvae recovered from the roots of the Chilean needlegrass were larger than those feeding on the native grasses. Downey and Sea (2012) report that in the Ginninderra Creek area the highest larval densities were found under the introduced Chilean needle grass (*Nassella neesiana*) tussocks (5-8 individuals/m^2) and lowest under native speargrass (*Austrostipa bigeniculata*) tussocks (<2 individuals/m^2).

The long term suitability of Chilean needle grass as habitat is uncertain. Nevertheless, likely potential habitat includes areas that have an understorey in which *Austrodanthonia* is a common element or areas of such grassland which have been invaded by Chilean needle grass. (The low dispersiability of GSM means that in most situations it would not be able to find and colonise previous non habitat areas now invaded by chilean needlegrass).

6.2 Slope

Transect surveys undertaken at Lawson have predominately found moths on land of a 0-3^0 slope (Dunford 2005 unpublished data). However a comprehensive 2003 survey of Canberra airport (Rowell 2003) located 4890 (93%) of moths on the 250 ha of flat land at the airport and only 376 (7%) on the 180 ha (42% of airport land) that has a slope of 0-3^0. Similarly a 2005 survey of Barby located most of the Macgregor golden sun moth population on land that had a slope of 3-5%. In 2011 various surveys were undertaken across habitat at Throsby, Mulangarri, Taylor, Mulligans Flat, Crace nature reserve and Kinlyside. Combined results indicate that the highest densities of moths were found on those areas with a slight slope, but that many moths were also observed outside this range. Nevertheless of the 1800 ha of golden sun moth habitat in the ACT, 1677.5 ha (93%) is found on land with a slope of 5^0 or less.

Aspect does not seem to be a good predictor of habitat suitability in the ACT. The data from the survey information described above indicates that moths are at there densest on flat land and then most numerous on land that faces to the east or south, rather than to the north. Moths were observed on all aspects.

6.3 Degree of shade

As part of the recent connectivity analyis, a tree density (or Above Ground Biomass) map for the ACT Region was produced from interpretation of satellite radar imagery (Barrett and Love 2012). 72% of all known golden sun moth habitat occurs with the lowest category of no or highly spaced canopy, while a futher 16% occurs in the next category, that corresponds to an open paddock tree situation.

Table 5: Moth Numbers observed along transects crossing differing slopes

Slope	Transect metres surveyed	Number of moths observed on transects	Moths per Km
0	24793	249	1
0-3	6328	104	1.6
3-5	6309	58	0.9
>5	4081	18	0.44

6.4 Potential habitat mapping

In order to gauge the possible extent of GSM habitat within the ACT all land that had a slope of less than 4^0, occured in the lowest (i.e. most open) Above Ground Biomass class and was likely to support wallaby grass or stipa was identified. The grassland mapping used was that produced by the Environmental Research and Information Consortium (2001) as part of the *Planning Framework for Natural Ecosystems of the ACT and NSW Southern Tableands.* This involved remote sensing detection of native grasslands using multi-image spectral analysis. The grassland types 13, 14, 15, 16, 17 and 18 within the spring-summer grassland layer were utilised as these classifications are of drier native grassland type, most liklely to contain significant wallaby grass and/or stipa cover.

Given that golden sun moth is essentially a species of natural temperate grasslands and nearby open woodland areas, the combined slope-shade-grassland type mapping was restricted to those areas predicted as formerly supporting natural temperate grassland or within five kilometres of the predicted grassland areas. This is referred to medium probability habitat in Figure 4.

This mapping was further refined to show only those areas of the slope/shade/grassland analysis that occur in better condition vegetation, mapped as either natural temperate grassland (ACT Government 2005) or yellow box – Blakely's red gum woodland (Maguire and Mulvaney 2011). This is referred to as high probability habitat in Figure 4.

As indicated in Figure 4 the model was fairly good at identifying those vicinities in which golden sun moth is known to occur. The exceptions are the small urban habitats and that of the Yarralumla – North Curtin area. The main reason for the lack of identification of these areas is that they are nestled amongst ornamental plantings or consist of a thin strip on the edge of woodland, and the Above Ground Biomass analysis did not identify these areas as open to the sun.

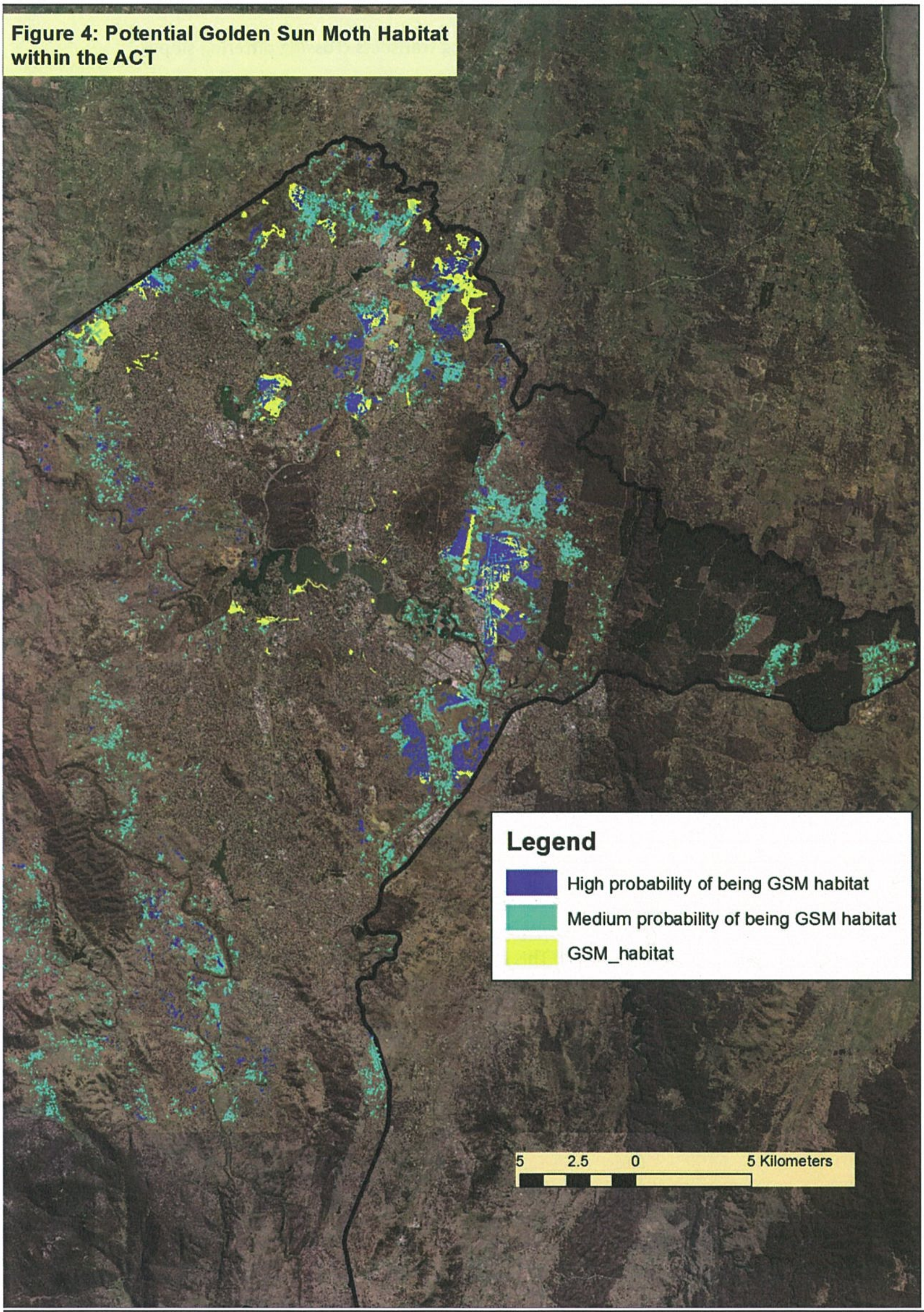
Figure 4: Potential Golden Sun Moth Habitat within the ACT
Legend
High probability of being GSM habitat
Medium probability of being GSM habitat
GSM_habitat
5 2.5 0 5 Kilometers

The medium probability layer mapped 5058 hectares of which 616 hectares (12%) is known GSM habitat. The high probability layer mapped 1636 hectares of which 545 hectares (33%) is known GSM habitat. Thus the modelling does not have a high degree of precision to currently known habitat, but does provide an indication as to other vicinities in the ACT where the moth may occur.

In this regard there are few vicinities identified in the mapping that aren't already known to support GSM, or like the Molonglo Valley, have been subject to GSM survey in which no moths were located. Areas considered to have a high probability of being GSM habitat, that are yet to be subject to survey include Commonwealth land (in the Majura Army Training Area, South Jerrabomberra and in between Dunlop grasslands and Hall) and a mixture of Territory and Commonwealth land in the Newline area, south-east of the airport.

Additional areas of moderate habitat probability are identified at Kowen, west of the Monaro Highway in the vicinity of Royalla and on the grassland flats above the Murrumbidgee from about Tharwa downriver to the back of Weston Creek.

The assessment of potential habitat, suggests that most of the currently utilised habitat is already known or has been subject to survey. It appears that there will be little further identification of additional large habitat areas in the ACT.

7. Threats

7.1 Loss and degradation of habitat

The greatest threat to GSM habitat in the ACT is clearance for urban or infrastructure development. Of the 1800 ha of habitat 378 ha (21%) is approved or proposed for clearance, while a further 23% of the habitat occurs on Commonwealth land and has an uncertain future. 850 ha (or 47% of the total habitat) is within existing or proposed nature reserve or existing or proposed EPBC offset areas. Table 5 shows all the land uses that occur across GSM habitat and the percentage that each land use occurs over the total extent of known GSM habitat. Figure 5 plots the distribution of the differing current and proposed land uses. The red to green shades show the relative level of threat. Lands with red shades are under threat, while those shaded green are protected. The future of yellow shaded habitat is uncertain.

Not only is about a fifth of the current habitat likely to be cleared within the next 5 years, but much of that clearance will be in the most important habitat areas. Table 6 shows the extent of clearance or conservation management occurring or proposed for those sites which have a large or very large area and/or those sites from which a very large moth count has been recorded. Of the fifteen sites identified, nine have developments proposed over at least part of them. All of the three habitat areas, which are greater than 100 hectares, are likely to be reduced in area by at least 25% in the next few years.

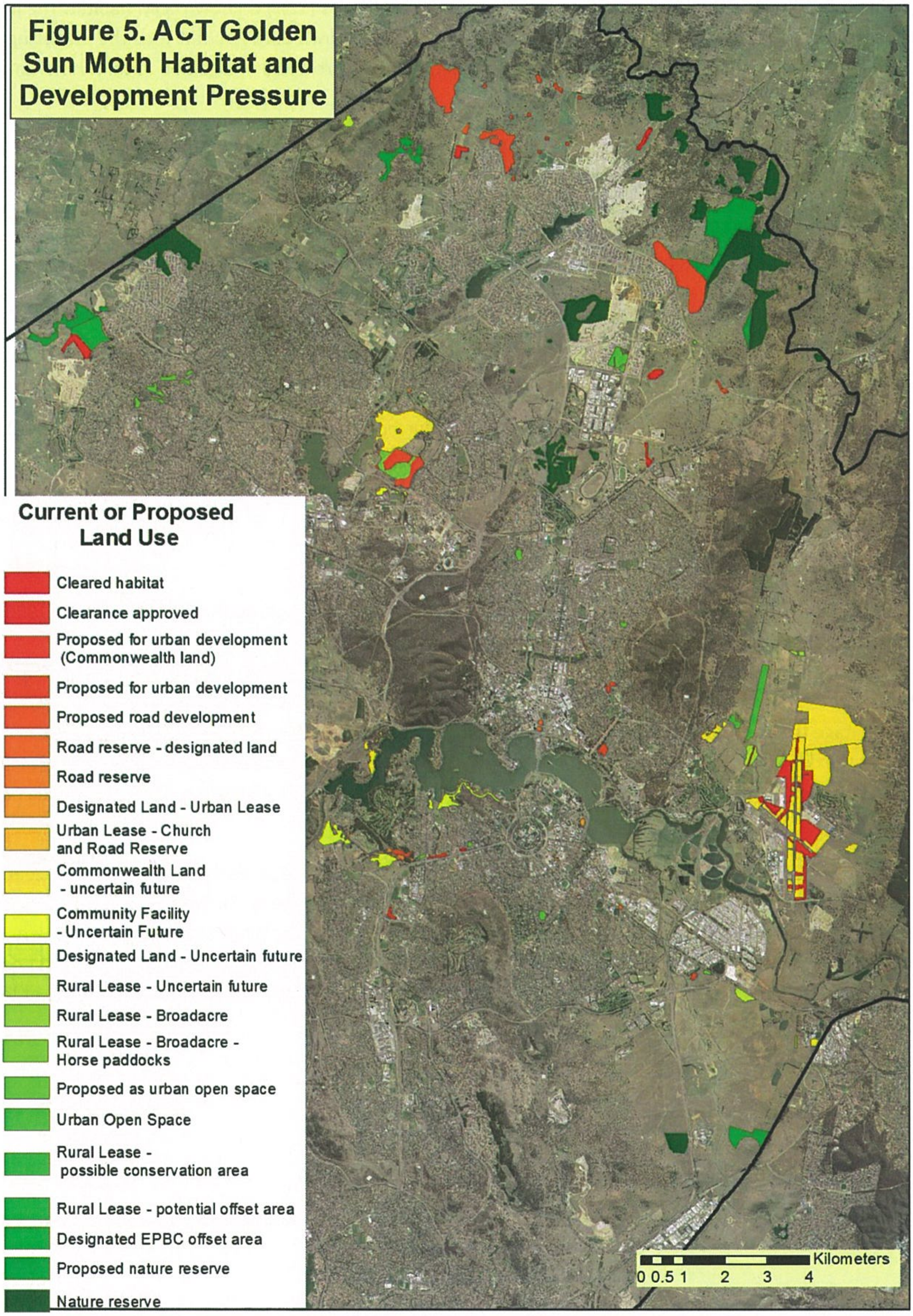
Figure 5. ACT Golden Sun Moth Habitat and Development Pressure
Current or Proposed Land Use
Cleared habitat
Clearance approved
Proposed for urban development (Commonwealth land)
Proposed for urban development
Proposed road development
Road reserve - designated land
Road reserve
Designated Land - Urban Lease
Urban Lease - Church and Road Reserve
Commonwealth Land - uncertain future
Community Facility - Uncertain Future
Designated Land - Uncertain future
Rural Lease - Uncertain future
Rural Lease - Broadacre
Rural Lease - Broadacre - Horse paddocks
Proposed as urban open space
Urban Open Space
Rural Lease - possible conservation area
Rural Lease - potential offset area
Designated EPBC offset area
Proposed nature reserve
Nature reserve
Kilometers
0 0.5 1 2 3 4

Table 6: Distribution of remaining GSM habitat across current or proposed land uses

LAND USE	No. of sites affected*	Habitat area (ha)	% of Total GSM habitat
Recently cleared for development	4	21	1
Approved for development	6	120	7
Proposed for urban development	12	237	13
Commonwealth land (uncertain future)	8	415	23
Designated land (uncertain future)	4	53	3
Canberra University (uncertain future)	2	5	<1
Road reserve	11	14	<1
rural lease	7	31	2
Urban lease (church)	3	3	<1
Proposed urban open space	3	31	2
urban open space	10	43	2
EPBC offset area	3	112	6
Proposed Nature Reserve	7	220	12
Nature Reserve	11	531	29

*Note: some sites are spilt into more than one landuse

The Canberra airport is arguably the most significant golden sun moth habitat area in the ACT and one of the most significant in Australia. Recent or approved clearing has or will reduce the extent of habitat by about half of what it was ten years ago. The latest clearance activity was subject to EPBC approval on 11 November 2009. This approval required the establishment of offsets, but these offsets did not need to be found on airport land. If the current rate of clearance continues then it is likely that there will be very little habitat remaining at all within Canberra airport over the next few decades. Continuous habitat on the airport land and adjoining defence and other Commonwealth land is likely to be further diminished if proposed fast train and the Kowen link road infrastructure proposals occur.

The remaining three of the four largest habitat sites (Goorooyarroo-East Mulligans-Throsby, North - South Lawson and West McGregor-Jarramlee) are all subject to development approvals or negotiations that would result in clearance of 18-40% of the current habitat and reservation of about 50-80% of habitat.

Only four of the fifteen major population or habitat area sites are totally within conservation reserves. Around 30% of the habitat of the major sites is approved or proposed for clearance, within the next five years. This clearance will further fragment and isolate ACT's GSM population.

It is probable that some GSM habitat will be retained as open space within new suburban developments such as Taylor or Moncrieff. Given the ability of the moth to survive (at least in the medium term) in small grassland fragments within urban areas, it is likely that at least some moths will live on within the new suburbs. However, the viability of such populations will be significantly reduced, and the remaining habitat will be more susceptible to other threats such as weed invasion, erosion, soil compaction, excessive nutrient and water input from urban runoff, physical disturbance by the provision of infrastructure and difficulty in appropriately controlling grass biomass.

Table 7. Area of proposed clearance and reservation within major habitat sites

Habitat location	Area (Ha)	Max. Moth count	Area approved for clearance	Area proposed to clear	Area Reserved	Area proposed for conservation
Goorooyarroo - East Mulligans - Throsby	442	210	-	80 (18%)	239 (54%)	123 (28%)
SE Majura Valley (airport, Malcomvale + MTA)	396	5347	95 (25%)	-	-	-
North and South Lawson	150	1053	-	36 (24%)	-	About 75 ha (50%)
West McGregor - Jaramlee	96	1830	17 (18%)	-	-	79 (82%)
Dunlop Grasslands	86	116	-	-	86 (100%)	-
Mulanggari Nature Resrve	81	28	-	-	81 (100%)	-
Crace Nature Reserve	65	163	-	-	65 (100%)	-
Majura West - Campbell Park	59	39	2 (2%)			35 (59%)
Taylor	56	92	-	56 (100%)	-	-
Dudley St Yarralumla - North Curtin horse paddocks	22	373	-	11 (50%)	-	
York Park + Sydney Avenue median strip	0.4	163	-	0.02 (5%)	-	-
Jerrabomberra West Reserve	22	452				22 (100%)
Black St - Stirling Ridge Yarralumla	20	200	-	2 (10%)	-	-
Commonwealth Avenue/Parks Way Coverleaf	2	200	-	-	-	-
Lady Denman Drive - Yarralumla Woolshed	24	188	-	-	-	-
TOTALs	**1519**	**10,454**	**116 (8%)**	**269 (22%)**	**387 (25%)**	**321 (21%)**

7.2 Climate change

The temperature in the ACT is likely to become warmer over the coming decades, with more hot days and fewer cold nights. The amount of overall rainfall is likely to remain much the same, but with more intense storm events, wetter summers and autumns, and drier winters and springs. The higher temperature and greater storm runoff is likely to result in overall drier conditions (ACT Government 2007).

The ecology of GSM is not well enough known to determine whether the above predicted changes in climate will impact on the moth. Peak emergence of adults is during dry periods, so that spring emergence events may become more common than early summer. As the moth tends to occur amongst *Austrodanthonia* grassland on well drained areas, drying of native grasslands may extend its habitat at the expense of wet *Themeda* or *Poa Labillardieri* grasslands that currently occur in wetter sites. However, plants use water more efficiently at high concentrations of CO_2, so the impact of drier conditions may be somewhat masked.

The increasing level of CO_2 in the atmosphere is probably a greater threat to the moth than changes in temperature and rainfall. Richter et. al. (2011) found that GSM had a dietary preference for grasses with the C3 photosynthetic pathway. These authors note that higher CO_2, along with hotter drier conditions favour C4 grasses over C3. If there is a decline in the cover of C3 grasses through being out competed by C4 grasses, the lack of food availability may become a major issue for this moth, which only has a limited dispersal capability.

Higher CO_2 levels are also likely to favour shrubs and woody plants over grasses and thus aid the regeneration or spread of woody plants in or near open woodland habitat, currently occupied by the moth (Berry and Roderick 2005).

Increased shading from the woody plant growth may make the current woodland/secondary grassland habitat unsuitable for the moth.

7.3 Weed invasion

Invasion by exotic grasses and broadleaf weeds is an ongoing threat to the integrity of native grasslands (NSW Office of Environment and Heritage 2012), and particularly so for GSM habitat which tends to be in small isolated patches. In the ACT the exotic grasses *Phalaris*, *Paspalum*, wild oats, African love grass, serrated tussock and Chilean needlegrass along with St John's wort and *Verbascum* are particularly damaging. The impact of the invasion of Chilean needlegrass and other C3 grasses such as serrated tussock is difficult to determine as these species will, in the case of Chilean needlegrass, or may, in relation to other C3 invaders, provide an additional food source for GSM. The Commissioner for Sustainability and the Environment (2009) concluded as part of her lowland native grassland investigation that control of weeds is a critical management component and that the aim of weed management should be to reduce populations of the most invasive weeds present.

7.4 Inappropriate habitat management

Inter-tussock spaces are considered important in assisting patrolling males to locate females displaying from a sedentary position (Gilmore and Mueck 2010). *Austrodanthonia* also tends to do best in areas where grass height is kept low. Without some type of management the grassy habitat will develop into dense swards of rank grass with few inter-tussock spaces. Biomass management is therefore essential. There are three basic methods of biomass control; Grazing with domestic stock or kangaroos; mechanical slashing; or controlled burning. GSM are known to occur in areas where each of these methods have been regularly undertaken (Gilmore and Mueck 2010). Overgrazing can reduce both the cover and diversity of habitat and result in modification of soil structure through compaction (NSW Office of Environment and Heritage 2012). Of 38 natural temperate grassland sites in the ACT investigated in 2008, 11 sites were judged to be overgrazed by kangaroos; four suffered overgrazing from rabbits and seven by stock (Hodgkinson 2009).

Application of fertiliser or input of nutrient from urban runoff will be detrimental to *Austrodanthonia* and promote weed growth. Ploughing effectively destroys the root zone of the plant which is a key habitat component for the larval stage of the golden sun moth (Dear 1997, NSW Office of Environment and Heritage 2012).

Part 2: Strategic Conservation of the golden sun moth

8. Strategic objective

It is clear that the current extent of GSM habitat within the ACT will be substantially reduced (by about 20%) in the next few years and that much of this reduction is in the biggest habitat areas, supporting what appear to be relatively large populations. As much of the proposed clearing is already approved or is envisaged as part of well advanced planning processes, there is probably little that can be done to prevent most of the 400 hectare loss. Thus the current extent and viability of the moth in the ACT will not be maintained or improved, rather it will be reduced.

On the other hand, of the remaining 1400 hectares of known habitat about 800 hectares or 57% is likely to be under conservation management within a few years. This will include eight habitat areas of 50 hectares or greater. This is a larger habitat area than was known at the time when the species was listed as endangered.

The key objectives for the golden sun moth in *the ACT Lowland Native Grassland Conservation Strategy* (*Action Plan 28* p 41) were to:

1. protect in perpetuity the existing viable populations of Golden Sun Moth in secure native grassland habitat across the range of the species in the ACT; and

2. maintain the potential of the species for evolutionary development in the wild.

The conservation actions (p42 -44) to achieve these objectives were to

- conduct further survey to more accurately determine the area of occupancy;
- undertake research into the biology and ecology of GSM as the basis for adaptively managing the species and its habitat;
- continue to monitor habitat and GSM populations at major sites, including impacts of management practices, particularly grazing; and
- seek protection of key habitat known to support viable populations across their range in the ACT, noting that insufficient is known about what constitutes a viable population, some of the known habitat is on Commonwealth land.

Strategic Actions are discussed under section 13, but the key strategic objective is to provide for the long term viability of GSM in the ACT and hopefully reduce the threats its faces, with the long term goal of it being listed as vulnerable to extinction rather than endangered. It is envisaged that this will largely be achieved through greater security and better management of much of the 1400 hectares not currently targeted for development.

Hogg (2009) proposes a strategic conservation approach of protecting viable populations in each of the Gungahlin, Belconnen, Majura, Jerrabomberra and Central Canberra valleys. Even though the genetic analysis suggests the valleys do not each support different populations, conserving the moth across its range and in each local valley is a laudable conservation objective, which should be pursued.

9. Offsets

Offsets try to match the biodiversity loss at a development site, through biodiversity gains made through improved management at offset sites, so that overall there is no net loss in the biodiversity feature being offset. The Commonwealth has established principles for the use of biodiversity offsets (Australian Government 2007). Offsets are not appropriate where impacts can be reasonably avoided or minimised, and at a minimum should be commensurate with the magnitude of the impacts of the development and ideally deliver outcomes that are "like for like". The use of an offset should seek to maintain and enhance the health, diversity and productivity of the relevant species or community being affected.

The ecology of the golden sun moth is not well enough known to conclude that conservation management actions at an offset site would so improve the health, diversity and productivity of the offset population that the population gain would be commensurate with the loss at a development site. A positive response at an offset site would also be problematic to monitor and gauge, as any response is likely to be masked by the marked yearly variations in moth emergence. Commonwealth approvals have tried to address this uncertainty by ensuring that offset sites are from three to five times larger than development areas and by requiring that offset sites be secured for conservation. Nevertheless the offset is really about preventing development or future degradation of offset sites, rather than gaining a measured increased in population through enhanced management. It is not a "no net loss "outcome, but is some compensation for loss.

Field trials undertaken by Greening Australia in Victoria and Canberra airport, have shown success in reconstructing or restoring natural temperate grassland (and golden sun moth habitat) (Gibson Roy 2008). Such habitat reconstruction techniques could be suitable for extending or connecting known habitat.

The ACT Government is currently developing an offset policy and rules. The relevant draft rules applying to the golden sun moth require:

> No loss of habitat patches >50ha AND supporting populations of more than 50 moths. Any offsets should be a mixture of placing known sites under secure conservation land use and contribution of significant funds towards research in: (1) Preferred habitat of the moth (which may relate to topographic structure and grassland types or grassland species present); (2) The use of and viability of the moth within patches of Chilean Needlegrass; (3) The response of the moth to management prescriptions; and/or (4) The ability of the moth to disperse to new habitat.

If applied across the ACT the rule would mean no clearance of habitat at Canberra airport, Malcolmvale, the Majura Training Area, McGregor- Jaramlee, Belconnen Naval Transmission Station, Dunlop Grasslands Nature Reserve, Crace Nature Reserve, South Lawson, Taylor, Mulligans Flat Nature Reserve, Goorrooyaroo Nature Reserve and Throsby residential area.

It seems likely that most of the key development decisions concerning these areas have or will be made prior to formal adoption of an ACT offset policy and process.

The Commonwealth has recently released an offsets policy and calculator. A feature of this policy is that direct offsets (or conservation management of currently threatened lands) should form the bulk of an offsets package. In the past the Commonwealth has allowed research into habitat restoration and translocation to be a substantial part of offset packages for loss of habitat in the ACT. While research can still be part of an offset package, it is likely that the Commonwealth will only approve this if the offset package includes a substantial land acquisition/conversion component.

10. Translocation

As stated in EPBC Policy Statement 3.12 (DEWHA 2009b), translocation of the golden sun moth is not considered to mitigate or offset the impact of an action, as it is unlikely to result in a positive outcome for the species. The policy allows that in limited circumstances salvage translocation may be tried as an experiment, in addition to appropriate mitigating measures. Such translocation may be considered as compensation, and must be undertaken in association with a fully costed and funded monitoring program and adaptive management strategy with clearly stated criteria for identifying success.

As part of a development approval under the EPBC Act for Forde, Delfin Lendlease Pty Ltd agreed to provide funding to investigate possible methods for the translocation of GSM. The University of Canberra has begun research focused on translocating larvae. Two hundred larvae have been removed from West McGregor by digging up grass tussocks and sorting through the soil. The larvae were then transported to a University glasshouse, measured and placed into a pot containing either stipa or Chilean needlegrass tussocks, also obtained from West McGregor. Some larvae bearing pots were also placed outside of the glasshouse. Examination of how optimal environmental conditions (warmer winter temperatures and healthier plants) contribute to larger and healthier GSM larvae will be measured by higher growth and survival rates of larvae. Some pots will also be dug into on-campus grassland and any emergence of adult moths monitored (Downey and Sea 2012).

It appears that larvae can be readily transported (with no mortality amongst the 200). Preliminary examination of larvae in a few pots has shown survival rates (after 1 month) exceeded 75%, likely higher since no dead larvae were found. The results are promising, but at an early stage, and it has yet to be demonstrated that moths can emerge from the glasshouse translocated larvae or that this can happen in the field.

Potential sites for researching translocation could include sites from where the moth is thought to have become extinct, or high probability habitat connection areas, which have been adequately surveyed and found to not currently support the moth.

11. Site ranking

Given the inherent limitations of both offsetting and translocation, the main approach proposed to retain the viability of the species within the ACT is to protect and enhance key habitat areas.

Hogg (2009) suggests that viability could be protected by having two grassland reserves and two further protected habitats in the four main valleys and protecting six apparently stable habitat sites in Central Canberra, together with protection of some sites that have been subject to long term monitoring or are an example of atypical habitat.

To assist in a strategic consideration, the relative importance of the 73 known habitat sites for golden sun moth conservation in the ACT was ranked against the following criteria.

1. Habitat size (>150 ha ✓✓, 50 -150 ha ✓, 20 - 49 -, 5-19 X, < 5 XX).
2. Maximum Moth Count(>150 ✓✓, 51 -150 ✓, 21 -50 -, <21 X)
3. Connected to other habitat patches (Strong connection ✓✓, weak connection✓, no connection X)
4. Main Vegetation Type (Grassland ✓, Open Woodland -, Woodland X)
5. Mainly high quality understorey (Natural Temperate Grassland or EPBC woodland ✓, native or exotic pasture X) and
6. Other threatened species share habitat (3 or more species present✓✓, 1-2 species present ✓, no other threatened species present X).

The total number of cross (X) features at a particular site were subtracted from the total number of ticks (✓) to provide a range of totals from +9 to -6. Sites were then ranked according to their scores. The rankings are shown in Table 8, while the distribution of ranked sites is at Figure 6.

The top 22 ranked sites cover 1623 hectares or 90% of the total known GSM habitat. Seven of the sites are fully within a current or proposed nature reserve and cover about 750 hectares. Seven of the sites are at least partially owned by the Commonwealth, with about 520 hectares of Commonwealth land of which around 100 ha is proposed to be cleared by Commonwealth authorities. A further 200 hectares is proposed to be cleared on Territory land.

12. Current and proposed protection of sites in each of the ACT valleys supporting GSM

12.1 Gungahlin

The current planning for Gungahlin will essentially destroy large areas of habitat at Moncrieff, Taylor and part of Throsby (a total area of 184ha), but most of the remaining habitat would be conserved. Relative large populations and areas of habitat would be protected in the existing, expanded or new reserves of Kinlyside, Mulligans Flat, Goorooyarroo, Crace and Mulanggari. The extent of reserved habitat would be about 550 hectares. Smaller populations and areas of habitat would be also retained within Gungaderra Nature Reserve. The Kinlyside, Mulligans Flat and Goorooyarroo populations are within open box gum woodland. Regeneration of this woodland may shade and thereby degrade the habitat for the moth. The reserves will require specific and focused management of regeneration to prevent increased sapling and shrub growth from having a significant impact on the occurrence and viability of the moth. The "Throsby Heel" area is a large area of land, mapped as high probability habitat, that is proposed to add to Goorooyarroo Nature Reserve. Currently only a few scattered moths have been observed in this area, it is possible that with better conservation management the population of moths may expand in this area.

Surveys during the spring and summer of 2010–2011 and 2011–2012 across Crace, Mulanggari, Goorooyarroo, Mulligans Flat and Gungaderra nature reserves as well as the Jacka, Taylor, Throsby, Kinlyside and One Tree Hill areas helped to well define the extent of occupied habitat across Gungahlin.

In the next five years as much as 33% of the remaining habitat in Gungahlin will be cleared, while five major habitat areas will remain across several grassland and woodland reserves. While the inevitable loss of almost one third of the GSM habitat in Gungahlin will compromise the viability of the population, the areas to be retained together with the proposed reserves should be sufficient to ensure the persistence of the moth in the local area.

12.2 Belconnen

There are three priority habitat areas in Belconnen. South Lawson suburban development will result in the loss of about a third of the Lawson habitat, while the long term future of the Commonwealth's Belconnen Naval Transmission Station (BNTS) is uncertain. It is important that the critical habitat at BNTS is protected and that connectivity between the habitat remaining within the open space areas of South Lawson and the BNTS is retained.

Nearly all of the known habitat at McGregor – Jarramlee and Dunlop Grasslands is or will shortly be under conservation management. Chilean needlegrass is a significant invader of the McGregor -Jarramlee site, with research currently underway as to how areas heavily invaded by Chilean needlegrass can be restored back to native wallaby grass dominated grassland. The recent dietary analysis may indicate that the threat posed by Chilean needlegrass invasion is not as significant as initially feared (Richter et al 2011). However, Chilean needlegrass still poses a threat to the integrity of native grassland and raises a dilemma for weed management for sites where GSM occur.

Table 8 Ranking of Golden Sum Moth Habitat sites against conservation criteria (see section 11 for key)

Site name	**District**	**Habitat size**	**Pop. Size**	**Connected to other habitat?**	**Main Vegetation Type**	**Under-storey quality**	**Other threatened species**	**Rank**
North and South Lawson	Belconnen	✓✓	✓✓	✓	✓	✓	✓✓	1
SE Majura Valley (airport, Malcolm vale + MTA)	Majura	✓✓	✓✓	✓	✓	✓	✓✓	1
Crace Nature Reserve	Gungahlin	✓	✓✓	✓✓	✓	X	✓✓	3
Goorooyarroo - East Mulligans, Throsby	Gungahlin	✓✓	✓✓	✓	X	✓	✓	3
Jerrabomberra East	Jerrabomberra	_	X	✓✓	✓	✓	✓✓	5
Dunlop Grassland Reserve	Belconnen	✓	✓	✓✓	✓	✓	X	6
Black St - Stirling Ridge	Central Canb.	_	✓✓	X	✓	✓	✓	7
Harman Residential Area	Jerrabomberra	XX	✓	✓✓	✓	✓	✓	7
Jerrabomberra West Reserve	Jerrabomberra	_	✓✓	X	✓	✓	✓	7
Majura West + Campbell Park	Majura	✓	_	✓	✓	X	✓✓	7
West McGregor - Jarramlee	Belconnen	✓	✓✓	✓✓	✓	X	X	7
ACT Bonshaw lease (next to Harman)	Jerrabomberra	XX	_	✓✓	✓	✓	✓	12
Dudley St Yarralumla - North Curtin horse paddocks	Central Canb.	_	✓✓	✓✓	✓	X	X	12
Mulanggari Nature Reserve	Gungahlin	✓	_	X	✓	✓	✓	12
Lady Denman Drive - Yarralumla Woolshed	Central Canb.	_	✓✓	✓✓	✓	X	X	12
Amtech site Fyshwick JE09	Jerrabomberra	XX	X	✓	✓	✓	✓✓	16
York Park + Sydney Avenue median Strip	Central Canb.	XX	✓✓	X	✓	✓	✓	16
East Bonner/ Horse Park	Gungahlin	_	_	✓	X	✓	✓	16
Guilfoyle St Yarralumla	Central Canb.	XX	✓	X	✓	✓	✓	19
Cookanella	Jerrabomberra	X	X	✓✓	✓	X	✓	19
North Mitchell	Gungahlin	X	_	X	✓	✓	✓	19
Kinleyside	Gungahlin	_	✓	✓	X	✓	X	19
Block 799, Gungahlin	Gungahlin	X	X	✓	✓	X	✓	23
St Marks Barton	Central canb.	XX	_	X	✓	✓	✓	23
East Crace Nature Reserve	Gungahlin	XX	X	✓✓	✓	X	✓	23
Taylor	Gungahlin	✓	✓	✓	X	X	X	23
Umbagong Park, Latham BEO4	Belconnen	X	X	✓	✓	✓	X	23
Campbell Office Site/Constitution Avenue	Central Canb.	XX	✓	X	✓	X	✓	28
St Johns Church Reid	Central Canb.	XX	✓	X	✓	✓	X	28
Majura Road West - southern section	Majura	XX	X	✓	✓	X	✓	28
Moncrieff	Gungahlin	_	✓	✓	X	✓	X	28
North Gungaderra Nature Reserve	Gungahlin	XX	X	✓	✓	X	✓	28
West Gungaderra Nature Reserve	Gungahlin	XX	X	✓	✓	X	✓	28
Commonwealth Avenue/Parks Way Coverleafs	Central Canb.	XX	✓✓	X	✓	X	X	35
Giralang Roadside Balamara st	Belconnen	XX	_	✓	✓	X	X	35

Site name		Habitat size	Pop. Size	Connected to other habitat?	Main Vegetation Type	Under-storey quality	Other threatened species	Rank
Goorooyarroo East	Gungahlin	XX	_	✓	X	✓	X	35
Majura Road Tree Planting	Majura	XX	_	✓	✓	X	X	35
NW Mulligans Flat	Gungahlin	X	X	✓	X	✓	X	35
Limestone Avenue median strip	Central Canb.	XX	_	✓	✓	X	X	35
ACT Bonshaw lease (Canberra Avenue)	Jerrabomberra	XX	X	✓	✓	X	X	40
Goorooyarroo S-E section	Gungahlin	XX	X	✓	X	✓	X	40
Haig Park	Central Canb.	XX	X	✓	✓	X	X	40
Little Mulligans North	Gungahlin	XX	X	✓	X	✓	X	40
McGregor Isolated patch	Belconnen	XX	X	✓	✓	X	X	40
Mulligans Flat South West	Gungahlin	XX	X	✓	X	✓	X	40
Mulligans Flat West	Gungahlin	XX	X	✓	X	✓	X	40
North Jacka	Gungahlin	XX	X	✓	X	✓	X	40
North Mulligans Flat	Gungahlin	XX	X	✓	X	✓	X	40
SE Airport	Majura	XX	X	✓	✓	X	X	40
Bass Gardens	Central Canb.	XX	_	X	✓	X	X	50
One Tree Hill - South	Gungahlin	XX	_	✓	X	X	X	50
Brisbane Avenue median strip	Central Canb.	XX	X	X	✓	X	X	53
Captain Cook Crescent Griffith	Central Canb.	XX	X	X	✓	X	X	53
Cowper St - near Church	Central Canb.	XX	X	X	✓	X	X	53
Elmgrove	Gungahlin	XX	X	✓	X	X	X	53
Hampton Circuit Park Yarralumla	Central Canb.	XX	X	X	✓	X	X	53
Horse Park Drive West	Gungahlin	XX	X	✓	X	X	X	53
Horsepark	Gungahlin	XX	X	✓	X	X	X	53
Jacka	Gungahlin	XX	X	✓	X	X	X	53
Jacka south	Gungahlin	XX	X	✓	X	X	X	53
Kenny	Gungahlin	XX	X	✓	X	X	X	53
Lyneham	Central Canb.	XX	X	X	✓	X	X	53
Mcintyre Street - Griffith	Central Canb.	XX	X	X	✓	X	X	53
Moncrieff North	Gungahlin	XX	X	✓	X	X	X	53
North west Kenny	Gungahlin	XX	X	✓	X	X	X	53
One Tree Hill -North	Gungahlin	XX	X	✓	X	X	X	53
Roundabout Canberra and Sturt Avenue	Central Canb.	XX	X	X	✓	X	X	53
South East Captain Cook Crescent	Central Canb.	XX	X	X	✓	X	X	53
Taylor East	Gungahlin	XX	X	✓	X	X	X	53
University of Canberra NE	Belconnen	XX	_	X	_	X	X	53
University of Canberra NW	Belconnen	XX	_	X	_	X	X	53
Beale Cr Deakin	Central Canb.	XX	X	X	_	X	X	72
Fisher Park Ainslie	Central Canb.	XX	X	X	_	X	X	72
East Lake Ginninderra Foreshore		Extinct						
CSIRO Headquarters, Campbell		Extinct						

Site name		Habitat size	Pop. Size	Connected to other habitat?	Main Vegetation Type	Under-storey quality	Other threatened species	Rank
Yarramundi Reach		Extinct						
Forde North		Destroyed						
Harrison 4		Destroyed						
Ngunawall 2C		Destroyed						
Srilankan Embassy Yarralumla		Destroyed						

Linking the Dunlop and McGregor – Jarramlee habitat areas should be a major management goal. This connection could be either on the ACT, NSW or preferably both sides of the border. Areas of high probability habitat to the west of Jarramlee, should be subject to survey – prior to any development and if observed at this location habitat linkages to Jarramlee should be retained and enhanced.

12.3 Central Canberra

Most of the sites in central Canberra are small in size and recorded population number and isolated from other moth occurrences. The key exceptions are the

1. Black St – Stirling Ridge (Alexandra Drive) area,
2. Yarralumla woolshed equestrian area and habitat along Lady Denman Drive; and
3. Dudley St – North Curtin Horse paddocks

None of these sites are within conservation reserves, and most of these lands are not specifically managed for golden sun moth conservation. The Dudley St habitat although known to support a relatively large number of moths was previously considered to be small and isolated. However, as moths have been observed in the adjacent cotter road median strip and the North Curtin horse paddocks, moth habitat is more widespread that initially thought, though it is dissected by sealed roads. It is also possible that the Dudley St and Yarralumla woolshed populations are currently or could be linked via existing or restored habitat within the Royal Canberra Golf Course and potentially Government House.

Housing has been proposed over the Dudley St area, while the North Curtin horse paddocks have been suggested as a site for embassy development. Chilean needlegrass and to a less extent other exotic grasses such as Fescue and Phalaris are common at all of the three key central Canberra sites. The full extent of moths at these locations should be ascertained. Major habitat areas and their connectivity should be maintained and subject to golden sun moth specific conservation management.

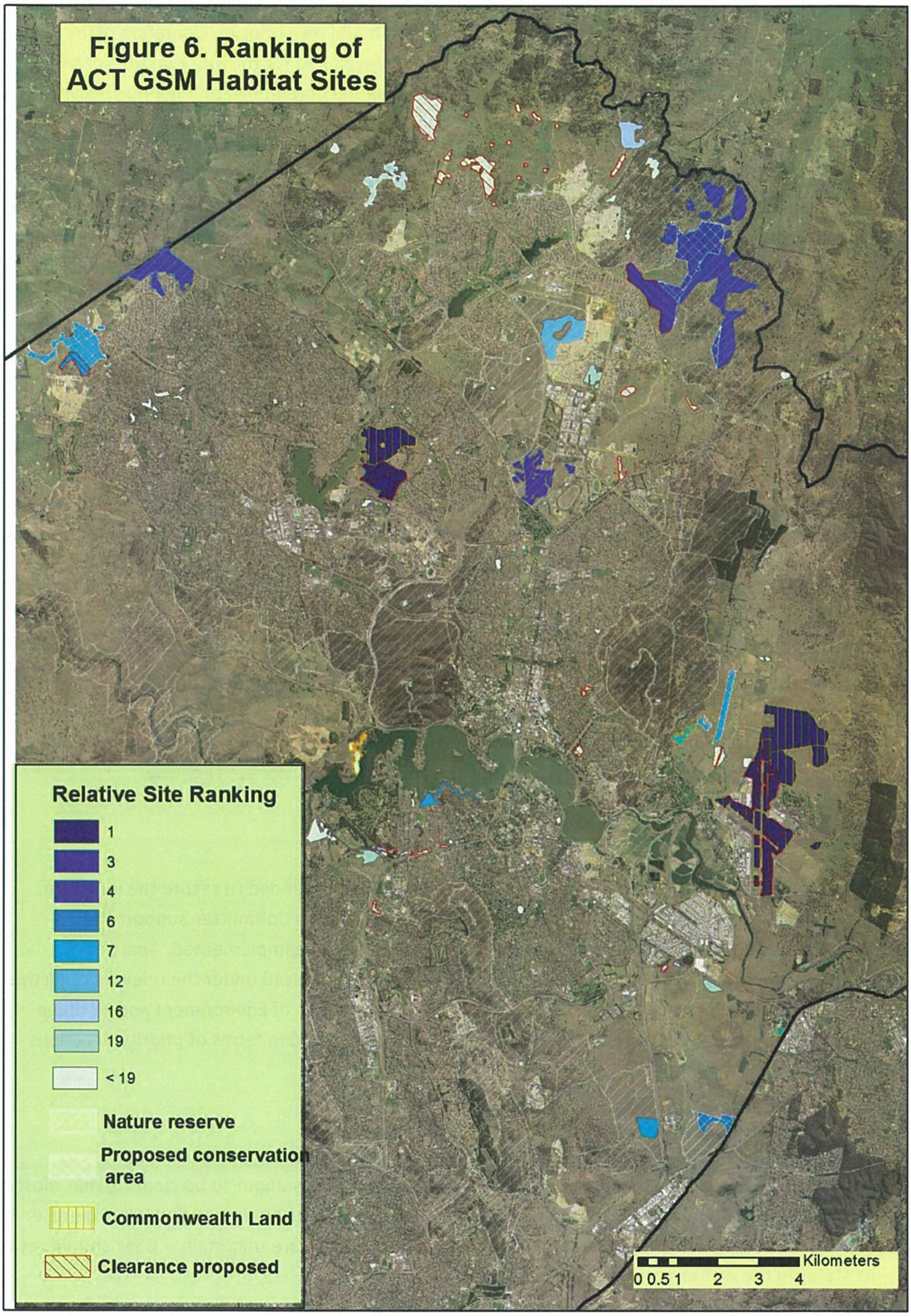

Figure 6. Ranking of ACT GSM Habitat Sites
Relative Site Ranking
1
3
4
6
7
12
16
19
< 19
Nature reserve
Proposed conservation area
Commonwealth Land
Clearance proposed
Kilometers
0 0.5 1 2 3 4

Relatively large populations of moths also occur at York Park and to a less extent at Guilfoyle Street and St Marks. Protection of moth habitat at these sites should be a priority. Operation plans designed to favour the golden sun moth should also be developed for the more important sites that occur within road reserves or urban open space, including the Commonwealth Avenue flyovers, Haig Park, Limestone Avenue median strip and Bass Gardens.

12.4 Majura

There are two key habitat areas in the Majura Valley. The Canberra airport –Majura Army Training Area is entirely Commonwealth land. The other key habitat area is a combination of Defence and Territory land. The Territory land component is currently managed as if it is reserve. This area is also habitat of threatened reptiles and is likely to become a reserve as part of an offset established for loss of striped legless lizard habitat at Kenny. Conservation management currently occurs over much of the remaining habitat on Commonwealth land, but the long term future of this land is uncertain. The viability of the species in the Majura Valley will require favourable Commonwealth land use decisions.

Survey for the moth should occur in the Newline area (south and east of Canberra airport) and over a wider area within the Majura Army Training Area, than what appears to have been subject to previous survey.

12.5 Jerrabomberra

The two key known habitat areas within Jerrabomberra Valley are within existing or proposed nature reserves at East and West Jerrabomberra. Survey and enhanced connection should occur on the grasslands on the Commonwealth land to the north of East Jerrabomberra. Planning in this valley should seek to conserve and link all populations to the east of the Monaro Highway.

13. Strategic Actions

The following list of proposed strategic actions are being recommended to secure the long term viability of GSM in the ACT. It is proposed that the Flora and Fauna Committee support the recommended actions and advise the Minister that they should be implemented. Apart from recommendation 1, all of the recommended actions have been placed under the relevant objective headings of the *Draft National Recovery Plan for GSM* (NSW Office of Environment and Heritage 2012). In this document, the objective headings have been ordered in terms of priority of actions within the ACT.

Status of GSM in the ACT

Recommendation 1: Given that 20% of the current GSM habitat is about to be cleared, that most of this clearance will be of the best habitat, that 800 hectares of habitat is or will shortly be reserved and that potential impacts of climate change and weed invasion are uncertain – GSM should retain its status in the ACT as an endangered species.

Increase the representation of golden sun moth and its habitats in reserves or areas under secure long-term conservation management across the species range.

Recommendation 2: As shown in Figure 5 there are several key habitat areas that have been proposed as reserves as part of development and planning decisions. It is recommended, for the long term viability of golden sun moth in the ACT that Jarramlee, East Jerrabomberra, Kinlyside, Majura West and the "neck and heel" components of Throsby be added to the formal nature reserve estate.

The Flora and Fauna Committee recommend to the Minister that he write to the Conservator of Flora and Fauna stressing the importance that the addition of the above areas to the nature reserve estate has in retaining a viable GSM ACT population.

Recommendation 3: The Flora and Fauna Committee recommend that the Minister write to the Commonwealth Ministers responsible for environment, defence, the National Capital Authority and Canberra airport providing a copy of this strategic conservation plan and detailing desirable Commonwealth actions if sustainable populations of the moth are to be retained in all of the ACT valleys in which it occurs. The importance of habitat at the Belconnen Naval Transmission Station and in the Majura Valley for secure long-term conservation management of GSM, should be stressed.

Identify and reduce the impact of threats to the species and its habitats.

Recommendation 4: The Flora and Fauna Committee advise the Minister that key habitat within Yarralumla and North Curtin should be identified and protected from development.

Recommendation 5: The Flora and Fauna Committee advise the Minister that isolation of ACT habitat fragments be improved by weed control, plantings or other restoration work that enhances habitat connectivity between

- South Lawson and the Belconnen Naval Transmission Station
- Dunlop Grasslands and Jarramlee – West Mcgregor
- Dudley St and Yarralumla Woolshed; and
- The north and south ends of Jerrabomberra valley

The possibility of improving habitat connectivity within Crace, Mulangarri and Gungaderra Nature reserves be also investigated.

Recommendation 6: The Flora and Fauna Committee advise the Minister that clearance of habitat >50 hectares and which supports > 50 moths, not be supported unless this loss is part of a strategic planning process, that ensures a viable population will remain within the valley of investigation.

Recommendation 7: The Flora and Fauna Committee advise the Minister that offsets be required for any loss of habitat, which will both dissuade against loss and provide some compensation if loss occurs.

Recommendation 8: The Flora and Fauna Committee advise the Minister that management prescriptions be developed for golden sun moth habitat within woodland conservation areas, particularly those with active woody plant regeneration.

Recommendation 9: The Flora and Fauna Committee advise the Minister that African lovegrass, a highly invasive C4 grass, which is present but not yet widespread across many of the GSM habitat locations, be a particular focus of weed control in and around habitat areas, so that it doesn't expand beyond its current extent and hopefully its presence on GSM habitat is reduced.

Recommendation 10: The Flora and Fauna Committee advise the Minister that research directed towards the following should be encouraged and supported;

- the use of and viability of the moth within patches of Chilean needlegrass; and
- the response of the moth to management prescriptions, including use of herbicides and other chemicals.

Recommendation 11: The Flora and Fauna Committee advise the Minister that when best practice management guidelines have been developed as part of the National Recovery Planning for the moth (Environment and Heritage 2012), these be applied to ACT conservation and offset areas.

Determine the species' distribution in areas that have not been the focus of targeted surveys.

Recommendation 12: The Flora and Fauna Committee advise the Minister that targeted surveys for the golden sun moth occur (certainly prior to any development) in the following areas of habitat potential:

- grasslands within Kowen
- grassland and open woodland in the Newline area and south-east of the airport
- open woodland within the Majura Training Area
- grassland and open woodland in the Hall – Dunlop area
- grassland to the west of Jarramlee
- grassland in the vicinity of Yarralumla woolshed, North Curtin ovals and the Royal Golf Course
- Commonwealth land within the Jerrabomberra Valley
- Grassland to the west of the Monaro Highway, in the vicinity of Royalla; and
- grassland flats above the Murrumbidgee from about Tharwa downriver to the back of Weston Creek.

Increase the knowledge of life history, demographics, habitat requirements and conservation genetics of the species to enable effective management.

Recommendation 13: The Flora and Fauna Committee advise the Minister that research that will be encouraged and supported in the ACT be research that:

- Identifies the preferred habitat of the moth (which may relate to topographic structure and grassland types or grassland species present);
- Assesses the ability of the moth to disperse to new habitat;
- Examines further the use of pupal cases for monitoring; and/or
- If results of initial research are promising, further explore the possibility of moth translocation.

Determine population trends across the species' range in response to management and threat abatement actions.

Recommendation 14: The Flora and Fauna Committee advise the Minister that monitoring programs and reactive management is undertaken within formal offset areas

Recommendation 15: The Flora and Fauna Committee advise the Minister that monitoring guidelines should be established for the species.

Recommendation 16: The Flora and Fauna Committee advise the Minister that several long term monitoring sites (in addition to York Park and Canberra Airport) be selected and regularly and consistently monitored to gauge the long term population trends across the Territory.

Identify the potential impacts of climate change on the species and determine management responses to reduce these impacts.

This will not be a focus of ACT supported research except where it relates the other five research priority areas previously listed. This is more appropriate for national funding.

Increase community awareness and involvement in the golden sun moth recovery program.

Recommendation 17: The Flora and Fauna Committee advise the Minister that the use of volunteers for survey and monitoring continue to be fostered.

Recommendation 18: The Flora and Fauna Committee advise the Minister that the known distribution of golden sun moth habitat be regularly updated on ACTMAPi, survey reports conducted by or for Conservation Planning and Research will be available on the ESDD website.

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Appendix 1 – GSM known habitat locations

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Peak moth count	Source of max count	Date of max count	Other survey information	other counts and sources	Other species present *
Dunlop Grasslands	Belconnen	NTG	Austrodanthonia, Austrostipa, Themeda	86.0	116	Biosis (2010)	2, 3 + 4/12/2010	1.5 moths per 100m of transect	Edwards (10/12/93) Richter (2009)	
Giralang Roadside Balamara street	Belconnen	Exotic Grassland	Chilean needlegrass, Austrodanthonia	0.7	21	Richter (2009)	Two visits spring/summer 2008	Totals from circular counts		
McGregor Isolated patch	Belconnen	Exotic Grassland	Chilean Needlegrass	0.2	4	Biosis(2010)	4/12/2010	Transect survey	Braby (2005)	
North and South Lawson	Belconnen	NTG, Native pasture	Austrodanthonia, Austrostipa	150.4	1053	Ricther (2009) Hogg 2010, Rowell 2009	Spring/summer 2009	Totals from circular spot counts	2008 and 2009 Dunford – BNTS approx numbers	SLL,P, RC
Umbagong Park, Latham BEO4	Belconnen	NTG, Exotic Pasture, Native Pasture	Chilean Needlegrass, Themeda	16.2	6	Rowell 2012	1/1/2012		Hogg 2010 Osbourne, Richter (2009)	
University of Canberra NE	Belconnen	Native Pasture	Austrodanthonia, Austrostipa	1.8	43	Osbourne (2009)	1/12/2009	Opportunistic meander and whole site count		
University of Canberra NW	Belconnen	Native pasture	Austrodanthonia, austrostipa	3.1	32	Osbourne (2009)	1/12/2009	Opportunistic meander and whole site count		
West McGregor West - Jaramlee	Belconnen	Exotic Grassland - Native Pasture	Chilean needlegrass - Austrostipa	95.7	1830	Braby (2005)	11-22/12/2004	28 moths per 100m transect	3 x 2004 Dunsford 2 x 2003 Braby + Biosis 2010	
CSIRO Headquaters, Campbell	Central Canberra	NTG	Themeda	3.0	1	Edwards	1/12/1994	Opportunistic sighting	Richter (2009)	
Guilfoyle St Yarralumla	Central Canberra	NTG	Dry Themeda, Austrostipa, Chilean needle grass	2.7	66	Dunsford (2006)	23/11/2006	Single walk and count across whole site	7/12/2008 Mulvaney (2008)	BW

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Max moth count	Source of max count	Date of max count	Other counts	Source of other counts	Other species present
St Johns Church Reid	Central Canberra	NTG	Bothriochloa, Paspalum	0.9	100	Dunsford (2005)	27/11/2003	Meander over site	22/11/2005 Dunsford , Richter 2009	
St Marks Barton	Central Canberra	NTG	Themeda	1.9	22	Dunsford (2005)	27/11/2003	Meander over site	Richter (2009)	BW
Bass Gardens	Central Canberra	Exotic Grassland - NTG	Chilean needlegrass, Themeda Austrodanthonia	3.1	25	Mulvaney (2010)	30/12/2010	Single walk and count across whole site		
Beale Cr Deakin	Central Canberra	Exotic Grassland - Natiive Pasture	Chilean Needlegrass, Austrostipa, Bothriochloa	2.8	4	Hogg (2009)	Spring/summer 2009			
Black St - Stirling Ridge	Central Canberra	NTG, Exotic Grassland	Chilean Needlegrass, Themeda, austrodanthonia	20.0	200	Clark (1999)	1/12/99	Opportunistic count	21/12/2008 Mulvaney (2008) 15/12/03 Dunford 05	BW
Brisbane Avenue median strip	Central Canberra	Exotic Grassland, Native Pasture	Chilean Needlegrass, Austrodanthonia	0.1	4	Rowell (2006)	1/11/2006	Opportunistic count		
Campbell Office Site/Consitution Avenue	Central Canberra	Exotic Grassland, NTG	Chilean Needlegrass, Austrostipa, Themeda	4.0	63	Richter (2009)	Spring/summer 2008	Average of 7 moths counted in 15m circle	Hogg (2007), Rowell (17/12/2009)	RC
Captain Cook Crescent Griffith	Central Canberra	Exotic Grassland	Chilean Neeedlegrass, Austrodanthonia	1.0	6	O'Sullivan (2009)	28/11/2009	Opportunistic count over two days		
Commonwealth Avenue/Parks Way Coverleafs	Central Canberra	Exotic Grassland - Native Pasture	Chilean Needlegrass - Austrostipa	2.2	200	Rees (2009)	16/11/2009	Opportunistic count		
Dudley St Yarralumla - North Curtin horse paddocks	Central Canberra	Exotioc Grassland, NTG, Native pasture	Chilean Needlegrass, Austrodanthonia, Themeda	22.9	373	Richter + Mulvaney (2008)	3 visits November/December 2008		14/11/05 Dunsford, 15/12/03	

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Peak moth count	Source of max count	Date of max count	Other survey information	other counts and sources	Other species present *
Fisher Park Ainslie	Central Canberra	NAtive Pasture, exotic grassland	Chilean Needlegrass, Austrostipa, Austrodanthonia	1.6	1	Dunford (2004)	1/11/2004	Total from circular counts		
Haig Park	Central Canberra	Exotic Grassland	Chilean Needlegrass, Austrostipa	1.0	20	Pullen(2006)	1/11/2006	Opportunistic count		
Hampton Circuit Park Yarralumla	Central Canberra	Exotic Grassland - Native Pasture	Chilean Needlegrass, Paspalum, Austrodanthonia	1.0	2	Dunsford (2006)	23/11/2006	Single walk and count across whole site	7/12/2008 Mulvaney (2008)	
Lady Denman Drive - Yarralumla Woolshed	Central Canberra	Exotic Grassland, Native Pasture, NTG	Austodanthonia, Chilean needlegrass	21.5	188	Mulvaney (2008)	7/12/2008	Opportunistic counting of whole site		
Limestone Avenue median strip	Central Canberra	Exotic Grassland, native Pasture	Chilean Needlgegrass, Austrostipa	1.3	30	Pullen (2006)	1/11/2006	Opportunistic count	27/11/2003 Dunsford,	
Lyneham	Central Canberra	Exotic Grassland, NTG	Chilean needle grass, Austrostipa	3.4	2	Rowell (2006)	1/11/2006	Opportunistic count		
Mcintyre Street - Griffith	Central Canberra	Native Pasture, Exotic Grassland	Austrodanthonia, chilean needlegrass	0.1	5	Rowell (2006)	1/11/2006	Opportunistic count		
South East Captian Cook Crescent	Central Canberra	Exotic Grassland, native pasture	Chilean Needlegrass Austrodanthonia	0.9	4	O'Sullivan (2009)	28/11/2009	Opportunistic count over 2 days		
York Park + Sydney Avenue median Strip	Central Canberra	NTG, Exotic Grassland, Native Pasture	Austrostipa, Austrodanthonia, Chilean NeedleGrass	0.9	163	Harwood et al (1995)	17/11/94 - 2/1/95	Estimate from capture and release study	Cook et al 1993 1994, Rowell 06 Richter 09	RC
Block 799, Gungahlin	Gungahlin	Native Pasture	Austrostipa, Austrodanthonia	5.2	7	Hogg and Moore (2011)	Nov -Dec 2010	<1 moth per 100m of transect		SLL
Name of site	**District**	**Main Habitat Types**	**Dominant species present**	**Habitat size (ha)**	**Peak moth count**	**Source of max count**	**Date of max count**	**Other survey information**	**other counts and sources**	**Other species present ***

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Peak moth count	Source of max count	Date of max count	Other survey information	other counts and sources	Other species present *
Elmgrove	Gungahlin	Native pasture, Exotic Pasture	Austrodanthonia	1.3	11	Hogg (2010)	12/12/2009	Meandering traverse 2 moths observed a minute		
North Mitchell	Gungahlin	NTG, Native Pasture	Austrodanthonia	14.6	28	Richter (2009)	Two visits spring/summer 2008	<1 moth per 15m circular rotation	10/12/2003 Dunford	SLL
Little Mulligans North	Gungahlin	Open Woodland	Themeda, Austrodanthonia	1.3	4	Ecological Australia 2011	29/11/11 and 7/12/2011	Meander survey		
Mulligans Flat South West	Gungahlin	Open Woodland	Themeda, Austrodanthonia	3.1	2	Ecological Australia (2011)	29/11/11 and 7/12/11	Meander survey		
Mulligans Flat West	Gungahlin	Open Woodland	Themeda, Austrodanthonia	3.0	3	Ecological Australia (2011)	29/11/11 and 7/12/11	Meander survey		
Crace Nature Reserve GU03	Gunghalin	NTG, Native Pasture	Austrodanthonia, Austrostipa	64.8	163	Osbourne (2010)	26/11/2009		Richter 2009) Blue Gum (29/11, 15,22/12/11)8/12 /03	SLL,P,BW
East Bonner/ Horse Park	Gunghalin	Open Woodland	Themeda, Austrodanthonia, Phalaris	30.0	38	Edwards 1994	30/11/93	Fixed circular counts 9.5 per minute	17/12/2009 Rowell (2009)Nash, Hogg, Rowell (2008)	P
East Crace Nature Reserve	Gunghalin	NTG, Native Pasture	Austrodanthonia, Austrostipa, Phalris	3.9	6	Blue Gum 29/11, 15.22/12/11, 8/12/11	26/11/2009	<2 moths per 100m transect		SLL,P,BW
Forde North	Gunghalin	Exotic Pasture, Native Pasture	Phalaris, Austrostipa, Austrodanthonia,	0.0	34	McIntosh, Nash and Hogg (2010)	26/11/2009, 8,13+15/12/2009	5 moths per fixed circular count		

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Max moth count	Source of max count	Date of max count	Other survey information	Source of other counts	Other species present *
Goorooyarroo - East Mulligans, Throsby	Gunghalin	Open Woodland Native Pasture	Austrostipa, Austrodanthonia, Themeda	442	210	Blue Gum 2012, EA + Rowell (2009)	15/12/10, 27/01/2011, 29/11/11, 22/12/11	<2 moths per 100m transect	Rowell Dec 2009, ecological Australia (2011)	
Goorooyarroo East	Gunghalin	Open Woodland	Austrostipa, Austrodanthonia, Themeda	0.9	50	Holliday (Oportunist sighting)	1/12/2005	Opportunistic sighting		
Goorooyarroo S-E section	Gunghalin	Native Pasture	Austrostipa, Austrodanthonia	3.7	13	Blue Gum (2012)	15/11/2011, 28/11/2011	<2 moths per 100m transect		
Horse Park Drive West	Gunghalin	Native Pasture - Exotoc pasture	Austrodanthonia, Austostipa, Phalaris, Fescue	2.5	4	Hogg (2012)	15/11/2011, 9/12/2012	<2 moths per 100m transect		
Horsepark	Gunghalin	Native Pasture, Exotic Pasture	scattered patches of Austrodanthonia, Phalarus	0.8	2	Hogg (2010)	12/12/2009	Meandering traverse <2 moths per minute		
Jacka	Gunghalin	Native Pasture	Austrostipa	0.9	2	Hogg (2010)	12/12/2009	Meandering traverse <2 moths per minute		
Jacka south	Gunghalin	Native Pasture, Exotic Pasture	scattered patches of Austrodanthonia, Phalarus	1.6	6	Hogg (2010)	12/12/2009	Meandering traverse <2 moths per minute		
Kenny	Gunghalin	Native Pasture	Austrostipa	2.8	7	Moore atal (2011)	17/01/2011	Meandering traverse <2 moths per minute	16/12/2009 Hogg and McIntosh (2010)	
Kinleyside	Gunghalin	Open woodland	Austrostipa, Themeda, Austrodanthonia	28.6	114	Ecological Australia (2011)	28/11/2011, 9/12/11, 21/12/11	Meander survey	24/11, 13/12/2010, 24/01/2011 Ecological 2011	

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Max moth count	Source of max count	Date of max count	Other survey information	Source of other counts	Other species present *
Moncreiff North	Gunghalin	Native Pasture, Exotic Pasture	scattered patches of Austrodanthonia, Phalarus	0.8	2	Hogg (2010)	12/12/2009	Meandering traverse <2 moths per minute		
Moncrieff	Gunghalin	Native Pasture Open Woodland	Themeda, Austrodanthonia	35.5	114	Hogg (2010)	23/12/2010	Transect count	17/12/2009 (Hogg 2010)	
Mulanggari Nature Resrve	Gunghalin	NTG	Austrostipa, Themeda, phalaris, cocksfoot	81.8	28	Dunsford 2005	8/12/2003	Meander over whole site	Hogg 2011 15/12/94 Edwards Richter 2009	SLL,P
North Gungaderra Nature Reserve	Gunghalin	NTG, Native Pasture, Exotic pasture	Themeda, Phalarus, Austrodanthonia, Austrostipa	0.9	2	Richter (2009)	1/11/2009		Richter (9/11/2008) 3/12//11+3,18/1/12 SMEC (2012)	SLL,P
North Jacka	Gunghalin	Native Pasture, Exotic Pasture	scattered patches of Austrodanthonia, Phalarus	4.3	13	Hogg (2010)	12/12/2009	Meandering traverse <2 moths per minute		
North Mulligans Flat	Gunghalin	Open Woodland	Austrostipa, Austrodanthonia, Themeda	1.0	5	Ecological (2012)	27/01/2011, 29/11/11, 22/12/11	Meander survey		
North west Kenny	Gunghalin	Native Pasture	Austrostipa, Austrodanthonia	0.8	5	Nash, McIntosh + Hogg (2010)	17/01/2011	<2 moths per 100m of transect		
NW Mulligans Flat	Gunghalin	Open Woodland	Themeda, Austrodanthonia	10.8	13	Ecological Australia (2011)	29/11/11 and 7/12/11	Meander survey		
One Tree Hill - South	Gunghalin	Open Woodland/Open Forest	Austrostipa, Austrodanthonia	4.7	23	Ecological Australia 2010	23/11/2010, 23/12/2010, 35/01/11	Meander survey		
One Tree Hill - North	Gunghalin	Open Woodland/Open Forest	Austrostipa, Austrodanthonia	3.9	13	Ecological Australia 2010	23/11/2010, 23/12/2010, 35/01/11	Meander survey		

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Max moth count	Source of max count	Date of max count	Other survey information	Source of other counts	Other species present *
Taylor	Gunghalin	Native Pasture	Austrostipa, Austrodanthonia	56.0	92	Moore Nash +Hogg (2012)	15/11/2011, 9/12/2011	Meander survey 1 moth per 3 minutes	15 + 31/12/2010 Moore, McIntosh + Hogg 2011	
Taylor East	Gunghalin	Native Pasture	Austrostipa, Austrodanthonia	0.9	6	Moore Nash +Hogg (2012)	15/11/2011, 9/12/2011	Meander	15 + 31/12/2010 Moore, McIntosh + Hogg 2011	
West Gungaderra Nature Reserve	Gunghalin	NTG, Native Pasture, Exotic pasture	Themeda, Phalaris, Austrodanthonia, Austrostipa	1.1	4	Richter (2009)	2 visits spring/summer 2008		1/11/94 Rauhala 3/12//11+3,18/1/12 SMEC (2012)	SLL,P
Jerrabomberra East	Jerrabomberra	NTG	Austrodanthonia, Austrostipa	23.2	7	Osborne (2009)	19/11/2009	7 moths per circular count		GED,SLL,RC
ACT Bonshaw lease (Canberra Avenue)	Jerrabomberra	Native Pasture	Austrostipa, Austrodanthonia	0.3	10	Ecological (2012)	8/11/2011 + 6/12/2011	meander		
ACT Bonshaw lease (next to Harman)	Jerrabomberra	Native Pasture - Exotic Pasture	Austrostipa, Austrodanthonia	0.9	24	Ecological (2012)	15/11/11	meander		GED,SLL,
Amtech site Fyswick JE09	Jerrabomberra	Native Pasture, NTG	Austrodanthonia, Austrostipa	2.6	11	Rowell (2009)	4/12/2009		Richter (2009)	SLL,P,RC
Cookanella	Jerrabomberra	NTG	Austrostipa, Austrodanthonia	8.0	10	Ecological (2012)	13 + 23/12/2011	meander		GED,P
Jerrabomberra West Reserve	Jerrabomberra	NTG	Austostipa, Austrodanthonia	21.6	452	Osborne(2009)	19/11/2009	7 moths per 100m of transect	Richter (2009),16/12/03 Dunsford 29/11/93 Edwards	GED
Majura Road Tree Planting	Majura	NTG, Exotic Grassland	Austrostipa, Chilean needlegrass	2.8	40	Wong (2008)	1/12/2005	Opportunistic counting of whole site		
Majura Road West - southern section	Majura	Native Pasture	Austrostipa/Austrodanthonia +exotics	3.9	1	Rauhala (1994)	1/11/1994	Opportunistic sighting		SLL

Name of site	District	Main Habitat Types	Dominant species present	Habitat size (ha)	Max moth count	Source of max count	Date of max count	Other survey information	Source of other counts	Other species present *
Majura West + Campbell Park	Majura	NTG, Native Pasture, Exotic Grassland	Austodanthonia, Austrostipa	59.3	39	Biosis + Rowell (2011) CPRichter (2009)	WM 28/11/2011 CP 2 visits Spring.summer 2008	Opportunistic sighting	WM SMEC (2012 + 2008) CP 6 +16/12/03 Edwards	GED,SLL,P, BW
SE Airport	Majura	NTG, Native Pasture, Exotic	Austrodanthonia Austrostipa + exotics	4.4	17	Richter (2008)	9/11/2008	Circular count <2 moths per count	Rowell (2004)	
SE Majura Valley (airport, malcomvale + MTA)	Majura	NTG, Native Pasture, Exotic	Austrodanthonia Austrostipa + exotics	395.9	5347	Rowell (2003) Rowell 2004 (MV) Edwards 94 MTA	Nov -Dec 2003	Transect count	December 2006 Rowell, Richter (2009)	GED, SLL, P,RC,BW

* GED = Grassland Earless Dragon, SLL = Striped Legless Lizard, P = Perunga Grasshopper, RC = Canberra Raspy Cricket, BW = Button Wrinklewort

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The habitat of the Golden Sun Moth *Synemon plana* (Lepidoptera; Castniidae)

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The Golden Sun Moth *Synemon plana* Walker 1854 is a diurnal moth belonging to the family Castniidae in the insect order Lepidoptera. The Castniidae includes 30 genera with representatives in the Neo-tropical, Oriental and Australian regions indicating a Gondwanan origin. The Australian species are represented by a single endemic genus (*Synemon*) which contains about 43 species (E. D. Edwards, CSIRO Entomology, pers. comm.), seven of which are found in Victoria (Douglas 1993). Many of these are considered endangered or vulnerable. *S. plana* was once widespread and relatively continuous throughout its range in southeastern Australia (Fig. 1) showing a close correlation with the distribution of grasslands dominated by *Danthonia*. It was once found as far north as Bathurst and the Yass Plains in New South Wales (Edwards 1991), throughout central and southern Victoria, and in Bordertown in South Australia (Atlas of Victorian Wildlife Database, Department of Natural Resources and Environment; Fig. 1). It also occupied large areas of the Australian Capital Territory (Edwards 1991; Fig. 1). Throughout the processes of urbanization and expansion of agriculture, most of the grassland habitat within which *S. plana* survives has disappeared. Native grasslands within Victoria have been reduced by 99% since European settlement in 1778 (Groves 1979; Department of Conservation and Environment 1992). Populations of *S. plana* have become fragmented and isolated. In 1996, *S. plana* was only known from 10–12 sites in the Australian Capital Territory, five to six sites in Victoria and one site in New South Wales (Fig. 1). Consequently, *S. plana* is listed as endangered and is protected in all states under their respective legislations.

S. plana adults are unique among *Synemon* species for having semi-flightless females and exhibiting a high degree of sexual dimorphism. Adult males are bronzy-brown and black, undersides are pale grey and brown, with a wingspan of about 3.5 cm. Adult females have relatively reduced (3.0 cm) bright-orange hindwings with black submarginal spots. The females emerge from the pupa with fully developed eggs, ready to mate. Although females can fly they tend to lay in wait, flashing their hindwings to catch the attention of patrolling males (Harwood *et al.* 1995). This reduced inability to fly long distances (<100 m from the habitat) makes (re)colonization difficult if not unlikely. The females deposit the eggs between the tillers of *Danthonia* tussocks where it is thought that they hatch in about 21 days. It is probable that the first instar larva tunnels into the tillers of the food plant feeding internally on the plant tissue for 11 months and then migrates into the soil to feed externally on the rhizomes and roots for probably an additional 11 months (see Common and Edwards 1981). While it is thought that *Danthonia* is the preferred food plant it is not known for certain, this information being based on the presence of cast pupa shells and tunnels leading to nearby tussocks. Before pupation, a vertical tunnel to the soil surface is constructed, housing the pupa until eclosion (Common and Edwards 1981). After six weeks, adult moths emerge and are active in the hottest part of sunny days between mid November and mid December. Each individual survives for up to four days, unable to feed because they lack functional mouthparts (Edwards 1991).

There is little information about the ecology of *S. plana*, or its habitat requirements, which is vital information for restoration efforts. The aims of this study were to describe its habitat and to determine the components necessary for its survival. Twelve current sites (eight in the Australian Capital Territory and four in Victoria) and two historical sites (Victoria) were investigated and compared. The differences between the historical and current sites highlight the components that make the site unsuitable for *S. plana*. Six of the sites in the Australian Capital Territory are on public land such as roadside verges, one was on private land and one was protected within a conservation reserve. Three of the Victorian sites are

Pp. 322–24 in *The Other 99%. The Conservation and Biodiversity of Invertebrates* ed by Winston Ponder and Daniel Lunney, 1999.
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Figure 1. The historical (o) and current (■) distribution of *Synemon plana*. The historical distribution was determined from museum specimens and entered into the Atlas of Victorian Wildlife Database, Department of Natural Resources and Environment. (O'Dwyer and Attiwill, submitted).

protected within reserves and only one was on private property.

Floristic and soil surveys showed that the habitat of *S. plana* was a native grassland dominated by *Danthonia*, particularly, *D. carphoides*, *D. auriculata*, *D. setacea*, and *D. eriantha*. The percentage cover of *Danthonia* at all sites was greater than 40% (O'Dwyer and Attiwill, submitted). At some sites the cover of *Danthonia* was between 50 and 75%. Other vegetation included *Bothrichloa macra*, *Themeda triandra*, *Stipa bigeniculata*. *Wahlenbergia* spp., *Chrysocephalum apiculatum* and *Lomandra filiformis*. The percentage cover of annual grasses, *Vulpia bromoides*, *Briza minor* and *Aira elegans* was low (between 1 and 5%). The soils from all sites inhabited by *S. plana* ranged from sands to clays to loams, and soil pH was slightly acidic to basic. Soil chemistry varied among the sites, with the concentration of available phosphorus (P) being always less than 14 μg/g within the current sites (O'Dwyer and Attiwill, submitted). Concentrations of available P above 14 μg/g were associated with weeds that have a competitive advantage over *Danthonia* and hence reduce the habitat occupied by *S. plana* (O'Dwyer and Attiwill, submitted). Weeds reduced the growth of *Danthonia* and therefore resulted in the loss of habitat occupied by *S. plana* (Dear 1997).

This study clearly shows relationships between soil fertility, the percentage cover of weeds and the percentage cover of *Danthonia*. This enables some predictions about the habitat and the habitat requirements of *S. plana*, which are necessary for the development of a conservation strategy or a recovery plan. Past management practices also need to be considered to determine suitable management regimes. For example, the persistence of native grassland vegetation within the Australian Capital Territory is a consequence of the dry, cold conditions and the accumulation of pockets of cold air in the floor of valleys, creating temperatures too low for the survival of tree and shrub seedlings (Chan 1980). Grazing within the Victorian sites prevented the regeneration of a shrubby-woodland and hence maintaining an open native grassland. Understanding these relationships will enable land managers or land-owners to react to changes in vegetation and to implement a regime that increases the percentage cover of *Danthonia*, and decreases the cover of weeds, thereby protecting the native grassland habitat and the associated components, including *S. plana*.

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A comparative study of habitats of the Golden Sun Moth *Synemon plana* Walker (Lepidoptera: Castniidae): implications for restoration

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Abstract

The Golden Sun Moth (*Synemon plana*) is currently known from about 10–12 sites in the Australian Capital Territory, 5–6 sites in Victoria and 1 site in New South Wales. It is listed as endangered and is protected in these states. Soils and vegetation of sites inhabited by *S. plana* and of two historical locations were compared. The habitat of *S. plana* is native grassland dominated by *Austrodanthonia* spp., in particular *A. carphoides, A. auriculata, A. setacea*, and *A. eriantha*. The percentage cover of *Austrodanthonia* spp. at currently inhabited sites was greater than 40%. Soils were variable, ranging from sands and clays to loams. The pH of the soils was slightly acidic to basic but concentration of available P at inhabited sites was always less than 14 $\mu g\ g^{-1}$. At the historical sites concentrations of available P were greater than 14 $\mu g\ g^{-1}$ and were associated with weeds that have a competitive advantage over *Austrodanthonia* spp. and hence reduced the habitat occupied by *S. plana*. *Lolium perenne* (perennial ryegrass), an exotic species introduced for agriculture is common in many areas occupied by *A. eriantha*. A pot experiment was established to determine the effects of added phosphorus on competition between *A. eriantha* and *L. perenne*. The application of phosphate did not affect growth of *A. eriantha* but increased the growth of *L. perenne*. The growth of *A. eriantha* decreased when grown with *L. perenne* and it is hypothesised that allelochemicals exuded by the roots of *L. perenne* decreased the rate of uptake of P and N by the roots of *A. eriantha*.

Keywords: *Synemon plana*; *Austrodanthonia eriantha*; Restoration; Moths; Habitat; Phosphorus; Soil chemistry

1. Introduction

The Golden Sun Moth (*Synemon plana* Walker), endemic to Australia, is a small brightly coloured diurnal moth (family Castniidae, order Lepidoptera). At the time of European settlement, *S. plana* was widespread in southeastern Australia and relatively continuous throughout its range, showing a close correlation with the distribution of native grasslands dominated by *Austrodanthonia* spp. (Edwards, 1993; formerly *Danthonia* DC: Linder, 1997). Historical records show that *S. plana* was found as far north as Winburndale near Bathurst and the Yass Plains in New South Wales (NSW) (Edwards, 1991). *S. plana* once inhabited vast areas of central Victoria from Bright in the east to Nhill in the west, through to Bordertown in South Australia (Fig. 1). It also occupied large areas of the Australian Capital Territory (ACT) (Edwards, 1991). Concurrently, native grasslands covered about a third of Victoria (Groves, 1979). Today these grasslands occupy less than 0.5% of their original range, persisting as small remnants along railway lines, on road verges, and in cemeteries (Kirkpatrick, 1993). Fragmentation of the grassland habitat dominated by *Austrodanthonia* spp. has resulted in *S. plana* becoming restricted in its range (Falconer, 1991). In 1994 *S. plana* was known from ten sites in the ACT, 5 sites in Victoria and 1 site in NSW (Fig. 1). The decline of *S. plana* is largely caused by the loss of suitable food plants. The widespread replacement of native vegetation with pasture plants and changes in vegetation due to ploughing, wetland drainage, the addition of agricultural chemicals, fire and grazing regimes and urbanisation have resulted in the decline of native grasslands and the loss of their associated invertebrate fauna. *S. plana* is now classified as endangered and protected under the Flora and Fauna Guarantee Act, 1988, Victoria, the Threatened Species

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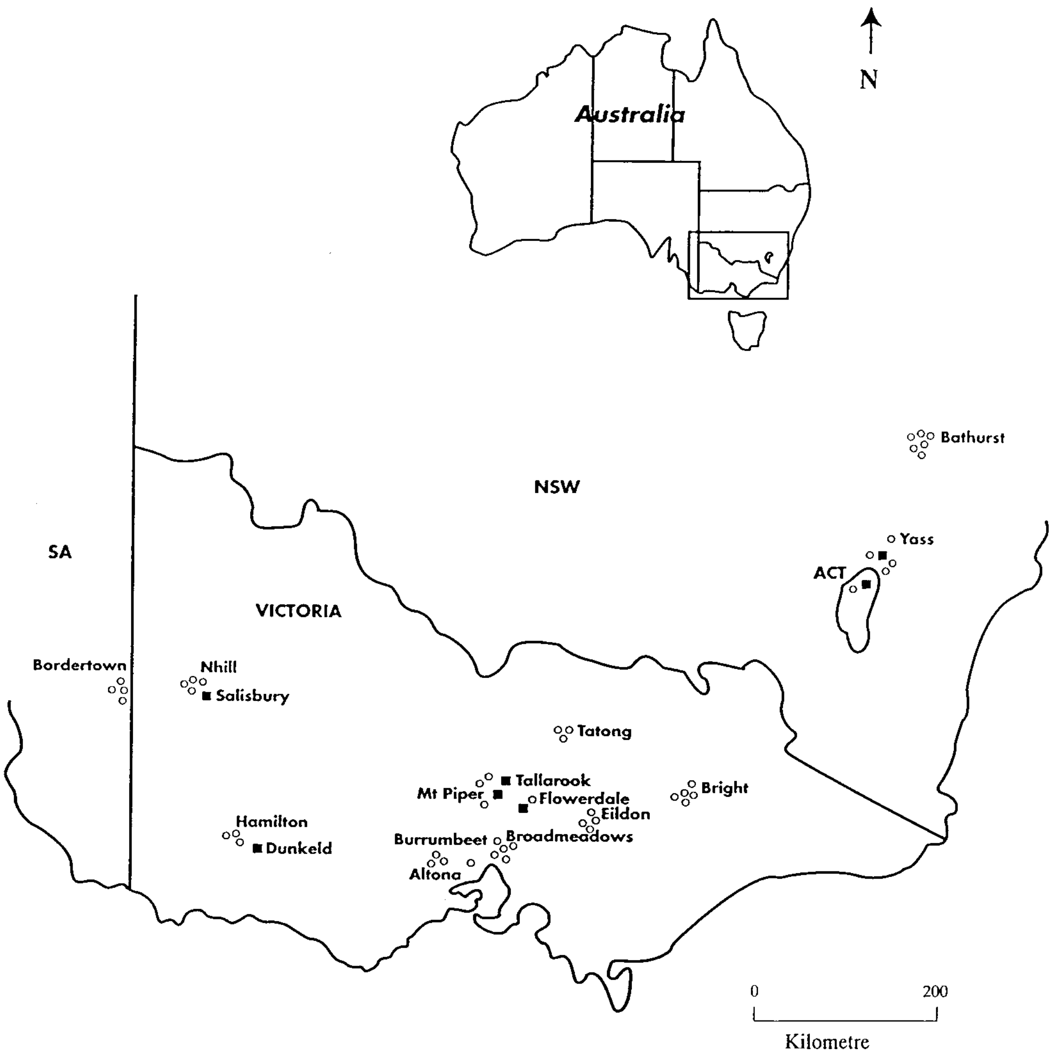

Fig. 1. Distribution of *Synemon plana* prior to European settlement (O) based on historical records (Department of Conservation and Environment, 1991; Edwards, 1991) and current distribution (■).

Conservation Act, 1995, NSW and the Nature Conservation Act, 1980 ACT.

There is little information about the biology, ecology and, in particular, the habitat requirements of *S. plana*. Common and Edwards (1981) described the life history of *S. magnifica* Strand and the life history of *S. plana* is probably similar (E.D. Edwards, pers. comm. 1996). The aim of this study is to analyse the vegetation, climate and soil of sites currently inhabited by *S. plana* and of historical sites (sites previously but not currently inhabited by *S. plana*). The data will then define common properties that make currently inhabited sites suitable for *S. plana*. Comparison of data between currently inhabited and historical sites will identify changes that make the historical sites no longer suitable for *S. plana*. The data are then used in an investigation of the effects of changed soil conditions in modified grasslands on the growth of *Austrodanthonia* spp. in competition with weed species.

2. Methods

2.1. Study sites in the Australian capital territory

Eight sites in the ACT were visited during September 1995 (Table 1). All of the sites were around the urban areas of Canberra. Areas within each site where *S. plana* had previously been observed (E.D. Edwards, CSIRO Division of Entomology, Canberra. pers. comm.) were studied.

2.2. Study sites in Victoria

Six sites (four current, and two historical sites of *S. plana*) were investigated within Victoria (Table 1). Whilst the management regimes on many of these sites do not specifically preserve the grasslands, many of the sites have been given reserve status, placing restrictions on the use of the land.

Table 1
Location of sites currently inhabited by *Synemon plana* and of historical sites no longer inhabited by *S. plana*

Site name	Location	Comments
Currently inhabited sites, Australian Capital Territory		
Army Firing Range	Majura Rd, Canberra, Lat 35° 16' 59" Long 149° 13' 12"	A large site located along the front of the entrance and extending into the range.
CSIRO[a]	Limestone Avenue, Canberra, Lat 35° 16' 37" Long 149° 8' 42"	A small site in front of the main building adjacent to a main road.
Department of Defence	Campbell Park Offices, Canberra, Lat 35° 16' 59" Long 149° 10' 16"	Opposite car park. Site is adjacent to private grazing properties, but it itself is protected from public access and grazing. An open site with a high percentage cover of bare ground.
Didams Parkland	Didams Rd, Canberra, Lat 35° 13' 59" Long 149° 04' 08"	A recreational parkland on the banks of Lake Gundaroo. The site is small (40 × 50 m).
Dudley Street	Dudley Street, Canberra, Lat 35° 18' 54" Long 149° 05' 35"	A small roadside verge on the northern side of Dudley street.
Maiden Street	Maiden Street, Canberra, Lat 35° 18' Long 149° 05' 53"	A small grassland site on the banks of Lake Burley Griffin. Oak trees boarded the site.
Mulligans Flat	Gundaroo Rd, ACT Lat 35° 02' 22" Long 149° 15' 06"	Mulligans Flat is a nature reserve which extends from the ACT and across the NSW boarder. A private sheep grazing property abuts the site on the ACT side.
York Park	Sydney Ave, Barton. ACT, Lat 35° 18' 40" Long 149° 07' 59"	The site is bounded by National Circuit near Parliament House. The population of *Synemon plana* at York Park has been extensively studied and is thought to be the largest known population.
Currently inhabited sites, Victoria		
Dunkeld	Woodhouse Rd, Dunkeld, Lat 37° 41' 50" Long 142° 21' 36"	A private sheep grazing property. *S. plana* was first found in 1995 (Dear, 1996). Native grassland areas are not fertilised.
Mount Piper	Jefferies lane, Broadford, Lat 37° 12' 07" Long 145° 00' 36"	A small conical peak 230 m above an undulating plain of private grazing properties (Ashton, 1976). It is an educational reserve managed by Parks Victoria. It is protected under the Flora and Fauna Guarantee Act as 'Butterfly Community No.1'.
Salisbury 1	Western Highway, Salisbury, Lat 36° 21' 57" Long 141° 46' 08"	A bushland reserve approximately 500 × 500 m in area. The Highway, dirt road and private properties bound the reserve.
Salisbury 2	Western Highway, Salisbury, Lat 36° 21' 47" Long 141° 46' 15"	The two Salisbury sites are located 100 m apart, separated by a large patch of *Avena barbarta*.
Historical sites, Victoria		
Flowerdale	Flowerdale/Whittlesea road, Lat 37° 19' 40" Long 145° 17' 53"	A population of *S. plana* was last recorded here in 1938 (Department of Natural Resources and Environment, 1995).
Tallarook	Hume Highway, Tallarook, Lat 37° 06' 03" Long 145° 06' 07"	The site is a roadside verge located 1 km north of Tallarook. A population of *S. plana* was last recorded here in 1993 (Douglas, 1993) but has not been observed since. Private properties border the site.

[a] CSIRO—Commonwealth Scientific Industry Resource Organisation.

2.3. Floristics

The percentage cover of all plant species was recorded using the Braun/Blanquet cover abundance scores located within 5 (1 × 1 m) quadrats within a 10 × 10 m plot on each site. Plant taxonomy follows that of Willis (1972) and Walsh and Entwistle (1995, 1996).

2.4. Bioclimatic prediction system

BIOCLIM (Nix, 1986; Busby, 1991) is a model that produces a climatic profile for a given site. Latitude, longitude and elevation for all the sites were sent to the Centre for Resource and Environment Studies (CRES), Australian National University, Canberra. From these data, 35 climatic variables (representing annual and seasonal means) were calculated. These variables were then used in BIOCLIM to define a climatic profile for *S. plana*. All the grid points falling within the climatic profile of *S. plana* were extracted, giving a predicted distribution of *S. plana*.

2.5. Soils

Soil profiles were described to a depth of 50 cm and were classified according to Northcote (1979). Four soil core samples (0–10 cm) were collected from each site around the perimeter of the 10 m quadrat and bulked together into one sample. This was replicated three times. The soils were air-dried and sieved to <2 mm. Soil particles >2 mm (gravel) were weighed and the percentage of gravel in the sample calculated. The soil fraction <2 mm was analysed for available phosphorus, extracted using Bray and Kurtz No. 2 solution (0.1 M $HCl + 0.03$ M NH_4F; Bray and Kurtz, 1945) and measured by automated colorimetry (Technicon, 1977).

Soils were digested on preheated blocks (Technicon BD-40 Block-digester: 340°C for 4 h) with 2 ml H_2SO_4 + Se (Bremner, 1960; Schuman et al., 1973) and analysed by Technicon Auto Analyser (Technicon, 1977) to determine the concentration of total nitrogen (N). Oxidisable organic carbon was determined using the Walkley-Black method (soil < 1 mm; Walkley, 1947) and the size distribution of particles (< 2 mm) in soil samples was determined using the pipet method (Gee and Bauder, 1986). The concentration of exchangeable cations was determined by leaching ammonium acetate (pH 7) through a 20 cm column containing 2 g air-dried soil + 4 g acid washed sand and analysing the extract by atomic absorption spectrophotometry. The soil/sand sample was washed with ethanol and 200 ml of 2 mol l^{-1} KCl was leached through the sample. The extract was collected and the NH_4^+ eluted was analysed (Technicon, 1977), to determine the cation exchange capacity (CEC) of the soil sample. Soil pH was measured in distilled water (1:5 soil/water ratio) after stirring for 1 h (Jackson, 1962).

2.6. Pot experiment

From the results of the studies described above, it was clear that an increase in weed cover and a consequential decrease in cover of *Austrodanthonia* spp. was associated with an increase in available P in the soil. A pot experiment was therefore established to determine the effects of added P on competition between *Austrodanthonia eriantha* and *Lolium perenne*, an exotic species present in large quantities at Mount Piper. *L. perenne* was introduced into Australia in the late 1850s (Cunningham et al., 1994) and is one of the most widely sown species of grass in Australia. *L. perenne* is common in areas inhabited by *A. eriantha*, prefers similar conditions and has the same photosynthetic pathway (C_3) as *Austrodanthonia* spp.

Seeds of *D. eriantha* and *L. perenne* were collected from Mount Piper, Broadford and stored in paper bags in the dark at 25°C. Seeds were dusted with fungicide (Thirum) and germinated on 2 layers of Whatman No. 41 filter paper in 9 cm Petri dishes with 5 ml of distilled water. In preliminary germination trials, *L. perenne* germinated within 3 days at 26°C, whilst *A. eriantha* germinated in 7 days at 15°C. Hence the preparation of seed lots was staggered so that all seeds germinated simultaneously. Seedlings were transplanted when they reached a height of 3 mm and potted 5 cm apart in 15 cm diameter pots filled with sieved surface soil (0–5 cm) collected from the field site at Mount Piper. Compaction of soil in the pots was reduced by mixing 300 g of soil with 700 g of a commercial sand mix in each pot. Prior to transplanting seedlings, the soil was kept moist to induce germination of buried seeds. Seedlings other than those transplanted were removed as they emerged. Pots were placed outside and covered with aviary mesh. The positions of the pots were alternated each week using randomly generated numbers.

Phosphorus was applied in 5 × 100 ml applications to give a total application equivalent to superphosphate at 125 and 500 kg ha^{-1}, as a solution of $NaH_2PO_4.2H_20$. The first 4 applications were made at fortnightly intervals after transplanting and the final application was given 2 months before harvest. Nitrogen was applied in excess in a 2:1 ratio (N:P) as a solution of $NaNO_3$ + NH_4NO_3. 100 ml of solution was applied evenly to each pot to minimise leaching, to ensure that the soil was saturated and that the nutrients were distributed evenly throughout the pot.

Four seedlings were planted in pots in the following combinations: (1) Four seedlings of *A. eriantha*; (2) Two seedlings of *A. eriantha* and two seedlings of *L. perenne*; and (3) Four seedlings of *L. perenne*. Phosphorus treatments were P_0 (control)—0 kg ha^{-1}; P_1—125 kg ha^{-1}; P_2—500 kg ha^{-1}. There were 5 replicates of each treatment and each planting, totalling 45 pots. The plants were harvested after 8 months, and the following indices were measured: tiller number per plant, dry weight of shoots/plant, dry weight of flowering stems/plant and dry weight of roots/plant. Plant material was oven-dried at 80°C and finely ground. A subsample was digested in concentrated H_2HO_4 + H_2O_2 and heated for 4 h at 320°C. The concentrations of P and N were determined colorimetrically using an Auto Analyser (Technicon, 1977).

2.7. Data analysis

Vegetation data were summarised using ordination methods to determine variations in the species compositions among samples. Distance matrices were produced using the Bray-Curtis coefficient of dissimilarity. Non-metric multidimensional scaling (NMDS) ordination was produced using the computer package DECODA (Kruskal, 1964; Minchin, 1989). Soil data were tested for normality and homogeneity of variance prior to statistical analysis by ANOVA. Data were transformed logarithmically where necessary. A *t*-test was used to compare the means after the analysis of variance and significance was determined at the $p < 0.05$ level. The statistical package STATSVIEW was used to test for significant differences.

3. Results

3.1. Floristics

Five species of *Austrodanthonia* spp. were identified: *A. carphoides, A. eriantha, A. auriculata, A. setacea* and *A. racemosa*. *A. carphoides* and *A. auriculata* dominated all the sites in the ACT. *A. setacea* was dominant at the

Salisbury sites, whilst *A. auriculata, A. carphoides* and *A. racemosa* were present in small populations at Mount Piper intermixed in the dense cover of *A. eriantha*.

The percentage cover of *Austrodanthonia* spp. at all the sites inhabited by *S. plana* was greater than 40%. However, the average cover by *Austrodanthonia* spp. at the Department of Defence, Dunkeld, Mount Piper and Salisbury was between 50 and 75% and in some areas within these sites the cover of *Austrodanthonia* spp. was 90%. *Hypochoeris radicata* (Asteraceae), a common weed of disturbed areas, was present at all but two sites, with a cover of 5–25%. The cover of other species—mainly annual grasses such as *Vulpia bromoides, V. ciliata, V. fasiculata, V. muralis, Briza minor, B. maxima* and *Aira elegans*—was between 1 and 5%. The number of species at all the sites was less than 20 and no other plant was common.

The site at Flowerdale was open woodland dominated by *Eucalyptus* spp., *Acacia pycnantha* and *Exocarpus cupressiformis*, with an understorey of grasses dominated by *Anthoxanthum odoratum* (70% cover). The Tallarook site contained mainly introduced species, particularly *Holcus lanatus* (40% cover), *Plantago lanceolota* (30% cover) and *Rumex acetosella* (4% cover). *Acacia pycnantha*, *A. paradoxa*, *Hibbertia raparia* and *Grevillea alpina* dominated the shrubby overstorey. Less than 1% cover of *Austrodanthonia* spp. was recorded in the quadrats at both Tallarook and Flowerdale. The percentage cover of weeds at Tallarook (85%) and Flowerdale (54%) was greater than at all the other sites.

All the sites were floristically different from one another. The vegetation at Mount Piper was similar to Mulligans Flat, and York Park was similar to Dudley Street and Didams Parkland (Fig. 2). Tallarook and Flowerdale, the historical sites, are floristically dissimilar from all the other sites and from one another ($p < 0.005$; Fig. 2). The percentage cover of weeds was negatively correlated with the percentage cover by *Austrodanthonia* spp. The data were best described by a linear function ($y = -1.16x + 61.70$; $R^2 = 0.74$; $p < 0.05$).

3.2. Climate

BIOCLIM predicted that the distribution of *S. plana* is limited to south-eastern Australia, particularly throughout the northern area of the ACT and central Victoria (Fig. 3).

3.3. Soils

The soils ranged from sandy loams to clays, with pH between 5.3 and 7 (Table 2). Concentration of nitrogen, carbon, exchangeable cations and cation exchange capacity ranged similarly over all the sites, both current and historical (Table 2). The only soil property to differ markedly between the current sites and the historical sites was the concentration of available phosphorus (Fig. 4). Concentrations of available P at the historical locations (29.4–35.9 μg g^{-1}) were significantly greater that those at all the current locations (range 5.6–13.1 μg g^{-1}, Fig. 4).

3.4. Pot experiment

Dry weight of both roots and shoots of *A. eriantha* at 8 months was less (up to 700% less) when grown with *L. perenne* under all three treatments of P relative to *A. eriantha* grown on its own [$p < 0.05$; Fig. 5(a)]. The

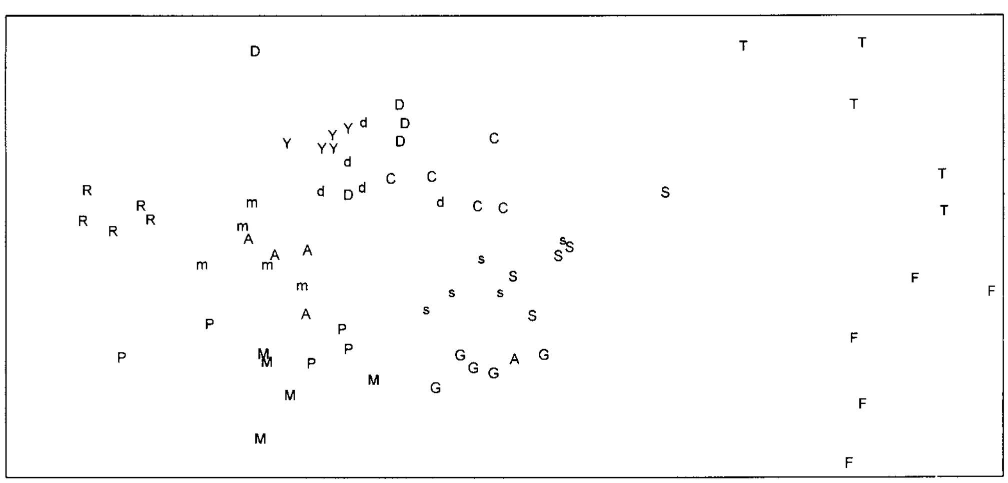

Fig. 2. Non-metric multidimensional scaling ordination of vegetation from *Synemon plana* sites. The location of each point indicates the degree of difference in plant species composition, the most different pairs of samples are those that are furthest apart in the ordination The Tallarook and Flowerdale sites are no longer inhabited by *S. plana*. Army Firing Range, ACT (R), CSIRO Headquarters, ACT (C), Department of Defence, ACT (A), Didums Parkland, ACT (D), Dudley Street, ACT (d), Dunkeld, Vic. (G), Flowerdale, Vic. (F), Maiden Street, ACT (m), Mount Piper, Vic. (P), Mulligans Flat, ACT (M), Salisbury 1, Vic. (S), Salisbury 2, Vic (s), Tallarook, Vic. (T), York Park, ACT (Y).

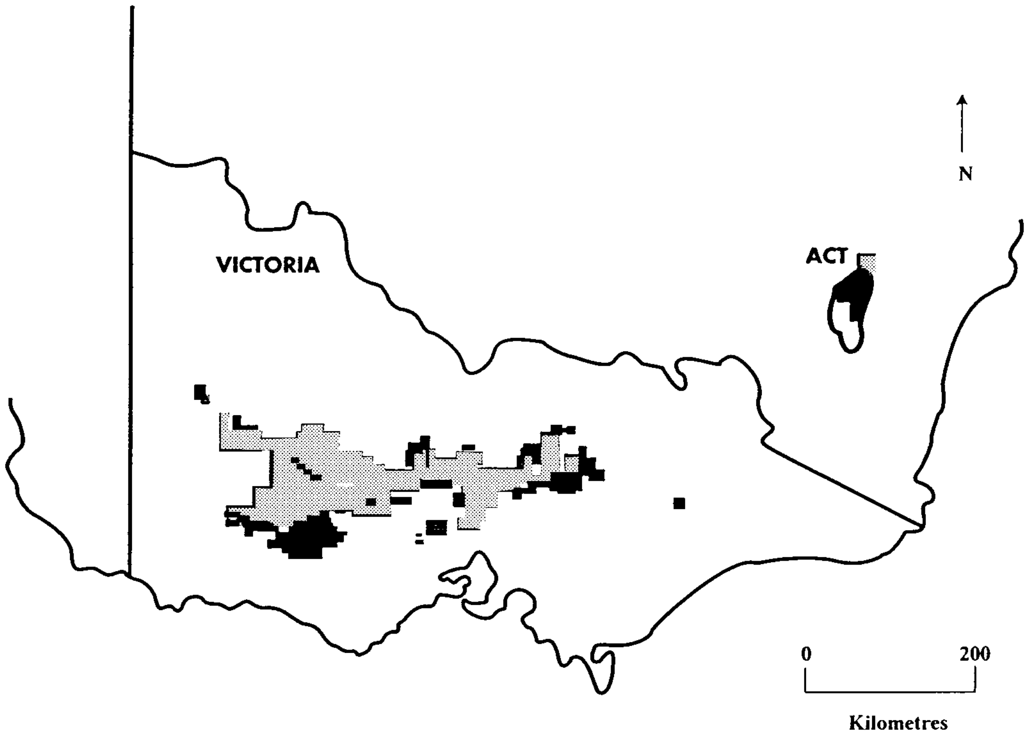

Fig. 3. Bioclimatic predictions of the distribution of *Synemon plana* based on the weather parameters of 14 sites inhabited by *S. plana*. Darker solid areas represent range limits. Information obtained from the Centre for Resource and Environmental Studies, Australian National University, Canberra.

Table 2
Soil properties at sites currently inhabited by *Synemon plana* and at historical sites where *S. plana* was previously, but is now no longer, observed

Property	Current sites—range (mean–standard error)		Historical sites (mean ± standard error)	
	ACT	Victoria	Flowerdale	Tallarook
Nitrogen, μg g^{-1}	887 ± 65–1840 ± 381	1042 ± 106–2435 ± 422	1558 ± 232	931 ± 182
Carbon, %	1.29 ± 0.06–4.35 ± 0.24	1.53 ± 0.25–4.12 ± 0.48	3.34 ± 0.22	1.79 ± 0.38
C/N	9.7–18.5	10.7–12.8	16.1	14.5
Calcium, cmol (1/2Ca^{2+}) kg^{-1}	2.7 ± 0.3–9.5 ± 0.7	0.8 ± 0.3–9.2 ± 2.3	1.3 ± 0.1	1.9 ± 0.5
Magnesium, cmol (1/2Mg^{2+}) kg^{-1}	0.9 ± 0.1–2.4 ± 0.1	0.3 ± 0.2–1.7 ± 0.3	1.0 ± 0.1	2.1 ± 0.4
Potassium, cmol (K^{+}) kg^{-1}	0.3 ± 0.1–0.6 ± 0.1	0.2 ± 0.1–0.8 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
Sodium, cmol (Na^{+}) kg^{-1}	0.0 ± 0.0–0.1 ± 0.1	0.0 ± 0.0–0.3 ± 0.1	0.0 ± 0.0	0.1 ± 0.0
Cation exchange capacity, cmol (p^{+}) kg^{-1}	9.4 ± 4.9–21.2 ± 4.8	10.4 ± 1.2–15.1 ± 4.2	9.1 ± 2.9	10.7 ± 1.4
pH	5.7 ± 0.04–7.0 ± 0.04	5.3 ± 0.03–5.9 ± 0.06	5.3 ± 0.07	5.6 ± 0.11
Soil type	Sandy loam - clay	Sandy loam - silt loam	Sandy clay loam	Sandy clay loam
Sand %	9 ± 1–69 ± 3	21 ± 2–75 ± 4	70 ± 1	54 ± 1
Silt %	10 ± 0–45 ± 3	10 ± 2–50 ± 1	11 ± 1	13 ± 1
Clay %	20 ± 3–63 ± 4	15 ± 2–28 ± 1	19 ± 1	33 ± 2

addition of P had no significant effect on dry weight of shoots and roots of *A. eriantha* grown on its own or together with *L. perenne*. However, P additions significantly increased the dry weight of shoots of *L. perenne*, particularly when grown with *A. eriantha* [$p < 0.05$; Fig. 5(a)]. The addition of P had no significant effect on the number of tillers/plant produced by *A. eriantha* and *L. perenne*. However, the number of tillers/plant was significantly less when *A. eriantha* was grown with *L. perenne* than when grown on its own (3.3 tillers/plant compared with 15 tillers/plant; $p < 0.05$).

Adding P had no significant effect ($p > 0.05$) on the dry weight of flowering stems produced by *A. eriantha* grown on its own. However, the dry weight of flowering stems of *A. eriantha* grown with *L. perenne* was significantly less (less than 0.001 g/plant compared with 0.057 g/plant; $p < 0.05$), and many plants of *A. eriantha* did not produce flowering stems. The dry weight of

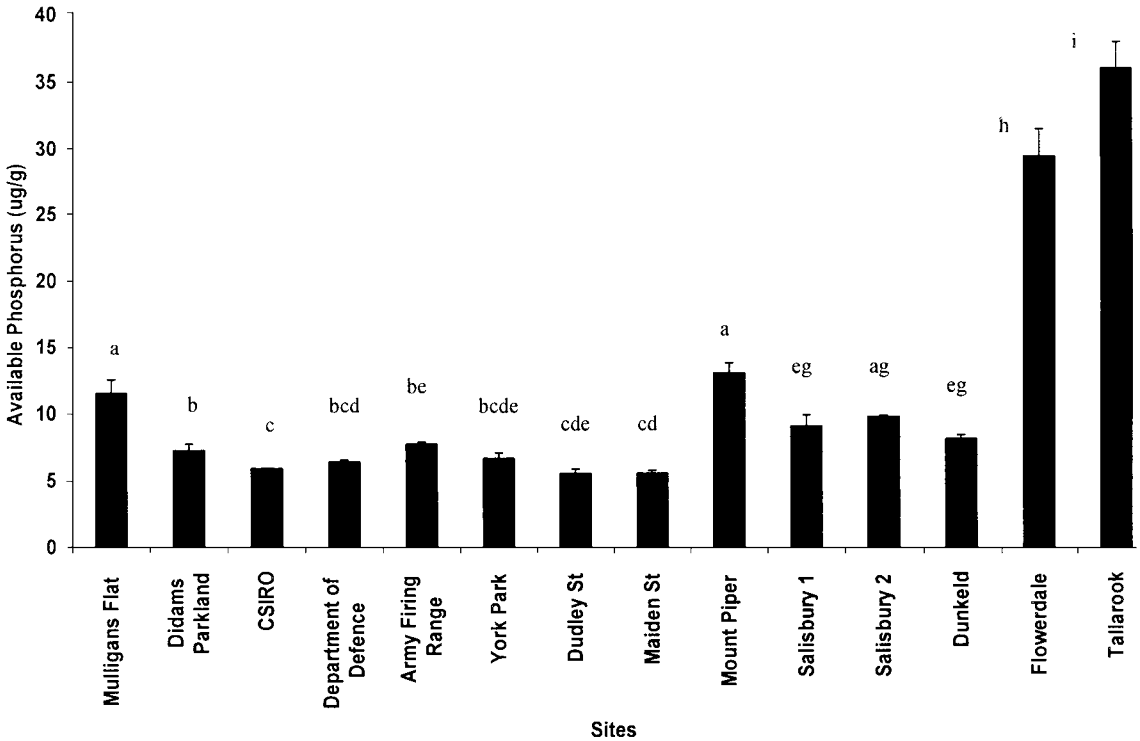

Fig. 4. The concentration of phosphorus (P) in soil samples collected from *Synemon plana* habitats. At each site soils from a depth of 5 cm were collected from 4 random locations and then bulked. Sites with the same letter are not significantly different from one another ($p > 0.05$).

florets produced by *L. perenne* was 4- and 50-fold greater in P1 and P2 respectively compared with P_0 ($p < 0.05$). There was no significant variation in the dry weight of flowering stems of *L. perenne* grown on its own or with *A. eriantha* ($p > 0.05$).

The concentration of P in shoots of *A. eriantha* was significantly greater than that of *L. perenne* at P_0 and P_1 [$p < 0.05$; Fig. 5(b)]. There was no significant variation in the concentration of P in roots of *A. eriantha* grown on its own in all treatments of P relative to the control (P_0), and between the concentration of P in roots of *L. perenne* [$p > 0.05$; Fig. 5(b)]. The concentration of P in shoots of *L. perenne* treated with P_1 was 50% greater, and a further 100% greater when treated with P_2 compared with the control [$p < 0.05$; Fig. 5(b)]. However the concentration of P in the shoots and roots of *A. eriantha* was 40 and 50% less when grown with *L. perenne* [$p < 0.05$; Fig. 5(b)]. There was no significant variation in the concentration of P in roots and shoots of *L. perenne* grown on its own or with *A. eriantha*.

There was no significant difference between the concentration of N in roots and shoots of *L. perenne* grown on its own or with *A. eriantha* in any treatment [$p > 0.05$; Fig. 5(c)]. However the concentration of N in the shoots of *A. eriantha* grown on its own was 50% greater than that of *L. perenne* grown on its own, and 60 to 70% greater than that of *A. eriantha* grown with *L. perenne* [$p < 0.05$; Fig 5(c)]. The concentration of N in the roots of *A. eriantha* when grown with *L. perenne* was 20 and 50% less relative to that of *A. eriantha* grown on its own [$p < 0.05$; Fig. 5(c)].

4. Discussion

S. plana inhabits native grasslands found throughout southeastern Australia, which have greater than 40% cover of species in the genus *Austrodanthonia*. These grasslands are found on soils that are low in phosphorus (Fig. 4). Other soil properties were similar between currently inhabited sites and historical sites (Table 2). Likewise the climatic data from the historical locations fell within the range of the other sites (Fig. 3) and it can be concluded that climate is not limiting the distribution of *S. plana* or the distribution of *Austrodanthonia* spp. at these sites. It is probable that the density of *Austrodanthonia* spp. and the concentration of available phosphorus (P) are limiting the distribution of *S. plana*.

The effects of fertilisers on soil fauna within Australian soils are not clear, varying with species and life-cycle, and with type and amount of fertiliser used. It is not known whether high concentrations of P (>14 µg g^{-1}) affect *S. plana* directly by having a toxic effect on the soil-borne larva. However, the addition of P increased the competitive ability of *L. perenne*, thereby decreasing the habitat and food source for *S. plana* (Fig. 5). A decline in host plant abundance ultimately leads to a decline in the dependent invertebrate fauna. Weeds alter

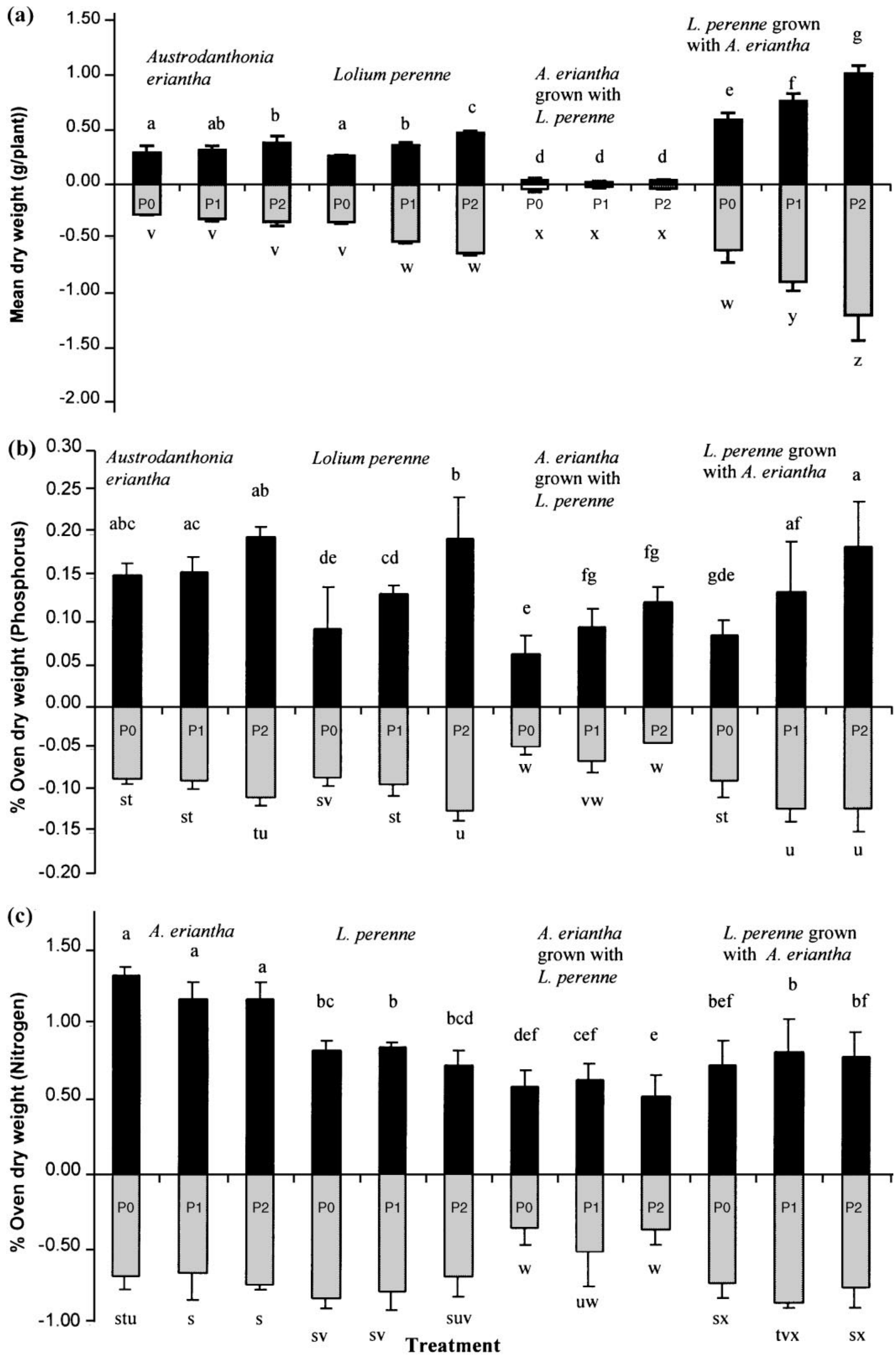

Fig. 5. (a) Mean dry weight (g plant^{-1}) of roots (■) and shoots (■) of *Austrodanthonia eriantha* and *Lolium perenne* grown on their own or together under three rates of phosphorus: P_0 (no phosphorus added); P_1 (phosphorus applied at the rate of 125 kg ha^{-1}); and P_2 (phosporus applied at the rate of 500 kg ha^{-1}). (b) The concentration of phosphorus in roots (■) and shoots (■) of *A. eriantha* and *L. perenne* grown on their own or together under P_0, P_1 and P_2. (c) The concentration of nitrogen in the roots (■) and shoots (■) of *A. eriantha* and *L. perenne* grown on their own and together under three rates of phosphorus: P_0, P_1 and P_2. Nitrogen was given in excess. The percentage over dry weight of shoots, roots, nitrogen and phosphorus was determined from 5 replicates each with four plants after 8 months growth. Histograms with the same letter are not significantly different from one another, $p > 0.05$.

the microenvironment and out-compete native flora for space, light and nutrients and hence cause the decline of native plants (Panetta and Groves, 1990).

An increase in soil fertility will also have direct effects on soil invertebrates if concentrations are toxic, or alternatively other components of the soil may be affected. The application of superphosphate increases soil acidity, which in turn can alter the water status and osmotic potential of the soil (see Morris, 1927; Huhta et al., 1967, 1969; Marshall, 1977). Changes in osmosis can cause irreversible dehydration or excessive uptake of water resulting in body rupture, particularly of larvae and other soft-bodied animals (Viglierchio et al., 1969). Under wet conditions, phosphates which contain calcium sulphates can be reduced to hydrogen sulphide (Alexander, 1977) which in turn may bind to the haemoglobin in an irreversible process similar to carbon monoxide and hydrogen cyanide poisoning (Doeksen, 1967). Alternatively, impurities in fertilisers may be directly absorbed through the bodies of soft animals (Carallero and Ravera, 1966).

The addition of fertilisers may indirectly cause a decline in invertebrate numbers due to changes within the host plant (Dale, 1988). Not only is the physiology of the plant altered but increased soil fertility may affect the plant's morphology and phenology (Dale, 1988). These changes alter the suitability of a plant as a host for certain insects. Potassium fertilisers cause a reduction of amino acids and reducing sugars in the sap, affecting sap-sucking insects (Chaboussou, 1972 cited in Dale, 1988). In addition, the sclerenchyma layer and silica content of the cells increase (Vaithilingham, 1972 cited in Dale, 1988). Phosphate fertilisers increase protein metabolism and auxin production whilst nitrogenous fertilisers make plants more succulent by increasing tissue softness and water content, and can also delay flowering and seed formation (Marshall, 1977).

In the field study, the percentage cover of weeds increased and the percentage cover by *Austrodanthonia* spp. decreased, with increasing concentrations of available P. The pot experiment showed that whilst the concentration of P in the soil did not inhibit or enhance the growth of *A. eriantha* when grown on its own [Fig. 5(a)], the presence of *L. perenne* reduced the rate of growth and concentration of both N and P [Figs. 5(b) and (c)] of *A. eriantha* under all rates of P. The concentration of available P in the experimental soil from Mount Piper was 13.1 $\mu g\ g^{-1}$ and was greater than the concentration of available P in all the other soils collected from sites inhabited by *S. plana*. However, the concentration of available P at Mount Piper is less than that in most agricultural soils. Considering that the growth of *L. perenne* at P_0 was less than the growth of *L. perenne* in P_1 and P_2 [Fig. 5(a)], the growth of *L. perenne* may be further reduced when growing in soils with a concentration of available P less than 13.1 $\mu g\ g^{-1}$. *A. eriantha* may therefore outcompete *L. perenne* under these conditions. The rate of uptake of P by *A. eriantha* did not alter with increasing concentrations of P, but P uptake by *L. perenne* increased [Fig. 5(b)]. Under field conditions the application of superphosphate therefore enhances the competitive advantage of *L. perenne*, and the local extinction of *S. plana* at the historical locations is probably due to the decline of *Austrodanthonia* spp. caused by an increase in available P, and a consequent increase in vigour of weed species.

Numerous studies have examined the allelopathic effects of *Lolium* sp. on associated plants (see Naqvi, 1972; Naqvi and Muller, 1975; Newman and Rovira, 1975; Newman and Miller, 1977; Prestidge et al., 1992; Wardle et al., 1992). Newman and Rovira (1975) found that leachate collected from soil under *L. perenne* inhibited the growth of *Holcus lanatus, Hypochoeris radicata*, and *Rumex acetosa*, and Wardle et al. (1992) found that *L. perenne* inhibited the growth of *Carduus nutans* and concluded that it was probably due to an allelopathic effect. Naqvi (1972) found that *Lolium multiflorum* suppressed germination and growth of many plant species and Naqvi and Muller (1975) found that leachate from soil occupied by *L. multiflorum* was toxic to *Avena* sp., *Bromus* sp., and *Trifolium* sp. Root exudates from one plant can influence the rate of P uptake by another plant (Robinson, 1972; Newman and Miller, 1977). It is possible that the reduced rate of uptake of P and N by *A. eriantha* and its reduced growth rate when grown with *L. perenne* (Fig. 5) may be due to root exudates produced by *L. perenne*.

Predictions about the habitat and habitat requirements of *S. plana* are necessary for the development of a conservation strategy or action plan. To restore the habitat of *S. plana* the cover by *Austrodanthonia* spp. must be increased to greater than 40%, weeds must be reduced and the concentration of P must be low (>14 $\mu g\ g^{-1}$; Fig. 4). In the process of restoration, weed control will be a major part of successful restoration of *S. plana* habitat. Whilst it is not known whether concentrations of available P greater than 14 $\mu g\ g^{-1}$ are toxic to *S. plana*, it may be necessary to reduce the concentrations of available P in reclaimed agricultural soils. Reducing soil fertility has been successful in England using various methods such as cropping areas with wheat, burning and by adding nitrogen (see Marrs, 1985; Marrs and Gough, 1989).

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Section 22 Barton, ACT
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Attachment C

Natural Temperate Grassland
Maintenance Plan

Natural Temperate Grassland Maintenance Plan Block 3 Section 22 Barton, ACT

June 2008

Department of Finance and Deregulation

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1. Background

1.1 The project

This Maintenance Plan has been prepared for the Department of Finance and Deregulation (Finance). The intent of this Maintenance Plan is to provide a framework for ongoing best-practice management of the ecological values associated with development and use of Blocks 3 and 7 Section 22 Barton, in the ACT.

PB has prepared a Master Plan for Block 3, which is proposed to be partially developed. The Master Plan identifies an area of Block 3 for ongoing conservation of the Natural Temperate Grasslands. This Maintenance Plan will integrate with the Master Plan in providing a framework for maintenance of the conservation area and an area of Natural Temperate Grasslands on the adjoining Block 7.

The south-eastern portion of Block 3 and the eastern portion of Block 7 contain a population of Golden Sun Moth (Synemon plana), in about 0.5 ha of Natural Temperate Grasslands, dominated by species of Wallaby Grasses (Austrodanthonia) (ACT Government 1997, 1998, 2005).

The Golden Sun Moth (GSM) is listed as Critically Endangered under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999, and Endangered under the ACT Nature Conservation Act 1980. Natural Temperate Grassland of the Southern Tablelands of NSW and the Australian Capital Territory is listed as an endangered community under the EPBC Act 1999 and the Nature Conservation Act 1980.

It is these values for which this Maintenance Plan intends to conserve.

1.2 Aim of the Maintenance Plan

The intent of this Maintenance Plan is to conserve native plant diversity while maintaining the structure and species composition thought to be favourable to the survival of the Golden Sun Moth. This involves retaining a high proportion of Wallaby Grasses (*Austrodanthonia* species) in a relatively low grassland with areas of bare ground between tussocks. This will be achieved through biomass management and control of exotic species, with monitoring of plant diversity, vegetation structure and the GSM population to gauge the success of the Maintenance Plan.

1.3 History of the site

Nearby remnant woodland (Capital Hill, West Block) shows that the subject site was near the boundary between woodland and grassland communities, as mapped in the *ACT Lowland Native Grassland Conservation Strategy* (ACT Government 2005, Figure 2.2).

When the Federal Capital Territory was created in 1911, the area around the subject site appears to have been open grazing land with few trees. In the 1920s, the Provisional Parliament House and some of the associated roads were built. A 1933 map shows that the subject site was then part of a larger undeveloped area bounded by National Circuit, State Circle, Kings Avenue and Canberra Avenue (Marshall 2007). At this time, the nearest building was the Methodist Church diagonally opposite. The subject site would have been connected to other grassland or native pasture until fairly recently, with surrounding blocks and roads being developed from the 1970s onwards.

The north-western part of Block 3 appears to have received fill during the construction of surrounding buildings, and is now dominated by exotic species.

2. Environmental values of the site

2.1 Natural Temperate Grassland

The Natural Temperate Grassland community in the ACT is found between 560 and 1200 metres altitude in valleys and broad plains. The dominant cover is native tussock grasses, with forbs such as daisies, lilies and native legumes in the inter-tussock spaces. It is estimated that approximately 5% of the original area of the community in the ACT survives in moderate to good condition (ESSS 2000).

The grassland on the subject site has been given a Botanical Significance Rating of 4 (Low), and a Conservation Rating of 2 (Complementary Conservation Site). The Conservation Rating reflects that the subject site has only a low to moderate Botanical Significance, but contains a population of a threatened species that is considered to be viable in the medium term (ACT Government 2005).

Since 1992, the Natural Temperate Grassland on the subject site has been part of a long-term grassland monitoring program being undertaken by Environment ACT, and the vegetation quality in Block 3 has been previously been assessed and mapped (Davis & Hogg 1992, ERM 2005, Rowell 2007). **Appendix A** contains a summary of plant species recorded on the subject site over this period. These data are not strictly comparable from year to year, having been collected by a variety of methods. However, the list shows trends such as the apparent loss of some native species and the recent arrival of some undesirable exotic species.

2.2 Golden Sun Moth Synemon plana

2.2.1 Distribution

Prior to European settlement the species was widespread in native grasslands in south-eastern Australia, from near Bathurst in New South Wales through the Australian Capital Territory and Victoria to Bordertown in South Australia (Edwards 1993, 1994). This distribution was correlated with grasslands dominated by low-growing Wallaby Grasses (*Austrodanthonia* species), and has contracted substantially over time (O'Dwyer and Attiwill 1999). The species is now only found in a few relatively small breeding areas due to habitat loss, fragmentation and degradation. Possibly less than one percent of the original habitat now remains, much of it degraded by weed invasion (Clarke & O'Dwyer 1997, O'Dwyer & Attiwill 1999, ACT Government 2005).

2.2.2 Description and life history

The GSM is a medium sized day-flying moth in the family Castniidae. The male has a wingspan of about 34 mm, the female slightly less. The upper forewings of both are grey/brown with paler patterns. The male has dark brown upper hind-wings, and in the female these are bright yellow/orange edged with black spots.

GSM larvae feed on the underground parts of Wallaby Grasses (Edwards 1993, O'Dwyer & Attiwill 1999), and may sometimes feed on other native and introduced grasses (Braby & Dunford 2006). Larval development time (and thus generation time) is unknown and may vary between one and three years.

The adults live for only one to four days after emerging during spring, and do not feed as they have no functional mouth parts. In the middle of the day when conditions are sunny and warm, males patrol the grassland in search of the females, which have reduced hind-wings and are poor fliers. The starting date and duration of the flight season vary from year to year, probably depending on spring weather conditions, with the season starting earlier in a warm dry spring (Cook & Edwards 1993). The limited flight ability of the female moths adds to the species' vulnerability to extinction on small sites, and makes natural re-colonisation from other sites unlikely.

2.2.3 The subject site

The subject site, although small, has received a Moderate Conservation Value rating, increased because of the previous scientific work undertaken (ACT Government 1998). Clarke (1998), also considered that the subject site warranted special attention due to its 'high profile and considerable research focus in past years'.

The area of the GSM habitat is about 5,600m², and the population has been intensively surveyed in the past. The previous studies include four mark-release-recapture surveys, producing estimates of population size (Cook & Edwards 1993 and 1994, Edwards 1994, Harwood *et al.* 1995, and Rowell 2007), and genetic analysis of the population (Clarke & O'Dwyer 1998). Provisional management recommendations were prepared for the subject site (Frawley 1995, Edwards 1995). These included rehabilitation of the vegetation by translocation of soil and grassland plants from a nearby area which was being developed (Davis and Hogg 1992, Harwood *et al.* 1995). **Appendix B** contains a summary of the GSM population studies to date.

2.2.4 Canberra Raspy Cricket Cooraboorama canberrae

Active burrows of the uncommon Canberra Raspy Cricket *Cooraboorama canberrae* are scattered across the subject site. This is a large wingless cricket, known only from relatively undisturbed grasslands in the lower parts of the Majura, Jerrabomberra and Molonglo valleys, and a small number of other locations in the ACT and nearby NSW (Queanbeyan-Bungendore). Much of its known habitat has been lost to housing in the ACT, and it is vulnerable to habitat fragmentation because it is flightless. It makes distinctive vertical burrows with a round cross-section, a clay and silk cap and a circle of bare soil around the entrance. The endangered Grassland Earless Dragon is known to generally use the abandoned burrows of this species as shelter sites. Information about this animal could be included in interpretative signage on the subject site.

3. Maintenance requirements

3.1 Weed management

Weeds are recognised as one of the most significant threats to biodiversity in the ACT. They displace native species, reduce habitat quality, modify vegetation structure and alter ecological functions (*Draft ACT Weeds Strategy 2007-2017*).

Figure 3-1 maps those areas of the subject site that have more than 50% native dominated vegetation and 50% weed cover. The NTG corresponds with the best GSM habitat, and chemical weed control in this area should be undertaken with caution and sparingly, as the effect of herbicides on GSM are unknown.

Several weeds of concern on the subject site are perennial grasses. These include exotic species and also two native species which have been planted on the subject site. These are Kangaroo Grass (*Themeda triandra*) and Poa Tussock (*Poa labillardieri*). Neither species is ideal GSM habitat, and they should be prevented from spreading beyond the original areas of planting (refer to **Figure 3-1**).

The weedy area at the southern end of the subject site results from attempted translocation of soil and native grasses from an area which was developed nearby. Other weed patches have developed where trees have been removed from the subject site, and where trees around the boundary shade the grassland.

If weed management is to be undertaking during the GSM flying period, generally late October to late December, this should be completed preferably in the morning hours. It is highly undesirable that any management practices be undertaken after 13:00 hours.

3.1.1 Objectives

The objectives of weed management are summarised in **Table 3-1**. They include:

- eradication – no plants of the target species remain on subject site
- suppression – reduce density of weeds within infested area and prevent infestation from spreading
- containment – define the boundary of existing infestation and prevent spread beyond that line.

3.1.2 Procedures

Table 3-2 summarises control methods and timing for weed species of concern. This table is indicative only, and timing can be varied to suit seasonal conditions or based on local experience. Triggers for weed management are discussed in **Section 4**.

- the subject site should be visited to treat weeds and assess the effectiveness of previous control in spring, summer and autumn. Attention should be paid to the plants listed **Table 3-1**
- a record should be kept of methods, area / numbers and species of weeds treated

3.1.3 Herbicide use

The following are key directions relating to the use of herbicides:

- operators/contractors should have significant prior experience (minimum of two years) in selective weed management in Natural Temperate Grassland, and demonstrated expertise in the identification and successful treatment of the key weed species
- the appropriate herbicide registered for use on particular species, the methods and rates of application, licensing requirements etc should be checked annually with ACT Territory and Municipal Services
- residual herbicides should not be used
- treatments should be timed to maximise results, i.e. prior to seeds forming and during active growth phases
- risks to non-target species should be minimised by avoiding the spread of herbicides on footwear and equipment, using spray hoods and shields, spraying under appropriate weather conditions etc.
- woody weeds should be treated by the cut-and-paint method, and regrowth should be spot-sprayed. Roots should not be dug out, to avoid unnecessary soil disturbance
- the effectiveness of all herbicide spraying should be monitored the following month, and follow-up spraying carried out if required.

3.1.4 Other methods

Hand-pulling

Small infestations of some weeds can be removed by hand-pulling after rain when the soil is soft. This ensures that all parts of the plant are removed. This method is suitable for small St John's Wort and Paterson's Curse plants (but not larger ones) and can be carried out during site inspections or monitoring visits.

Targeted slashing

Wild Oats can be slashed before the seed heads form. The plants often grow earlier and taller than surrounding native species, in response to soil moisture. The infestation of Wild Oats on the slight slope at the south end of the subject site should be treated by high slashing (e.g. with a brushcutter / line trimmer) as required, and the slashed material removed.

If some Paterson's Curse plants have begun to flower when spraying of rosettes is taking place, these flower stems also can be slashed and removed from the subject site.

Removal of mulch

The deciduous trees around the boundary cause drifts of dead leaves to build up on parts of the subject site at times. This mulch is likely to alter soil moisture, pH and nutrients in ways that will favour the growth of weeds. The problem is most noticeable near the oak trees on National Circuit. The leaves should be removed annually by careful raking.

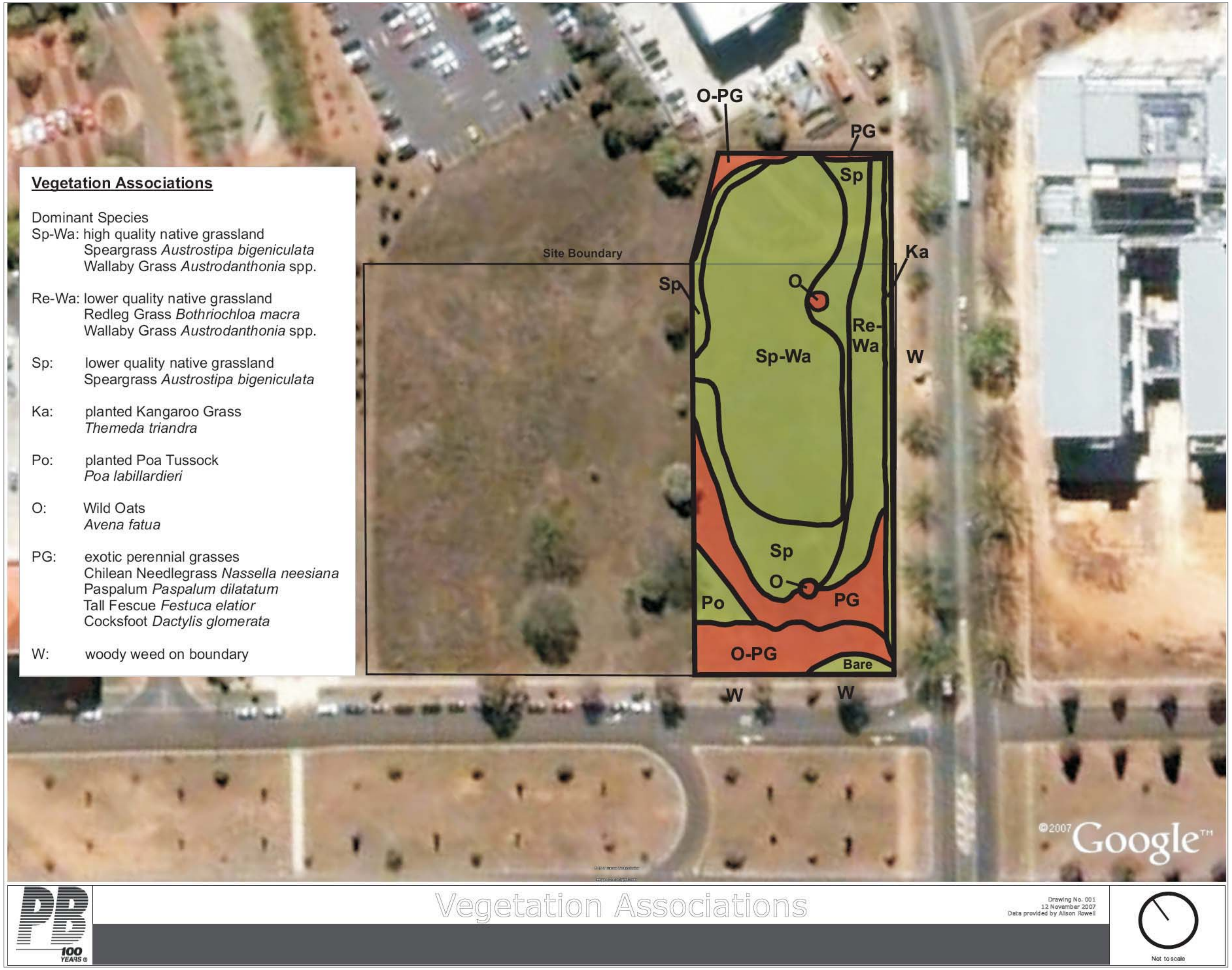

Figure 3-1 Vegetation associations

Table 3-1 Main plant species posing threat to Natural Temperate Grassland and/or Golden Sun Moth habitat

Species	Common name	Weed of National Significance	Declared Pest Plant in the ACT*	Aim of management
Exotic species				
Avena sp.	Wild Oats			Suppression
Dactylis glomeratum	Cocksfoot			Suppression
Echium plantagineum	Paterson's Curse		yes	Eradication
Eragrostis curvula	African Lovegrass		yes	Not present, requires vigilance
Festuca elatior	Tall Fescue			Suppression
Hypericum perforatum	St John's Wort		yes	Eradication
Nassella neesiana	Chilean Needlegrass	yes	yes	Eradication
Nassella trichotoma	Serrated Tussock	yes	yes	Eradication
Paspalum dilatatum	Paspalum			Suppression
Phalaris aquatica	Phalaris			Eradication
Plantago lanceolata	Ribbed Plantain			Suppression
Native species				
Poa labillardieri	Poa Tussock			Containment to planted area
Themeda triandra	Kangaroo Grass			Containment to planted area

*Pest Plants and Animals Declaration 2005.

Table 3-2 Summary of weed control methods and timing

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wild Oats									---Slash and remove stems----			
Cocksfoot									Slash and remove stems ---spot spray n/s or g/s--			
Paterson's Curse	remove				----spot spray rosettes------						Hand cut and seeding stems	
African Lovegrass	------spot spray-------								-------------------spot spray-------------------			
Tall Fescue									Slash and remove stems -------------------spot spray-------------------			
St John's Wort	hand-pull small plants after rain								hand-pull small plants after rain------------- spot spray bl/s or n/s----			
Chilean Needlegrass	--spot spray----------------------							--				
Serrated Tussock	-------spot spray---------								-------------------spot spray-------------------			
Paspalum									-------------------spot spray-------------------			
Phalaris									Slash and remove stems -------------------spot spray---------			
Ribbed Plantain	-------------------spot spray-----------------------							-------------------spot spray--------------------				

n/s = non-selective herbicide

g/s = grass-selective herbicide

bl/s = broadleaf-selective herbicide

3.2 Biomass management

In the absence of native grazers, biomass removal (defoliation) at appropriate levels and times is beneficial to many grasslands. It maintains an open structure, which enables native plants to flower and set seed, and allows their seedlings to become established. On the subject site, there is the additional requirement of maintaining a moderate proportion of Wallaby Grasses in the sward as food plants for GSM, and retaining open spaces between tussocks for basking and mating.

The subject site has been managed by slashing for many years. The population estimate for GSM last year suggested that this regime has favoured GSM, and the 2007 baseline vegetation composition data from the 20 m x 20 m quadrant can be used as a guide to appropriate proportions of bare ground and grasses (Rowell 2007). This will vary from year to year with variations in temperature and rainfall (refer to **Section 4**).

Slashing on the subject site should observe the following guidelines:

- sward not to be cut lower than 8 cm, using a flail mower to mulch and spread litter and reduce windrows. Any patches of mulched material should be removed from the subject site. The blade set height of the flail mower should be 12 cm, ensuring sward is not cut lower than 8 cm in height
- machinery not to be used when the ground is wet, to avoid soil compaction and damage to the soil crust
- machinery to be washed down before entering the subject site, to remove soil and seeds. The least weedy part of the subject site should be mown first, then the margins, and the weedier areas last, to avoid spreading weed seeds
- slashing to be carried out annually in August-September, before the emergence of adult GSM. This will help maintain the low open grassland favoured by GSM. In parts of the subject site dominated by tall weeds (e.g. Wild Oats), the slashed material should be removed (by raking or use of a grass-catcher) rather than left in windrows
- slashing to be repeated in February if necessary (average vegetation height >15 cm – Note: average vegetation height is the bulk of the vegetative material, not just the seed head).

3.3 Other management prescriptions

3.3.1 Record keeping

A diary of management actions and any other relevant occurrences should be kept. This can be in the form of notes in the work program and management checklist (refer to **Table 3-3**).

3.3.2 Memorandum of understanding

There are several key stakeholders that must be represented in the Memoranda of Understanding. These are:

- Lessor
  - interest in ongoing use of Block 3 Section 22

- Lessee (NCA)
  - role as the land manager
- ACT Government (Transport and Municipal Services)
  - management of road network and verges that adjoin Block 3 Section 22
- ACT Government (ACT Planning and Land Authority)
  - Consent Authority for development on the adjoining Block 7
- ACT Government (Wildlife Research and Monitoring)
  - role in reviewing the ongoing maintenance of the conservation area

The Memoranda should include agreement about activities such as construction, maintenance, landscaping, shading, irrigation and drainage which may affect Block 3 Section 22, and specifically the conservation area. Any proposal to extend or increase the height of the buildings on Block 7 (Territory land) should consider the potential impact on the Natural Temperate Grasslands and GSM.

3.3.3 Construction phase

The subject site should be protected from damage during the construction phase. It should be securely fenced, with signs on all fences stating that it is an environmentally sensitive site. There should be no vehicle or pedestrian access to the western part of Block 3 through the subject site, no dumping and no parking of vehicles or storage of machinery or materials. No trenching for pipes or cables should be allowed to cross the subject site. These restrictions should be noted in the works program.

3.3.4 Rehabilitation

No soil should be brought onto the subject site. Areas bared through control of large areas of weeds, or inadvertently damaged, should be rehabilitated using weed-free seed or thatch collected from the subject site. This should not include Kangaroo Grass or Poa Tussock.

3.3.5 Adjacent vegetation

The deciduous trees on the boundary of the subject site have degraded the adjacent grassland, as well as providing perches and nest sites for birds that feed on GSM. The size and location of any trees or landscape features on the western portion of Block 3 should be such that their shadow does not extend beyond the shadow of the buildings, as proposed in the Master Plan.

The landscaping should be designed to have low impact on the grassland. Specifically, it should have low irrigation and fertiliser needs, and not be a significant source of mulch or seeds. Non-local native grassland species should not be included in adjacent landscaping.

The use of pesticides on adjacent vegetation is undesirable, given the presence of rare / endangered insect species on the subject site.

3.3.6 Drainage

Development on the western portion of Block 3 should not cause any increase in drainage onto the subject site. Similarly, repair or replacement of the footpaths on National Circuit and Sydney Avenue should not increase drainage onto the subject site.

3.3.7 Fencing, signs and paths

Interpretive signs should be placed on the boundary of the subject site. Fencing and signs should not cast a significant shadow, nor provide perches for birds. There should be no paths, landscaping, seating or other structures within the conservation area. Pedestrian access from the western boundary or opportunities to be used as a thoroughfare should also be prevented. If a new fence is constructed, associated materials and vehicles should be kept off-site as far as practicable during construction.

Spot cleaning of the fencing and signage should be undertaken as necessary with products that pose limited risk of impacting on the Natural Temperate Grasslands and the Golden Sun Moth.

3.3.8 Site access

Access to the conservation area should be restricted to tasks essential for the ongoing maintenance tasks, as detailed in this Maintenance Plan. All personnel accessing the conservation area must be appropriately inducted.

Induction information

It is anticipated that there will be varying levels of induction, dependent on the role of the personnel to the conservation area. These groups of personnel include:

- construction and development workers during the construction phases
  - require a direct induction
- facility management and associated site contractor personnel for the ongoing management of completed development
  - require a direct induction
- all building occupants
  - awareness information should be made available to this personnel group.

The intent of this information is to identify with the inductees the strategic importance of this conservation area, and ensure a level of awareness for those working on Block 3 (during construction and for the ongoing management). This information includes, and can be specifically tailored for the different levels of induction:

- *the subject site contains a population of the critically endangered Golden Sun Moth (GSM), whose survival relies on the protection of its Natural Temperate Grassland habitat*
- *although the GSM is only noticeable when the adults fly in a few weeks in spring, it is present as eggs, larvae and pupae in the soil throughout the year*

- *access to the subject site should only be for activities related to its study or maintenance, and should take place according to the restrictions prescribed in Sections 3 and 4 of the Maintenance Plan.*

Conservation and education-related visits

As the subject site is sensitive, very small and can be viewed from all sides, educational visits by school and university classes should be restricted to viewing of GSM and their habitat from the edge of the subject site.

The potential need for referral and approval under the EPBC Act should be considered for any conservation activities that are not specifically nominated in this Maintenance Plan, and that the planning of such activities should first involve consultation with ACT Wildlife Research and Monitoring.

A Permit to Take should also be sought for all actions which interfere with the GSM, including physical handling, trapping, etc.. This includes the mark / recapture survey as detailed in this Maintenance Plan.

Activities should be planned to minimise foot traffic and site disturbance, and should especially avoid disturbing egg-laying females. This can be achieved by minimising activities on the subject site after 13:00 hours during the flying period, which may take between late October and late December.

Table 3-3 Work program and management record

Activity	Spring	Summer	Autumn	Winter	Reporting
Weed management	Slash and remove early flowering stems of Oats, Cocksfoot, Fescue, Phalaris Cut-and-paint woody weeds Hand-pull small St John's Wort after rain Follow-up treatments	Follow-up treatments Remove aerial parts Paterson's Curse Spot spray perennial grasses, Plantain Hand-pull small St John's Wort after rain	Spot-spray Plantain and Chilean Needlegrass Cut-and-paint woody weeds	Spot-spray Paterson's Curse and Chilean Needlegrass	Provide weed management record to DEWHA, NCA and ACT government biennially
Weed monitoring		Assess success of management			Provide results of monitoring to DEWHA, NCA and ACT government biennially
Biomass management	Slash to no shorter than 8 cm, Aug-Sep.	Slash if over 20 cm, Feb (average height should be > 15 cm)			
Grassland monitoring	Annually: photographs from reference points Biennially: step-point transects and quadrant				Provide results of monitoring to DEWHA, NCA and ACT government biennially
GSM monitoring	Annually: point counts Last year of 5-year plan: capture-release survey for population estimation				Provide results of monitoring to DEWHA, NCA and ACT government
Site inspection	Note condition, damage	Note condition, damage	Note condition, damage	Note condition, damage	
Review of Plan					Five-yearly

4. Monitoring

Monitoring should be carried out by appropriately qualified personnel, with supervisors having at least five year's experience in the assessment and management of Natural Temperate Grasslands and Golden Sun Moth populations.

4.1 Vegetation

4.1.1 Natural Temperate Grasslands

The condition of the grassland should be monitored every second year in spring (with the exception of photographs from reference points which occur annually), starting in 2009. **Appendix A** contains the results of grassland monitoring in spring 2007.

Species list

All plant species noted on the subject site during management and monitoring are recorded on a cumulative annual species list (**Appendix A**). This list records the arrival of species of weeds, or their eradication and the loss of native species. In combination with the assessments below, it will measure changes in species richness and site condition over time. A major aim of management of the subject site is to retain native species and eliminate or contain exotic species. Any observations of fauna of interest (e.g. Canberra Raspy Cricket) should be recorded at the same time.

Mapping of vegetation associations

Figure 4-1 shows the extent of the vegetation associations in 2007. The native-dominated areas have been divided by quality (native plant diversity) and dominant species, and the major weeds present in the exotic-dominated areas have been noted. The definitions of these associations are:

- **high quality native-dominated grassland**: >75% of vegetation cover is native, dominated by Tall Speargrass *Austrostipa bigeniculata* and Wallaby Grasses *Austrodanthonia* species, with a diversity of native forbs. These include species less tolerant of disturbance, such as:
  - Rock Fern *Cheilanthes sieberi*
  - Common Onion Orchid *Microtis unifolia*
  - Golden Lily *Bulbine bulbosa*
  - Early Nancy *Wurmbea dioica*
  - Curved Rice-flower *Pimelea curviflora*
  - Creamy Candles *Stackhousia monogyna*
  - Blue Devil *Eryngium rostratum*
  - Lemon Beauty Heads *Calocephalus citreus*
- **lower quality native-dominated grassland:** >50% of vegetation cover is native, dominated by Redleg Grass and Wallaby Grasses, with fewer native forbs. These include disturbance-tolerant species such as:
  - Swamp Dock *Rumex brownie*

Figure 4-1 Vegetation associations

Figure 4-2 Vegetation monitoring

- Australian Bindweed *Convolvulus erubescens*
- Tufted Bluebell *Wahlenbergia communis*
- Scrambled Eggs *Goodenia pinnatifida*
- Yellow Buttons *Chrysocephalum apiculatum*

- **exotic-dominated grassland:** >50% of vegetation cover is exotic. Species of particular concern are listed in **Table 3-1** above.

Biennial checking of the vegetation association boundaries in spring will provide information on the effectiveness of weed control. An aim of the Maintenance Plan is to contain or reduce the exotic-dominated areas, and to maintain or enlarge the high quality native-dominated areas.

Step-point transects

This method assesses the relative abundance of plant species, and gives an indication of the dominant species, degree of weed invasion and amount of bare ground (see Sharp *et al.* 2005). Two transects are surveyed along the long axis of the subject site in spring (refer to Error! Reference source not found.). Each consists of 100 steps. At each step, a long vertical wire is place ahead of the observer, and a record is made of what plants touch the wire (a 'hit'). 'Hits' on rock, bare ground, cryptogams and litter are also recorded. Results of the 2007 transects are in **Appendix A.**

An aim of the Maintenance Plan is to maintain a balance between bare ground and vegetation, and to keep the cover of presumed GSM food plants at current or increased levels. For the life of the current Maintenance Plan, the aim is for bare ground to be kept at 5-25%, the main native grasses at about 60% cover and 8-20 cm height, with Wallaby Grasses contributing 7% or more cover.

Quadrant assessment

A 20 x 20 metre quadrant in the middle of the subject site is assessed. This sector had a high number of GSM captures in 2006 and was in the high quality native-dominated association in 2007. Every species present in the quadrant and its percentage cover is recorded. An aim of the Maintenance Plan is to maintain the native plant diversity in this area.

Photographic record

A photographic record is to be made each spring, from the points indicated in **Figure 4-2**. The photographs from spring 2007 are in **Appendix C**. They give a general indication of vegetation structure on various parts of the subject site.

4.1.2 Weeds

In the second summer of this Plan (and every two years afterwards), the need for weed control should be compared with the previous year's activity, and assessed against the objectives in **Table 3-1** for particular species. Successful weed management will result in eradication of some target species, suppression or containment of others, and the identification and treatment of new weed infestations. Areas where treatment has been less effective should be noted, and future treatments adjusted accordingly.

Any increase in the area of vegetation dominated by exotic species measured in the mapping exercise described above should be a trigger for an increase in weed control effort, as should repeated or continuing infestations of weeds listed for eradication, or the spread of species required to be contained (including native grass species previously planted on the subject site).

4.2 Golden Sun Moth

4.2.1 Annual monitoring

The subject site is too small for standard transect surveys (e.g. Clarke & Dunford 1999) to be strictly comparable with larger sites. However, its size provides an opportunity for ongoing comparisons of observational data collection methods. Due to the small area to be surveyed and the potential for double counting, observational surveys will not give absolute numbers for a site, but provide an indication of density and activity of flying males. Repetition of counts allows averaging to reduce the variability that can arise from changes in wind speed or sunshine intensity between short counts on the same day. Suggested methods are:

- site visits in the second and fourth weeks of November, and the second week of December, on days of suitable weather. Surveys should be undertaken between 1130 and 1230 hours, in warm to hot, sunny, still conditions
- *transect surveys*: on each visit at 1130, 1200 and 1230 hours, observer to walk steadily on a 100 metre transect along the long axis of the subject site. All GSM seen flying ahead and on each side of the observer on each pass should be recorded on a hand-counter. Double counting of individuals to be avoided as far as possible. Results to be recorded as number of GSM per 100 m transect
- *Point observations*: to be undertaken twice on each visit in sets of ten, between the transect survey sessions. Observer to stand in centre of subject site, and rotate slowly (360º in 30 seconds). All GSM seen in a radius of 25 metres during rotation to be recorded, including double counting of individuals that change track and recross the observer's visual path. Results from ten rotations to be recorded in each of the two sessions, with the range and average calculated for each session (number of GSM per 30 second rotation)
- GSM seen will be mostly flying males; any females should be recorded separately.

4.2.2 Five yearly monitoring

Population estimation

Note: mark-recapture surveys involve repeated handling of animals, and require the prior issue of a Permit to Take by the Department of the Environment, Water, Heritage and the Arts. The personnel involved in the survey should be appropriately qualified and experienced in such work, and the application for the permit should be lodged three months before the proposed survey.

Previous population estimation surveys have involved daily capture of males (and females in some years) throughout the flying period. The impact of this on survival and breeding of GSM is not known, although numbers were not reduced when the procedure was carried out over three consecutive seasons in the 1990s. However, it is a very intrusive procedure, and could be damaging to the population in years when numbers are already low for other reasons.

An alternative method using a nested sampling structure is outlined below (designed by Anett Richter, University of Canberra). It allows population estimation with less interference, while also recording the ratio of males to females captured (in 2006, females were not captured to reduce interference to egg-laying). Capture, marking and release methods should be as described in Rowell (2007), with the addition of capture of females as well as males.

The Robust Design

This mark-recapture method allows population estimation without daily captures. It features a nested sampling structure, timed to take account of the short life-span of adult GSM (one to four days). The first level consists of primary sampling sessions. The population experiences mortality (and potentially immigration) between primary sessions, allowing application of open population models. The secondary level of sampling involves a short mark-recapture study within each primary session. Closed population models are used at this stage to estimate the animal abundance at each primary session.

The design of the mark-recapture study (primary and secondary sampling sessions) depends on the biology of the study species. Due to the short life span of GSM (average two days), secondary sampling sessions should take place within two days. It is suggested to have at least four secondary sessions within one primary session to obtain an appropriate number of captured and recaptured individuals. To verify a closed population (no immigration, emigration, birth and deaths) four secondary sessions need to take place within two days (see design below).

The first primary session should begin as soon as flying males are detected, and should be repeated every eight days until there are no new captures. Observational surveys of the subject site should be undertaken weekly from late October to determine the beginning of the flying period. Analysis is to be carried out using the software MARK. The package includes the estimation of total population size of closed and open populations based on the Robust Design. It also provides estimates of daily survival rates and recapture probabilities.

4.3 Recording and reporting

4.3.1 Management checklist

The annotated work program and data from periodic monitoring will provide a record of management actions and outcomes that can be submitted to the lessee (NCA), DEWHA and the ACT government biennially or as required.

A report should be prepared in the final year of the five year Maintenance Plan, detailing the results of management and monitoring, with recommendations for variations in the reviewed Maintenance Plan.

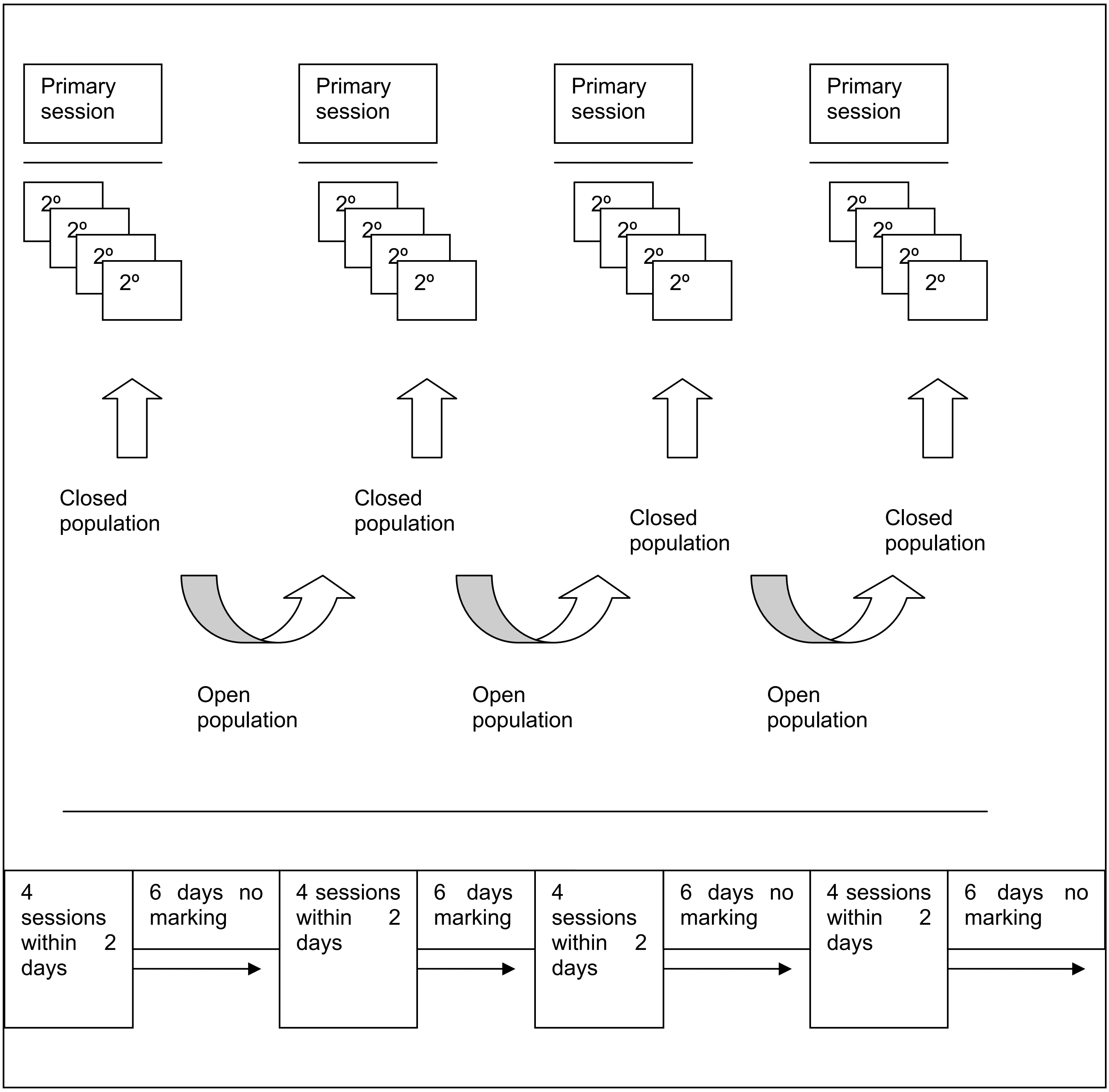

Figure 4-3 Experimental design for population estimation at Block 2 Section 22 Barton

Source: Anett Richter, University of Canberra, 2006

Figure 4-4 Golden Sun Moth Survey Sector (2006)

5. Review of the Maintenance Plan

The Maintenance Plan should be reviewed at the end of five years. A new draft Plan should be prepared by an appropriately qualified person, and be presented for review and approval by the National Recovery Teams for GSM and Natural Temperate Grasslands, or a committee of specialists from ACT government, NSW Department of Conservation and Climate Change, DEWHA, University of Canberra, Australian National University, CSIRO Department of Entomology etc.

6. Implementation of the Maintenance Plan

The leaseholder of the site will be responsible for the implementation and ongoing management of the Maintenance Plan and all associated costs.

All aspects of the Maintenance Plan should be carried out by:

- suitably qualified operators/contractors with demonstrated experience in Natural Temperate Grasslands, to be engage directly by the leaseholder of the site; or
- a recognised authority (e.g. the ACT Government), subject to an agreement, arrangement or Memorandums of Understanding with the recognised authority, with all expenses to be funded by the leaseholder.

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Appendix A
(to Maintenance Plan)

Summary of plant species

Vegetation composition at step-point Transect 1 (100 step-points) November 2007

Type	**Count**	**Frequency (% hits)**	**Recorder:** Isobel Crawford
Total step-points	**100**		
Total vegetation hits	**171**		
Rock	0	0	
Bare ground	20	20	
Litter	30	30	
Cryptogam	14	14	
Species	**Count**	**Frequency of species (% hits)**	**Composition of vegetation (%)**
Austrostipa bigeniculata	58	58	34
Bothriochloa macra	27	27	16
Austrodanthonia spp.	13	13	8
Chrysocephalum apiculatum	4	4	2
Lomandra bracteata	1	1	<1
Tricoryne elatior	1	1	<1
Goodenia pinnatifida	1	1	<1
Triptilodiscus pygmaeus	1	1	<1
**Dactylis glomerata*	13	13	8
**Plantago lanceolata*	13	13	8
**Hypochoeris radicata*	8	8	5
**Paspalum dilatatum*	8	8	5
**Avena barbata*	7	7	4
**Nassella neesiana (dead)*	5	5	3
**Nassella neesiana (alive)*	5	5	3
**Aira elegantissima*	2	2	1
**Romulea rosea*	2	2	1
**Cynodon dactylon*	1	1	<1
**Hypochoeris glabra*	1	1	<1

* denotes exotic species

Vegetation composition at step-point Transect 2 (100 step-points) November 2007

Type	**Count**	**Frequency (% hits)**	**Recorder:** Isobel Crawford
Total step-points	**100**		
Total vegetation hits	**159**		
Rock	0	0	
Bare ground	13	13	
Litter	30	30	
Cryptogam	8	8	
Species	**Count**	**Frequency of species (% hits)**	**Composition of vegetation (%)**
Austrostipa bigeniculata	57	57	36
Bothriochloa macra	29	29	18
Chrysocephalum apiculatum	18	18	11
Austrodanthonia spp.	11	11	7
Tricoryne elatior	3	3	2
Goodenia pinnatifida	3	3	2
Asperula conferta	1	1	<1
Elymus scaber	1	1	<1
Lomandra bracteata	1	1	<1
Wahlenbergia luteola	1	1	<1
**Avena barbata*	11	11	7
**Nassella neesiana*	7	7	4
**Plantago lanceolata*	7	7	4
**Dactylis glomerata*	3	3	2
**Hypochoeris radicata*	2	2	1
**Bromus* sp.	1	1	<1
**Paspalum dilatatum*	1	1	<1
**Aira elegantissima*	1	1	<1
**Cynodon dactylon*	1	1	<1

* denotes exotic species

VEGETATION SURVEY SHEET for 20 metre x 20 metre quadrant November 2007

Client: Finance	Project: Maintenance Plan	Date: 9 Nov 2007	Site name: York Park GSM site, 3&7/22 Barton.
Quadrant ID: 1	Landform: footslope/plain	Recorder: Alison Rowell	Average vegetation height: 15 cm
WGS84 Easting: 693832	Northing: 6090303	Aspect: NW	Soil: clay / loam/ sand / organic
% cover bare ground:5-25%	% cover litter: 5-25%	% cover cryptogam: 1-5%	% cover rock: 0
% cover kangaroo pellets:0	Cover scores:**5** >75%, **4** 50-75%, **3** 25 -50%, **2** 5-25%, **1** numerous/scattered < 5%, **+** few (~4-15), **r** solitary~1-3)		

No.	Native Species	Cover score		No.	Exotic Species	Cover score
1	*Austrostipa bigeniculata*	3		1	*Hypochoeris radicata*	2
2	*Bothriochloa macra*	2		2	*Plantago lanceolata*	1
3	*Chrysocephalum apiculatum*	2		3	*Vulpia myuros*	1
4	*Goodenia pinnatifida*	2		4	*Briza minor*	1
5	*Austrodanthonia auriculata*	1		5	*Hypochoeris glabra*	1
6	*Austrodanthonia carphoides*	1		6	*Aira elegantissima*	1
7	*Lomandra bracteata*	1		7	*Briza maxima*	1
8	*Wahlenbergia communis*	1		8	*Trifolium campestre*	+
9	*Wahlenbergia luteola*	+		9	*Gnaphalium americanum*	+
10	*Pimelea curviflora*	1		10	*Bromus hordeaceus*	+
11	*Panicum effusum*	1		11	*Avena* sp.	+
12	*Cheilanthes sieberi*	1		12	*Romulea rosea*	+
13	*Calocephalus citreus*	1		13	*Hypericum perforatum*	r
14	*Tricoryne elatior*	1		14	*Echium plantagineum*	r
15	*Convolvulus erubescens*	+		15		
16	*Elymus scaber*	+		16		
17	*Austrodanthonia* sp.	+		17		
18	*Senecio* sp.	r		18		
19	*Bulbine bulbosa*	r		19		
20	*Austrostipa scabra*	+		20		
21	*Oxalis perennans*	+		21		
22	*Lomandra* sp.	1		22		
23	*Eryngium rostratum*	r		23		
24				24		

Appendix B
(to Maintenance Plan)

GSM population studies and estimates

The previous studies of the Golden Sun Moth on the Site include four mark-release-recapture surveys producing estimates of population size.

Summary of mark-release-recapture results for male GSM.

Year* (period of captures)	**1992** (69 days)	**1993** (48 days)	**1994** (45 days)	**2006** (27 days)
Number of individuals captured	317	321	375	398
Total captures	354	389	419	423
Recaptures after 1 day	25	54	30	21
2 days	8	8	10	4
3	2	2	2	0
4	1	1	1	0
5	1	0	0	0
Estimated total male population during period of captures:				
Fisher-Ford method	**524**	**456**	**736**	
MARK method				**440**
JOLLY method				**1230**

* Cook & Edwards 1993 & 1994, Edwards 1994, Harwood *et al.* 1995, Rowell 2007.

Appendix C
(to Maintenance Plan)

Photographic records

Transect 1, taken from southern boundary. November 2007.

Transect 2, taken from southern boundary. November 2007.

Short axis of site, taken from western boundary. November 2007.

20 x 20 metre quadrant, taken from southern edge. November 2007.

Centre of 20 x 20 metre quadrant, detail. November 2007.

ARCHIVAL RECORD

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PhD thesis, Institute for Applied Ecology
University of Canberra, Canberra

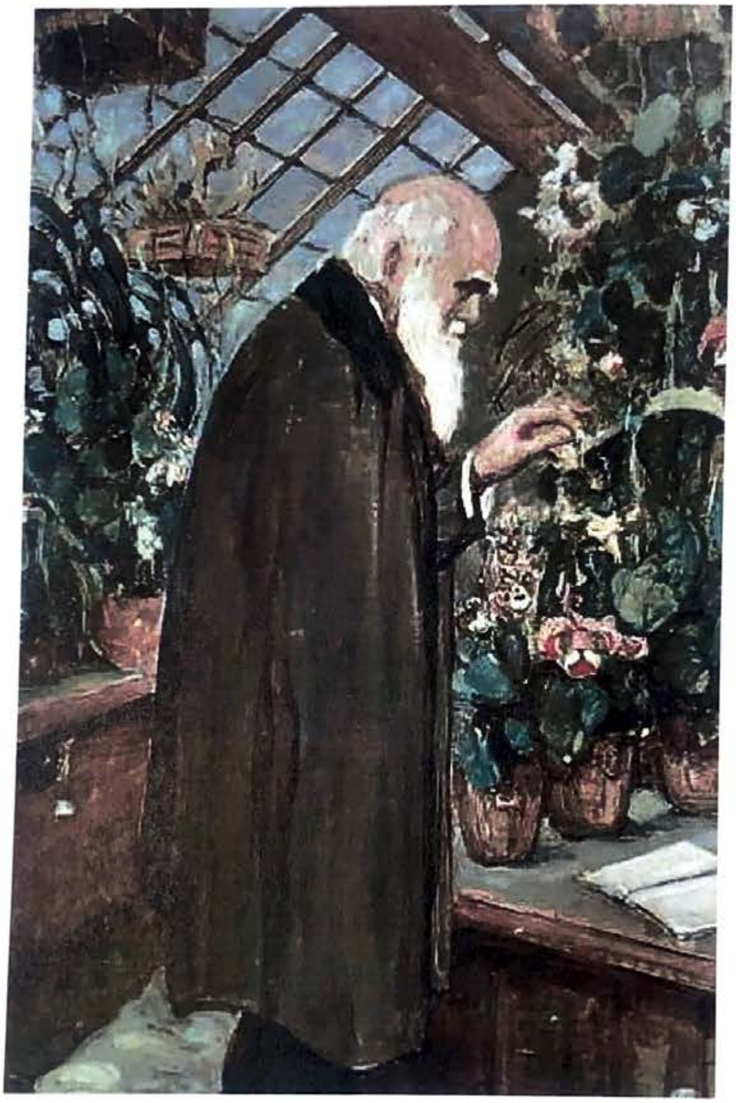
What makes species vulnerable to extinction following habitat fragmentation and degradation? A test using the insect fauna in native temperate grasslands in South-eastern Australia

Anett Richter

A thesis submitted in total fulfilment of the requirements for the degree of Doctor of Philosophy

Institute for Applied Ecology
University of Canberra

February 2010



"I have an old belief that a good observer really means a good theorist"

C. Darwin to Bates in 1860 as cited by I.R. Ball (1975)

Charles Robert Darwin (1809-1882) painted by John Maler Collier (1850- 1934)

Abstract

Landscape fragmentation and modification are the main factors believed to be responsible for the current high rates of species declines and extinctions. Native temperate grassland is one of the most threatened ecosystems in Australia having undergone extensive loss and degradation, to the extent that only less than five percent of the original community remains in reasonable conditions. Effective conservation of temperate grassland is hampered by our inability to predict the responses of the biota to further loss and fragmentation, and to changes in the way the grasslands are managed.

In this thesis, I report on a three year study of the conservation ecology of terrestrial insects in highly fragmented native temperate grassland in the Australian Capital Territory (ACT). I examine the vulnerability of carabid beetles (Carabidae, Coleoptera) and scarab beetles (Scarabaeidae, Coleoptera) to modifications in landscape structure and habitat quality following native grassland fragmentation. To complement that study, I also conducted an autecological study of the golden sun moth (*Synemon plana*, Castiniidae, Lepidoptera), a flagship species in the ACT grasslands which is classified as critically endangered at both the state and national levels.

Below, I outline the contents of each chapter that together comprise my PhD thesis.

To begin, **Chapter 1** provides an introduction to the thesis and an overview of our current understanding of the consequences of fragmentation on terrestrial biological diversity. The chapter introduces the reader to insect conservation in Australia with an emphasis on previous insect research conducted in native temperate grassland in the ACT and identifies the gaps in our understanding of how the Australian insect fauna has been affected by large scale natural habitat loss and fragmentation. The general methods of site selection and the rationale for the selection of insect taxa that were investigated are described. Furthermore, I present a summary of the climatic

conditions characterised by above average monthly temperatures and significant deficiencies in precipitation that occurred at the time of investigation.

In **Chapter 2** I review the influence of land use change and predicted climate change on temperate grasslands – an overlooked ecological community at the global scale - and identify future research strategies to halt the further loss of biodiversity in these grasslands. I discuss previous research that has contributed to our understanding of grassland ecology and describe how two major threats to temperate native grasslands (land use change and climate change) might affect the ecological integrity of these grasslands. Based on a consideration of research conducted in three native temperate grassland regions - North America, South Asia and South-eastern Australia - it is concluded that increasing legal protection, a wider public appreciation and more research is required to reverse the current trend of biodiversity loss and to improve the current lack of appreciation of temperate grasslands. In particular, there is a need for more detailed inventory surveys of the temperate grasslands biota and increased autecological research on the invertebrate fauna. The establishment of long term monitoring is required to provide a measurement of the success of conservation action and to relate the effects of historical and current threats to native grassland and component biodiversity.

In **Chapter 3** I modelled the response of carabid and scarab beetles to the effects of fragmentation in highly fragmented native temperate grassland. Zero- inflated models and ordination techniques were applied to relate beetle diversity to fragments size at the level of three basic characteristics of community structure: 1) the number of species (species richness), 2) the identity of those species (species composition) and, 3) the relative abundance of those species. My analysis revealed a clear relationship between the size of native temperate grassland remnants and beetle diversity at the community level and with respect to community composition. Specifically, fragments larger than seven hectares hosted higher numbers of species and individuals of carabid and scarab beetles. Similar trends of increasing diversity with increasing fragment size were observed in the composition of the scarab beetle community. Smaller fragments contained less diverse communities than larger fragments. Overall, these results indicate that carabid and scarab beetles are sensitive to the reduction of native grassland.

In **Chapter 4** I applied multiple hypotheses testing of single and combined ecological models using Akaike Information Criterion (AIC) analysis to test for: 1) the relationship between habitat heterogeneity and the diversity of carabid and scarab beetles, 2) the relationship between landscape structure and the richness of carabid and scarab beetles, and 3) the influence of kangaroo and livestock grazing and mowing on the richness and abundance of carabid and scarab beetles and arthropods in fragmented native temperate grassland. The analysis revealed that native grassland quality, specifically a rich diverse flora, best described the occurrence pattern of carabid and scarab beetles in the fragmented native grassland. The importance of the type of management was also evident at very high taxonomic resolution (species level). The analysis showed that while management that included mowing positively affected the richness and abundance of ground dwelling arthropods, kangaroo grazing was a factor positively associated with the diversity of carabid and scarab beetles. The intensity of management seemed not to have any significant influence on the distribution of the insect diversity.

In **Chapter 5** the hypothesis that life history traits of grassland beetles can be used as predictors for species sensitivity to fragmentation was tested using carabid beetles (Carabidae, Coleoptera). My aim in this chapter was to assess the relationship between environmental variables and life history traits in ground beetles and to test for the sensitivity of species and associated traits to the consequences of fragmentation. Ordination techniques and three table analysis (RLQ - Analysis) revealed that there was no overall significant effect of environmental variables on life history traits in ground beetles. However, I found significant relationships between the spatial patch characteristics of isolation and floristic diversity and life history traits that are shared among ground beetles found in fragmented native temperate grassland. Species of carabid beetles characterized by larger body size, lower dispersal abilities and restricted biogeographical distribution were most sensitive to the consequences of fragmentation.In **Chapter 6** I examined a range of quantitative characteristic of the biology and ecology of the critically endangered golden sun moth

(*Synemon plana*), a native grassland specialist and a flagship species for these grasslands. I tested the species vulnerability to fragmentation and grassland modification. My data provide clear evidence that *S. plana* at all its life stages (egg, larvae, pupae and adult stage) occupies habitats dominated by native grasses, particularly mixed wallaby grass (*Austrodanthonia* spp,) and spear grass (*Austrostipa bigeniculata*), but can also occur at sites comprised almost entirely of the exotic Chilean needle grass (*Nassella neessiana*). The size of grassland fragments proved to be of less importance. Based on field work conducted over two years I detected the species at 32 grasslands in the ACT with an overall characteristic of very low densities among most *S. plana* populations. The examination of empty *S. plana* pupae cases to identify the species sex ratio revealed a male biased sex ratio in the species. These findings about the species adult and larval biology and ecology fill important gaps in our understanding for one of the critically endangered insect species in Australia.

In **Chapter 7** – the final chapter I provide a synthesis of my results on the sensitivity of carabid beetles and scarab beetles to the effects of fragmentation and highlight the importance of maintaining a rich floristic diversity and the presence of kangaroo grazing (as opposed to livestock grazing and mowing) for a diverse ground dwelling beetle fauna in temperate grassland fragments. I highlight the significance of considering multiple taxa and taxonomic resolutions to predict the vulnerability of insects following fragmentation and provide suggestions for future insect conservation in native temperate grassland in Australia. Follow up research should a) address the spatial distribution of the terrestrial insect fauna in temperate grassland; focussing particularly on a range of types of grasslands, including identification of suitable and unsuitable habitat in the surrounding matrix and, b) should include the studies of the autecology of temperate grassland insects species to better link species ecology with native temperate grassland fragmentation and modification.

The research chapters in this thesis have been written as stand - alone manuscripts for later publication (except Chapter 1). As a result, there is some repetition between chapters, particularly in the Introduction and Method sections, although I have attempted to minimise this where ever possible by referring back to earlier chapters.

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My study was funded by the ACT government and by the University of Canberra Vice Chancellor scholarship. The community based golden sun moth monitoring program that I initiated through the Friends of Grassland Group (FOG) received financial support from WWF Australia. Overseas travel to international conferences and research visits were supported by the University of Canberra, the Institute for Applied Ecology and by the Early Research Network. I kindly received permission to access the native temperate grasslands from the Department of Defence, the International Airport Canberra, ACT Parks, Conservation, and Lands, Canberra Nature Park and private landholders. Permission to handle *Synemon plana* individuals and to collect ground dwelling insects in native temperate grasslands was provided by the Commonwealth Department of Environment, Water, Heritage and the Arts.

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Chapter 1

General Introduction

Biodiversity conservation in fragmented landscapes

In this century, we face a global loss of diversity at rates unequalled since the major extinction events of the geological past (Mulongoy and Chape 2004; Pimm and Raven 2000; Scholes and Biggs 2005). The number of threatened species has increased across almost all major taxonomic groups and extinction rates and species declines are between 100 to 1000 times higher than the background natural extinction rate (Baillie *et al.* 2004). There is no doubt that historic and ongoing habitat loss and fragmentation are major threats to our global biodiversity (Groombridge 1992; Henle *et al.* 1996; Laurance and Luizao 2007; Myers *et al.* 2000a).

Theoretical, experimental and observational research indicates that there are four major factors that affect the long term viability of biodiversity in fragmented landscapes: (1) loss and reduction of habitat area, (2) interference to the dispersal of individuals and species among fragments, (3) reduced habitat quality through edge and other associated effects and (4) the interruption of interspecific interaction. Factors associated with habitat loss and fragmentation are identified either singularly or in its combined influence as major drivers that threaten the viability of species and populations in fragmented landscapes (Fahrig 2002; Henle *et al.* 2004a; Holt and Debinski 2003; With and Crist 1995).

The disappearance of natural habitat has the most obvious and detrimental effect on the biota (Fahrig 2003; Holt and Debinski 2003). A reduction in habitat area leads to a reduction in the size of fragments and to an increase in fragment isolation leading to further reductions in population size and increasing risks of population and then subsequently species extinction (Andrén 1994; Henle *et al.* 2004a). Increasing isolation decreases the probability of recolonisation by individual species leading to a breakdown in metapopulation dynamics (Brown and Kodric-Brown 1977; Hanski and Gaggiotti 2004) with further declines in species and populations (Henle *et al.* 2004). The process of fragmentation per se may not lead to the same negative cascading effects as happens with the loss of habitat (Fahrig 2003). Fragmentation is defined as a process of the discontinuity of a previous homogeneous landscape into a landscape of smaller remnants of smaller sizes separated by a matrix of transformed habitats

(Fahrig 2003). Its effects will be to change the spatial (e.g. area size, connectivity, edges), physical (microclimate, nutrient flow) and qualitative (species composition, interactions) characteristics of remnants (Laurance 2000; Saunders *et al.* 1991).

The consequences of habitat loss and fragmentation for species and populations are complex (Fahrig 2003). Generally, it is expected that populations in fragmented landscapes will have an increased probability of local extinction as a result of the interacting forces of environmental, demographic and genetic stochasticity (Andrén 1994; Hames *et al.* 2001). However, not all species are effected in the same way by habitat loss and fragmentation and decline following fragmentation (Henle *et al.* 2004a). Biological specificity, such as dispersal ability, reproduction potential or microhabitat preferences (climate, soil conditions, host plant specificity or trophic interactions) and inter and intra specific interactions, determine the response of species to fragmentation (Henle *et al.* 2004a).

The understanding of the sensitivity of species to the consequences of habitat loss and fragmentation is a fundamental contribution to the improvement of ecological theories and assists in the identification of target species for applied conservation biology (Henle *et al.* 2004a). Furthermore, better knowledge about the link between ecological features of species and the effects of landscape modifications assist in defining management strategies to halt the decline and extinction of biodiversity (Cushman and McGarigal 2004; Henle *et al.* 2004a). Therefore, the study of how species and populations respond to landscape modifications remains a central research theme in conservation biology (Haila 2002).

Responses of insects to fragmentation

Most research on the responses of the biota to habitat fragmentation has focused on prominent and popular animals like mammals (Dunstan and Fox 1996; Laurance 1991; Lindenmayer *et al.* 1999), birds (Andrén 1994; Bentley and Catterall 1997; Fischer *et al.* 2008; Kruger and Lawes 1997), reptiles (Fischer and Lindenmayer 2005) and plants (Kiviniemi 2008; vanDorp *et al.* 1997). In contrast to the large variety of fragmentation studies on vertebrates, research on the effects of fragmentation on insects and other invertebrates is still relatively scarce (Davies and Margules 1998; Major *et al.* 2003; Zschokke *et al.* 2000). This is concerning because insects are one of the main contributors to global diversity and are essential for many ecosystem processes (pollination, decomposition, nutrient cycles) (Samways 2005).

Insects respond sensitively to human mediated changes in spatial and qualitative characteristics of their environment (Collinge and Forman 1998; Oliver *et al.* 1998; Tscharntke *et al.* 2002a). The sensitivity of insects to habitat loss and fragmentation is explained by their high level of specialisation – both with respect to their general biology and their ecology. In particular, specific microclimatic conditions, specialised food requirements and complex interactions with other biota (e.g. insect - plant associations, insect - parasitoid interactions), as well as high turnover of generations within a short time period, make insects particularly sensitive to the effects of habitat loss, fragmentation and degradation (Davis *et al.* 2001; Kitching *et al.* 2000). The effects of spatial and qualitative habitat alterations on insects suggest that there are both positive and negative responses (Abensperg-Traun and Smith 1999; Golden and Christ 1999). However, while Debinski and Holt (2000) found that arthropods were the most sensitive taxa to confirm the theoretical expectations of greater species richness in larger fragments, that generalisation is not always applicable to insects (Krauss *et al.* 2004; Steffan-Dewenter and Tscharntke 2000). These inconsistencies in responses to fragmentation among taxa can be explained by the varying effects of e.g. edge effects, competition and the spatial scale of experiments (Debinski and Holt 2000).

The highly fragmented natural temperate grasslands in south eastern Australia

Australia is well - known for its diverse, highly endemic and distinctive flora and fauna and has fascinated scientists from the time of its first discovery by European (Austin *et al.* 2004). The unique elements of the flora of Australia such as the omnipresent eucalypt trees, Banksias and Acacias, along with its distinctive marsupial fauna (Strahan 1995) and reptiles (e.g. varanid lizards; elapid snakes) (Cogger 1992) are renowned. Thus, it is not surprising that Australia is one of seventeen countries that are considered to be 'megadiverse', containing, as it does, more than seven percent of the world's total biodiversity and more than twice the number of species of Europe and North America combined (Mittermeier *et al.* 1999). However, Australia is also one of the countries with high extinction rates and a lengthy list of critically endangered species (Kennedy 1990). Extinctions and declines in Australian mammals (Short and Smith 1994), vascular plants (Briggs and Leigh 1996), amphibians (Shoo *et al.* 2006) and reptiles (Brereton *et al.* 1995; Shine 1991) are well documented. For other lesser known taxa such as invertebrates, there is little information about the levels of decline and extinction (Yen and Butcher 1997). Hence, the listing of 37 species of invertebrates as critically endangered, endangered or vulnerable is likely to be a gross under- representation of the true situation (Department of Environment and Heritage 1999). In fact, it is most likely that many species of invertebrates are in decline and endangered, or have already become extinct in Australia. The reason for the high extinctions rates in Australia is related to large scale modifications of ecosystems since European settlement and the introduction of exotic species. Today, more than 2800 ecological communities in Australia are threatened; with the highest number of threatened ecosystems occurring in southern and eastern Australia. Increasing fragmentation and natural habitat modification are considered to be major threats to the biodiversity of Australia (Commonwealth Australia 2002).

One of the most threatened ecosystems in Australia is the ecological community of native temperate grasslands in South-eastern Australia (Kirkpatrick *et al.* 1995). Prior to European settlement and the associated transformation of many ecosystems, the native temperate grasslands were patchily distributed throughout the temperate climate zone ranging from north of Adelaide in South Australia to northern New South Wales in south-eastern Australia, including parts of the Tasmanian midlands (Groves and Williams 1981) (Figure 1). Native temperate grasslands are characterised by naturally treeless grassy landscapes, or having less than 10% projected foliage cover of trees, shrubs and sedges in the tallest stratum (Moore 1964). After European settlement, native temperate grasslands rapidly became the resource base for the development of the pastoral industry in providing extensive areas for livestock grazing (Lunt *et al.* 1998) and more recently suitable land for urban development

(Williams *et al.* 2005b). Within a period of less than 200 years, more than 95% of the formerly widespread native temperate grassland has been almost completely lost or suffered irreversible transformations (Kirkpatrick *et al.* 1995)

The Australian terrestrial insect fauna in native temperate grassland

Compared to the vertebrate fauna of Australia, the terrestrial invertebrates of Australia are poorly documented (Nielson and West 1994) and generally largely underrepresented in ecological research (Yen 1992; Yen and Butcher 1997). This lack of taxonomy and ecological knowledge is a result of a generally poor appreciation by the public and governments of the importance of invertebrates, the limited number of specialists and entomologists in a country that is the fifth largest landmass in the world and has a young history of classical entomological research (Kitching 1993; Yen and Butcher 1997). The number of higher groups of invertebrates in Australia is still not known and there may be over two hundred thousand species not yet described, or even not collected (CONCOM 1998). Thus, it is not surprising that biological, ecological and conservation studies have been burdened in Australia by a "taxonomic impediment" and the lack of ecological insect studies (Taylor 1976; Yen and Butcher 1997). Despite the important ecological role that insects undoubtedly play in all terrestrial ecosystems (Samways 2005), the insect fauna in temperate grassland ecosystems in Australia is rarely considered as being one of the major ecological components (New 2007; Yen 1992). This is in stark contrast to their likely richness (in species), abundance and diversity in these grasslands. In Australia, little information exists about a) the composition of insects in native temperate grassland and b) how the insect diversity is affected by large scale habitat losses and reductions (Driscoll 1994; Yen 1992). This lack of understanding makes it difficult to predict which species or communities are at the greatest risk of becoming extinct or reduced as a result of the large scale anthropogenic land use changes in native temperate grassland. Basic ecological research on insects combined with investigations of the effects landscape modifications are urgently required to more comprehensively understand, and hence protect, the native temperate grassland ecosystem and its component insect diversity.

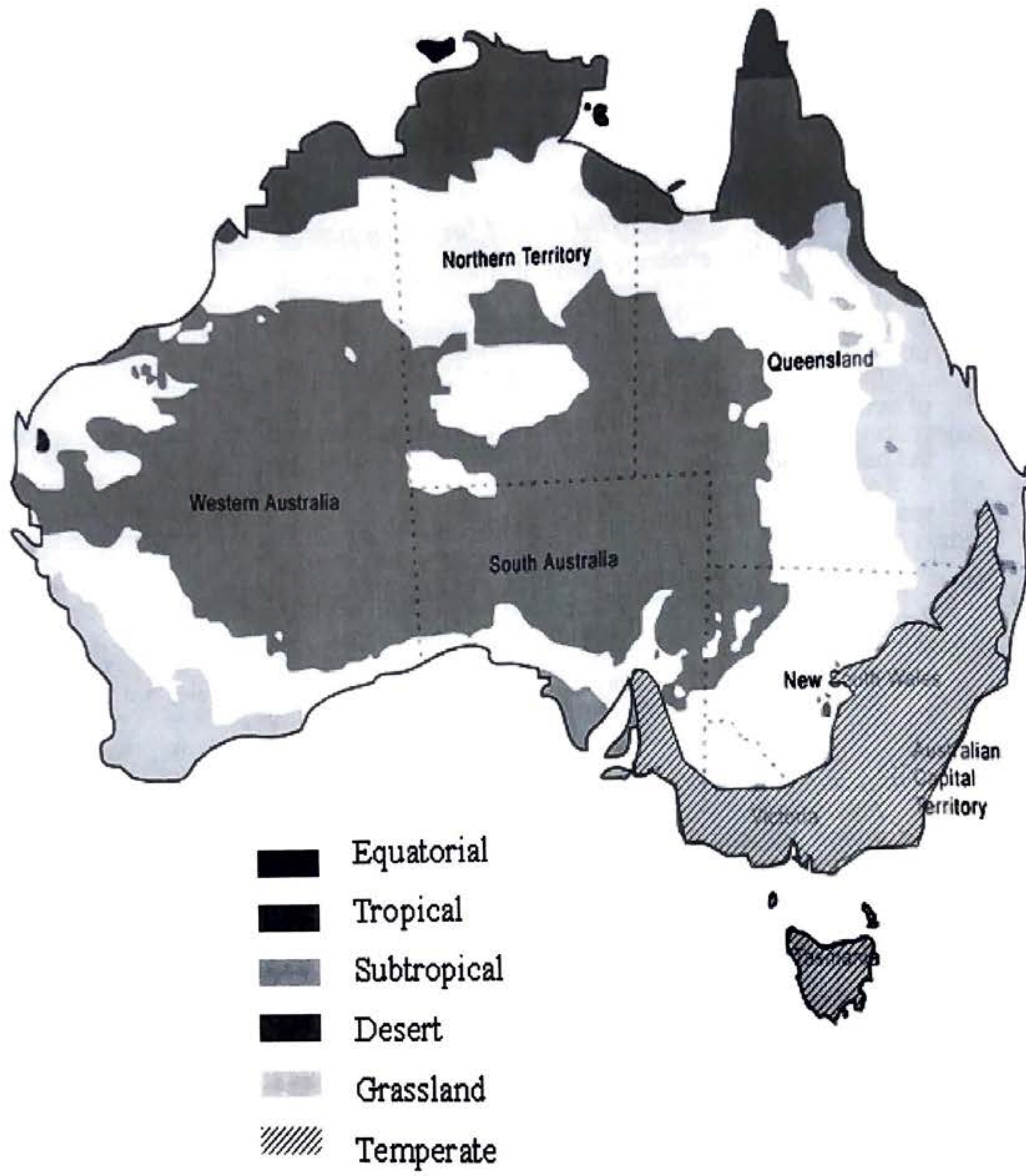


Figure 1 Distribution of major climate zones (indicated in various grey shades) and major treeless biomes (desert and grassland) in Australia. Prior to European settlement, native temperate grassland occupied large parts of the temperate climate zone in the south-east of the continent. Modified from: Bureau of Meteorology, Australia (BOM) http://www.bom.gov.au)

The situation in the Australian Capital Territory (ACT) is typical of the research scene more generally in Australia, with only a small number of ecological research projects that addresses the insect fauna (Driscoll 1994; Farrow 2006; Greenslade 1993; Melbourne 1993; Sharp 1997). Greater interest for research on insect species in the ACT has been applied to the critically endangered golden sun moth (*Synemon plana*). The golden sun moth (*S. plana*) is day active moth whose distribution parallels the distribution of native temperate grassland in South-eastern Australia. Historical records provide evidence of the occurrence of the golden sun moth throughout vast areas of natural temperate grassland in central Victoria, south-east New South Wales and the Australian Capital Territory (Edwards 1993). The loss and the degradation of most large continuous natural temperate grassland areas in South eastern Australia within the last 200 years is assumed to have lead to significant reductions in area of occupancy of the golden sun moth (Clarke and O'Dwyer 2000). The restricted geographical distribution of the species and the presence of ongoing threats such as further native grassland losses and continuous degradation lead to the listing of *S. plana* as critically endangered at the national and the state level (Threatened Species Scientific Committee (TSSC) 2002). The listing of the species has led to an increase in research into the ecology and biology of the golden sun moth. For example, the description of golden sun moth adults, male and female flying behaviour as well as the predominant presence of the species in mainly Wallaby grass (*Austrodanthonia* species) dominated grasslands were first described by Edwards (1991, 1993) from studies in the ACT. More recent research on golden sun moth populations in the ACT revealed the distribution of the species in both native and exotic grassland in the ACT Braby & Dunford (2006).

In stark contrast to the knowledge about the distribution of golden sun moth populations in the ACT and the species responses to habitat loss and fragmentation at the molecular level (Clarke and O'Dwyer 2000; Clarke and Whyte 2003), our understanding of the effects of fragmentation and degradation on other invertebrate taxa is very limited. The only published studies or theses that I am aware of that were conducted in the ACT were by Melbourne (1993), Robinson (1996), Sharp (1997), Greenslade (1993), Driscoll 1994; and Farrow (2006). These studies addressed the effects of floristic composition and structure on carabid beetles (Melbourne 1993) and ants (Robinson 1996) ;patterns of diversity in springtails (Collembola), mites (Acarina) and beetles (Coleoptera) at the taxonomic level of order and their relationships to floristic diversity and management (grazing versus mowing). Greenslade (1993) investigated the suitability of springtails as indicators for assessing the conservation value of native grassland remnants was tested by Greenslade (1993). A number of unpublished government reports have also focused on individual invertebrate taxa with the main outcome being the documentation of locations where species occur and the assessment for future conservation and research strategies (Driscoll 1994; Farrow 2006). Despite these investigations, research that directly addresses the vulnerability of selected insect species following native grassland fragmentation and degradation is missing. The limited understanding about the composition of insect species in native grasslands and the poor knowledge about the species responses to large scale losses, reductions and degradations of native grassland habitat hamper enormously the conservation and management of native temperate grassland remnants and associated remaining biodiversity. These shortcomings and deficiencies were the driving forces behind the conceptualisation of this presented study.

Aims of this study

This thesis contains an investigation of the vulnerability of selected species of insects to fragmentation and degradation in native temperate grassland in the Australian Capital Territory (ACT). It also includes an ecological study of the critically endangered golden sun moth (*Synemon plana*) in these same remnants.

The overall aims addressed in this thesis are:

- to review the current conservation status and major threats to native temperate grassland in Australia, and in other parts of the world, and to identify future research areas that are needed to fill important gaps in our knowledge of the conservation of temperate grasslands;
- to determine the composition of dominant ground dwelling insect communities in native temperate grassland and use that to model the effects of fragmentation, habitat alteration and current management on selected insects at the level of species and communities;
- to determine the sensitivity of beetle life history traits to the consequences of fragmentation in order to identify species and traits that are vulnerable to native grassland fragmentation and degradation,
- to identify key ecological traits of the critically endangered golden sun moth (*Synemon plana*) that contribute to its vulnerability to extinction; and
- to synthesise the results that were obtained in this study in order to provide guidelines for insect and native temperate grassland conservation and highlight future research that is required to better understand the responses of native temperate grassland fragmentation and alteration on insect diversity.

Material and methods

Area selection

Some of the largest remnants of native temperate grassland in Australia still occur in the Australian Capital Territory (ACT) (Figure 2). On the basis of floristic assessments, many of these grassland remnants are reportedly in moderate to good condition (Sharp and Shorthouse 1996). The presence of some of the largest intact native temperate grasslands (several sites with more than 100 ha) provide a suitable setting to study the effects of temperate grassland fragmentation and degradation on the resident terrestrial insect fauna. In the ACT, there are 991 hectares (less than 100 fragments) of known native temperate grassland (ACT Government 2005) (Figure 2). Approximately one third of all native temperate grasslands in the ACT are located within reserves; another 30% are under the authority of the Commonwealth Department of Defence and the Canberra Airport and 25% are under rural lease (data from ACT Government 2005). Many native grasslands in the ACT support several endangered or declining species of insects that are associated with high quality native grasslands (ACT Government 2005; Sharp and Shorthouse 1996). Most remaining patches of native grassland in urban Canberra are very small in size (less than 0.5 ha), isolated and highly disturbed. These native temperate grassland remnants provide an ideal setting for examining ecological and biological requirements for selected insect species and importantly for testing theories about the vulnerability of insect species and communities to native grassland habitat fragmentation and alteration.

Selection of study sites

The objective of the study was to analyse the impact of habitat modification on ground dwelling insects and on the golden sun moth (*Synemon plana*) in native temperate grassland remnants that were previously part of a large interconnected native temperate grassland complex in the ACT region (Figure 2). A two year field survey was established in 24 grassland remnants selected from 52 known remnants within the climax vegetation dominated by native wallaby grass (*Austrodanthonia* species) (ACT Government 2005). These remnants total to an area of 564 ha of which the selected remnants comprise about 60% (346 ha). The grassland remnants were selected using a stratified random approach using Geographical Information System (GIS) tool (ArcGIS 9.3.1) for plot selection. Fragments were classed in respect to their size as either very small sites (<0.2 ha), small sites (>0.2-1 ha), medium sites (>1.0-10.0 ha) or large sites (>10.0-100 ha). After all sites were examined it proved feasible to undertake research at six very small sites, six small, six medium sites and six very large sites (Figure 3, Figure 4). The approach adopted here was to confine the study to grassland fragments dominated by wallaby grass (*Austrodanthonia* spp.) to reduce the confounding effects of using different types of vegetation, such as kangaroo grass and/or spear grass (*Themeda australis, Stipa* spp.) dominated grasslands, and because of the close relationship between the occurrence of populations of the golden sun moth and the native wallaby grass (*Austrodanthonia* spp).

Selection of insect groups

A preliminary pilot study of the composition of ground dwelling arthropods in native temperate grassland in the ACT was conducted prior to the main sampling period to assist with the selection of insect groups for study. When compared to the previous study of grassland diversity in the ACT (Melbourne 1993), the pilot study revealed an overall low number of ground dwelling arthropods with most of the captured invertebrate taxa belonging to the order Coleoptera (beetles) and Hymenoptera (ants). These low numbers probably represent a direct response to the prevailing weather conditions which at the time were characterised as being extreme drought conditions (Figures 5 and 6). Ants (Formicidae) are one of the most dominant invertebrate groups in many Australian environments (Andersen *et al.* 2004). They have been widely applied as sensitive indicators to study the effects of disturbance (e.g. rangeland grazing) (Bromham *et al.* 1999), succession (Schnell *et al.* 2003), agricultural clearing and urbanisation (Majer and Beeston 1996), mining and fragmentation (Debuse *et al.* 2007). Three major ecological studies of the ant fauna have been conducted in the native temperate grasslands (Melbourne 1993; Moore *et al.* 2008; Robinson 1996).

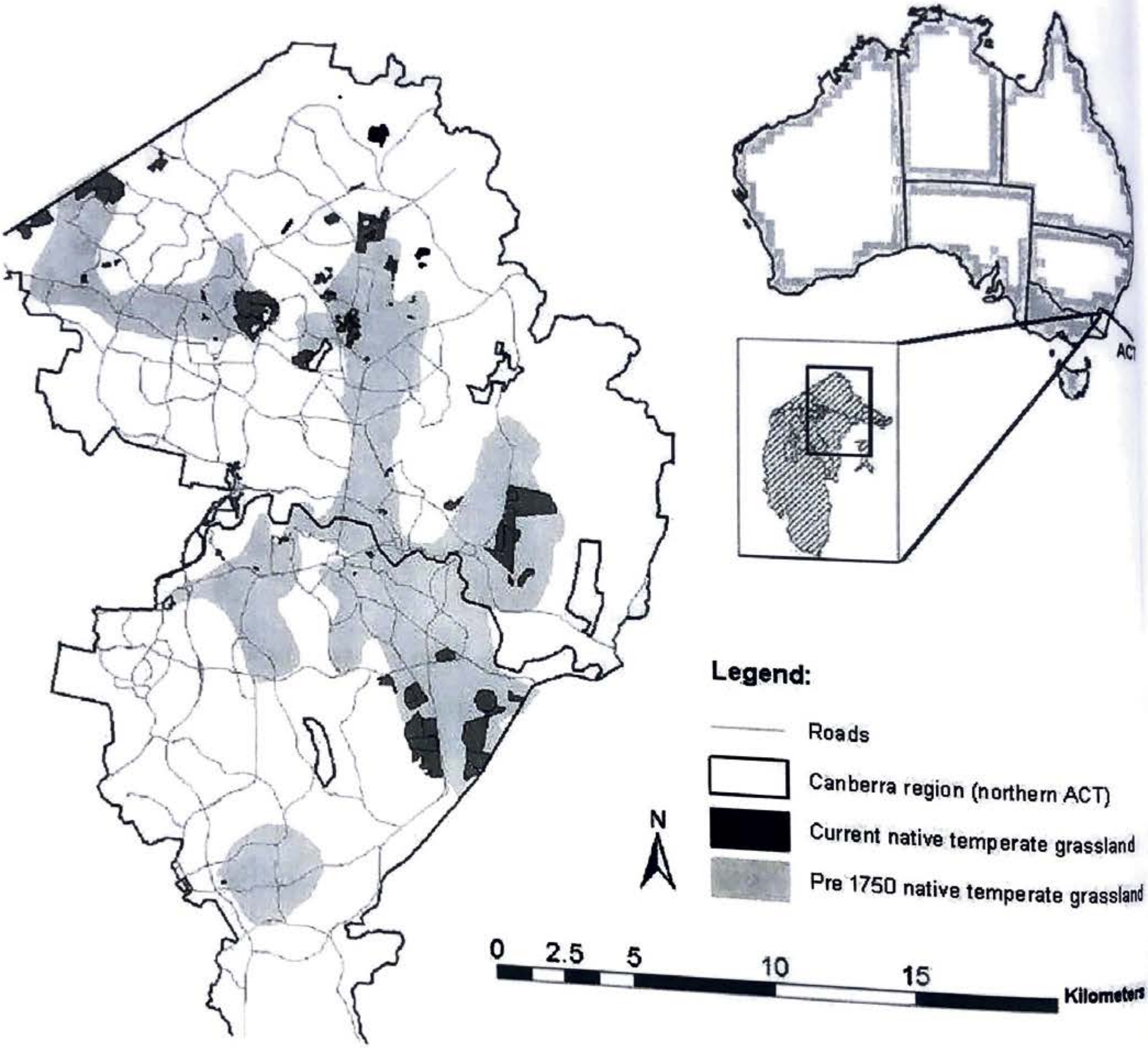


Figure 2 Historical (light grey) and current (dark grey) distribution of native temperate grassland in the Australian Capital Territory (ACT). Source: ACT Government 2005.

Figure 3 One of the largest (>100 ha) native temperate grassland study sites (former Naval Transmitting station in Belconnen, Canberra) located in Northern Canberra during the summer drought in 2006/2007.

Figure 4 One of the smallest (<0.2 ha) native grassland study sites (York Park, Barton) located in Central Canberra (flag post of the Australian Parliament house in the distance) surrounded by government buildings (Department of Foreign Affairs in the back) and planted non native shrubs and trees. In the centre of the figure is the location of one of the wet pitfall traps covered with metal shelter.

Melbourne (1993) aimed to assess the insect diversity in native grasslands on the basis of ants and ground beetles while Robinson (1996, 2008) investigated the ant communities at several native temperate grasslands sites in the Australian Capital Territory (ACT) and examined their relevance to an ant- associated lizard (*Aprasia parapulchella*, Pygopodidae) and the selection and sharing of sheltered nest sites by ants. The main findings of these two studies were that ant communities in the ACT grasslands were species poor with the majority of ants belonging to the dominant groups of Dolichoderinae, generalized Myrmicinae and other opportunists. Second, there was an overall lack of significant relationships between ant and vegetation communities (Robinson 1996) and between ants and ground beetles (Melbourne 1993). The ant community in native temperate grasslands in the ACT was highly variable between seasons (Robinson 1996) and strongly affected by different structured habitats (Melbourne 1999). Thus, it is unlikely that the ant community in temperate grassland would be useful as indicators for detecting the responses of the grassland insect fauna to environmental changes. This feature combined with the lack of any reference collection of the temperate grassland ant fauna lead me to exclude this taxonomic group from my study.

The pilot study revealed that carabid beetles (Carabidae), click beetles (Elateridae), rove beetles (Staphylinidae), weevils (Curculionidae) and scarab beetles (Scarabaeidae) were the most abundant beetle families present. Carabid beetles (Carabidae) are one of the most important indicator groups in almost all terrestrial ecosystems (Desender *et al.* 1994; Rainio and Niemelä 2003) and as such, have received considerable attention for studying the effects of land use change, particularly in many northern hemisphere countries where they are well studied (Diekotter *et al.* 2008; Grandchamp *et al.* 2005; Kotze and O'Hara 2003; Luff 1996; Niemelä 2001; Sroka and Finch 2006) (Lovei and Sunderland 1996; Niemelä 2001; Thiele 1977). Consequently, substantial ecological insight into environmental changes at the species level has been gained by their use owing to sufficient knowledge about their taxonomy and known species ecology (New 1998). Recently, carabid beetles have been the subject of a number of ecological studies in Australia aimed at testing the effects of fragmentation; the results of these studies merit the use of ground beetles as indicators for land use changes (Davies and Margules 1998; Driscoll and Weir 2005; Major *et al.* 2003). Davies and Margules (1998) found a sensitive response of ground beetles species life traits to the consequences of fragmentation (Davies *et al.* 2000) but detected an overall low level of species responses to isolation (Davies and Margules 1998). Driscoll and Weir (2005) detected a high sensitivity of carabid beetles to fragmentation processes in agricultural ecosystems with most of the declining beetle species being found to be dependent on large woodland remnants (Driscoll and Weir 2005). Although his samples were low in species diversity, Melbourne (1993) also detected sensitive responses of carabid beetles to the consequences of native grassland degradation. Melbourne (1993) showed that carabid beetle species richness was highest in wallaby grass (*Austrodanthonia* spp.) in comparison to other types of native grassland (e.g. kangaroo and spear grass grassland) and differed between native and introduced grasslands. In Australia, carabid beetles are one of the largest families of beetles (Moore 1965; Moore *et al.* 1987) and are assumed to be a diverse, highly endemic and specialised group of beetles with limited distributional ranges (New 1998). Many species are characterised by the inability to fly (flightless) and exhibit species specific activity patterns (Horne 1992).

The reported sensitivity of the Australian carabid beetles to the effects of habitat fragmentation and associated environmental changes combined with their internationally well recognised suitability for such research supported their use in this study. In addition, their taxonomy in the ACT grasslands is relatively well known (Melbourne 1993) and access to the Australian National Insect Collection (ANIC) and expert advice in Canberra was available.

The pilot study indicated that there was also an abundance of scarab beetles in temperate grassland fragments. Scarab beetles (Scarabeainae) are a large abundant subfamily of beetles that occur frequently in temperate ecosystems (Rosenlew and Roslin 2008). This group of beetles has been recognised as an important contributor to ecosystem functioning because of their role in the breaking down dung by shredding and relocating dung, consuming and metabolising it and by assisting in the action of decomposing microbes (Rosenlew and Roslin 2008). In the context that scarab beetles play such an important role in ecosystem functioning, it is expected that they will be directly affected by habitat loss and fragmentation (Feer and Hingrat 2005). Fragment size and reduced habitat quality have been shown to affect the activity of scarab beetles and the structures and richness of their assemblages (Andresen 2003; Davis 2001; Klein 1989; Larsen *et al.* 2008). In Australia, most ecological research on scarab beetles has been focused on introduced dung beetles associated with fly control (Davis 1996) and scarab beetle habitat specificity (Hill 1996; Vernes *et al.* 2005). Currently, no information exists about the composition of the temperate grassland scarab beetle fauna and the suitability of this group as indicators for detecting the effects of fragmentation and degradation on the beetle diversity. The scarab beetle assemblage was selected to compare findings of carabid beetles responses to fragmentation and degradation, and in doing so, to determine the suitability of scarab beetles in fragmentation studies in temperate grasslands and to improve the knowledge about the beetle fauna in native grasslands.

For the other less abundant beetle families that I found in my pilot study (e.g. click beetles (Elateridae), rove beetles (Staphylinidae) and weevils (Curculionidae) there is a lack of information of their taxonomy, ecological understanding and no supporting reference collections or taxonomic guides. Thus, these beetle families were considered unsuitable for the ecological investigation of the vulnerability of insects following fragmentation.

Finally, this study also incorporates the analysis of the day active golden sun moth (*Synemon plana,* Castiniidae*). Synemon plana* is one of the few flagship and indicator insect species found in native temperate grassland. The species is assumed to have a marked dependency on wallaby grass (e.g. *Austrodanthonia* spp.) grasslands. The listing of the species, nationally and at the state level as one of the few critically endangered insect species in Australia, has resulted in a range of research on its biology (Braby and Dunford 2006; Edwards 1994), habitat requirements (O'Dwyer and Attiwill 1999; O'Dwyer and Attiwill 2000), genetic population structure (Clarke 2000; Clarke and O'Dwyer 2000; Clarke and Whyte 2003) and population dynamics

(Gibson and New 2007). As such, this species provides the opportunity to study species specific aspects of a single species closely associated with these grasslands as well as characteristics that are essential to determining its response to habitat fragmentation and degradation.

Weather conditions during this research – ongoing drought

In the ACT, native temperate grasslands experience a distinctive climate characterised by hot dry summers and cold wet winters. Average annual precipitation in the Canberra region is 600 mm and seasonal average temperatures vary between 15° C in spring (October to November) and 5° C in winter (June to August). In almost all years during the past decade, rainfall in Canberra has been lower than the long term average, with the region frequently being in drought (Act Commissioner for the Environment 2007/2008 Report). The year 2006/2007 in which the study started was the hottest year on record in Canberra (Bureau of Meteorology, Canberra). During the spring months of October and November of 2006 record numbers of consecutive days with maximum temperatures above 30° C were recorded. The year 2006 was also the fifth driest year on record and had a record high amount of sunshine. The meteorological station at Canberra International Airport experienced its fifth lowest annual rainfall on record with a total of 360 mm (long-term average 622 mm). Only 69 rain days during 2006 were recorded, which was well below the historic average of 103 rain days (Bureau of Meteorology, Canberra). In the months during which my research was conducted, weather conditions were characterised by below average rainfall and above average monthly temperatures, leading to significant deficiencies in precipitation and very warm (hot) months (Figure 5, Figure 6).

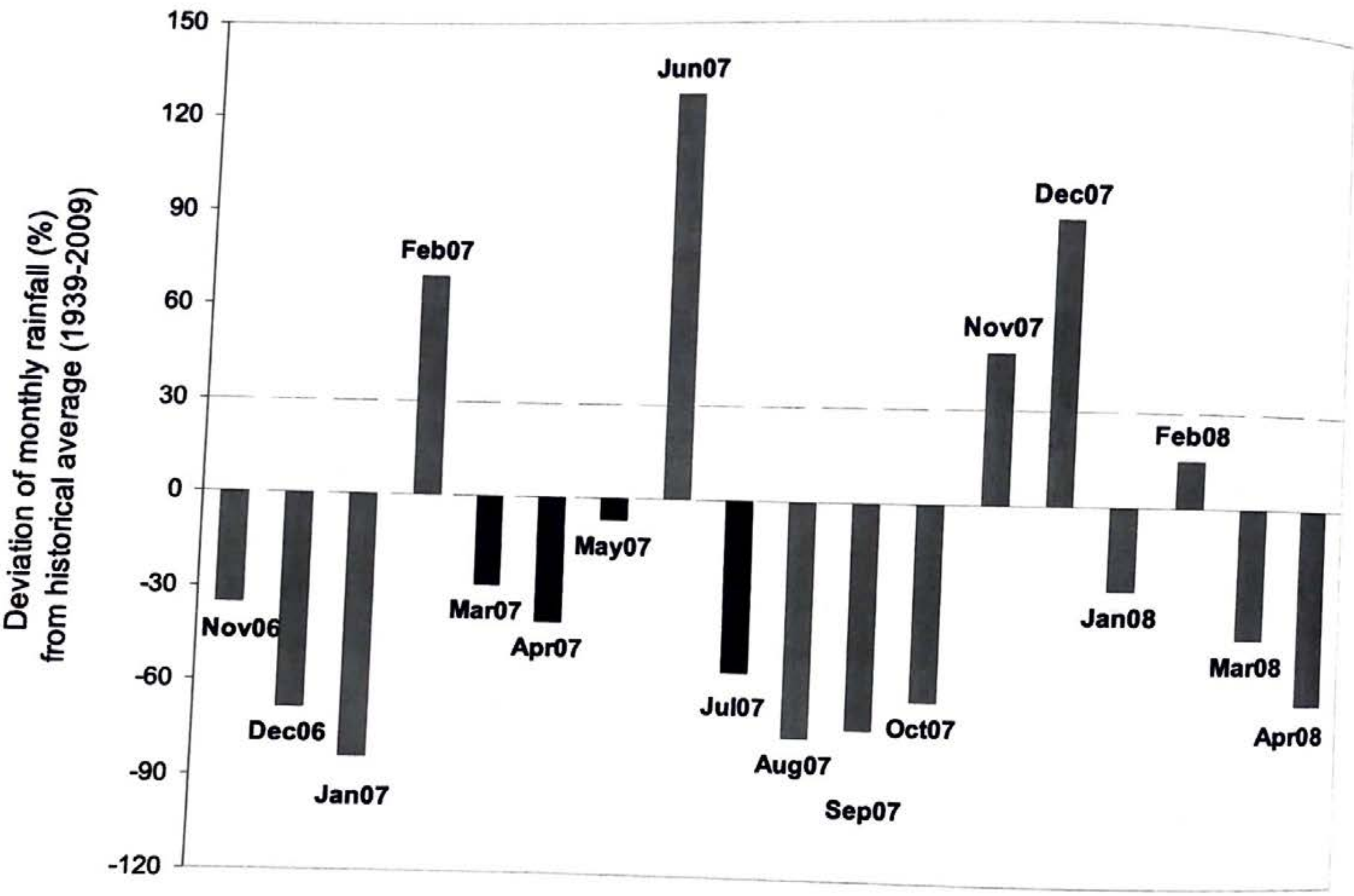


Figure 5 Rainfall deficiencies during the sampling periods from November 2006 – April 2008. Bars per month indicate the deviation (positive or negative) of the monthly rainfall from the historical average rainfall (1939-2009). Data from Bureau of Meteorology, Canberra.

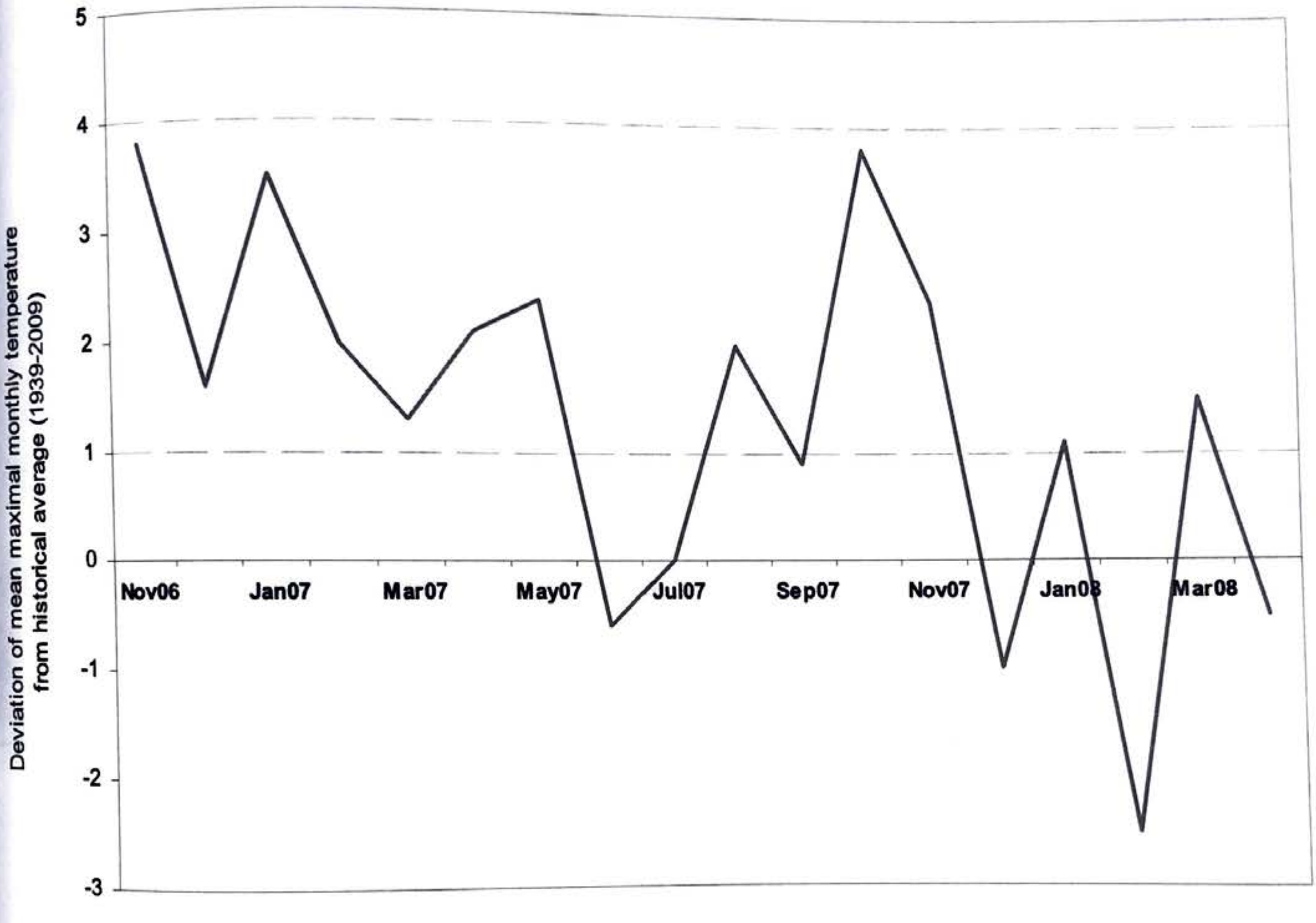


Figure 6 Temperature deviations in grad Celsius from the long term average during the sampling periods from November 2006 – April 2008. Graphs indicate the deviation (positive or negative) of the monthly mean maximal temperatures (C) from the historical average rainfall (1939-2009). Data from Bureau of Meteorology, Canberra.

Chapter 2

Temperate grasslands- out of sight, out of mind? Introduction to the conservation and future research for one of the world most threatened ecological communities

Introduction

'Heaven knows, we've got plenty of grass' (former Victorian Conservation Minister Australia)

Native temperate grasslands are ecological communities that have, at a global scale, undergone dramatic reduction and modification as a result of agricultural and, more recently, urban development (TGCI 2008). Much of this remarkable grass- dominated landscape has been completely lost and remains highly degraded. According to the Millennium Ecosystem Assessment (2005) nearly 80 percent of the world coverage of the temperate grassland biome has already been lost..Surviving intact remnants face an array of threats and are afforded poor conservation protection (Chape *et al.* 2008; TGCI 2008). On an international scale, native temperate grasslands are one ecological community that receive very low level of protection when compared to the situation for terrestrial biomes (Chape *et al.* 2008; TGCI 2008). However, in many countries, conservation efforts have helped to stem the ongoing destruction of grassland remnants whilst protecting them as endangered and threatened communities. Nonetheless, the level of protection applied to temperate grasslands at the global and regional level has been identified as not sufficient to stop further loss of biodiversity and ecosystem degradation.

In this chapter, I provide an overview of the vulnerability of native temperate grasslands to past and ongoing threats and identify priorities for future research and conservation in temperate grasslands. This chapter takes the form of a short review (overview) and provides an international perspective on the conservation of temperate grasslands. By examining key studies from East Asia, North America and South-eastern Australia I focus on the consequences of ; (1) habitat loss, fragmentation and degradation; (2) climatic change; and (3) biotic invasion to the biodiversity in temperate grassland. I selected these geographically remote temperate regions to demonstrate the global pattern of large scale temperate grassland modification and the effects of new arising threats such as climatic change. The selected regions once supported extensive areas of temperate grassland and are representative of the extent of temperate grassland modification at the global scale. This mini literature review enabled the identification of key issues currently underrepresented in native grassland research and enabled me to consider future research and conservation priorities of international relevance (see TGCI 2008 for details). This chapter is not intended to be an exhaustive review. Rather, it is an attempt to identify the knowledge gaps present in our understanding of native temperate grasslands as distinctive ecological communities, the threats posed to them from historic, ongoing and combined environmental changes, and the future research and conservation needed to maintain the viability of these unique types of grasslands.

The questions that I aim to answer with this review are:

1. What are the ecological characteristics of native temperate grasslands?
2. What are the historical and current distributions of temperate grasslands and what are the threats that they are exposed to?
3. How has past research improved the understanding about the ecology of temperate grassland and what were the most representative topics and taxa in temperate grassland research?
4. What direction should future research take to improve the conservation of native temperate grasslands?

Setting the scene

"Knowing trees, I understand the meaning of patience.
Knowing grass, I can appreciate persistence".
Unknown author.

In an international context, native temperate grasslands are recognised by many names. In North America they are known as short and tallgrass prairies, they are called steppes in parts of North central Eurasia, veldt in South Africa, pampas in South America, puszta in Hungary and lowland grassland in South-eastern Australia (ACT Government 2005; Gurevitch *et al.* 2002). The term 'temperate native grassland' is interchangeably used in the literature for 'natural temperate grassland' or 'native temperate grassland' or 'indigenous temperate grasslands' (Mark and McLennan 2005). I use the term 'native temperate grassland' throughout this overview (and thesis) and refer to a non-alpine primary grassland ecosystem that occurs between 300-600 metres above sea level in mainly flat to gently undulating landforms. Most native temperate grasslands are located in the interior of large continents in the rain shadow of mountain ranges where continental climate brings harsh winter conditions along with hot dry summers (Chape *et al.* 2008). All native temperate grasslands share the characteristic of the absence of a mature tree cover and the overall dominance of a ground layer of native perennial warm-season (C_4) and cold-season (C_3) grass species with a mixed forb layer (Duffey *et al.* 1974; Gurevitch *et al.* 2002). The dominance of grasses is explained by climatic conditions (mainly low rainfall and periodic droughts) and disturbance mechanisms such as fire (natural and anthropogenic origin) and grazing activities by native herbivores (Anderson 2006; Bredenkamp *et al.* 2002; Gurevitch *et al.* 2002; Walter 1968).

Although all major groups of fauna are represented in temperate grasslands, the overall diversity of species is lower in temperate biomes than in forests ecosystems and in the tropics (Sala *et al.* 2001). However, the flora and fauna in temperate grasslands is often diverse, highly specialised and endemic (Groombridge 1992). For example, in North America, more than 250 native plant species are found in tallgrass prairies with the majority belonging to perennial grasses (Freeman 1998). Around

350-400 vascular plant species have been recorded in temperate grasslands in China (Peng *et al.* 2008). The most obvious and iconic animals in temperate grasslands are the large herbivores which have prominence in secondary production (Sala *et al.* 2001). Bison are the most well known large ungulate grazers in North America that make a significant contribution to the functioning and production of the prairies through their impact on nutrient cycles, primary production and for the shaping of the composition of the flora (Frank *et al.* 1994; Frank and McNaughton 1992). Smaller-bodied vertebrates such as birds, rodents and reptiles also play an important role in shaping the distinctive biodiversity of temperate grasslands. Birds are perhaps the most iconic grassland fauna and thus, are one of the best documented groups in temperate grasslands (Brennan and Kuvlesky 2005; Chapman *et al.* 2004; Coppedge *et al.* 2001). The diverse plant assemblages in grasslands provide suitable habitat for many endemic and specialised grassland birds. Owing to the continental location of most temperate grasslands, such as the prairies in North America, they collectively often constitute a transition zone for birds where eastern and western bird species are found (Costello 1969). Reptiles comprise another grassland group that takes advantage of the characteristics of the grassy ecosystem. Microhabitat structure (grass tussocks, rocks and soil cracks), sufficient dietary supply (micro and macroinvertebrates) and high level of solar radiation provide ideal settings for a rich reptile fauna in temperate grasslands (Collins 1993; Osborne *et al.* 1993b). They are however, a much less diverse group than birds and mammals (Kauffman *et al.* 1998).

Invertebrates are one of the most diverse and abundant groups in grassland ecosystems. They are essential for the functioning of the ecosystems through their role as herbivores, pollinators, predators, parasitoids, and decomposers (Samways 2005). Despite the significance of the temperate grasslands insect fauna to the stability and functioning of grassland ecosystems (Mulder *et al.* 1999; Risser *et al.* 1981), this important and mega-diverse taxonomic group is often less appreciated in temperate grassy ecosystems as many species are inconspicuous or undertake lengthy stages of their life-histories below ground (Coupland 1979).

Historical distribution of temperate grasslands

Native temperate grasslands were once a major global vegetation system that occurred widely within the temperate climate zone between 30–40 ° latitude on all continents except Antarctica (Figure 7) and covered approximately eight percent of the earth's terrestrial surface (Duffey *et al.* 1974; TGCI 2008). In the northern hemisphere, extensive areas of native temperate grassland occurred in North America, covering large areas from the Chihuahuan desert in the south to southern parts of Canada in the north and from the Rocky Mountains in the west to the adjunct deciduous forests of the eastern United States. Vast areas of temperate grasslands extended from the Ukraine to China on the Eurasian- Asian continent. In the southern hemisphere, temperate grassland was the dominant vegetation type in the vast pampas and campos in South America and throughout much of the temperate climate zone in south eastern Australia (Sala *et al.* 2001) (Figure 7). The conversion of temperate grassland into agriculture land with its associated livestock grazing, transformation into pasture and crops; urban development with associated infrastructure; inappropriate fire regimes; and in some places excessive water extraction have resulted in large scale losses and degradation of most native temperate grasslands (TGCI 2008). Today, much of this remarkable landscape of grassland plains and prairies has been completely lost and remains highly degraded.

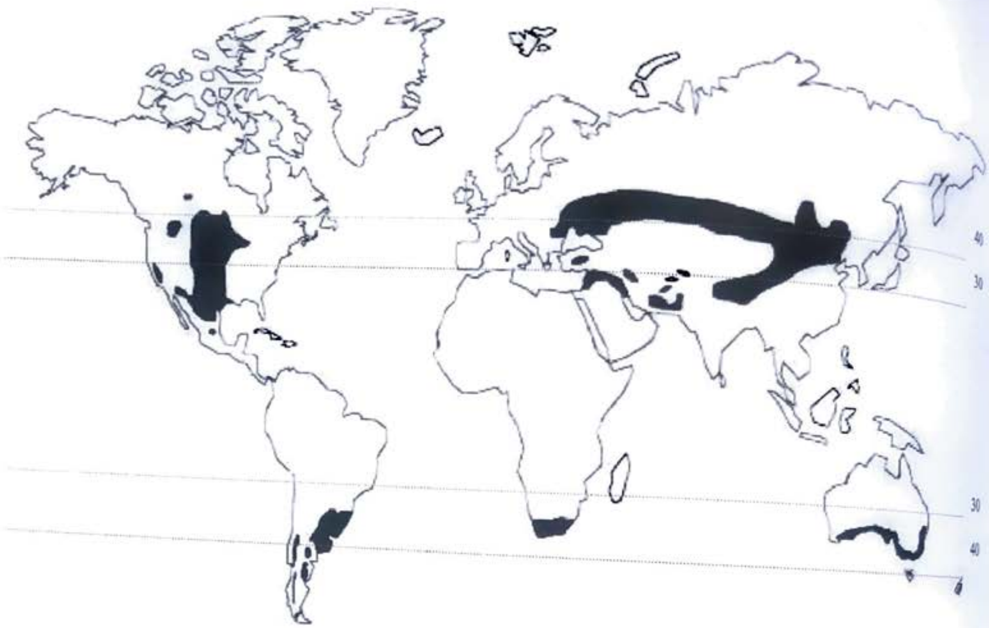


Figure 7 Extent of natural temperate grasslands (black areas) in the temperate zone between 30–40° latitude in both the northern and southern hemispheres prior to large scale anthropogenic modifications. Modified after Coupland (1992) and Bailey (1998). Note that these areas are indicative of occurrence in a general region, which may support a variety of vegetation types.

Threats to native temperate grassland- an international perspective

Congruent with other ecological systems, habitat loss, fragmentation and degradation are listed as singular major threats that, in combination with the overarching threat of climate change, add pressure to the integrity of the biodiversity in temperate grasslands. Climate change acts as a singular factor but more importantly with its additive power, in combination with anthropogenic native temperate grassland modifications (Figure 8). The World Temperate Grassland Conservation Initiative (TGCI) is an established project developed by the Grasslands Protected Area Task Force of the World Commission on Protected Areas (WCPA) of the International Union for Conservation of Nature (IUCN). The TGCI considers that temperate grasslands are one of the world's most threatened ecosystems because of the extensive losses of temperate grassland at a global scale. Based on the example of three international temperate regions, I highlight the severity of these large scale losses and degradations of temperate grasslands.

East Asia has one of the largest areas of temperate grassland on Earth (Kehui *et al.* 2007) (Figure 7). The East Asian temperate grasslands are recognised as being a fundamental natural resource that is important to economic growth and to the cultures in this region (Qi *et al.* 2007; Zhan *et al.* 2007). Most of the temperate grasslands in East Asia are densely populated by herders and farmers, along with their millions of livestock. For example, in China more than 196 million ha are classed as temperate grassland and meadow, but these areas also support 110 million people and their livestock (Peng *et al.* 2008). Unsustainable grazing and the transformation of the natural temperate grasslands into farmland and urban land, combined with the effects of prolonged droughts, have led to large scale degradation of the original temperate grasslands. According to recent reports, most of temperate grassland in China has been highly degraded. Estimates of the amount of remaining temperate grassland in reasonable condition range from 10 to 50 percent (see citation within Peng *et al.* 2008). Large scale modification of temperate grassland throughout temperate East Asia has caused adverse ecological effects at local and regional scales threatening the sustainability of natural temperate grasslands throughout East Asia (Parton *et al.*

1994; Reynolds 2005). Limited food supply and a lack of arable land elsewhere will lead to even greater pressure on these East Asian grasslands in future (Reynolds 2005; Suttie 2005). Thus, the temperate grasslands in East Asia are under ongoing pressure, leading to further degradations and losses.

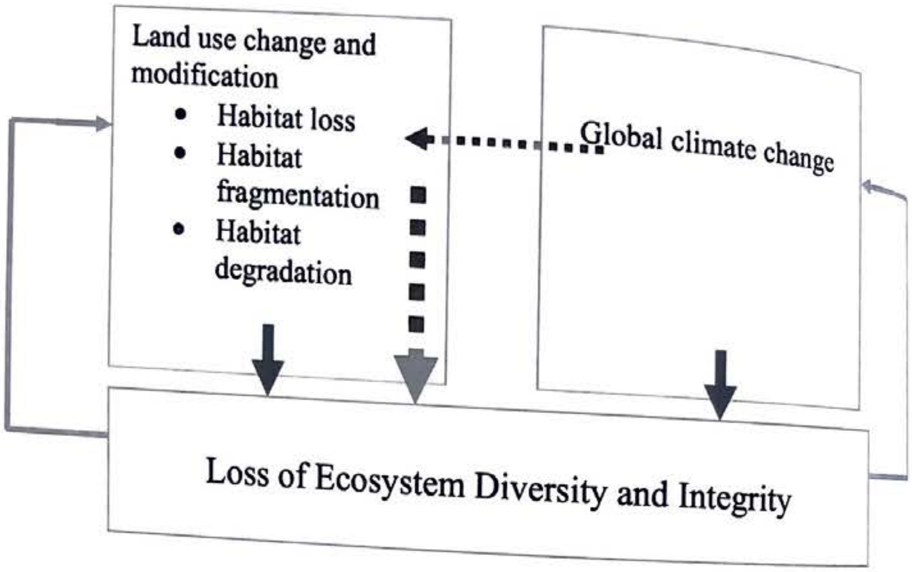


Figure 8 Schematic diagram modified from TGCI (2008) showing interactions between the major threats of land use changes and global climate change to temperate grasslands ecosystem services. Global climate change acts as a singular factor and with its additive power.

In North America, the first European settlers experienced the temperate grasslands (prairies) of the Central Grasslands and Great Plains as being pristine with little anthropogenic modification (Pieper 2005). However, following the introduction of European agricultural practices, most of the historical grasslands of North America were rapidly transformed into crops (Wiken *et al.* 2008). Today, most remaining native grasslands are comprised of short grass prairies (Samson and Knopf 1994) (Figure 9). It is estimated that less than five percent of the pre European settlement tall-grass prairies remain intact (Coppedge *et al.* 2001; Fletcher and Koford 2002; Vanderhoff *et al.* 1994). Not surprisingly, the extensive reduction and modification of North American temperate prairie grasslands into agricultural land has lead to significant population declines and the extinction of many prairie dependant species (Hyde 1996). According to Sampson and Knopf (1994), in the United States 55 grassland species are listed as threatened or endangered with more than 700 additional species being candidates to become threatened or endangered.

Approximately one third of the species considered as endangered by the Canadian Committee on the Endangered Wildlife are associated with grasslands (World Wildlife Fund Canada (WWFC) 1988). Today, the intrinsic values of the North American prairies for the provision of ecosystem services are recognised. However, an recent review of protected areas of temperate grassland in North America (federal, provincial and state parks and the central plains grasslands) indicated clearly that the level of protection is not adequate to conserve the full extent of the remaining intact prairie grasslands (TGCI 2008).

The third example is from Australia where native temperate grasslands were once widely distributed in the temperate climate zone and covered extensive areas throughout the South-east of the continent. Not surprisingly, these open (treeless) grasslands were first settled by Europeans as a consequence of receiving relatively consistent rainfall and the presence of suitable soils for agricultural development (Benson 1994; 1997; Lunt *et al.* 1998). The lack of historical records, that could confirm the extent of the pre-1750 grassland in South-eastern Australia, makes it difficult to determine which grasslands are anthropomorphic in origin. It is not always clear which grasslands have formed as a result of land clearing after European settlement (i.e. so-called secondary grasslands) or have formed as a result of earlier deliberate burning practices by indigenous people over the last 40 000 years (Bowmann et al. 1990, Crowley and Garnett 1997). Despite these difficulties, there is considerable consensus that, within the temperate climatic zone, native temperate grasslands comprised an extensive part of the landscape (Lunt 1997). Since European settlement in Australia enormous effort has been applied by farmers to improve the productivity of natural grasslands, leading to the large scale transformation of native grassland into native and exotic pasture (Kirkpatrick *et al.* 1995; Taylor 1998). At present it is estimated that less than 100000 ha of the former extensive temperate grassland in South-eastern Australia remain in a reasonably natural state, indicating that more than 95 percent has been destroyed or significantly altered (ACT Government 2005; Kirkpatrick *et al.* 1995; State of Victoria Department of Infrastructure 2000). As has happened elsewhere, the biota is expected to have undergone significant declines and extinction as a result of such extensive large scale loss of natural habitat and historical and ongoing degradation.

More recently, many of the remaining, often highly fragmented, native temperate grasslands have become threatened by urban development. This is in particular the case for the temperate grasslands in South Eastern Australia where rural expansion through the spread of small holding farms and the growths of cities have increased the pressure of remaining temperate grasslands to become developed into urban land (ACT Territory Plan 2008; State of Victoria Department of Infrastructure 2000). The cities of Melbourne (Victoria) and Canberra (Australian Capital Territory) provide examples of modern metropolitan areas situated in temperate grassland regions undergoing rapid urban expansion. Much of Melbourne is situated on the former grassy volcanic plains that surrounded Port Phillip Bay, whereas Canberra was built on the so-called Limestone Plains, an area of treeless grasslands. Both cities require a steady supply of land for residential and industrial development; generally supplied at the expense of surrounding grasslands (Sharp and Shorthouse 1996; Williams *et al.* 2005a). This constant high demand for urban development has lead to ongoing losses of temperate grasslands in both cities and surroundings. Melbourne and Canberra have experienced losses of 36 percent of lowland native grassland and a 44 percent reduction in grassland area respectively over a 15-year period (1985–2000) and overall the destruction of 70 percent of temperate grassland over the 16 year period from 1980 to 1995 owing to increasing urban and rural development and weed invasion (Benson 1994; Morgan 1998; Stuwe and Parsons 1977) (Figure 10).

Considerable effort by the Australian governments has been executed to legally protect and manage the remaining natural temperate grasslands in Melbourne and Canberra -which today contain the largest native grassland remnants in Australia (ACT Government 1999; 2005). Despite these attempts, it is likely that further destruction and degradation of native grassland will occur in these remnants, especially those with high perimeter to area ratios, and in close proximity to major roads and residential and industrial areas (Williams *et al.* 2005a).

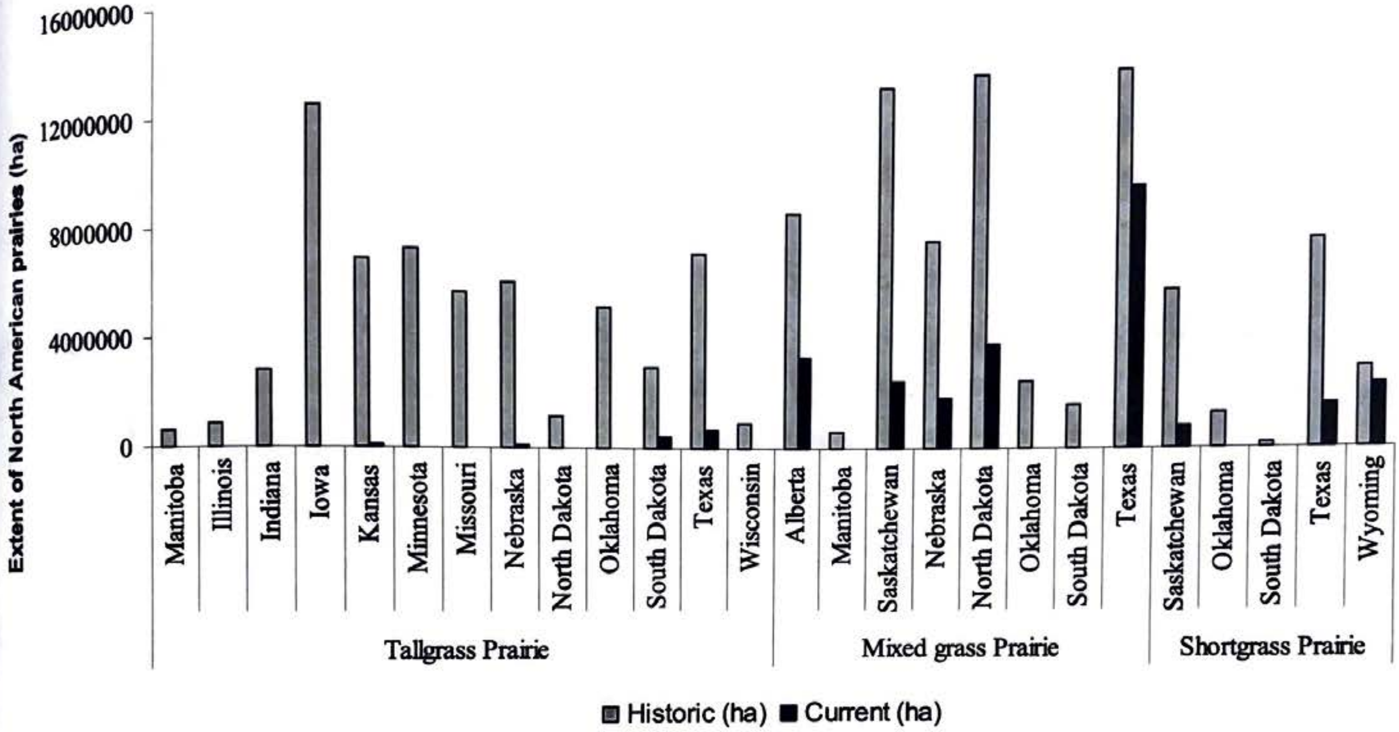


Figure 9 The extent of prairie declines in North America based on information provided by Samson and Knopf (1994). The figure summarise the estimated current areas and historic area of the tallgrass, mixed grass, and short grass prairies. For full details see Sampson and Knopf (1994).

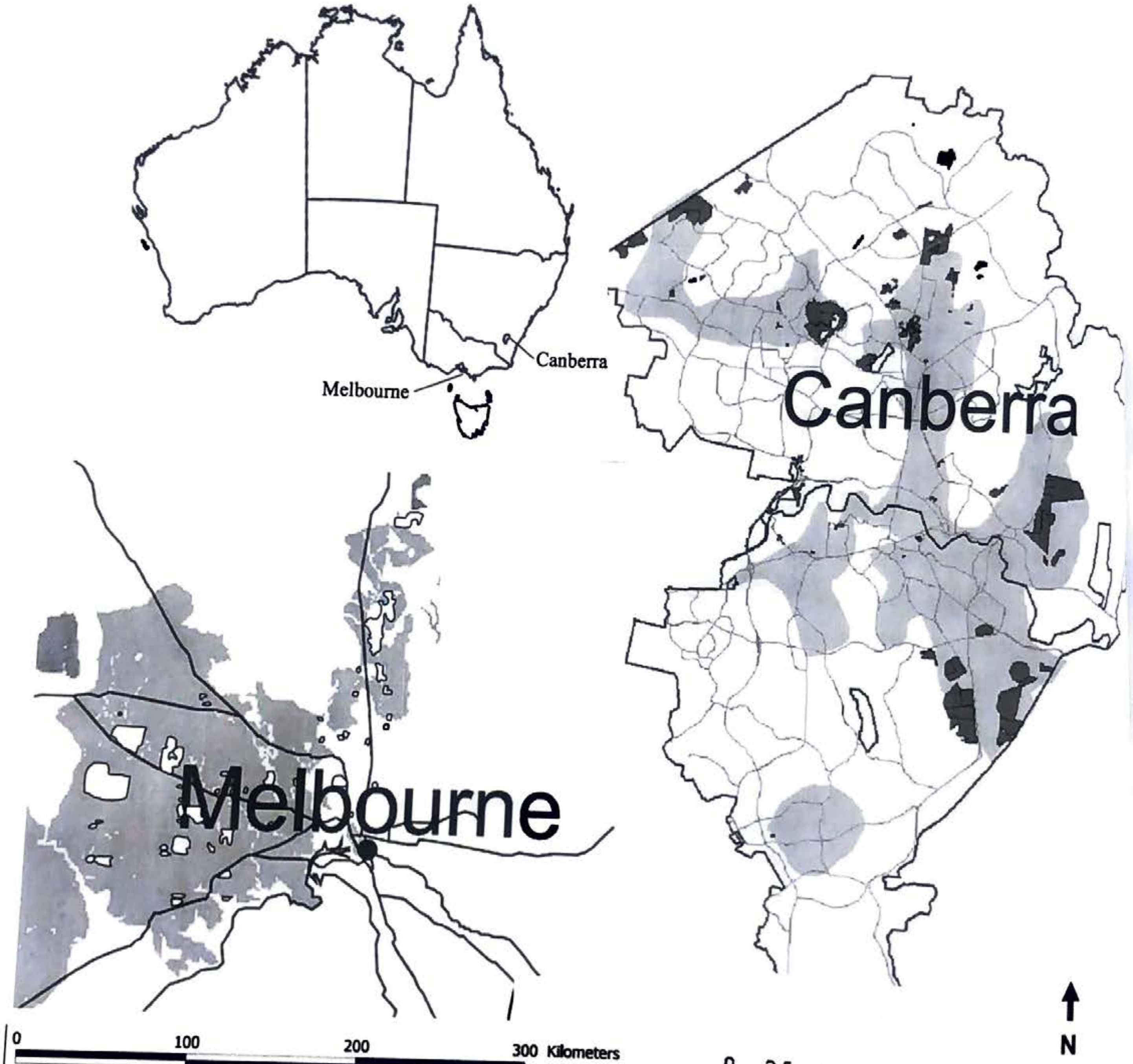


Figure 10 Extent of losses and fragmentation of native temperate grassland within the vicinity of the two Australian cities: Canberra and Melbourne. Light grey areas indicate extent of pre-European settlement native grassland distribution. Locations in Melbourne indicated as white (no fill) and in Canberra as dark grey fill show remaining native grassland fragments. Sources: ACT Government (2005) and modelled native vegetation data from the Department of Sustainability and Environment (DSE) Corporate Spatial Data Library (2005).

Native temperate grassland: ecosystem services, monitoring and research

From a human point of view, temperate grasslands, even in an unmodified condition, provide a range of ecological services for the well being of humans. For example, temperate grasslands contribute enormously to livestock production and agricultural development (Conner *et al.* 1998), regulate ecological processes through biochemical processes such as soil, water, atmospheric carbon and nitrogen flows (Brye *et al.* 2004) and are of significant value for the cultural and spiritual well-being of indigenous people. The ability of ecosystems to continuously provide ecosystem services (provisioning, regulating, supporting and cultural services) is generally expected to be dependent on the maintenance of an intact biological diversity as a result of the strong correlation between ecosystem process rates and biological diversity (Schläpfer 1999). Therefore, the maintenance of the genetic, biotic and landscape diversity of temperate grassland is important because of its role in securing future ecosystem services.

From an ecological perspective, temperate grasslands, in unmodified and modified condition, have provided an ideal setting for ecological research and for conducting long term monitoring to search for and test fundamental principles in ecology and conservation biology (Golley 1993; Kang *et al.* 2007; Knapp *et al.* 1998). Two central questions in ecology: 1) the relationships between ecosystem productivity and stability, and 2) the relationship between ecosystem productivity and biodiversity, were examined in temperate grasslands (Bai *et al.* 2004; Chalcraft *et al.* 2009; Jennings *et al.* 2005; Tilman and Downing 1994; Tilman *et al.* 2001). Bai et al. (2007) studied temperate grassland at field sites across the Mongolian temperate region and reported on the positive linear relationships between productivity and diversity at multiple organisational levels and across landscape scales. Their results are in contrast to findings of no positive linear productivity- richness (hump-shaped) relationships in the terrestrial ecosystems of Europe, Africa and North America (Bai *et al.* 2007; Coupland 1992). These results highlight the importance of testing general ecological hypotheses in ecosystems that may share taxonomic similarities e.g. the

North American Prairies and the Eurasian steppe, but differ in climatic conditions, soil, plant and animal functional traits (Hector *et al.* 1999; Tilman 1997; Tilman *et al.* 2001; Tilman *et al.* 1996). Such significant contributions to ecological theory have considerably influenced the current debate about the relationship between biodiversity and the functionality of ecological systems in the light of the loss of biodiversity and have provided insight into the role of ecological processes involved in the maintenance of ecosystem stability.

Along with basic ecological research, temperate grasslands provide particularly suitable settings for research aimed at detecting the responses of the biota to environmental changes over time. The monitoring programs in temperate North America (International Biological Program IBP) and China (Chinese Academy of Science) were established in the 1960's and early 1970's (Hobbie *et al.* 2003) and provide ecologists with comprehensive and comparable data sets of enormous value. The analysis of long term data have improved enormously our understanding of the ecological requirements of many temperate grassland species and are now used to predict the ecological effects of changes in climate and land use (Bai *et al.* 2004; Fan *et al.* 2008; Liu *et al.* 2006; Shi *et al.* 2002; TGCI 2008). The prediction about the effects of changing climatic conditions in temperate grasslands is of particular conservation interest because temperate grasslands are considered to be particularly vulnerable to climate change as a result of a long evolutionary history between climate and grassland productivity, nutrient cycles and the evolution of species (Johnson *et al.* 2005; Niu *et al.* 2008; Sala *et al.* 1996; Soussana and Luescher 2007).

Consequences of climate change for native temperate grassland

Climate is an important component of a set of global-scale environmental changes that drives evolutionary, ecological and demographic changes in species and populations (Hazler *et al.* 2006). For example, variation in rainfall determines physiological and phenological processes in organisms, controls the pattern of migration of highly mobile populations (Newton 1998) as well as influences annual variation in population size in birds and mammals (Stenseth *et al.* 2002). Thus, changes in climatic variables, including temperature and rainfall, will ultimately directly and indirectly influence the distribution and the composition of species populations and communities as well as affect their inter and intraspecific interactions (Hughes 2000; 2003; Parmesan 2007; Parmesan *et al.* 1999; Thomas *et al.* 2004).Temperate grasslands contribute substantially to the storage of soil carbon and are recognised as significant contributors to the global carbon cycling processes (Bertin 2008; Fischlin *et al.* 2007). Rising carbon dioxide levels and increased temperatures are likely to lead to an increase in plant productivity, resulting in changes in plant species composition and their demography (Williams *et al.* 2007). Generally, it is hypothesized that elevated atmospheric carbon dioxide levels will stimulate C_3 plant species to a much greater extent than C_4 species and increasing CO_2 input may cause persistent increases in primary production, leading to greater storage of carbon in plant residues and soil organic matter (Hunt *et al.* 1991). However, research on C_3 and C_4 grasses in South-eastern Australian by Williams et al. (2007) found significantly reduced plant growth in a dominant C_3 grass exposed to elevated carbon dioxide and markedly warmer conditions. These results indicate that responses by plants species to increased atmospheric carbon dioxide can be variable and the subsequent feedback loops unclear.

Although native temperate grasslands experience droughts on a regular basis (IPCC 2001; Parton *et al.* 1994), native grasslands are highly sensitive to limited soil water availability associated with significant rainfall deficiencies (Kammer 2002; Sebastia *et al.* 2008). Increasing periods of drought may cause quantitative and qualitative changes in species composition and configuration by altering the density and frequency of the species involved (Frank 2007; Morecroft *et al.* 2002). This process can even persist for several years after the drought event (Frank 2007; Kammer 2002). Changes in precipitation and associated changes in the availability of water are likely to have effects on the composition and structure of temperate vegetation (Frank and McNaughton 1992), primary net production, consumption, nutrient flux and on the life history of species associated with temperate grasslands (George *et al.* 1992; Macias-Duarte *et al.* 2004; Manzano-Fischer *et al.* 1999). For example Bernays and Chapman (1973), observed slow development, poor survival and small size of *Chortoicetes terminifera* (Orthoptera) individuals under drought conditions and related their results to species desiccation rather than to starvation. Drought conditions also affect the survival, population dynamics and dynamics of larger grassland species such as birds (Yarnell *et al.* 2007), reptiles (Sperry and Weatherhead 2008), small mammal (Cairns and Grigg 1993; Caughley *et al.* 1985) and marsupials (Munn and Dawson 2010). Changes in climate may also reduce species survival indirectly as a consequence of changed herbivore-plant-insect interactions, changed predator-prey interactions and cascading effects (Goulson *et al.* 2005). Combined changes in spatial and temporal patterns of precipitation, temperature, and increasing atmospheric carbon dioxide as predicted under current global climate change scenarios, are expected to profoundly influence the diversity, productivity and stability in temperate grasslands (Borchert 1950). In particular, significantly more disturbances, especially increasing fires and more frequent periods of lower amounts of rainfall (droughts) are predicted to occur in the future in temperate grassland, placing greater stress on the survival of biota in native grasslands and the integrity of the grassland ecosystem functions (Fischlin *et al.* 2007).

One major economic and ecological concern related to the impacts of climate change is the increasing likelihood of pest population outbreaks and increasing capability of exotic species to become established (Dukes and Mooney 1999; Goulson *et al.* 2005; Kreyling *et al.* 2008). Research on the factors that trigger pest outbreaks indicates that there is a close relationship between the timing of outbreaks and precipitation (Patterson *et al.* 1999). Under the predicted climate scenarios, pest outbreaks and the speed of invasion may increase with raising temperatures and changes in precipitation. Consequently, climatic anomalies such as extreme drought and floods have the ability to strongly affect the periodicity and severity of pest outbreaks and invasion. However, the prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather and the effectiveness of pesticides on targeted pests might change under changing climatic conditions (Harrington *et al.* 2001).

Native temperate grasslands have been exposed to a long history of invasions of anthropogenic, natural and unknown origins. For example, in North America, shrubs have successfully encroached into native grassland resulting from changes in climatic pattern with consequences for the conservation of native species (Grant *et al.* 2004; Van Auken 2000). In south-eastern Australia, South-American grass species such as Chilean Needle Grass (*Nassella nessiana*) and Serrated Tussock (*Eragrostis curvula*) have successfully invaded many temperate grasslands and are threatening the existence of grassland fragments that are already highly vulnerable to disturbance (ACT Government 1999; 2005). Much less is known about the invasion of invertebrates and other faunal taxa into temperate grasslands in Australia and the interactions between invaders and natives under varying climatic conditions.

In summary, there are several reasons for our overall concern about the future viability of native temperate grasslands. These grasslands have declined extensively at the global scale and remaining temperate grasslands, that are still intact, are threatened by historical and ongoing threats of habitat loss, fragmentation, and degradation in combination with climate change. Thus, native temperate grasslands around the globe are at the risk of becoming one ecological community that is at the brink of extinction. Important ecosystem services that are provided by native temperate grasslands are expected to become reduced and limited as a result of these historic and ongoing alterations.

Identifying the gaps in native temperate grassland conservation research

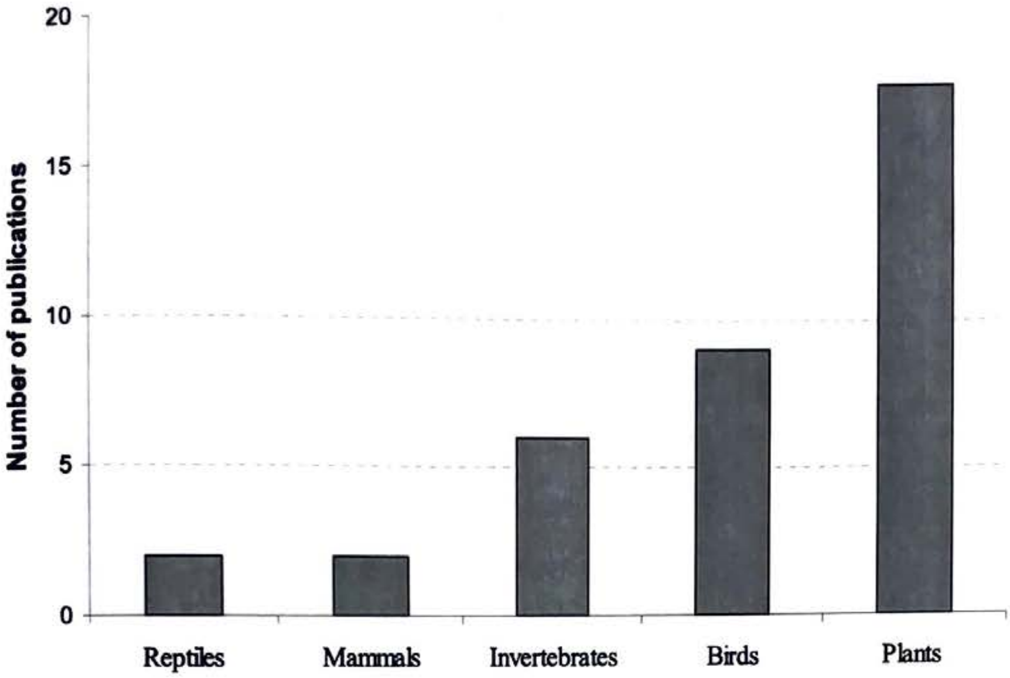
Earlier in this review, I considered the extent of temperate grassland loss and degradation at the global scale and highlighted the factors that are likely to threaten the survival of the temperate grassland biome in the future. According to the World Temperate Grassland Conservation Initiative (TGCI) there are two main concerns regarding the future of temperate grasslands: first, the overall insufficient level of legal protection for the grasslands, and second, the challenge of managing temperate grassland in the face of widespread livestock grazing, the introduction of exotic species, fire management and the loss of grasslands through urban and forest encroachment. In addition grassland conservation is threatened by the overarching, yet not well understood, impact of global climatic changes (TGCI 2008).

Conservation research is one important tool that is essential for defining management prescriptions and for the identification of the relationship between the biota and the application of management under various conditions (climatic conditions, intensive management).To set future conservation research priorities it is important to identify key gaps in knowledge. To do this I examined 78 international publications that matched with the keyword search ("temperate grasslands conservation") in the Web of Science. The publications that I found displayed a major focus on temperate grassland plants and birds (Figure 11). Despite their recognised contribution to biodiversity in grasslands, invertebrates were widely underrepresented in the literature that I found. Less than 10 percent of all studies focused on invertebrates in temperate grassland conservation research. Most of the ecological studies that I examined were related to management, conversion and modification of grasslands, indicating a general concern about large scale changes in temperate grassland (Figure 11). Surprisingly, topics such as climate change and invasion were scarcely addressed. Although I specifically focused on conservation research in temperate grasslands, I recognize that much more extensive literature is available but much of this is unpublished and difficult to access or would have been found under different "key word" searches. Nevertheless, the publications that I found addressing the conservation in temperate grassland are likely to provide a balanced view of recent research in temperate grassland conservation as the type of conservation journals, where the publications were found, represent a broad range of research platforms (Appendix I). My mini literature review also covered research activities for most of the continents with known past and current temperate grasslands (except Asia and South Africa).

In addition to the review of recent literature mentioned above, I compiled information from the TGCI report (and Appendix) to further identify future conservation research in temperate grassland at the global scale (TGCI 2008). Based on information provided by experts on temperate grassland conservation it was clear that considerable insight into temperate grassland ecology and the effects of climate change, invasion and management has been gained from North America and to a much smaller extent from Australia and South Africa (Figure 11, Table 1). In North America and Asia long term ecological monitoring programs are established, however, in Australia, South America and South Africa there appears to be a lack of any coordinated monitoring program (TGCI 2008). All temperate grassland experts that were invited to the workshop agreed on the fact that all regions of native temperate grasslands experience a low public awareness (with the exceptions of the North American prairies) and increasing "public environmental education" is needed (Table 1).

The development of mechanisms for improving the international collaboration related to temperate grassland conservation was identified as one major global strategy for future temperate grassland conservation (TGCI 2008). This can be achieved through multidisciplinary research networks that assist in gaining insight into ecological pattern and processes in temperate grasslands at a larger scale. Collaborative efforts will lead to a better understanding of the ecology of temperate grassland and such approaches should be developed and expanded to regions where such networks do not exist. The establishment of networks of monitoring and research sites in temperate grasslands as demonstrated by the LTER monitoring scheme (http://www.lternet.edu) provides great opportunity for developing an understanding of ecological processes in temperate grasslands over long temporal and broad spatial scales.

Although some temperate grassland ecosystems are ecologically well understood (e.g. North America), temperate grasslands in other regions such as in South Eastern Australia, South Africa and South America still lack up to date species inventories and basic ecological information (Table 1). The lack of taxonomy for many species, in particular for invertebrates, is the greatest impediment for collecting information of the species composition in temperate grassland. Similar challenges involving the lack of species inventories also face tropical ecosystems in remote areas that are often considered as biodiversity hotspots. However, studies to include the knowledge of indigenous people and to train amateur ecologist/taxonomist in tropical ecosystems have assisted greatly with the mapping of the flora and fauna and has provided insights about the feasibility of such an approach (Stringer *et al.* 2003). Similar attempts to encourage and educate the people that live in and around temperate grasslands should play a much stronger role in the future of temperate grassland conservation at a global scale. In Australia, well advised community groups such as Friends of Grassland have made major contributions in this way (Richter *et al.* 2009).



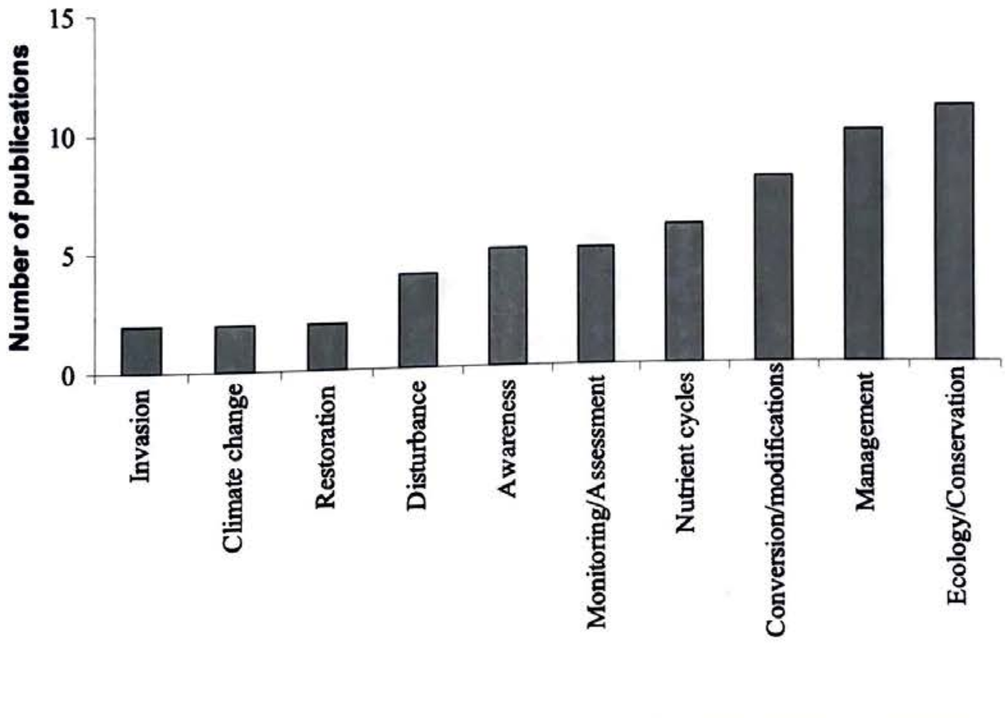


Figure 11 Representation of taxa (a) and research topics (b) in temperate grassland conservation. Results obtained from a search of 78 publications that were published in international journals. Publication list retrieved from the Web of Science and individually searched for the presence of each category. Studies that addressed organic matter and chemical cycles are excluded from the top graph.

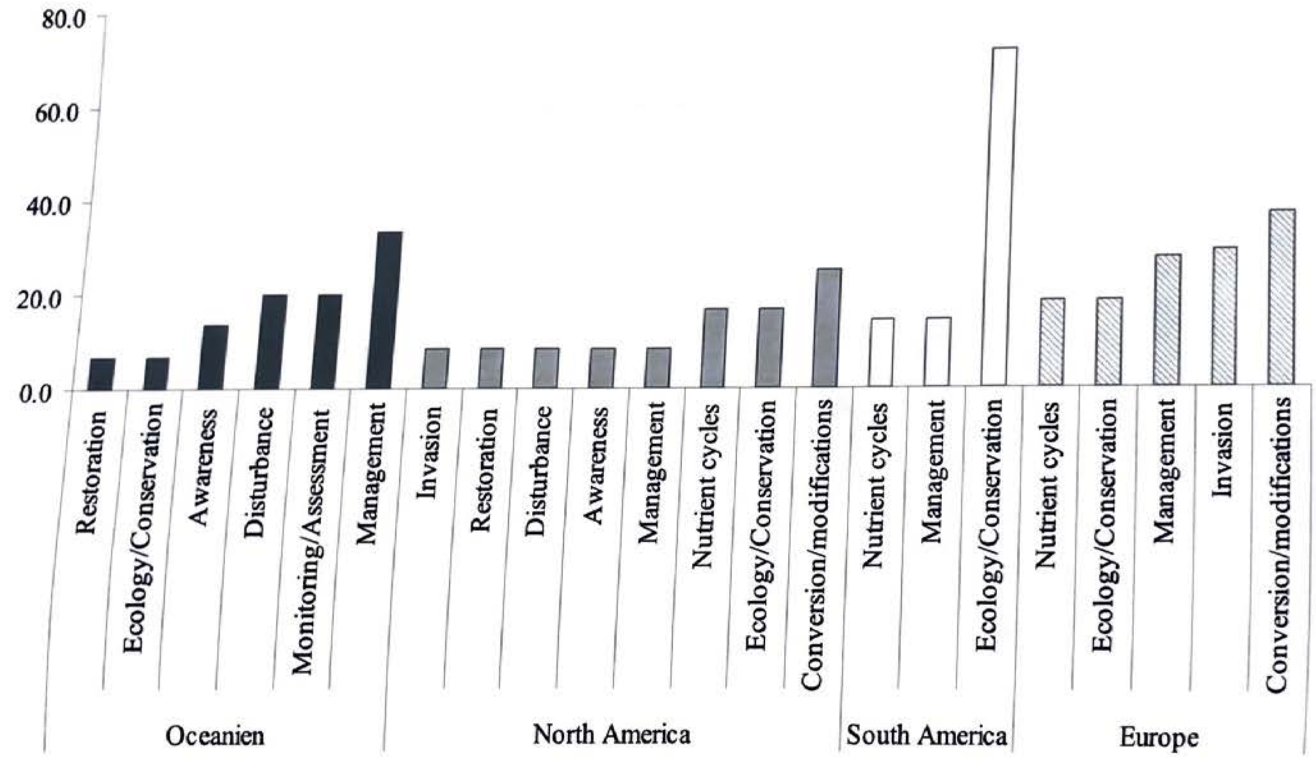


Figure 12 Proportion of literature that addressed conservation research topics (e.g. Ecology/Conservation, management, restoration) in native temperate grassland classified according to the continent where the study was conducted. The information is based on published literature found under the keyword search "temperate grassland conservation" at the Web of Science.

Table 1 Identification of potential research and conservation priorities for native temperate grasslands. Symbol X indicates existing information and attempts to address these issues; O indicates areas that are important to improve in future and are currently not sufficiently addressed, "minus" indicates that not sufficient information were found. All information presented in this table obtained from contributions of invited authors at the World Temperate Grassland Conservation Initiative Workshop 2008 report (TGCI 2008).

Conservation/research action in native temperate grasslands		South East Asia	North America	South Africa	South Eastern Australia	South America
Legal protection and conservation		O	O	O	O	O
Long term monitoring		X	X	O	O	O
Species inventories		O	X	X	O	O
Research	Climate Change	X	X	O	O	-
	Management	O	X	X	X	-
	Management + Climate Change	O	X	-	O	-
	Fragmentation/Habitat Loss	-	X	X	X	-
	Grassland Restoration	-	X	-	X	-
	Alien Species invasion/Pest outbreaks	X	X	-	O	-
Public awareness		O	X	O	O	O

Conservation research for native temperate grassland- Where to go from here?

My overview clearly indicates that native temperate grasslands throughout the world have been exposed to an extensive array of threats and human activities. These impacts will continue to alter the extent and quality of temperate grasslands to such a level that there is concern about their long term viability. Thus, keys to improving the long-term survival of the temperate grassland are (a) increasing legal protection, (b) the establishment of reserves that are large enough to maintain the diversity of habitats and species that are characteristic for the region, and c) a significant increase in conservation- related research to better understand the functioning of native temperate grassland that in turn will assist with the management and conservation of remaining grasslands (Bomar 2001; Martin and Wilsey 2006; Piper *et al.* 2007; Ries *et al.* 2001; TGCI 2008).

My review has found that, in comparison to research on the effects of land use changes in temperate grassland, there is an underrepresentation of research that addresses the effects of the threats of climate change and biological invasion. Climate change and biological invasions are two major threats to the diversity and integrity of temperate grasslands. Thus, research that contributes to our understanding of the effects of climate change and invasion, singularly and in combination, is essential to inform temperate grassland mangers how to best maintain and manage grassland remnants. Research about the underlying mechanism for invasion under climate changes, the consequences of management strategies under changing climatic conditions and the effects of climate change on the temperate grassland biota (e.g. population dynamics, dispersal, interactions) will play an important role in future grassland conservation – this is made more imperative with the growing clear evidence that that climate change is a reality, and that there is considerable uncertainty about its direct and indirect effects.

I have found little information about the application and potential for rehabilitation and restoration of temperate native grasslands. This limitation leads to the need for action that the targets the expansion of the size of native temperate grassland reserved areas and for the better protection of existing temperate grassland remnants. The rehabilitation of degraded areas that are contiguous with intact grasslands and the establishment of corridors and adequate buffers are predicted to play an important role in future temperate grassland research. Several studies undertaken in the North American prairies show that at least some trial restoration of native grasslands has been successful (Vogel *et al.* 2007). Other attempts have had limited success (Pywell *et al.* 2002). In particular, combined approaches involving several different treatments such as species introduction and the reduction of dominant competitive species (invasive species) will be required for successful restoration of grasslands (Hobbie *et al.* 2003). It is acknowledged that restoration and re-vegetation are costly in labour and time and dependant on a particular range of environmental conditions and a high level of cooperation among government agencies, non profit organisations and private landowners. However, such approaches will be paramount to achieving conservation of temperate grasslands in the future. Until we have established successful ways to rehabilitate and restore temperate grasslands, land managers and conservationists urgently require scientific evidence about the tolerable levels of grassland losses, fragmentation and degradation among a range of taxa and various scales prior to the application of adaptive management tools to prevent further declines in species and communities.

My review has demonstrated that, at the level of individual taxonomic groups, invertebrates have been underrepresented in temperate grasslands research during the past decade. This is in sharp contrast to their proportional occurrence in these grasslands. Thus, research topics on temperate grassland invertebrates should be granted much greater consideration for research than previously received. One opportunity to study long term effects on all taxa are monitoring programs that should be established in temperate regions that have undergone dramatic declines of temperate grassland to assist in determining the level of impacts of environmental change on the grassland biota and on ecosystem functioning. Long term observations over time and across landscape scales will provide a sound basis for detecting the generality in ecological questions, will assists in the assessment of biodiversity losses, allow early detection of changes, and aid in recognising the impacts of anthropogenic induced climate change. Such findings are of enormous relevance to the broader community and are essential for future conservation successes in native temperate grasslands (Parton *et al.* 1994). Clearly, regions where long term monitoring has not yet taken place would benefit from the establishment of monitoring sites to record changes and to guide subsequent appropriate management.

I conclude that to achieve effective conservation of native temperate grasslands a multiple approach involving legal protection, practical restoration, and adaptive management combined with applied research will be required. Balancing these priorities will be a future challenge in native temperate grassland research and can be overcome by integrating multi-disciplinary research that assists with the development of protection and conservation policies (Lemaire *et al.* 2005). Through such integrative research, an understanding of the resilience of temperate grasslands to historical and ongoing threats can be gained. Future temperate grassland research and conservation will be needed to be set in the socio-political and economic context that will drive human decision-making processes and lead to better on-ground conservation action. National and international networks and collaborations (such as the LTER network or the TGCI initiative) build suitable platforms to achieve such an inter-disciplinary approach and should be considered in future.

Chapter 6

Moths in fragments - distribution, population biology and habitat use of the endangered Golden sun moth (*Synemon plana*) in native temperate grassland remnants in the Australian Capital Territory (ACT)

Introduction

Internationally, the listing of most threatened species rests on substantial, sound ecological knowledge (Possingham *et al.* 2002). However, in Australia, the formulation of prescriptions for conservation and management of most endangered species are seriously hampered by a lack of detailed demographic and biological information. This is particularly the case for many Australian species of insects that are taxonomically and ecologically poorly understood (Yen and Butcher 1997). Declines in insect populations have been underestimated in Australia because of a limited understanding of their responses to ecosystem transformations such as native vegetation clearance and fragmentation, livestock grazing, inappropriate fire regimes, and the introduction of exotic species (Yen and Butcher 1997). Knowledge of population structure and dynamics, habitat requirements and basic biological and ecological information such as reproductive capacity is critical for the management and future listing of many species of insects in Australia.

The golden sun moth (*Synemon plana*, Castiinidae) is one of only three Australia-wide critically endangered insect species that is also listed as endangered under state legislation in New South Wales (Threatened Species Conservation Act 1995) and the Australian Capital Territory (ACT) (Nature Conservation Act 1980), and listed as a threatened taxon in Victoria (Flora and Fauna Guarantee Act 1988). The original natural habitat of the species is believed to have been lowland natural temperate grassland, a community characterised by a naturally treeless landscape that is often located in frost hollows and on open plains (Edwards 1994). Prior to European settlement, the natural temperate grasslands were distributed patchily over a wide range of the temperate climatic zones in south-eastern Australia (Kirkpatrick *et al.* 1995). Since European settlement more then 95 percent of these grasslands have been lost or highly modified as a result of agricultural, rural and urban development (Kirkpatrick *et al.* 1995). Consequently, this ecological community is one of the most threatened in Australia and has a very high conservation priority (Kirkpatrick *et al.* 1995).

Synemon plana is likely to have been widely distributed across native grasslands at the time of European settlement (Clarke and Whyte 2003). Large scale losses, degradation and fragmentation of native temperate grasslands have resulted in the local extinction and reduction of *S. plana* populations throughout its former range (Braby and Dunford 2006; Clarke and O'Dwyer 2000). The species is currently known from 125 sites (records post 1990) in its potential distributional range, with 48 sites located in New South Wales, 45 in Victoria and 32 in the ACT. Most of the grassland sites with records of the species are smaller than five hectares and face the ongoing pressures from rapid urban and rural expansion and degradation (Braby and Dunford 2006; Gibson and New 2007; Gilmore *et al.* 2008). Although *S. plana* has been assumed to be a native grassland habitat specialist, several *S. plana* populations have been recorded at sites dominated by the exotic grass Chilean needle grass (*Nassella neessiana*) (Braby and Dunford 2006; Gilmore *et al.* 2008). The viability of populations at these disturbed sites is not known but is of considerable interest because non native grasslands were previously considered to be unsuitable habitat for the *S. plana*.

Since the recognition of *S. plana* as a critically endangered species and the listing of its habitat as a critically endangered ecological community, the moths have attracted the status of a flagship and indicator species for native temperate grassland conservation (ACT Government 1999; 2005). This has led to research on its biology (Braby and Dunford 2006; Edwards 1994), habitat requirements (O'Dwyer and Attiwill 1999; O'Dwyer and Attiwill 2000), genetic population structure (Clarke 2000; Clarke and O'Dwyer 2000; Clarke and Whyte 2003) and population dynamics (Gibson and New 2007). Despite these studies, many aspects of the species biology and ecology remain unknown. Of particular concern is the lack of information on habitat specificity at both adult and larval stages, female reproductive capacity, relative and absolute abundance, and population demography, including the sex ratio of populations. Information on biological and ecological variables (sex ratio, habitat specificity, reproduction) from populations that are found in native and exotic grassland are required to assess the vulnerability of the species to the effects of native grassland fragmentation and modifications. Specifically, the role that exotic grasslands may play for the persistence of the species in fragmented native grasslands is of particular conservation and management interest.

Here, I investigate the population demographics and habitat specificity of *S. plana* in the ACT with a particular focus on the population structure of the adults and larvae in both native temperate grassland and grasslands invaded by exotic Chilean needle grass (*Nassella neessiana*). My primary aim is to fill critical gaps in our understanding of the life history of *S. plana* and to describe more precisely the habitat requirements of the species.

Methods

Study Area

The study area was located in the Australian Capital Territory (ACT) in south-eastern Australia; a temperate region that experiences hot summers (December to February) and cold winters (June to August) and an even distribution of rainfall throughout the year. Average annual precipitation in the Canberra region is 600 mm and average temperatures vary between 15° C in spring (October to November) and 5° C in winter. The characteristic soils of the tableland plains in the ACT are podzolics and grey and brown clay soils that support a rich floristic diversity of annual and perennial native grasses (Sleeman and Walker 1979). Tussock forming grasses such as kangaroo grass (*Themeda australis*), spear grasses (*Austrostipa* spp.) and wallaby grasses (*Austrodanthonia* spp.), mixed with a variety of annual and perennial forb species, are characteristic of the tableland plains (Costin 1954). Between 2005 and 2008 forty seven grassland sites, totalling to more than 570 ha, containing the floristic association of native temperate grassland, native pasture or exotic grasslands dominated by the introduced Chilean needle grass (*Nassella neesiana*) were surveyed for golden sun populations (ACT Government 2005). Most of the sites surveyed were located in native temperate grassland and reflect the known distribution of *S. plana* in the ACT (ACT Government 2005, pers comment M. Dunford, T. Edwards and A.

Rowell, A.Richter pers. observations). Exotic grasslands were selected randomly based on the available floristic mapping of grasslands in the ACT (ACT Government 2005). The sites were evenly distributed throughout the northern lowland areas of the ACT in and near Canberra (Figure 27).

The population ecology of adults

Relative and absolute estimates of population size

Surveys for *S. plana* were conducted at 15 locations in the ACT (Figure 27) over three years from mid October to the end of January in each year (2006 to 2008) in native and exotic grasslands. The absence of the species was confirmed if individuals were not found after four site visits of at least 20 minutes during suitable weather conditions during the daily flight period. At sites with the presence of *S.plana*, the population abundance during the flight period was estimated using modified Pollard-Yates transect counts (Pollard, 1977). Linear transect counts following the procedure by Pollard and Yates (1993) include a survey route that is typically 3 km long and need to be surveyed for the presence of species and their abundance for at least 60 minutes. To compensate for the length of survey route in my study being 100 metres long, I restricted the time of survey to 20 minutes across all sites. Twenty four study sites were surveyed for the presence of *S. plana* with the modified Pollard-Yates transect count method. Additional surveys of the relative abundance of the species were conducted using circular point counts (Gibson and New 2007) during 2008/2009 as part of a community-based (volunteer) program coordinated with the Friends of Grassland (FOG) community group in Canberra (Richter *et al.* 2009). Circular point counts were considered to be more feasible for use by the trained volunteers than transect counts. Field assistance and practical training for the community was provided (see Richter *et al* 2009 for details). Thirty one locations were surveyed using circular point counts to record the relative abundance of *S. plana* populations distributed throughout the ACT.

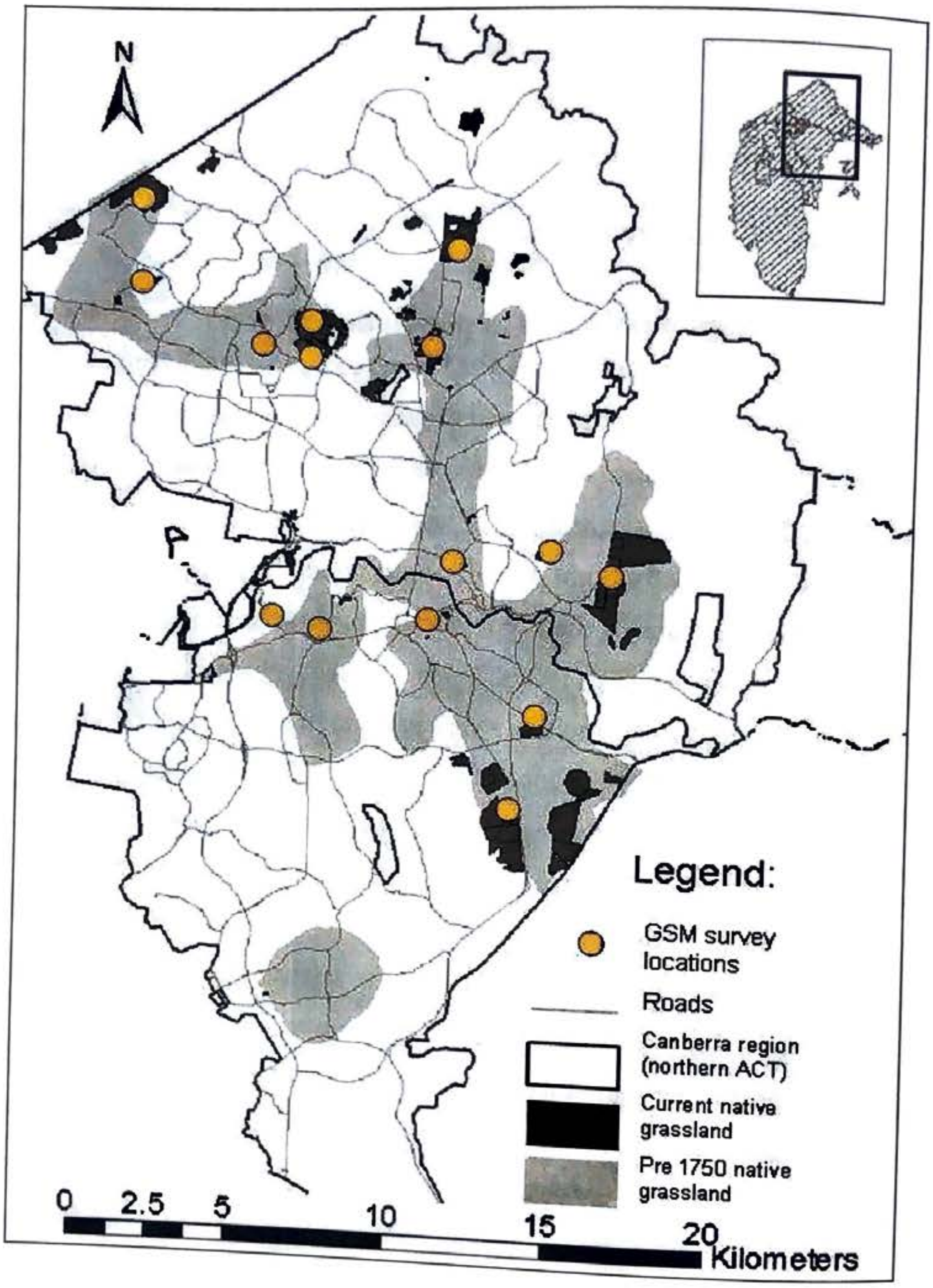


Figure 27 Map of the northern parts of the Australian Capital Territory (ACT) with the outline of the city of Canberra. Dark grey areas indicate current distribution and size of native temperate grassland remnants. Light grey areas indicate distribution of pre 1750 native grassland. Circles show the locations where *S. plana* (GSM) populations were surveyed.

The Pollard-Yates method involved counting moths within each site along a 100 metre linear or curved transect. Each transect was observed for a minimum time of 20 minutes per observation and all flying male adults were counted and grouped into abundance classes (I: 0, II: 1-5. III: 6-20, IV: 21-50, V: >50). Females were recorded but not analysed as they are poor fliers, capable of flying only a few metres when disturbed. Counts were undertaken between late October and early January on sunny days during non windy weather. All counts were conducted between 11:00 and 15:00 hours (Eastern Daylight Saving Time)- the main flight period for the species (Edwards 1994). I attempted to survey each site as often as possible, with at least three consecutive days during each flight season. The circular spot count involved standing at the census site and turning slowly through a full 360 degrees rotation over approximately 30 seconds, counting all males seen flying within 15 metres of the observer. Information on *S. plana* phenology, such as first sightings, duration of flight period and the dates of peak activity, were obtained from the same data set and additional information arrived from sightings in the area by experienced volunteers and local entomologists.

Mark Release Recapture study

Mark release recapture (MRR) methods are the most precise way of estimating the absolute abundance of populations, but are also laborious and require skill in capturing and marking the organisms of concern (New 1991; Nowicki *et al.* 2005). There is only one location in the ACT (York Park; less than 0.2 ha) where the absolute abundance of the *S. plana* has been estimated previously (Cook and Edwards 1994). This site was resurveyed in 2007 and the results compared with those collected in 1993. Adult males were captured and individually marked between 18 November and 19 December 2006, from 10:30 to 12:30 hours. Moths were captured randomly with 40 cm butterfly nets and marked with a number on the underside of the hindwing, using a quick-drying, xylene-free, metallic ink pen (Artline 999XF Silver). Recaptured moths were kept in the shade, along with newly marked moths, in a mesh-sided holding cage with a cloth cover to reduce damage from fluttering. All individuals were released in the centre of the site at the end of the collection period each day. Only males were marked as study permits did not allow for the capture and marking of females. Thus, no information about the adult life span and population size can be provided for female moths.

Habitat specificity and habitat use, species reproduction and sex ratio

In response to recent sightings of *S. plana* in exotic grassland in the ACT (Braby and Dunford (2006), I also surveyed 20 randomly selected, largely non-native grassland sites, that were previously considered unsuitable for *S. plana*. At all 47 surveyed sites (native and non-native) information about the quantitative vegetation composition was collected in 2007/8 to characterise the habitat at each of the sites by recording the plant species richness and the abundance of each species within six randomly placed 1 × 1 m quadrats at each site. In terms of their floristic composition, all of the surveyed grasslands were also classified according to criteria in the the ACT Lowland Native Conservation Strategy (2005)

Occasionally, in 2006, 2007 and 2008, female *S. plana* were caught accidentally as bycatches in wet pitfall traps designed to capture ground dwelling arthropods. These individuals were dissected under the microscope to obtain information on the species fecundity. Each female abdomen was opened with a scalpel and her eggs removed. Several female specimens showed signs of having laid eggs prior to capture and were therefore not included in the final analysis. The length (mm) of single eggs (n=100) from five different locations was measured under the microscope (Figure 28).

Figure 28 Shape, colour and size of *S. plana* eggs, dissected from captured females. Single grid size is 1 x 1 mm.

Empty pupae cases of *S. plana* were randomly collected in native and exotic grasslands to identify the sex ratio of the species. Each pupae case was removed from its silk tunnel, cleaned and placed under a microscope for sexing. These pupae cases were identified by comparison with a reference collection of male and female *S. plana* pupae cases on the basis of morphological features and confirmation by T. Edwards (CSIRO, Division of Entomology, Canberra) (Figure 29).

Figure 29 Female (left) and male (right) *S. plana* empty pupae cases after removal from silk tunnel and cleaning. Sizes are not scaled.

Larval biology and habitat specificity

To observe feeding and to obtain information about *S. plana* larval habitat specificity, I conducted intensive searches for its larvae in late autumn and spring between 2007 and 2009 at sites known to have large populations of golden sun moths. Special attention was given to detect signs of larval feeding within grassland that had been invaded by Chilean needle grass (*Nassella neesiana*). Soil cores of approximately 20 x 20 x 10 cm were removed with a small spade and the soil carefully searched for *S. plana* larvae. Collections were made in both natural temperate grassland and in grassland dominated by *Nassella neessiana*. When any larvae were found, information on their location within the soil and feeding behaviour were recorded. The dominant grass species were described for each soil sample, and for larvae still in situ in the soil the roots of the grass species closest to the larvae were identified. All larvae found were brought to the laboratory, where their length was measured, and they were weighed and stored at -80 C for further genetic analysis.

Statistical Analysis

The capture-recapture data were analysed using open-capture models (Jolly Seber Collmark) in the programs MARK v.4.2 (White and Burnham, 1999) and JOLLY. Within MARK, the subprogram POPAN provides a parameterization of the Jolly-Seber model (Schwartz and Arnason, 1996) using individual capture histories to estimate population size and variance. This approach generated population estimates of the number of adults in the population over the entire, non-overlapping flight period. A set of a priori models was initially developed, analysed and then ranked by the AICc (Akaike's information criterion) values following analysis in the program MARK. The model with the lowest AIC's criteria was considered the best fitted model and its estimates of N (population size), phi (survival probability) and p ((re)capture probability) were used for further analysis. One-way and two-way factorial analysis of variance (ANOVA) using generalized linear models (GLM SPSS) were applied for testing statistically for effects in the presence and absence of adults and larvae in different grassland types and sizes, differences in sex ratios among types of grassland and in sizes of pupae cases and larvae. Statistical tests of homogeneity for variability were performed between abundance classes and years and abundance classes and within vegetation climax. Descriptive statistics were all performed in SPSS (version 17.0).

Results

S. plana populations were recorded at 32 of the 47 grasslands surveyed between 2006 and 2009. The main activity period of adult *S. plana* varied between the years. Active flying male and female moths were observed between 23 October and 27 December in 2006, from 20 October 2007 to 14 January 2008, and from 29 October to 13 January 2009.

Relative and absolute population estimates of adult moths and their daily flight activity

The relative abundance estimates among sites and years for the populations of *S. plana* ranged from no sightings, through very few sightings, to several hundred sightings (Figure 30). Most populations were characterised by few individuals. Only a small number of sites (n=6) were observed to have populations that numbered in the several hundred (Figure 30). The proportion of sites surveyed with no or low numbers of golden sun moths increased from 56% to 70% between the 2006 and 2009 flight seasons (Figure 30) although the numbers in abundance classes did not change significantly over those years (F=0.122, df=2,62, p=0.885). Nor did they vary significantly among vegetation type (*Austrodanthonia*, Wet *Themeda*, Dry *Themeda*, *Austrostipa and exotic grassland*) (F=0.174, df=4,31, p=0.950) or among years within vegetation type (F=0.602, df=8,62, p=0.772).

Of the 419 adult male *S. plana* captured and individually marked between 17 November and 14 December 2006 at the York Park remnant, twenty-five individuals were recaptured. Survival probability and recapture probability were very low (Table 22). Seven females were observed over the same period. Male adult life span was on average 1.08 days (± 0.119 95% CI). No moths were captured more than two days after marking. The Jolly-Seber model, with both survival rate (phi) and capture probability (p) assumed to be constant per unit time, estimated a mean daily population size of 42 individuals (S.E. 4.20) with ranges from a minimum of nine individuals on 13 December (S.E. 4.73) to a maximum of 66 individuals (S.E. 18.05) on 2 December 2006 (Figure 31).The best approximating model for open populations used for the analysis for total population size was with a constant parameter for survival and recapture. The total population of York Park *S. plana* for 2006 was estimated to be 440, with a range of 412 to 520 individuals. This compares to 520 (468-572) total adult population size estimated by Cook and Edwards (1994). Flight activity at *S. plana* populations at three locations (Former Transmitting Belconnen Naval Base, Dudley Street Canberra, Crace Nature Park) was observed to occur between 10 am and 2:15 pm. The numbers of active male adults were highest between 11 am and 1:30 pm (Figure 32).

Adult habitat use

Overall, I observed an effect of vegetation community (natural temperate grassland, native pasture, exotic pasture) and vegetation type (*Austrodanthonia* spp., *Austrostipa bigeniculata* and *S.scabra*, dry and wet *Themeda australis*, *Nassella neesiana* and *Phalaris aquatica*) on the presence and absence of *S. plana* (Figure 33). The majority of sites where the species was present were characterised by *Austrodanthonia* spp., and other native grass species such as *Austrostipa bigeniculata* and *Themeda australis*. Sixty-nine percent of sites containing *S. plana* were classified as grasslands dominated by wallaby grass (*Austrodanthonia* spp.). A small proportion of sites (9 percent) were dominated by Chilean needle grass (*Nassella neesiana*), spear grasses (*Austrodanthonia* spp.) and kangaroo grass (*Themeda australis*). *Synemon plana* were not found in *Phalaris aquatica* grassland. Moths were present in more than 90 percent of *Austrodanthonia* dominated grasslands and in 75 percent of *Nassella neessiana* grasslands of all surveyed sites. The generalized linear binominal regression model showed that species presence and absence were significantly associated with grassland community (x^2=8.286, df=2, p=0.016) and with climax vegetation (x^2= 22.040, df=5, p=0.001) (Figure 33). The presence and absence of *S. plana* were not significantly affected by overall grassland area (fragment size) (x^2=1.057, df=1, p=0.304) nor was the presence or absence of the species significantly affected by grassland area (size) within each climax vegetation (x^2=0.912, df=5, p=0.340)

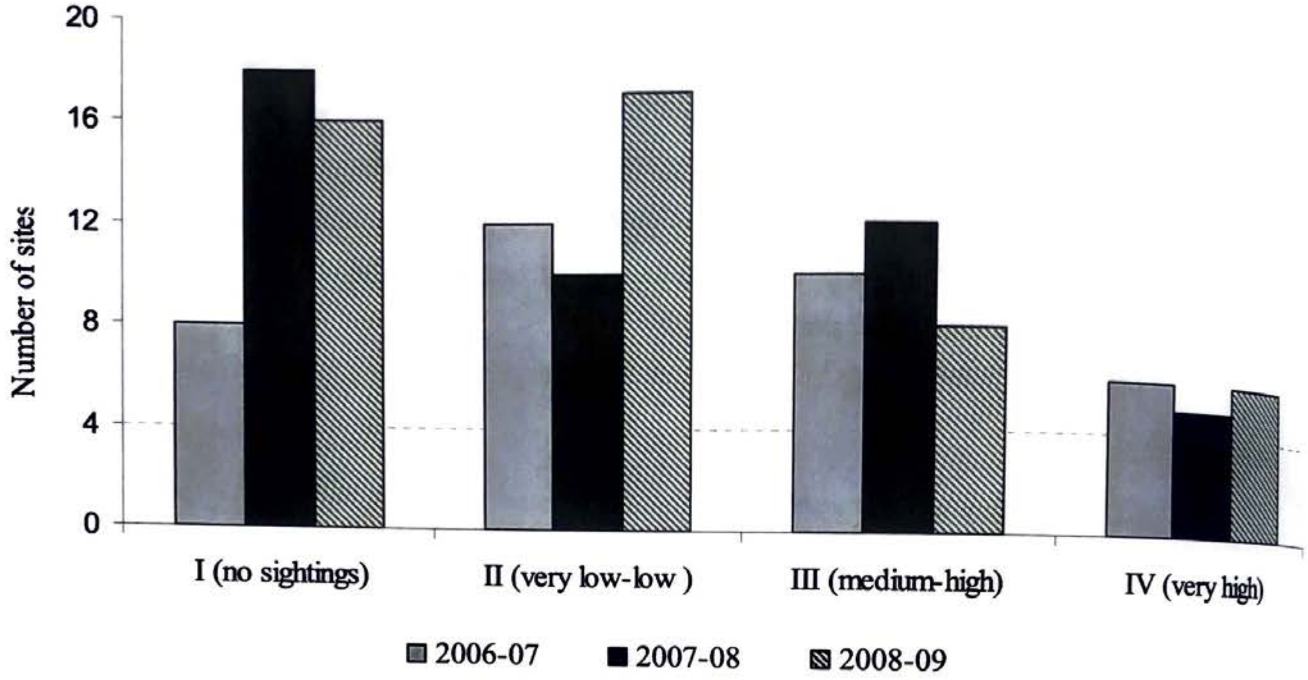


Figure 30 Absolute numbers of sites by relative abundance classes of *S. plana* adults at all sites surveyed in the ACT between 2006 and 2009. Abundance estimates are based on surveys of moths for a minimum of 20 minutes per grassland sites (n=47) either by transect or circular point counts. Abundance classes are classified as follows: I: no sightings, II (very low-low): 2-50 individuals, III (medium-high): >50-100, IV (very high) : >100 individuals.

Table 22 Survival probability (phi) and recapture probability (p) of *S. plana* during the MRR study at York Park in 2006.

Parameter		Variance	S.E.	95% C.I.
Phi (.)	0.1599	0.0007961	0.028	0.1046 - 0.2153
P (.)	0.3300	0.0051096	0.072	0.1899 - 0.4701

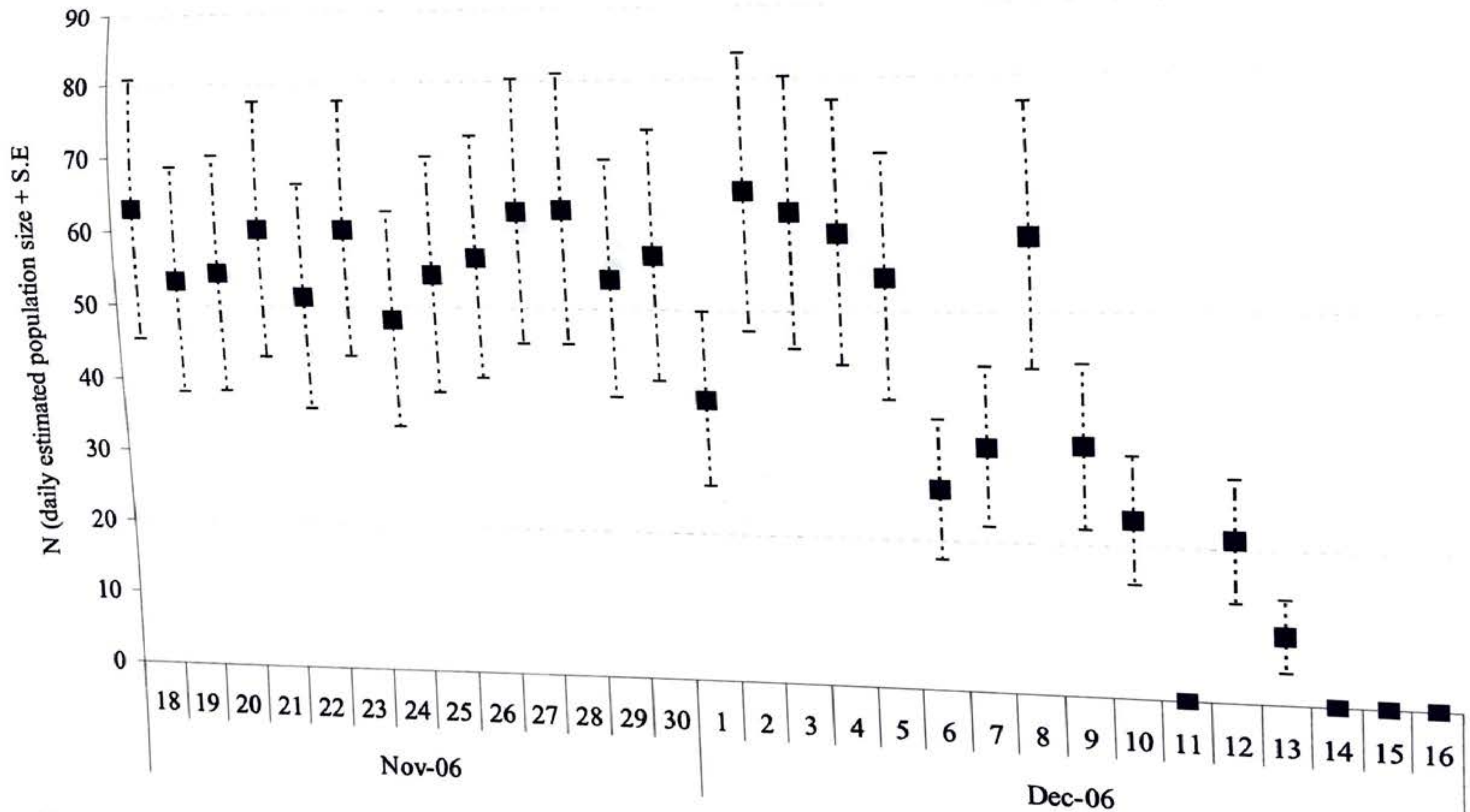


Figure 31 Estimated daily (18.11.-16.12. 2006) population sizes (N) for the *S. plana* population at York Park, Canberra, ACT. Bars indicate standard error.

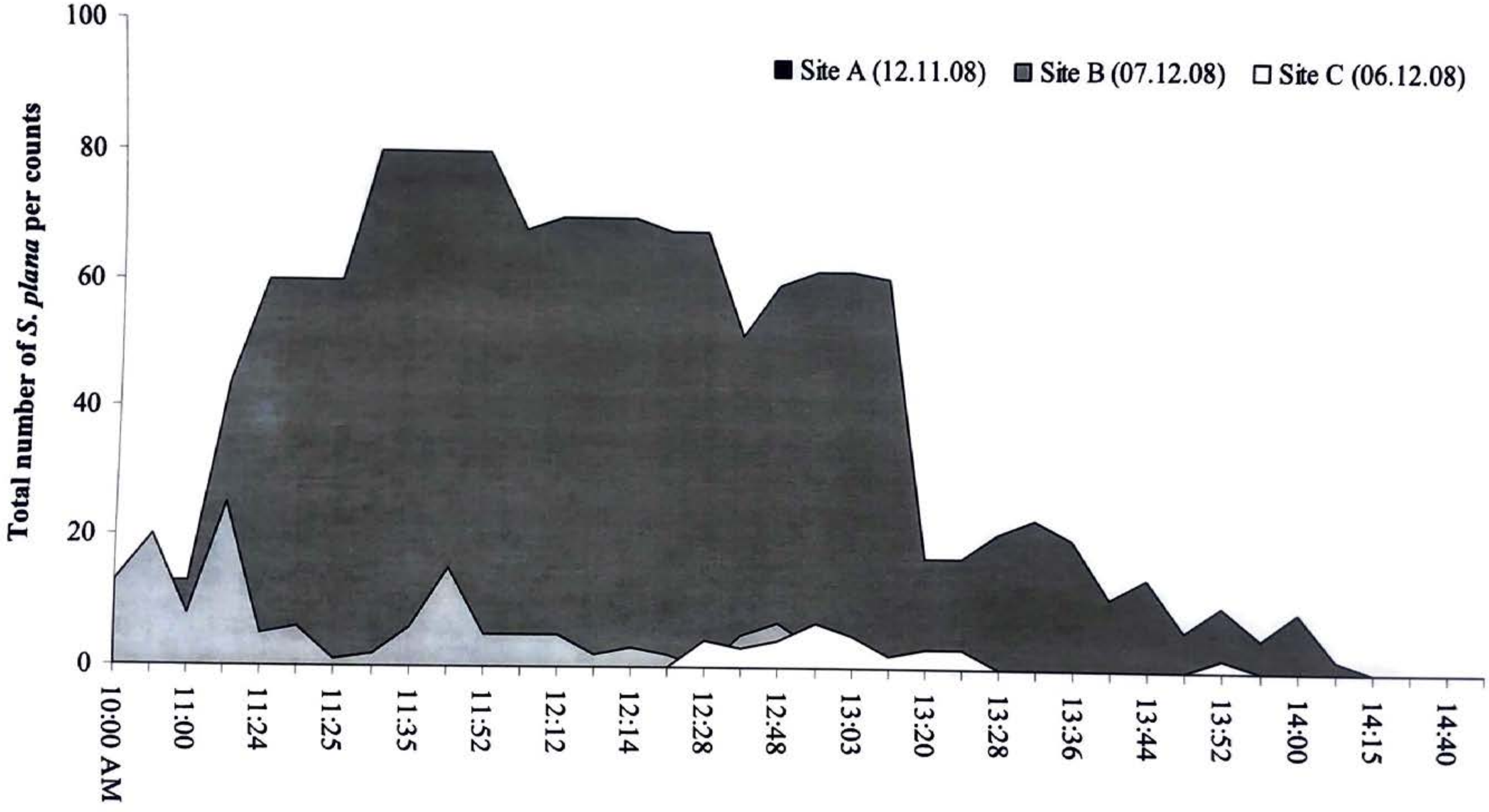


Figure 32 Flight activity of adult *S. plana* between 10 am and 2 pm at three grassland monitoring sites (A: Former Transmitting Belconnen Naval Base, B: *Dudley Street* Canberra, C: Crace Nature Park) in the ACT. The relative abundance of moths was estimated using circular point count.

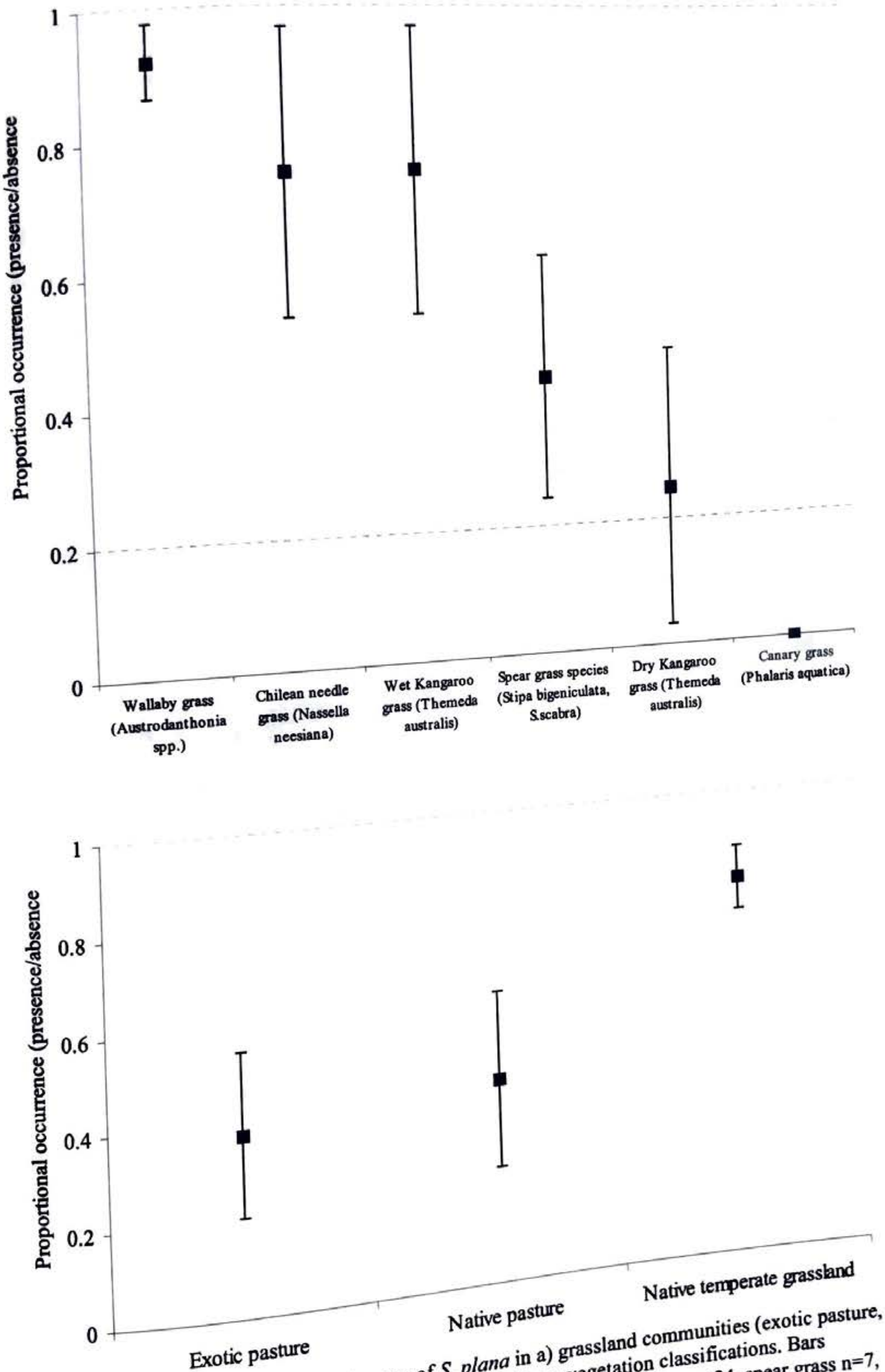


Figure 33 Proportion of presence and absence of *S. plana* in a) grassland communities (exotic pasture, native pasture and natural temperate grassland) and b) in climax vegetation classifications. Bars indicate standard error. Sample size for grasslands dominated by wallaby grass n=24, spear grass n=7, Chilean needle grass n=4, wet and dry kangaroo grass n=4 (each) and Canary grass n=4.

Female reproduction and sex ratio

Seventy-one *S. plana* females from eight different natural temperate grassland sites were dissected under the microscope to assess fecundity. A mean of 74 eggs per female were found (27.4 SD) ranging from a minimum of 31 eggs to a maximum of 148 eggs. The mean egg length was 2.24 mm (0.17 SD). Eleven percent of females contained more than 100 eggs. Simple linear regression showed a strong positive linear relationship between female abdomen length (body size) and number of eggs ($F= 56.071$; $df=1,40$; $p<0.001$). Fecundity (numbers of eggs) increased with increasing female abdomen size (Figure 34).

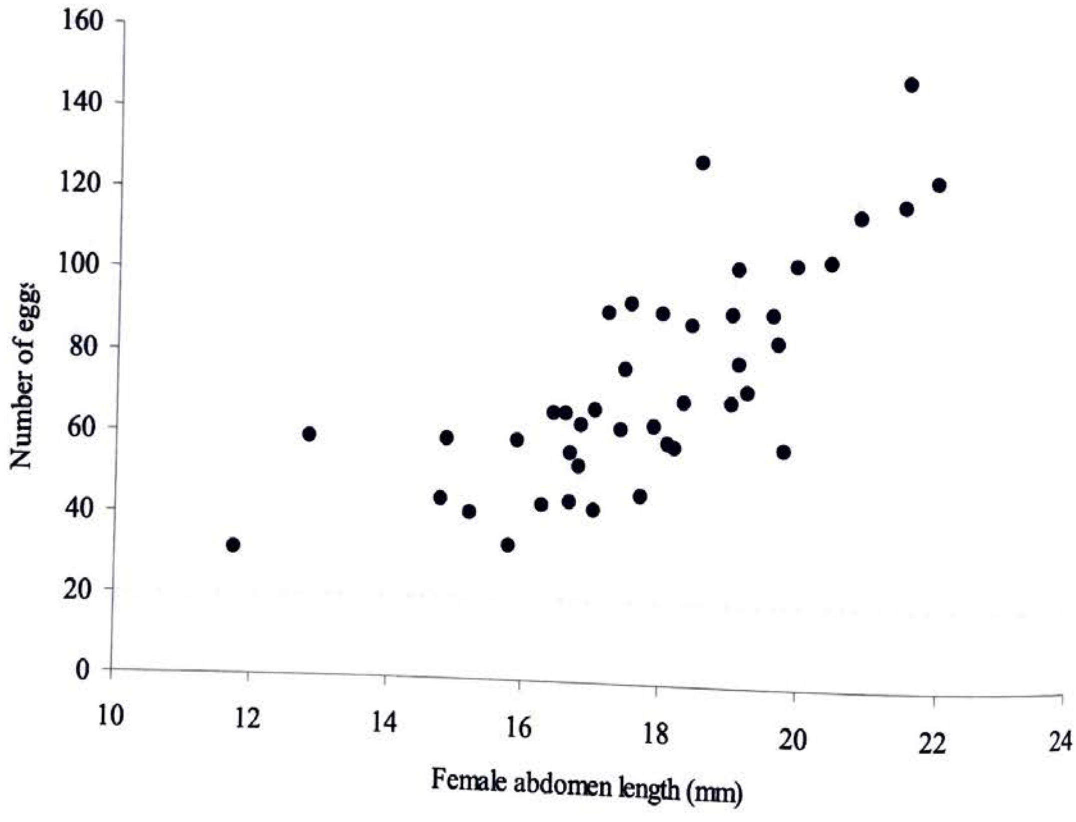


Figure 34 Linear relationship between *S. plana* female abdomen lengths and numbers of eggs.

A total of 650 pupae cases were collected in 2007 and 2008 of which 479 were obtained from eight native temperate grassland (NTG) locations and 171 from three grasslands that were dominated by the exotic Chilean needle grass (CNG). At sites surveyed, the sex ratio of *S. plana* populations in native temperate grassland was found to vary between 0.6 and 3.5 more males than females (Table 23). Nearly twice as many *S. plana* males than females were found at sites dominated by Chilean needle grass (*Nassella neessiana*). The sex ratio bias towards males did not vary between the two years studied (Figure 35).

Table 23 Sex ratio variations in *S. plana* populations between Chilean needle grass sites (A-C) and native grassland sites (1-8).

Site	Vegetation Climax	Male: Female	Sample size
A	CNG	2.5	14
B	CNG	2.1	114
C	CNG	1.9	43
1	NTG	3.5	9
2	NTG	2.5	14
3	NTG	2.4	111
4	NTG	1.8	91
5	NTG	1.3	7
6	NTG	1.3	214
7	NTG	0.6	8
8	NTG	0.6	25

Average female pupae case size was 23.15 mm (n=145, 0.18 S.E.) and average male pupae case size measured 21.66 mm (n=238, 0.24 S.E.). Female pupae cases were significantly larger than male cases (F=11.451, df=1,377, p=0.001). Pupae cases collected from native pasture and exotic grassland (Chilean needle grass) were significantly larger than cases collected in natural temperate grassland (F=30.299, df=2.377, p=0.000).

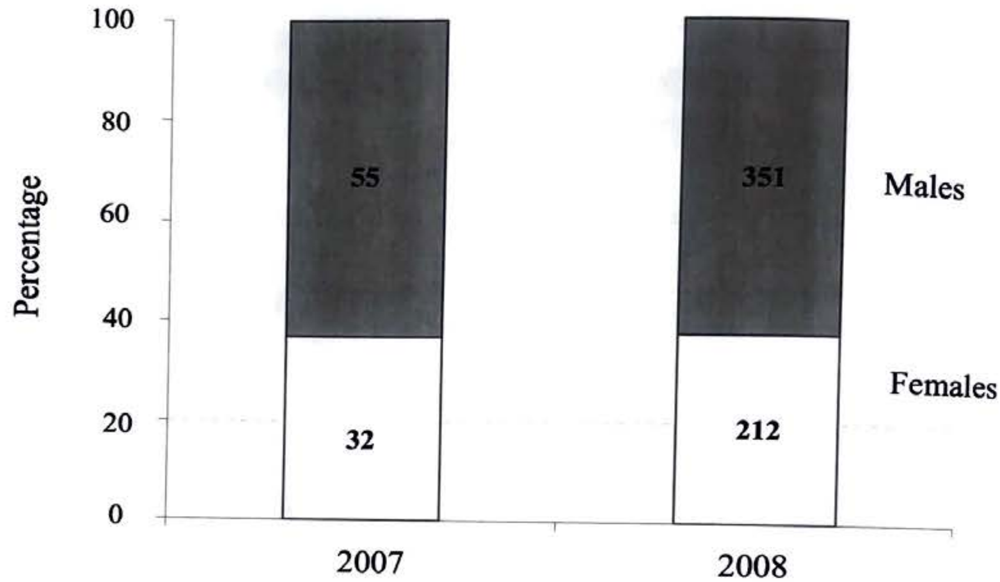


Figure 35 Sex ratio in *S. plana* populations based on pupae case identification from samples (n=650) obtained in 2007 and 2008 in native temperate grassland and exotic grassland dominated by Chilean needle grass (*Nassella neessiana*). Males are indicated by shaded bars, females by open bars. The number of specimens examined in each year is listed within the bars.

"Survival" of S. plana pupae cases

The survival analysis performed in program MARK (version 5.1) on 31 empty pupae cases showed that under natural conditions *S. plana* pupae cases had a high "survival" rate (phi= 0.9-1.0) between one and 17 days after marking (Figure 36). The majority of empty cases (68%) could still be found (had not decomposed) after 17 days. Their survival decreased after 17 days, and after 29 days only 9.6% of *S. plana* cases were still present and identifiable in the field. At the last visit to check for the presence of the empty cases after 50 days after initial marking, all cases had degraded.

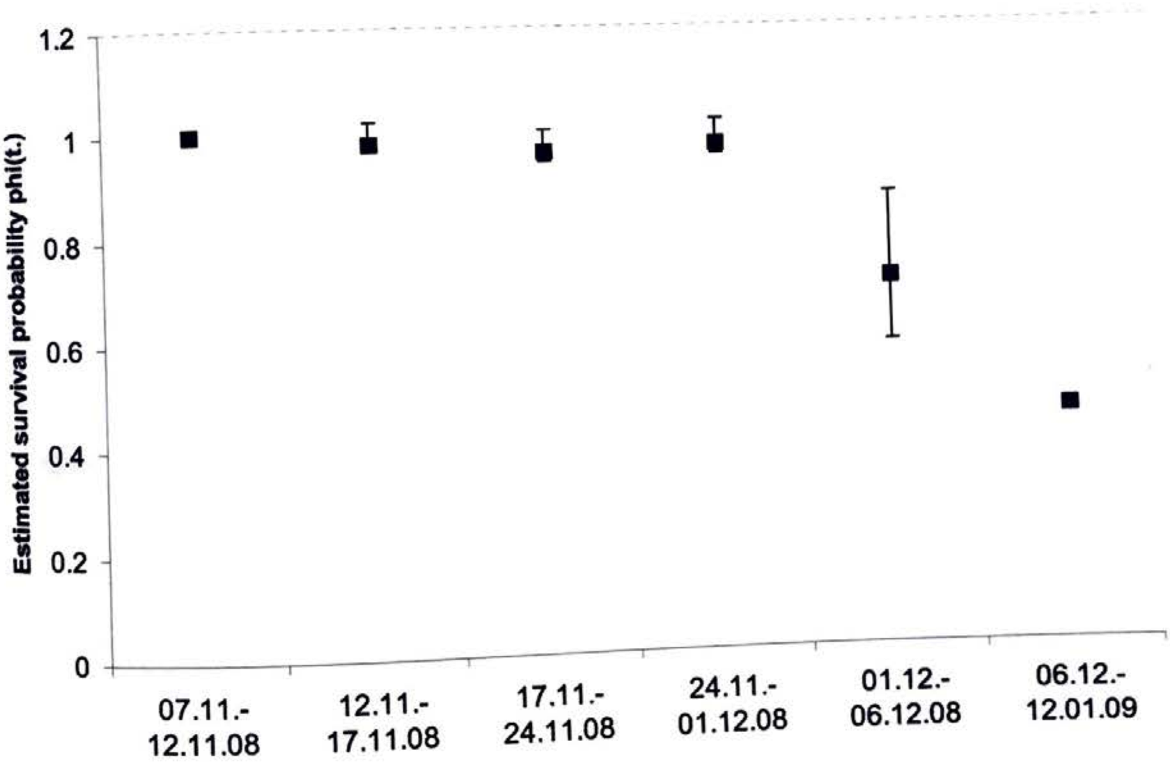


Figure 36 Pupae case intactness probability (phi(t.)) under natural conditions between 07.11.2008 – 12.01.2009 at one of the largest natural temperate grasslands in the ACT (former Belconnen Naval Transmitting Station). Bars indicate standard error.

Larval biology and habitat usage

Ninety-two *S. plana* larvae were found in soil cores from native and exotic grasslands. Thirty–seven larvae were collected from grasslands that were dominated by the exotic grass *N. neessiana* (Chilean needle grass), and 55 from native temperate grassland. The majority (44%) of larvae from the native temperate grasslands were found in soil among the roots of tall and slender spear grass (*A. bigeniculata, A. scabra*) or a mixture of wallaby grasses (*Austrodanthonia* spp.) and spear grasses (*Austrostipa* spp.). Only a small proportion of *S. plana* larvae were restrictively associated with wallaby grass species (Figure 37).

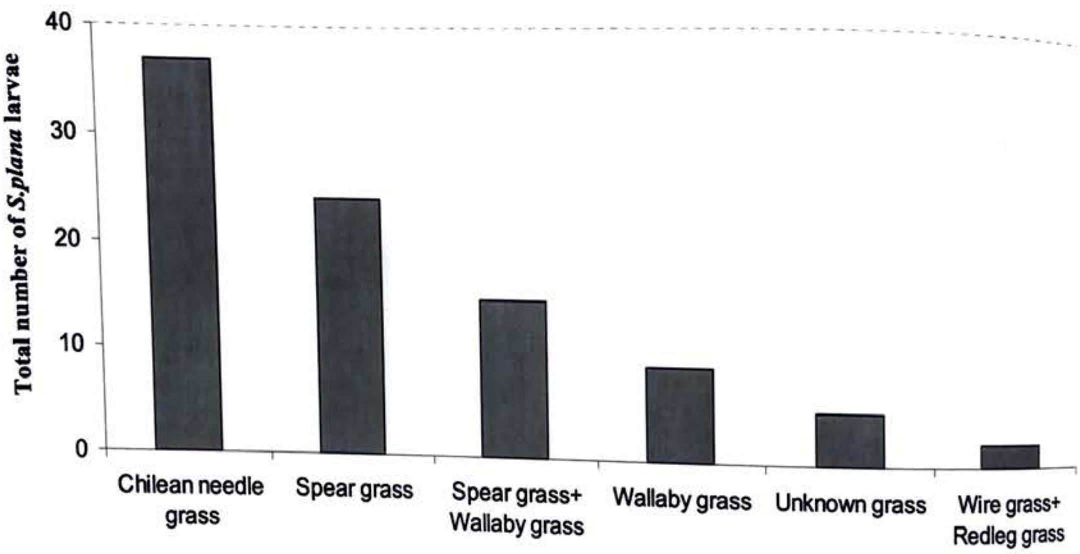


Figure 37 Total number of *S. plana* larvae with associated grass species found in native and exotic grasslands in the ACT.

The average length of the larvae was 18.2 mm; and individuals ranged from a minimum of 6.0 mm to a maximum of 28.0 mm. Within a specific collection season larvae collected in Chilean needle grass were significantly larger than larvae collected in natural temperate grasslands ($F=12.515$, $df=1,80$, $p=0.001$). Larvae ($n=12$) found in October were on average 3.2 cm (S.D. 1.65) below the soil surface and no obvious tunnel systems were observed whilst searching through soil samples. Most larvae did however appear to be associated with silk lined tunnels below the basal of the grass tussock.

Discussion

Our knowledge of the ecology and biology of endangered insect species in Australia is limited (despite the small size of the current list), and thus it is difficult to evaluate conservation strategies for these species. In this study I have attempted to fill key gaps in the knowledge of the field biology of the critically endangered golden sun moth (*S. plana*) - one of the four nationally listed critically endangered insects species in Australia. Through an improved understanding of the species biology and ecology, a more critical evaluation of threats to this species can be undertaken, thus assisting in the evaluation of future research actions. I analysed the association of the species at the adult and larval stage to native and exotic grasslands, estimated absolute and relative population sizes for adult *S. plana,* reported on the activity season of male adults, and for the first time described the sex ratios among golden sun moth populations.

The main finding of this study is that *S. plana* is a grassland species strongly associated with native temperate grasslands and also occurs over a range of grassland types, including in exotic grasslands dominated by the South American noxious weed *Nassella neessiana* (Chilean needle grass). Adult moths and larvae were associated with several grassland vegetation assemblages, with breeding aggregations found in native grasslands dominated by *Austrodanthonia* spp., *Austrostipa* spp., and occasionally in sparse or low cover of *Themeda australis* as well as in exotic *N. neessiana* grasslands. The majority of *S. plana* populations found in native temperate grasslands were small, with only a few sites supporting large populations (hundreds of individuals). Rare species of butterfly have been shown to be affected by reduced habitat area and by the consequences of fragmentation such as reduced habitat quality (Summerville & Christ 2001, Zschokke *et al.* 2000).

The presence and absence of the *S. plana* was not significantly affected by grassland area and vegetation association. This was also indicated by the Mark-Release-Recapture study conducted at York Park- a native temperate grassland patch of less than 0.2 ha in size, that showed little change in total population size between the estimates made in 1994 by Cook & Edwards (1994) and the estimates obtained from this study. However, future monitoring is required to determine the thresholds for the persistence of *S. plana* populations and the extent of an annual variation in population sizes related to grassland conditions and to the size of the grassland fragments. The abundance of populations currently present in grasslands dominated by the exotic *N. neessiana* ranged from medium to very high throughout all years surveyed. At present, it is concerning that the largest populations of *S. plana* in the ACT are associated with very few sites of native temperate grassland and in several grasslands dominated by *N. neessiana*.

The location of adult and larvae *S. plana* populations in disturbed *N. neessiana* grassland is in agreement with findings of other observers who have reported the golden sun moths occur in disturbed patches throughout the range of the species in south-eastern Australia (Braby and Dunford 2006; Gilmore *et al.* 2008). However, my findings indicate that the occurrence of *S. plana* populations in Chilean needle grass are not accidental or ephemeral incidences, rather my observations over the two years support the evidence that the species has successfully established in these exotic grasslands and is currently utilising *N.neessiana* dominated grasslands for development and reproduction. It is particularly surprising that the larvae, and consequently pupae cases, were significantly larger in size in *N. neessiana* dominated habitats than those found in native grasslands. I suggest two possible scenarios to explain these observations. Firstly extant, but perhaps declining, populations of *S. plana* have increased their population size in situ in response to increasing dominance of the sites by *N. neessiana* or secondly there has been a rapid switch in the dietary preference of the moths from native grass species to *N. neessiana* followed by rapid invasion of these exotic grasslands. The proposition of a dietary shift in *S. plana* towards the exotic grass species is supported by a few studies that provide evidence of host plant shifts in herbivore insect specialists in situations where introduced plant species is closely related to its native congener (Connor *et al.* 1980). From a historical biogeographical view, the South American continent, the origin of the Chilean needle grass, and Australia were in ancient times connected through the Trans-Antarctic connection leading to the variance between the two continents (Bremer 2002). Phylogenetic studies (cladistic analysis of morphology and DNA sequences) revealed that, owed to this connection, ancestors of major groups of plant taxa were restricted to either or both continents (Bremer and Janssen 2006). Thus, it can be hypothesised that the South American Chilean needle grass (*N. neessiana)* and the Australian native grasses, in particular spear grass (*Austrostipa spp.*), may share similar origins that in turn could facilitate the dietary shift. Dietary analysis and metabolic studies are urgently required to investigate the extent of the utilisation of Chilean needle grass and native grass as host plants for *S. plana* and to identify the patterns that drive the potential shift or expansion in the dietary preferences within the species.

Another important finding from my study was the detection of a clearly biased sex ratio in *S. plana* populations across the two study years in both native and exotic grasslands. The operational sex ratio (OSR), the ratio of reproductive males and females in the population, is a central life history parameter that affects the population's growth rate and determines the strength of sexual selection through competition for access to mates of the minority sex (Emlen and Oring 1977). Most lepidopteran species, reared in captivity, produce an unbiased primary sex ratio (offspring sex ratio at the time of conception) regardless of their sex determining system (Ehrlich *et al.* 1984). An equal primary sex ratio is expected when species exhibit a genetic sex determining system (GSD) with heteromorphic sex chromosomes, such as the mammalian XY/XX or the avian ZZ/ZW systems. In such cases, the equal primary sex ratio is expected to result through the meiotic division and chromosomal segregation of the gametes. Under such circumstances, deviation from parity is expected to be corrected through frequency dependent selection which acts to equalize parental investment in the two sexes (Fisher 1930). Such correction arise through the fitness advantage incurred by the individuals that are genetically predisposed to bias their brood towards the minority sex, which in turn are more likely to encounter a mate that members of the majority sex and therefore provide a higher reproductive return and fitness gain to their parents.

The factors which maintain a male bias in *S. plana* populations are unknown. To further understand the conditions which facilitate such dynamics, both physiological and ecological parameters of the species life history must be considered. For instance, sex determination might be influenced by environmental factors such as incubation temperature, which in turn could account for some or all of the observed bias.

Variable sex ratios are commonly observed in lepidopteran species. Species which produce a male bias are common as well as those which produce equal sex ratios or only female offspring (Adamski 2004; Jiggins *et al.* 1998). The underlying causes of such variations in the primary sex ratios are unknown but suggestions have included maternal inheritance (Jiggins *et al.* 1998), biased predation as a consequence of sexual dimorphism (Bhattacharya 2004) and differences in microhabitat selection, differences in "catchability" or lags in emergence times of females relative to males (protandry) (Ehrlich *et al.* 1984; Frey and Leong 1993). In the case of adult *S. plana*, males and females differ significantly in their morphology and behaviour. Males are less brightly-coloured and are much more competent flyers (Edwards 1994). In contrast, females are less cryptic, having bright orange wings which they expose in the sun light to attract males but are poor dispersers themselves (Edwards 1994). Thus, adult males and females are very likely to differ in their predation risks, catchability and visibility which will greatly influence any evaluation of the adult sex ratio within populations. In my surveys I circumvented the factors biasing these estimates by including the method of identifying individual sex based on the empty pupae cases. It is therefore significant that the imbalance in the sex ratio observed in the pupae case sex ratio mirrored that of the adults.

Implications for future research and monitoring

Conservation and monitoring programs provide strategies and tools to conserve and manage ecosystems that contain endangered species and communities (Settele and Kuehn 2009). Ecological research combined with long term observation of demographic trends (monitoring) allow for assessment of biological responses to changes in the environment at different spatial and temporal scales (New 2006; Spellerberg 2005). Thus, monitoring programs and ecological research are essential ingredients of an adaptive approach to endangered species conservation biology (Lindenmayer and Burgman 2005; Spellerberg 2005) and key components of recovery programs for many threatened species (Clark *et al.* 2002; Harvey *et al.* 2002). The effective diagnosis of declines and evaluation of risk in endangered species is dependent on a comprehensive and reliable knowledge of the ecology and field biology of these declining species (Caughley and Gunn 1995) and an evaluation of the methods that have provided this data.

My research on the critically endangered golden sun moth (*S. plana)* has revealed natural history features that are an important consideration in determining future conservation and research action. Although the documentation of geographic areas of occupancy of the golden sun moth and the estimation of abundance of *S. plana* populations is challenging owing to the species biological and ecological requirements and the lack of standardised sampling protocols (Gibson and New 2007), I attempted to apply a combined approach of the estimation of relative (counts) and absolute population estimates (MRR). Relative abundance estimates showed that the moths occupied a wider range of grasslands than previously considered, including exotic and disturbed grasslands whereas the intense MRR study showed that the species has the ability to occur in large numbers of individuals in very small patches over long time periods. The knowledge that the species' distribution is broader than originally thought requires a change in our understanding of where to survey for the species and highlights the importance of gaining a better ecological understanding about the species that we seek to conserve (New 2007).

Future monitoring of the species distribution and its abundance is needed to focus on both- native and exotic grasslands. Count based estimates of population sizes is one of the most common used method in lepidopteran monitoring because, by contrast to Mark Release Recapture studies, it does not require any handling of fragile individuals and can be undertaken by professionals and amateur entomologists (Pollard and Yates 1993). However, this method is not always reliable as it normally yields only relative indices of abundance (New 1991; Pollard and Yates 1993) and is not always linearly correlated with absolute numbers of individuals (Nowicki *et al.* 2005). A mixed approach that combines estimates that have been gained from short term capture-recapture studies with results obtained from transect counts are considered to be the best balanced approach in achieving accurate monitoring information with the most minimal interaction with the species (Gross *et al.* 2007).

My finding that empty pupae cases of *S. plana* were still present and identifiable under natural conditions for at least two weeks after being found indicates the potential use of pupae cases as additional evidence for the species' presence. The advantage of this approach is that finding empty pupae cases is not limited in the same way as finding adult moths by factors such as flight activity and required weather conditions. Quantitative evaluation is required in order to examine the relationship between active adults and pupae cases as a precursor to developing their use as monitoring tools. Despite the fact that the collection of *S. plana* pupae cases is straightforward even with the help of trained volunteers (Richter *et al.* 2009), independent on the species activity and required weather conditions, the success of finding cases depends on the species density. Failing to find them or to correctly identify the species will not be sufficient to confirm absence.

The most important discovery regarding the species future conservation has been the finding of a close association of *S. plana* adults and larvae with the exotic Chilean needle grass. These findings raise questions about how important exotic *N. neessiana* grasslands are for the ongoing survival of *S. plana* populations. There is urgent need for a better understanding of how these exotic grasslands act as a surrogate habitat for retaining viable populations of the moths and how in fact the moths will respond to the likely long term establishment of *N. neessiana* in the region. It is also possible that the presence of *N. neessiana* may prove inadvertently to be an important low cost component involved in the conservation of populations of *S. plana* at seriously weeds invaded sites that have few other conservation values. It is important to note that all *N. neessiana* grasslands in the ACT where *S. plana* were found are surrounded by native grasslands. Thus, it is likely that these grasslands have only been recently invaded by this highly invasive grass. Therefore, it is not clear if golden sun moth populations have moved from native to exotic grassland or – more likely -are remnant populations of previously native grasslands populations responded *in situ* to the spread of *N. neessiana.* Because of the uncertainty involved in our understanding about the relationship between *N. neessiana* and the golden sun moth, I recommend that future conservation and research programs for the species to take into account the species wider distributional ranges, including the utilisation of the exotic grassland dominated by Chilean needle grass.

Chapter 7

"Ecological patterns, about which we construct theories, are only interesting if they are repeated. They may be repeated in space or in time, and they may be repeated from species to species. A pattern which has all of these kinds of repetition is of special interest because of its generality, and yet these very general events are only seen by ecologists with rather blurred vision. The very sharp-sighted always find discrepancies and are able to say that there is no generality, only a spectrum of special cases. This diversity of outlook has proved useful in every science, but it is nowhere more marked than in ecology."

–Robert MacArthur, 1968

Synopsis

The adventurer, evolutionary biologist, ecologist and entomologist Charles R. Darwin (1809-1882) stated that the process of observing things in detail is the first step towards critical thinking and the development of theories that explain these observations. Science has always received evidence through observation with the consequences of trying to answer the "how's" and "why's" through further observation, experiments and detailed investigation. This curiosity leads us to new ideas about the processes that underscore the complex functioning of nature.

Over recent decades, many scientists have 'observed' and reported on the increasing numbers of threatened species with current rates of extinctions being between 100 and 1000 times higher than the background of natural extinction rates (Baillie *et al.* 2004; Vié *et al.* 2009). Large scale losses of natural habitat and fragmentation have been identified as the main drivers for this increasing loss of biodiversity at all scales - from genetic diversity within populations, to species and community diversity across landscapes and continents (Henle *et al.* 2008; Pimm and Raven 2000; Pimm *et al.* 1995; Sala *et al.* 2000; Saunders *et al.* 1991). The conservation of biodiversity in ecosystems that have undergone large scale land use changes, modifications and degradations is thus of high priority for conservation action. In order to achieve the goal of conserving biodiversity in fragmented landscapes, we require an under-standing of how both the loss of natural habitats and habitat fragmentation and associated consequences (e.g. reduced habitat quality) affect species, populations and communities. It is important that research that examines the effects of habitat loss and fragmentation includes a range of taxa that is representative of different levels of species organisations; and is conducted at different scales to allow for general prediction about the vulnerability of biodiversity to landscape modifications and to assist in prioritising appropriate conservation and management actions.

Insects are diverse and abundant and comprise a significant proportion of the terrestrial biodiversity. Intact insect communities maintain the ecological integrity of ecological systems (e.g. through nutrient cycles, decomposition, pollination)

(Groombridge and Jenkins 2002; Samways 2005) and are important for the functioning of many inter and intraspecific biotic interactions (e.g. plant-insect, parasitoid-insect interactions). In stark contrast to the proportionally high diversity and abundance of insects in terrestrial biodiversity, this group has been much less intensively studied with regard to their responses to habitat loss and the consequences of fragmentation (Davies and Margules 1998; Major *et al.* 2003; Zschokke *et al.* 2000).

In preparing this series of papers I have contributed to the science of insect conservation and provided essential knowledge to the management and the understanding of the causes of the current biodiversity crisis in fragmented landscapes. I have used insects to test the vulnerability of species to the effects of fragmentation and degradation and filled gaps in the ecology of Australian beetle species and the critically endangered golden sun moth (*Synemon plana*). The highly fragmented native temperate grasslands (less than 5% remaining) in South-eastern Australia provided an ideal setting for testing the consequences of habitat fragmentation and modification on the insect fauna. I presented empirical work on the responses of carabid (Carabidae, Coleoptera) and scarab beetles (Scarabs, Coleoptera) and the golden sun moth (*Synemon plana*, Castiinidae, Lepidoptera) to changes in the landscape structure and habitat quality following fragmentation of native temperate grasslands in South-eastern Australia. The main findings of this investigation are summarised below.

Temperate grasslands around the world are under great threat from historical and ongoing pressures of agricultural and urban development and large scale degradation. In order to secure the viability of temperate grasslands and its component biota, increased legal protection, a wider public appreciation and a greater emphasis on research is required.

In Chapter 2 I reviewed the important ecological role of temperate grasslands and showed, using examples from South-eastern Australian, East Asia and North America, the biogeographical extent of losses and degradations of native grasslands in these countries – a situation that is repeated in all continents that have naturally occurring temperate grasslands. On the basis of literature searches and compiling information about the taxa and topics studied in temperate grasslands, I showed that invertebrates and research that addresses the effects of invasion and climatic change in temperate grassland are currently underrepresented in temperate grassland research and conservation. This finding provided the rationale for the thesis to address some of the overall shortcomings in insect conservation in temperate grasslands. In my review chapter I illustrated how long term monitoring and research in temperate grassland has contributed to the understanding of ecological principles and, following the example set by China and North America, considered the proposal of the establishment of long term monitoring programs in temperate grasslands in countries like Australia where such monitoring programs do not exist. At a very specific level a non invasive monitoring method for insects, such as pupae case detection for one of the native grassland flagship species, the golden sun moth, was presented in Chapter 5.

Native temperate grassland fragmentation and the consequences of the reduction in habitat quality negatively affected a range of insect taxa among different levels of species organisations.

I provided empirical evidence that two insect groups, the ground and dung beetles, responded sensitively to changes in the landscape structure and habitat quality following native grassland fragmentation and degradation (Chapter 3, 4). I found that larger native grassland fragments supported more species of dung and ground beetles and a higher level of abundance than smaller fragments. At the community level, dung beetles were negatively affected by fragment size with smaller fragments containing a less diverse dung beetle community than larger fragments whereas the ground beetle assemblages did not respond in the same manner.

Adequate grassland remnant size and quality are essential for the persistence of an intact insect community in fragmented native grassland.

In chapter 3 I reported on an observed threshold of 7 ha in native grassland fragment that seems to be required to increase the diversity of ground and dung beetles. Currently, the majority of remaining temperate grasslands in the ACT are smaller than 7 ha and thus, most are not likely to be large enough for maintaining a viable insect fauna. Consequently, some of the invertebrate biodiversity will be held in a very small number of places. In Chapter 4 I provided evidence of the importance of floristically diverse habitats for the maintenance of the beetle diversity and showed how increasing floristic diversity enhances the beetle diversity. My findings regarding the effects of landscape structure and habitat quality on the temperate grassland insect diversity are of national relevance. Native grassland insect communities in grassland remnants in Victoria and New South Wales share similar historical threats involving habitat loss, fragmentation and degradation and face ongoing pressure of urban development. Thus, my findings may be of assistance in determining how to best conserve and maintain intact temperate grassland insect diversity in South-eastern Australia.

Predicting the effects of fragmentation needs the consideration of multiple taxa and levels of species organisations (species versus community).

The sensitivity to fragmentation and grassland modification in both beetle families (Chapter 3, 4, 5) makes them suitable groups to use in future investigation of the effects of fragmentation and modification. However, in predicting the effects of fragmentation on the beetle fauna, the levels of organisations need to be considered. I have shown that both beetle groups (Carabidae and Scarabaeidae) responded sensitively to the reduction of fragment size at the community level but inconsistently at the level of the community assemblage level. The assemblages of scarab beetles were more negatively affected by the reduction of native grassland than were the carabid beetles (Chapter 3).

Kangaroo grazing enhanced the diversity of beetles in temperate grassland and different management practices were found to differentially influence the temperate insect fauna at different taxonomic resolutions. The conclusions drawn from this is that not one type of management suits all taxa.

In chapter 4, I investigated the fundamental questions of which factors were the main drivers of species distribution in fragmented landscapes. The type of management was found to determine the distribution of the arthropod fauna and to a much lower extent the distribution of the ground and dung beetle fauna. Management that included mowing positively affected the richness and abundance of ground dwelling arthropods, whereas kangaroo grazing was positively associated with dung and ground beetle richness and abundance. Interestingly, the intensity of grazing by kangaroos and livestock had no influence on the occurrence of ground and dung beetles across the study sites. As a result of the inconsistent responses to kangaroo and livestock grazing and mowing, my results demonstrate that the type of management depends on the particular insect group being considered. For example, if the aim of the management is to enhance the general insect orders, mowing seems to advance the richness of taxa and numbers of individuals. In contrast, if the aim of the management focuses on beetle diversity at the community level, kangaroo grazing seems to be the best management strategy. Because I did not specifically investigate how management affects threatened insect species (e.g. *Synemon plana*) specific recommendations for management of grassland remnants for these species are not possible. At this stage my results are the first reported that demonstrate responses of insect diversity to different management types in grassland remnants. Thus, there is a need for additional manipulative experiments to test how grazing and other forms of management (disturbance) under different climatic conditions and at different levels of fragmentation affect the insect biodiversity or selected threatened insect species in fragmented native temperate grasslands.

The life history traits of body size, dispersal ability and rarity are potentially good predictors for the sensitivity of ground beetles to temperate grassland fragmentation.

In chapter 5, I provided some indication that the life history traits of rarity, as well as body size and the closely related trait of dispersal ability are good predictors for the sensitivity of beetle species to fragmentation. Species of ground beetles that are characterised by being rare, that have medium to large body size and occur in grasslands characterised by high isolation and low floristic diversity are at the highest risk of declines and extinctions. These results assist in prioritizing conservation measurements for ground beetles that share these traits and are expected to be more vulnerable to extinction than species which do not share these traits. Further research is required with species that are found in other types of grassland to test these findings.

The critically endangered golden sun moth (S. plana) showed little vulnerability to the reduction of grassland area but was significantly associated with the type of grasslands. The moths were found to be strongly associated with native grassland characterised by wallaby grasses (Austrodanthonia spp.) but also showed the ability to successfully establish in a range of grassland communities, including the exotic Chilean needle grass (Nassella neessiana).

In contrast to my findings of the sensitivity to fragmentation in ground and dung beetles (Chapter 3, 4, 5), I found no evidence that the endangered golden sun moth is vulnerable to spatial changes in grassland remnants. Rather, the species current distribution is influenced by the availability of a range of types of native grasslands and the presence of the exotic Chilean needle grass. Evidence for the ability of the species to successfully establish in Chilean needle grass dominated grasslands was supported by my findings of the presence of the species at all its life stages in Chilean needle grass grasslands. I reported on the generally low abundance of populations of *S. plana* in the ACT at least over two seasons that I studied which lead to further questions about the factor that drives the densities of *S. plana* populations and about other risk that the species may face and have not yet been studied (lack of genetic diversity, predation risk, dispersal barrier). My findings of the sex ratio being biased towards males add another distinctive element to the other distinctive features that characterise this unusual moth (short life span, restricted activity, sex biased flight abilities, and dietary specialisation). This requires further investigation.

Future research

The consequences of the extensive losses, fragmentation and degradation for the insect diversity in temperate grassland will only be identified through further comprehensive, well designed experiments, tested over multiple scales and among several taxa. Despite the insights of this study regarding: 1) the composition of ground and dung beetle assemblages in native temperate grasslands, 2) the vulnerability of these beetles to the effects of fragmentation and modifications, and 3) the ecological information that I obtained for ground beetles, dung beetles and the golden sun moth, the results do not mean that all insects will respond in the same manner to temperate grassland fragmentation and degradation. In order to generalize the findings from this study, it is essential that the outcomes generated from this thesis be tested over a range of grassland types and for other insect species. My research was deliberately restricted to one type of grassland to avoid confounding effects of different types of vegetation and the associated insect fauna. Future research on beetles should be expanded to include a range of temperate grassland types, including pasture and exotic grassland. This expansion of habitats would also benefit the conservation of the golden sun moth whose relationship to exotic grassland (in particular to Chilean needle grass dominated grasslands) still remains unknown.

Although the temperate grasslands in the ACT regions are fragmented and highly isolated from a human perspective, nothing is known about the direct impact of the surrounding matrix on the beetle assemblages. A major criticism in fragmentation research that is based on simple island-sea models with a lack of the consideration of the "matrix" (Driscoll 2005). The "matrix" is used as a term that describes the landscape in which fragments are embedded. For many species, the matrix may be hostile and thus, the occupants of the fragments will strongly be influenced by their interaction with this surrounding matrix. The matrix can influence dispersal and colonisation rates and may provide (temporarily or permanently) habitat to species from nearby patches. It may also provide a source for species that "invade" fragments as the surrounding provides habitats for new species (Fahrig and Merriam 1994). Although my study gained insight into the pattern that determine the occurrence of the beetle species in wallaby grasslands, further research is clearly needed to study how the surroundings may govern extinction.

For the native grassland specialist - the golden sun moth, future investigations are required that examine the association with exotic Chilean needle grass and the determination of the mechanism that drive the male biased sex ratio. Long term monitoring of the distribution, the abundance and the sex ratio variations in *S. plana* throughout the species distributional range (including populations from Victoria and NSW) as well as examination of the sex specific risks at both adult and larvae stages, are required to link my findings with the survival of the species in native and exotic grasslands.

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