Melbourne Water Corporation

Sugarloaf Pipeline Project

Sheoak Golden Sun Moth and Vegetation Monitoring

May 2014

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Abbreviations

CMP	Conservation Management Plan
DEPI	Victorian Department of Environment and Primary Industries
DotE	Commonwealth Department of the Environment
GSM	Golden Sun Moth
HLPS	High Lift Pump Station
LU	Landscape Unit
MWC	Melbourne Water Corporation
OMP	Offset Management Plan
SLL	Striped Legless Lizard

1. Summary of project

1.1 Introduction

The approved Golden Sun Moth – Offset Package Proposal (Document No. SPA-REP-GL-ENV-0019) September 2009 obligated Melbourne Water Corporation (MWC) to carry out Golden Sun Moth (GSM) surveys across the broader Sheoak property for a five year period, and report on the patterns in species numbers and distribution. Specifically this document requested surveys that monitor ‘Five flight seasons within the broader Sheoak property (i.e. in parts of the property beyond the construction footprint)’ be undertaken. In addition the completion of the 2013/2014 Golden Sun Moth survey season represents the completion of MWC’s obligation under prescribed ‘monitoring post five year of construction’ obligation as prescribed under EPBC Act obligations.

This monitoring period has come to a conclusion; this summary represents a brief overview of the findings of the required monitoring over this period.

1.2 Background

The Golden Sun Moth – Offset Package Proposal (Document No. SPA-REP-GL-ENV-0019) September 2009 identifies some issues and background regarding GSM populations in the local area. Firstly, there was no previous long term data on GSM within the local area and only one historic record from the greater GSM region. Due to land access constraints very few GSM surveys were undertaken in the 2008/09 flight season, though as survey intensity increased on Sheoak, GSM were detected in most parts of the property.

In general the 2008/09 GSM flying season was considered to be favourable to GSM emergence across Victoria, with larger than normal, and many new populations of GSM being detected across suitable habitat. This was considered a “bumper year” though there was some suggestion that the increase in records was also a function of increased survey effort across many areas of Victoria, coupled with improved observer experience leading to an increase in detections.

It is also thought that eggs and pupae can persist underground for more than one year, and the emergence of adults in any single year can represent past favourable breeding conditions or survivorship. Conversely the reduction in the number of emerging adults may reflect extant conditions that are not suitable for emergence or poor condition in previous years where breeding success was reduced. These are typical patterns in the ecology where abundance of populations cycle annually and over longer time periods (multiple years or decades), depending on environmental conditions, and other factors such as competition and predation.

1.3 Survey methods 2008/09 to 2011/12

The initial GSM surveys on the property were undertaken in the summer of 2008/09. The focus of these surveys was the impact area of the pipeline and construction footprint of the HLPS. The GSM surveys were largely opportunistic presence and absence surveys using broad walking survey sweeps. These were supplemented by pupa case and larvae surveys to determine if there was any breeding activity.

Subsequent surveys in the summers of 2009/10, 2010/11 and 2011/12 assessed abundance of GSM across the entire Sheoak property. Surveys were conducted in the peak flying period (once there was evidence from reference and other sites in Victoria that the GSM had begun to emerge and commenced breeding), and involved random, continuous 100 m transects across the property during the warmest part of the day between 10 am and 2 pm when temperatures were in the recommended range for surveys (usually > 20 degrees Celsius) and when cloud cover and wind were minimal. This survey method was recommended by Victorian Department of Environment and Primary Industries and largely follows the recommendations of the Department of the Environment. For each 100 m transect the start and end location, the time and the number of GSM were recorded. No vegetation or habitat data were recorded along these transects.

1.4 Survey methods 2012/13 to 2013/14

The approach to the GSM surveys shifted slightly in the 2012/13 to 2013/14 seasons, though the methods (100 m transects sampled between 10 am to 2 pm in the flying season with temperatures > 20 degrees) remained the same, transects were stratified via key landscape variables (grassland condition, aspect and landscape position) and permanently marked. More detailed vegetation and habitat data (floristic composition, structure and biomass) on each transect was also collected (unlike previous surveys) and this new array and data collection was designed to enable more informed decisions regarding grazing impacts on GSM habitat and ecology and best practice ecological grazing management on Sheoak. Overall, a total of 90 transects were permanently established and surveyed across the 16 landscape units.

1.5 Changes in abundance 2009/10 to 2013/14

The distribution and abundance of GSM have changed substantially over time since the initial surveys in 2009/10. The total number of GSM (and male and females) is presented in Table 1, and the proportion of the area where GSM were recorded in presented in Table 2 and Figure 1. The total numbers substantially declined from the bumper year of 2009/10 (n=1896) to a nadir of 37 in 2013/14. However during the years 2010/11 to 2013/14 the total GSM were all substantially lower than the initial year of survey and fluctuated from a minimum of 37 to a maximum of 245. The trend was not monotonic – that is the decline was not consistent in subsequent years – instead there were two peaks (2010/11 and 2012/13) and two troughs (2011/12 and 2013/14).

The distribution of GSM on Sheoak also decreased in the proportion of the Sheoak property, when one examines the distribution of 100 x 100 m grids where they were recorded as present. Again in 2009/10, GSM occurred on 74% of the property, but in the “non-bumper” years, this ranged from 11-35% of the property. Given the strong association of GSM breeding locations with a northerly aspect and native grasses, this distribution seems to match the extent of suitable habitat. And despite the fluctuations, the locations where GSM are recorded is consistent (Figure 1).

Table 1 GSM abundance from 2009/10 to 2013/14

Year	Male	Female	Total
2009/10	1890	6	1896
2010/11	244	1	245
2011/12	68	0	68
2012/13	146	4	150
2013/14	36	1	37

Table 2 GSM distribution from 2008/09 to 2013/14

Year	No. grids surveyed	No. girds present	Proportion
2009/10	209	156	74%
2010/11	209	74	35%
2011/12	194	37	19%
2012/13	175	60	34%
2013/14	175	19	11%

1.6 Interpretation of GSM changes

The changes in GSM numbers over the five year survey period suggest a natural spatial and temporal fluctuation in the population at Sheoak, with the high numbers in the first year of survey representing an unusual circumstance where GSM numbers spiked dramatically across Victoria. We undertook detailed analysis of the determinants of GSM abundance and distribution in the years 2009/10 to 2011/12, and then (once the monitoring array had been adjusted) in the years 2012/13 to 2013/14. The key patterns and conclusions from these analyses were:

- In 2009/10 the last year of what was a 13 year drought GSM was still widely distributed across the Sheoak property and within almost 74% of grids. In February 2010, drought breaking rainfall commenced. The 2010/11 season was one of the wettest years on record with a seven month period of double average rainfall for each month. The GSM abundance and distribution contracted markedly.
- In the 2011/12 survey season, the property was still extremely wet after the record rainfall period and the surveys identified GSM presence in approximately 19% of grids, having contracted further from the previous year.
- The review of the historical survey data indicated that climate (in particular changing annual weather patterns and elevation position) were a strong determinant of GSM distribution and abundance, and this is the first time such patterns have been reported convincingly with respect to the biology of this species. The location of the GSM records from 2009/10 to the 2011/12 shifted from downslope to upslope locations, in effect from run-off (wet) to run-on (dry) locations in concert with the change in weather conditions. It is speculated that waterlogging or increased moisture of soils where GSM previously occurred may effect egg and pupae survival.
- GSM abundance was strongly associated with sites with a northerly aspect, and with predominantly native vegetation. These are typical patterns for GSM and reported for the first time in this district.
- The 2012/13 and 2013/14 surveys using the new transect array indicated that there are potential thresholds and consistent predictors of GSM abundance, and these appear to be higher native vegetation cover and height, and Wallaby and Spear grass species richness and cover (i.e. *Austrostipa* spp. height 30-80 cm, Wallaby grass species richness of 1-3; *Rytidosperma* spp. cover 5-40%). This is important information to help manage the grazing regimes on Sheoak, and will provide triggers for stock manipulation and useful surrogates for monitoring the condition of GSM habitat across the property.

- Though some of the relationships between the environmental factors and GSM abundance are linear, as the data is accumulated, there seem to be intermediate ranges of which GSM are associated. These intermediate patterns are typical in ecology where the extremes (very high or very low cover abundance for example) are not suitable for many species. This suggests that the grazing patterns that might be suitable for GSM will be intermediate also – neither too high nor too low – and the relationship with weather pattern will be critical. For example, if dry conditions are predicted or prevail, grazing might have to be reduced in order to prevent native vegetation cover declining below the thresholds identified above.

1.7 Contribution to knowledge of GSM ecology

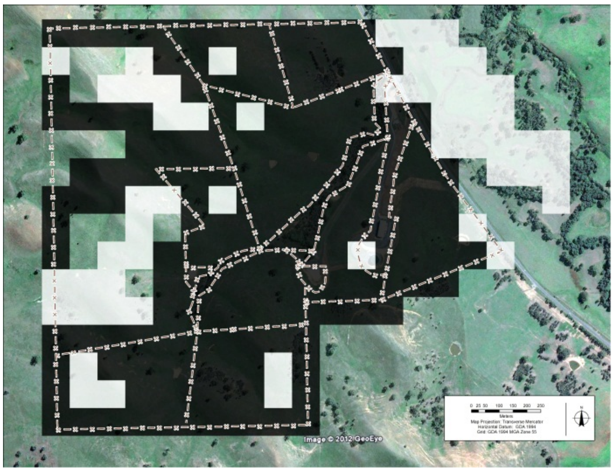
As part of the revision of the survey methods, a key commitment from MWC was to ensure that the valuable data on this critically endangered species would be contributed to the broader body of knowledge base about GSM population ecology. The revised methods would also provide important information on the relationship between GSM occurrence and fine scale determinants of their abundance (i.e. relationship to vegetation parameters) which then could be used to define clear ecological grazing regimes for Sheoak.

To this end, a manuscript has been submitted to *Austral Ecology* which was accepted for publication after revision and some reanalysis of the data. After the third summer of sampling for the current monitoring (i.e. summer 2014/15) a further publication will be prepared on the more recent results, the target journal being *Wildlife Research*.

Kutt, A.S., McKenzie, V.J., Retallick, R.W.R., Dalton, K., Kay, N., and Melero-Blanca, E. (2014) Determinants of Golden Sun Moth *Synemon plana* abundance in space and time. *Austral Ecology*. Accepted with minor revision

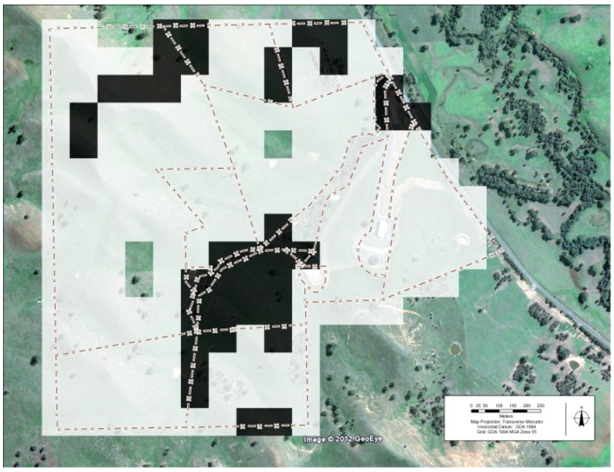
Figure 1 The change in distribution in GSM from 2009/10 to 2013/14 survey seasons

(a) 2009/10

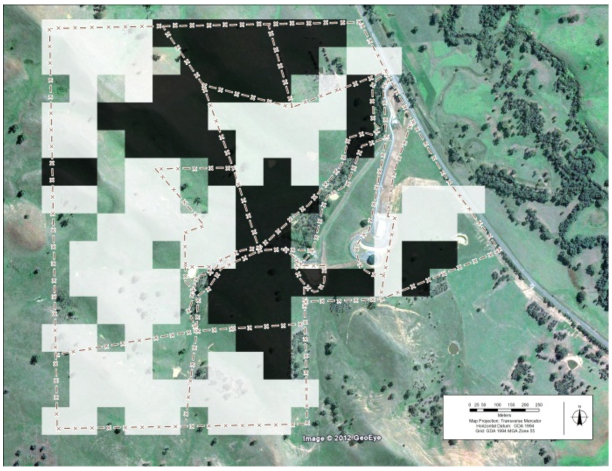


(b) 2010/11

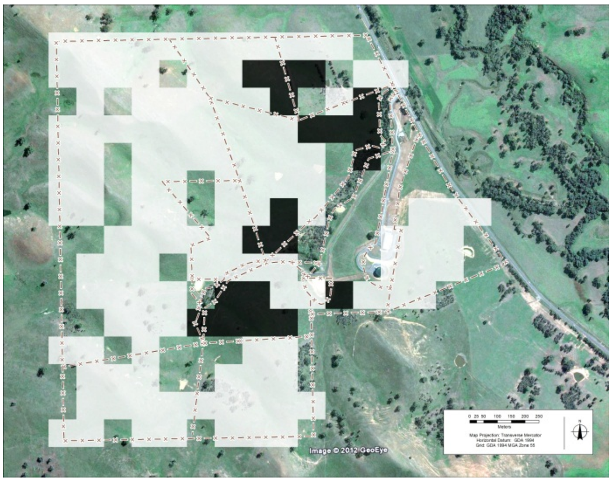
(c) 2011/12



(d) 2012/13



(e) 2013/14



2. Introduction

This report presents the results of the second year of a proposed long term Golden Sun Moth *Synemon plana* (GSM) and vegetation monitoring program at Sheoak. The broad aim of the monitoring is to provide annual data on the patterns of GSM in context of the vegetation patterns, which will inform ecological grazing management. The purpose of the first year of the program was to investigate the past data collected from the site (2008/09-2011/12) and use this information to design and stratify a sensible and statistically valid adaptive monitoring array (GHD 2013). This document reports the results of the second year of the new monitoring program, and reviews this in context of the previous year's work.

2.1 Background

The Sheoak property, located approximately 3 kilometres south of Yea, was purchased by Melbourne Water Corporation (MWC) in early 2008 for construction of the High-lift Pump Station (HLPS), as part of the Sugarloaf Pipeline Project. The property was found to support significant ecological values, including the presence of two fauna species listed under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. These are Striped Legless Lizard (SLL) (*Delma impar*) and Golden Sun Moth (GSM) (*Synemon plana*).

Due to the presence of these nationally significant ecological values, MWC determined that the large portion of the Sheoak property not required for the HLPS would be set aside for conservation purposes and managed as part of the Project's agreed biodiversity offsets, in accordance with *Victoria's Native Vegetation Management: A Framework for Action* (DNRE 2002). Approximately half of the site will be managed in accordance with the approved offsets package (Offset Management Plan (OMP) area), while the other half will also be managed for conservation purposes (Conservation Management Plan (CMP) area).

A key compensatory action under the offsets package agreed to by the Commonwealth Department of the Environment (DotE) and the Victorian Department of Environment and Primary Industries (DEPI) was that parts of the Sheoak property were to be managed in perpetuity for native grassland values, including threatened flora and fauna species such as the GSM (irrespective of land ownership in the future).

Six years of GSM monitoring (late 2008 – early 2013) have now been completed across the Sheoak property using methods that were developed in conjunction with DEPI and DotE prior to pipeline and HLPS construction. These methods comply with the *EPBC Act Policy Statement 3.12 - Significant Impact Guidelines for the Critically Endangered Golden Sun Moth (Synemon plana)*.

Grazing will be excluded from the OMP area but not the CMP. The use of ecological grazing regimes to control grassland biomass, maintain native species diversity and cover, and maintain/enhance the biodiversity values of the property will be an important conservation management tool. The livestock grazing will need to be carefully managed and the identification of stocking rates and trigger levels for introducing or removing stock into the different paddocks within the CMP is required to be based on local evidence regarding the GSM and vegetation patterns at Sheoak.

This report presents the results of the second year of a long term monitoring program established in 2013 (described below) designed to investigate and report on the effects of grazing on grassland composition, cover, diversity, dominance, structure and biomass, and therefore GSM populations and their conservation management.

2.2 Previous survey results

This 2013 annual report reviewed the GSM data collected at Sheoak from the 2008/09 to the 2011/12 GSM survey seasons, used this information to design a long term monitoring array and undertake the 2012/13 GSM survey using this new program. The key outcomes of this work were:

- Over the survey period from 2008/09 to 2012/13 the distribution and abundance of GSM changed markedly on an annual basis, largely due to changing weather patterns (from long term drought to above average rainfall). Distribution and abundance declined, and though GSM were still predominantly located on north facing slopes and in native species dominated vegetation, the landscape position of the recorded populations of the GSM shifted from downslope (wetter, run-on areas) to upslope sites (drier, run-off areas).
- Though the GSM presence sites cluster in a loose group in the ordination, there is a large degree of overlap in the vegetation composition of GSM presence and absence sites. This suggests that in general, at least for the first year of survey over the 2012/13 summer, there is little to distinguish vegetation composition between sites where GSM occurs and sites where GSM does not occur.
- In transects within the CMP only, where GSM were recorded as present; forb richness, native graminoid mean cover (%), *Rytidosperma* spp. mean cover (%), *Rytidosperma* spp. richness and *Austrostipa* and *Rytidosperma* spp. richness were significantly higher. These provided preliminary thresholds; i.e. where native graminoid mean cover is less than about 10%, GSM are absent, but where it increases to 15%, GSM are present.
- Using regression analysis, four variables were significantly linked with increasing GSM abundance: native graminoid mean cover (%); *Rytidosperma* spp. mean cover (%); *Austrostipa* spp. richness; and *Austrostipa* and *Rytidosperma* spp. richness. This result is in keeping with existing understanding that GSM is strongly associated with native grasses and in particular *Rytidosperma* spp. (Wallaby Grass) (DSE 2004).

2.3 Scope

The objective of this project is to implement a long term monitoring program for both GSM and ground cover vegetation and provide data and recommendations that:

- Enable informed decisions on best practice ecological grazing management in the context of a conservation regime aimed at protecting the habitat of GSM.
- Provide guidance for an ongoing ecological grazing regime of sheep and cattle including:
  - Optimum stocking rates and times for the various management zones of the property in order to maintain and enhance habitat for the local populations of GSM.
  - Measureable triggers for movement of stock to other management zones at various times of the year.
  - Measureable triggers for removing stock altogether.
- Will contribute to the broader body of knowledge about ecological grazing regimes and their influence on grassland habitat for GSM.

The program was implemented in the summer of 2012/13, and is proposed to continue to January 2019. The 2013/14 round of monitoring represents the second GSM and summer vegetation survey, and the first spring vegetation survey.

3. Methods and analysis

The review of the previous Sheoak GSM monitoring data, and the use of this to develop the current long term monitoring array is presented in last year's annual report (GHD 2013).

3.1 Stratification of monitoring array

The current monitoring array is based on the stratification of the Sheoak property into 16 unique combinations of landscape and environmental factors ('landscape units' (LUs)), namely: broad planning areas (Conservation Management Plan area and Offset Management Plan area); grassland condition (native or non-native); aspect (north or south); landscape position (wet or dry).

In 2012, the location of transects in each of the landscape units was automated by GIS so that a single transect was placed automatically within each discrete landscape unit. Transects had to fully fit within a designated landscape unit and not cross paddock boundaries. Landscape units were not evenly distributed across the property; however, there was sufficient variation to include at least three replicate transects in each of the 16 landscape unit treatments (Table 3).

A total of 90 transects were permanently established and surveyed across the 16 landscape units. Due to time constraints, only 74 of these were surveyed for vegetation from spring 2013. These 74 maintained a minimum of three replicate transects for each landscape unit. The full 90 transects have been surveyed for Golden Sun Moths in both the 2012/13 and 2013/14 season.

Each landscape unit had a minimum of three replicate transects. As some of the landscape units were large and known to be used by GSM, additional transects were included. The number of transects included in each landscape unit is shown in Table 3.

In 2013, as part of quality assurance of the final monitoring array, our proposed design and revised survey methods were peer reviewed by Dr John Morgan, Plant Ecology Lab at the Department of Botany, La Trobe University, Victoria.

Table 3 Distribution of monitoring transects across the treatment combinations

Treatment	Number of transects (GSM Survey)	Number of transects (Vegetation Survey)
CMP, Native, North, Dry	13	8
CMP, Native, North, Wet	6	6
CMP, Native, South, Dry	8	6
CMP, Native, South, Wet	4	4
CMP, Non-native North, Dry	3	3
CMP, Non-native, North, Wet	5	5
CMP, Non-native, South, Dry	3	3
CMP, Non-native, South, Wet	4	4
OMP, Native, North, Dry	8	6
OMP, Native, North, Wet	3	3
OMP, Native, South, Dry	9	6
OMP, Native, South, Wet	3	3

Treatment	Number of transects (GSM Survey)	Number of transects (Vegetation Survey)
OMP, Non-native, North, Dry	3	3
OMP, Non-native, North, Wet	5	4
OMP, Non-native, South, Dry	6	6
OMP, Non-native, South, Wet	7	4

3.2 GSM survey 2013/14

The GSM survey methods follow that of previous surveys and are in line with those recommended by DEPI, and largely follow the recommendations of DotE (DEWHA 2009). Surveys were conducted in the peak flying period (once there was evidence from reference and other sites in Victoria that the GSM had begun to emerge and commenced breeding), and involved walking the permanent 100 m transects during the warmest part of the day between 10 am and 2 pm when temperatures were in the recommended range for surveys (usually > 20 degrees Celsius) and when cloud cover and wind were minimal (Clarke and O'Dwyer 2000; Gibson and New 2007). As with the previous year's survey:

- The surveys were conducted along 90 transects permanently marked at the 0 and 100 m points.
- The transects are distributed across 16 landscape unit treatment combinations.
- Incidental data on GSM presence and abundance were collected on the walks between the start and end of each transect surveyed.
- Vegetation data are collected along transects to aid the interpretation of the GSM patterns.

3.3 Vegetation survey

The vegetation surveys for the 2013 spring and 2013/14 summer were each conducted over four days (17-20 September 2013 and 11-13 and 17 December 2013 respectively). Survey was completed by pairs of botanists, with the lead botanist undertaking the structure and composition component and the accompanying botanist undertaking the biomass component of the assessment.

Grassland dominance and height was recorded at 40 points along the 100 m transect, at 2.5 m intervals. The species and height (in 10 cm intervals) of the tallest vegetation touching a 2 m polypipe pole with height gradations marked on it at each point was recorded. The graminoids *Rytidosperma* and *Austrostipa* were only recorded to genus level due to the difficulties in keying them further in the field (especially when infertile during the spring survey). Height was recorded as the upper limit of the category, so that vegetation at a height of 32 cm would be recorded as 40 cm.

At the 50 m mark of each transect, a 5 x 1 m quadrat was established and surveyed. A full species list and Braun-Blanquet cover abundances were recorded for each quadrat.

Vegetation biomass was indexed using a method developed by the Morgan Plant Ecology Lab at La Trobe University in conjunction with Parks Victoria. The method has been trialled in grasslands across Victoria and a significant relationship exists between biomass and golf ball visibility. Two 1 x 1 m quadrats along the transect (at the 33 m and 66 m marks) were delineated using a collapsible poly-pipe frame. Into each quadrat 18 yellow golf balls were dropped haphazardly from a height of approximately 1.3 m. If balls rolled out of the frame, they were retrieved and re-dropped. Where golf balls fell atop grass tussocks, the grass was gently parted to allow the ball to fall amongst the vegetation. A photo was then taken parallel to the ground, from a height of 1.3 m, over the centre of the quadrat. The cover of bare ground, native graminoids, native forbs, introduced graminoids and introduced forbs was also recorded at each quadrat.

Photos were analysed following fieldwork. For golf balls where <33% of the surface was visible a score of zero was attributed. Where 33-90% of the ball was visible a score of 0.5 was given. Where >90% of the ball was visible, a score of one was recorded. The scores for each quadrat (maximum possible 18) across the transect were averaged to give a biomass index for the entire transect.

3.4 Analysis

Three approaches to the analysis of the data were undertaken, namely: multivariate analysis to examine patterns in plant species composition across the transects and where GSM were recorded; non-parametric analysis to examine variation in the environmental variables between transects where GSM were present or absent; and generalised linear modelling where combinations of environmental variables are the best predictors of GSM abundance.

At this stage, new paddocks have been delineated in the CMP area and there is an expectation that differing grazing regimes will be employed in the CMP and OMP areas. Changes in livestock management between the two areas at Sheoak have not yet occurred and as a consequence no analysis is undertaken with respect to grazing effects, variation in stocking rate, variation in new paddocks or differences in the CMP and OMP.

3.4.1 Composition

The variation in floristic composition across the transects were examined via ordination and analysis of similarity. We used all data combined (summer 2012/13, spring 2013, summer 2013/14), the summer survey data combined, and the summer 2013/14 data alone. We created Bray-Curtis dissimilarly matrices from the transect by species data in Primer (Clarke and Gorley 2006) and examined the general patterns on change in floristic composition over each survey period visually via ordination (multi-dimensional scaling). We also examined if there were any *a priori* patterns of spatial variation in the vegetation patterns using analysis of similarity (ANOSIM). We tested season, elevation (wet/run-off versus dry/run-on), aspect (north versus south), vegetation mapping (native versus non-native), and GSM presence and absence. ANOSIM calculates a Global R value (analogous to a correlation coefficient), where an absolute measure of group separation is based on the factor tested. Like a correlation, Global R is distributed around zero, with zero indicating completely random grouping, and one indicating complete separation (Clarke and Gorley 2006).

3.4.2 Presence absence

The variation in vegetation or environmental factors in sites where GSM is present or absent, was tested using non-parametric Mann–Whitney *U* test of the null hypothesis; that is that the two locations (GSM present or absent) are the same against an alternative hypothesis. These tests assume all the observations from both groups are independent of each other and the responses are ordinal (i.e. one can at least say, of any two observations, which is the greater). We used the program Statistica for these analyses (StatSoft Inc. 2011).

3.4.3 Regression

Nonlinear regression is a general technique to fit a curve through data. It fits data to any equation that defines Y as a function of X and one or more parameters. It finds the values of those parameters that generate the curve that come closest to the data (minimizes the sum of the squares of the vertical distances between data points and curve) (Payne *et al.* 2010). We used generalised linear/non-linear modelling to examine the variation GSM abundance in relation to a range of prospective predictive vegetation and environmental models. As there were a large number of potential predictor variables we tested subsets that represented key potential determinants of GSM abundance and groups that can be measured and/or respond to grazing pressure. For each, we derived minimum adequate models using a backwards-stepwise procedure, and a Poisson (log-linear) error distribution (Crawley 1993). For each minimum adequate model, we report the intercept, the significant effects (and standard error), the test statistic (Wald), the P level and the percent deviance explained (strength of the model) as identified by the goodness of fit (deviation from the null model). We again used the program Statistica for these analyses (StatSoft Inc. 2011).

We tested the following groups of variables together:

- **Landscape model:** Elevation (m), Aspect (degrees)
- **Height model:** Mean height (cm), *Austrostipa* spp. height (cm), *Rytidosperma* spp. height (cm)
- **Biomass model:** Biomass (i.e. golf ball visibility) mean
- **Cover model:** Bare ground (%), Introduced forbs (%), Introduced graminoids (%), Native forbs (%), Native graminoids (%)
- **Wallaby grass cover model:** *Rytidosperma* total cover (%) *Rytidosperma* species richness, cover (%) of *Rytidosperma caespitosa, Rytidosperma eriantha, Rytidosperma penicillatum, Rytidosperma racemosum, Rytidosperma setaceum*
- **Spear grass species model:** *Austrostipa* total cover (%), *Austrostipa* species richness, cover (%) of *Austrostipa densiflora, Austrostipa scabra, Austrostipa* unidentified
- **Other native grasses model:** cover (%) of *Elymus scaber, Microlaena stipoides, Themeda triandra*

4. Results and discussion

4.1 GSM survey

During the 2013/14 GSM transect survey 21 Golden Sun Moths were observed, with an additional 5 observed as incidental observations (between transects). This is much lower than the 2012/13 survey season, when 150 Golden Sun Moths were observed, with 81 observed as incidental observations (between transects). A further 11 GSM were observed during the summer 2013/14 vegetation survey. The raw data for the 2013/14 season GSM survey are presented in Table 4.

Table 4 GSM observations 2013/14

Observation Type	Location		Date	Males Flying	Females Flying	Males Ground	Females Ground	Total
Transect	Transect 75		12/12/2013	1	0	0	0	1
Incidental	Between transects 75-76		12/12/2013	1	0	0	0	1
Transect	Transect 11		13/12/2013	2	0	0	0	2
Transect	Transect 10		13/12/2013	1	0	0	0	1
Transect	Transect 12		13/12/2013	1	0	0	0	1
Incidental	Between transects 7-8		13/12/2013	4	0	0	0	4
Vegetation survey	361172 E	5877376 N	13/12/2013	8	0	1	0	9
Vegetation survey	361652 E	5878033 N	13/12/2013	1	0	0	0	1
Transect	Transect 53		17/12/2013	7	0	0	0	7
Transect	Transect 10		17/12/2013	1	0	0	0	1
Vegetation survey	361652 E	5878033 N	17/12/2013	1	0	0	0	1
Transect	Transect 83		18/12/2013	3	1	0	0	4
Transect	Transect 77		18/12/2013	1	0	0	0	1
Transect	Transect 82		18/12/2013	1	0	0	0	1
Transect	Transect 84		18/12/2013	1	0	0	0	1
Transect	Transect 82		27/12/2013	1	0	0	0	1

4.2 Weather conditions

All GSM surveys were undertaken on days when the weather conditions conformed to the DotE GSM survey guidelines (DEWHA, 2009), that is:

- Warm to hot day (above 20 degrees Celsius by 1000 hrs)
- Warmest part the day (that is, 1000 to 1400 hrs)
- Clear or mostly cloudless sky
- Still or relatively still wind conditions during the survey period
- At least two days since rain

The weather conditions for each survey undertaken during the 2013/14 season are presented in Table 5.

Table 5 Weather conditions for the 2013/14 survey season

Survey Date	Start Time	End Time	Average Temp °C	Average Humidity	Average Wind speed (km/h)	Average Cloud cover	Total GSM (Transects)
12/12/2013	10:00 AM	2:00 PM	20	nr	15	5%	1
13/12/2013	10:00 AM	2:00 PM	21	50%	13	36%	4
17/12/2013	9:00 AM	2:00 PM	25	46%	18	0%	8
18/12/2013	10:00 AM	2:00 PM	28	39%	13	39%	7
27/12/2013	10:00 AM	2:00 PM	24	46%	18	24%	1
8/01/2014	10:00 AM	2:00 PM	25	30%	17	3%	0
15/01/2014	10:00 AM	2:00 PM	39	17%	22	29%	0

4.3 Variation in floristic composition

The ordination of the floristic composition indicated that there was clear separation and variation in the vegetation for the three survey periods ($R = 0.673$, $p < 0.001$) (Table 3, Figure 2) and between the summer 2012/13 and 2013/14 surveys ($R = 0.285$, $p < 0.001$) (Table 3, Figure 3). The ANOSIM of elevation, aspect, vegetation and GSM (present or absent) categories indicated that for all surveys combined, the summer surveys and the summer 2013/14 alone there was little clear pattern or separation for these categorisations. This was a similar pattern to that recorded in the 2012/13 survey, indicating that vegetation composition is broadly the same across the entire property, and it changes at a landscape scale, likely in response to property-wide changes in climate, local weather patterns, and perhaps annual grazing patterns. Once there is a more controlled pattern of grazing in the CMP management paddocks, changes in composition may be noted at this smaller scale.

Table 6 ANOSIM results (*R* values)

Factor	All surveys	Summer 1213 and 1314	Summer 1314
Season	0.673***	0.285***	-
Elevation (wet/dry)	0.036 ns	0.107***	0.103**
Aspect (north/south)	0.033 ns	0.062 ns	0.093 ns
Vegetation (native/non-native)	0.027 ns	0.071 ns	0.062*
GSM (present/absent)	0.029 ns	0.037 ns	-0.101 ns

ns: non-significant

An asterisk indicates statistical significance: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Figure 2 Ordination of vegetation composition across all transects (spring and summer)

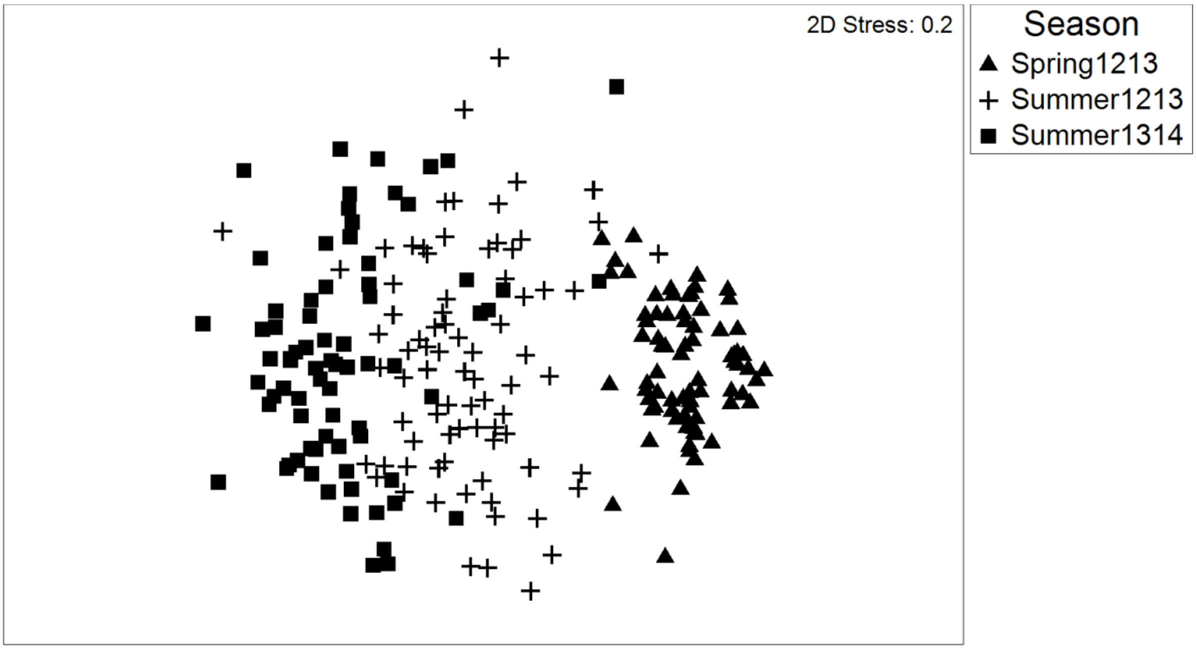


Figure 3 Ordination of vegetation composition across all transects (summer only)

4.4 Variation in transects with GSM present or absent

The variation in 34 factors was examined with respect to transects where GSM were present or absent. These factors represented landscape variables (elevation and aspect), height, biomass, cover, Spear Grass cover and species richness, Wallaby Grass cover and species richness and other native grass cover (Appendix B). The GSM presence and absence data were tested for all the transects sampled over time (summer 2012/13, 2013/14 combined), the summer samples alone and the spring 2013/14 data using the GSM presence absence data recorded for the summer 2013/14 season (as the expectation was that these data would be most closely allied to the upcoming emergence season).

For the combined summer data (all data), there were 19 factors that varied significantly between GSM present and absent transects and 15 of these were related to native grass, *Rytidosperma* and *Austrostipa* cover and species richness. All of the relationships were positive (i.e. higher cover or species richness in GSM present sites), except for *Themeda triandra* and native graminoid cover in total, both of which had higher cover in GSM absent transects.

In the summer 2012/13 and 2013/14 surveys, there was a reduction in the number of factors that varied significantly between GSM present and absent transects, (n=10 and n=8 respectively), though in general these were predominantly related to native graminoid species and covers. The data from the spring 2013/14 were poorly associated with the GSM present and absent transects from the 2013/14 survey.

The mean (and standard error) for key factors for the 2012/13 and 2013/14 summer data are presented in Figure 4, Figure 5 and Figure 6. GSM are present in transects of lower elevation, though aspect is not significantly different for the past two years survey (Figure 4). In the summer 2012/13 survey *Austrostipa* height and cover, *Rytidosperma* cover and richness and biomass were higher in GSM present transects Figure 5. Comparing this to the 2013/14 survey, a similar pattern was recorded though biomass was largely similar in presence and absence sites Figure 6. These data begin to reinforce which factors are consistently predictors of GSM presence and the variation between GSM presence and absence sites. This suggests ranges for potential trigger levels to monitor with respect to grazing pressure. For example, *Austrostipa* height was >40 cm in both years where GSM was present, *Rytidosperma* cover was >10% and *Rytidosperma eriantha* was present in sites where GSM was present and not recorded where it was absent even though other *Rytidosperma* species were present.

Figure 4 Variation in elevation and aspect for GSM present and absent sites for the 2012/13 and 2013/14 summer surveys. Bars represent mean score (and whiskers the SE)

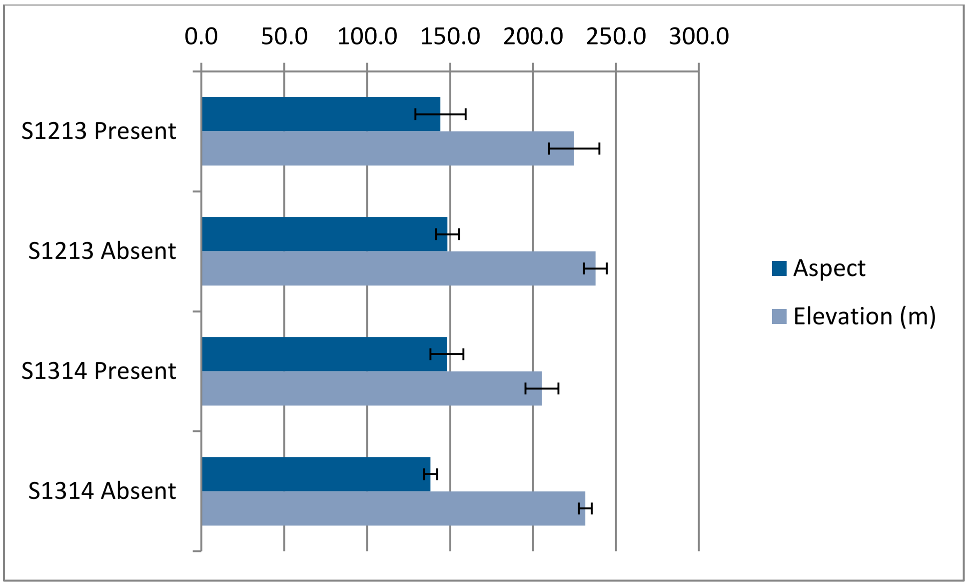


Figure 5 Variation in key vegetation variables for GSM present and absent sites in 2012/13 survey. Bars represent mean score (and whiskers the SE)

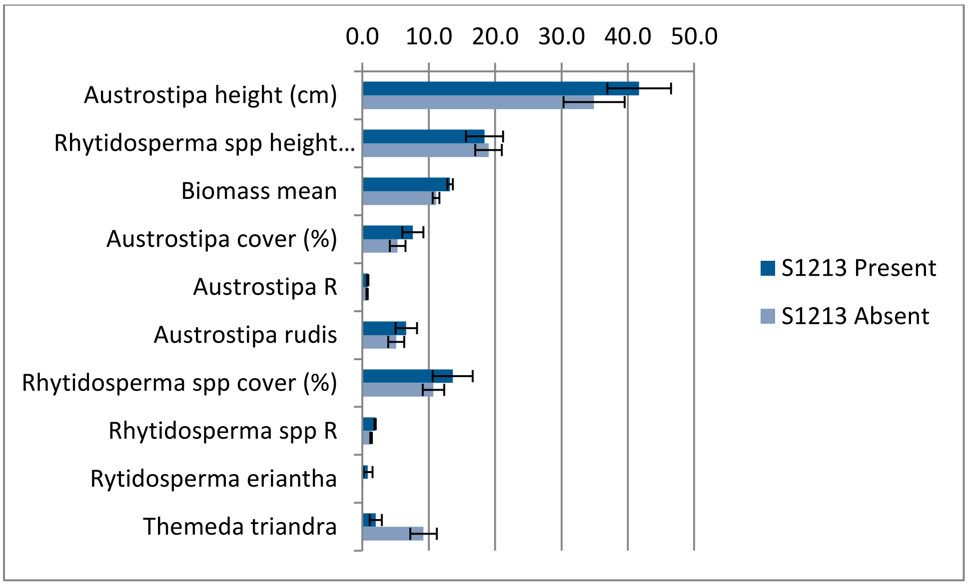
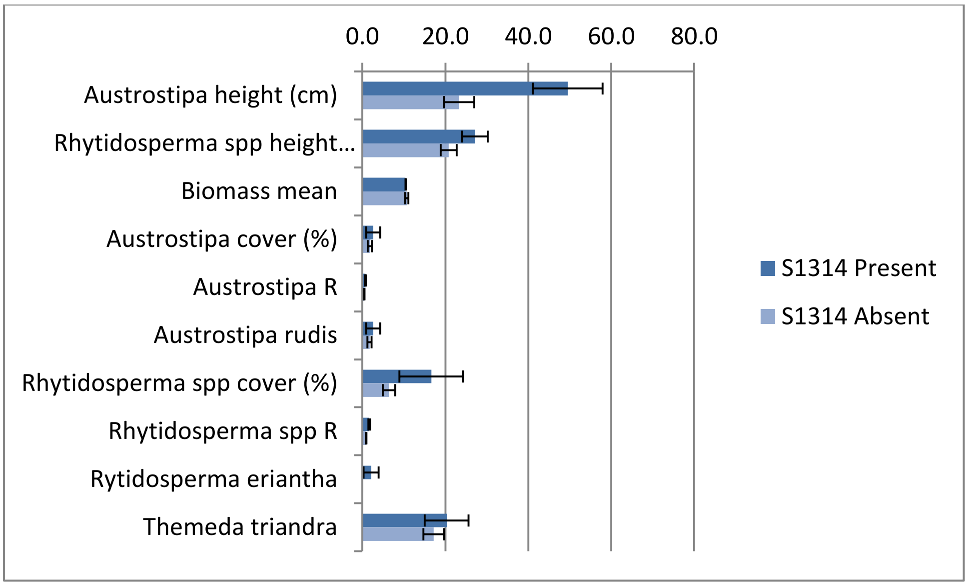


Figure 6 Variation in key vegetation variables for GSM present and absent sites in 2013/14 survey. Bars represent mean score (and whiskers the SE)



4.4.1 GSM abundance models

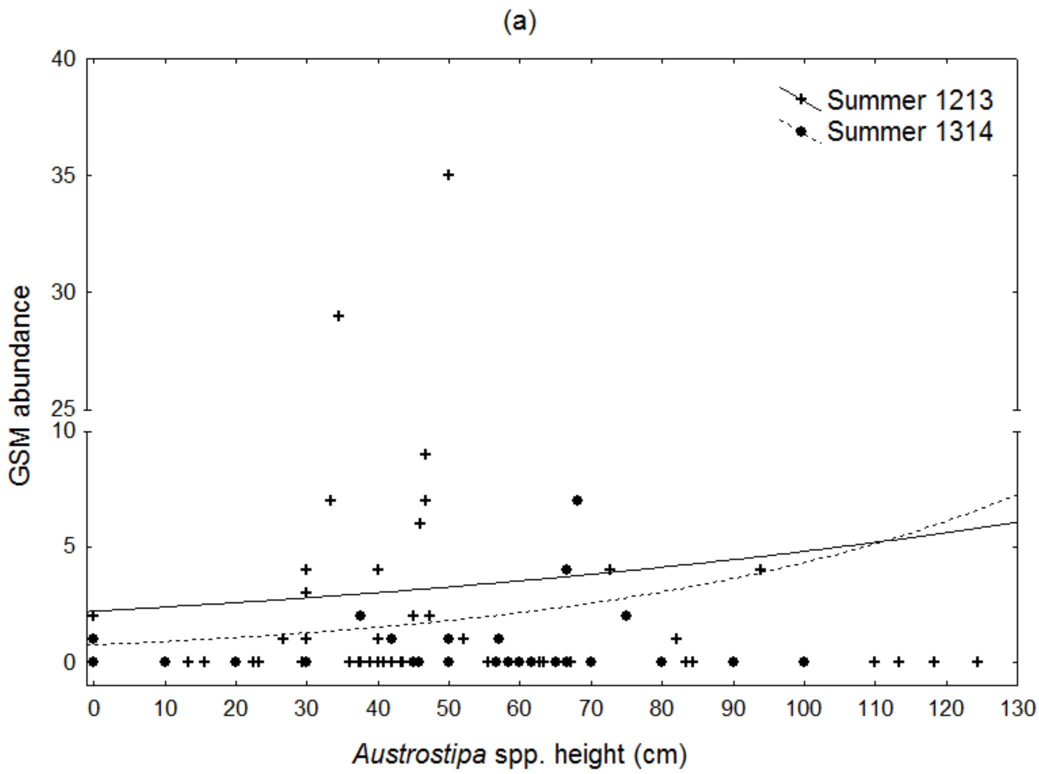
The generalised linear models provide a more complex pattern with respect to the more nuanced relationships between changing GSM abundance and the combination of environmental and vegetation factors. The minimum adequate models with the best deviance explained over the summer 2012/13 and 2013/14 data combined were the vegetation cover (31%) and the *Austrostipa* grass model (39%). For the summer 2012/13 transect data alone it was vegetation cover (24%), *Rytidosperma* grass model (34%), *Austrostipa* grass model (46%) whereas for the summer 2013/14 transects, the landscape model (54%) and vegetation cover model (37%) (Appendix C). As with the GSM presence and absence data, the spring 2013/14 floristic data suggest that there were few native grass species associated factors that were predictive of GSM abundance, and the landscape factors and grass height were predominant. Other key results from the presentation of all the models (Appendix C) include:

- Vegetation cover is a consistent predictor of GSM abundance and native graminoids and introduced forbs seem to be consistent components over the summer survey periods.
- The Wallaby grass and Spear grass models are also strongly associated with GSM abundance, but highly parameterised (i.e. many terms in the models) suggesting that there is a complex combination of total cover, richness and individual species cover that is associated with GSM abundance.
- Elevation, and particularly the lower (run-on) sites, is the consistent landscape factor for the recent years of surveys, unlike the review of past survey data, which indicated that both aspect and elevation were key interactive predictors of GSM. The weather patterns have shifted to average to below average rainfall again, and GSM it seems have shifted in distribution again to the lower elevation transects.

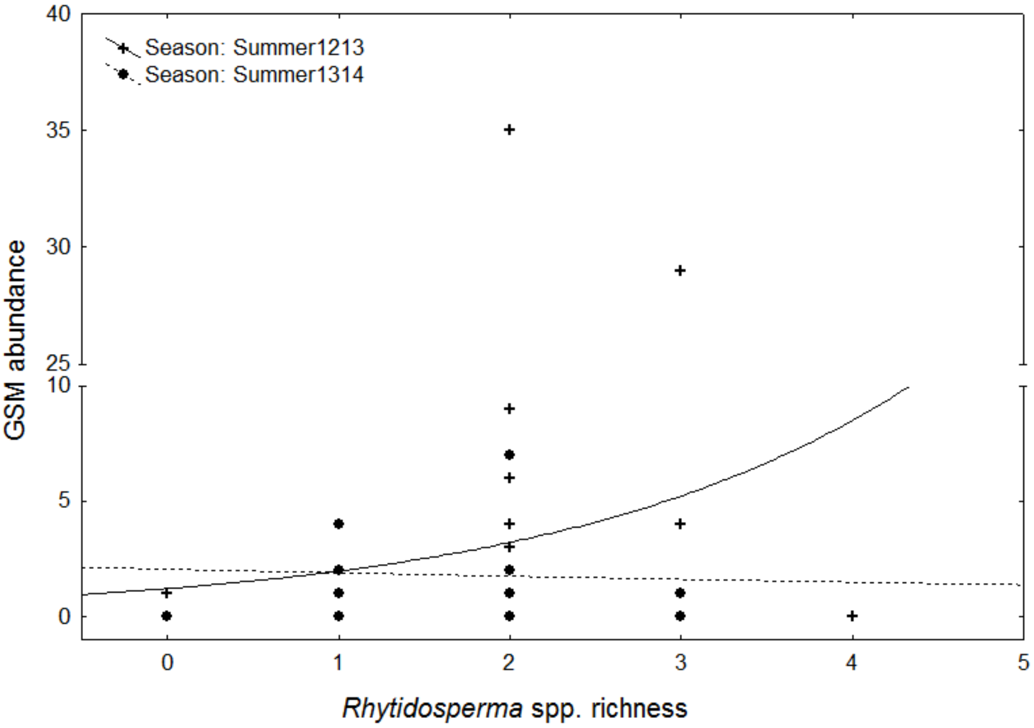
Figure 7 we examine the relationship between GSM abundance in summer 2012/13 and 2013/14 for four environmental factors, and this demonstrates both the prospects for identifying trigger points for GSM presence and abundance over multiple years, and the varying nature of the relationship between factors from one year to the next. This re-emphasises the importance of multiple year data to clarify patterns over time. These figures suggest:

- GSM abundance increases with increasing *Austrostipa* spp. height, though there seems to be an intermediate height (30-80 cm) where GSM abundance is the highest.
- GSM abundance increases with *Rytidosperma* species richness, though the summer 2013/14 data indicates little trend. Wallaby grass species richness of 1-3 are associated with the peak abundances.
- GSM abundance increases with decreasing biomass to a point where it peaks at 11-16 out of 18 on the golf ball visibility index, though the summer 2013/14 data indicates little trend. Again low to intermediate biomass seems more closely associated with higher abundances.
- GSM abundance increases with increasing *Rytidosperma* cover, with maximums between 5-40%.

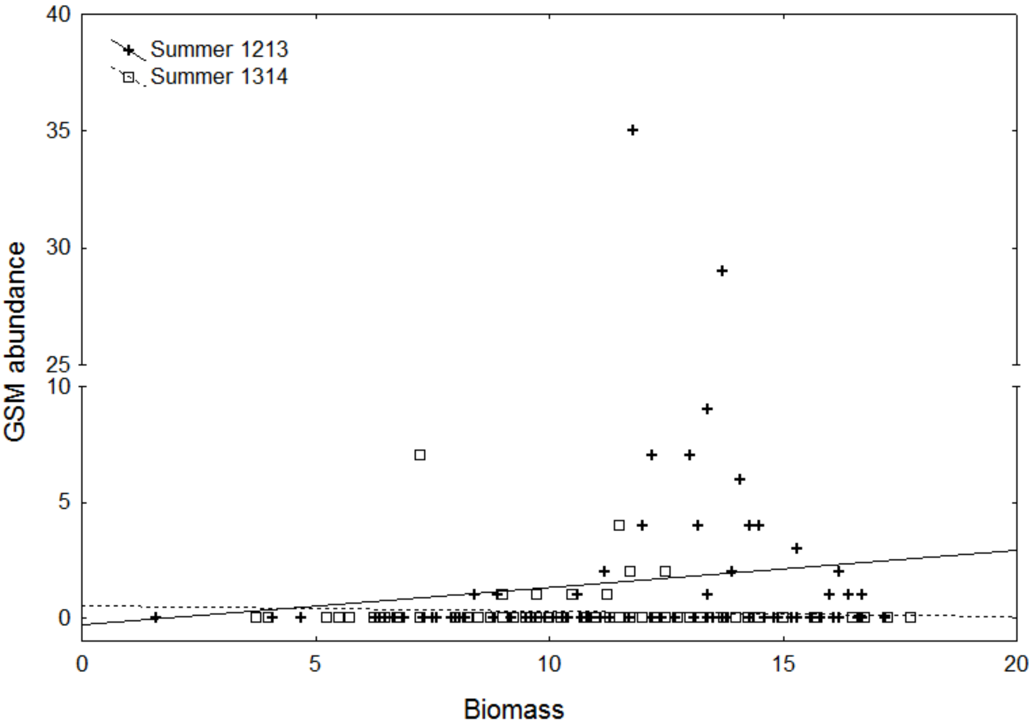
Figure 7 The general linear and non-linear relationships between key variables that were significantly related to GSM abundance for the summer 2012/13 and 2013/14 surveys: (a) *Austrostipa* spp. height; (b) *Rytidosperma* spp. richness; (c) biomass; (d) *Rytidosperma* cover

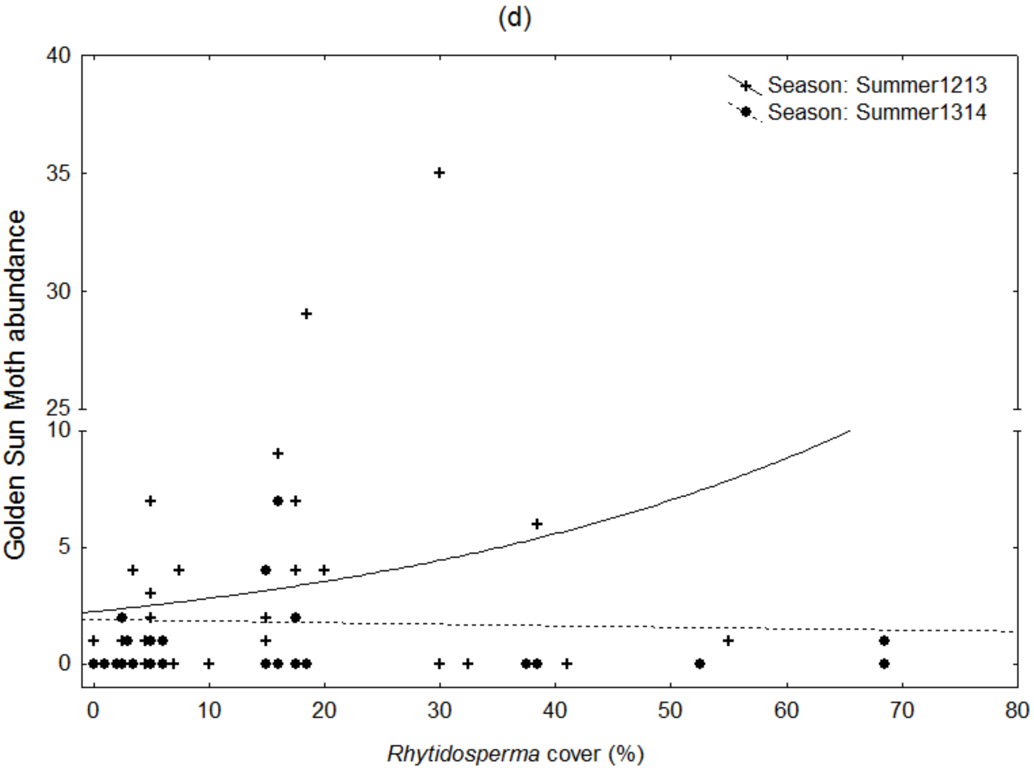


(b)


Season: Summer1213
Season: Summer1314
40
35
30
25
10
5
0
GSM abundance
0
1
2
3
4
5
Rhytidosperma spp. richness

(c)


Summer 1213
Summer 1314
40
35
30
25
10
5
0
GSM abundance
0
5
10
15
20
Biomass


(d)
Season: Summer1213
Season: Summer1314
Golden Sun Moth abundance
40
35
30
25
10
5
0
0
10
20
30
40
50
60
70
80
Rhytidosperma cover (%)

5. Discussion

This report presents the results of the second year of a proposed long term Golden Sun Moth *Synemon plana* (GSM) and vegetation monitoring program at Sheoak. The broad aim of the monitoring is to provide annual data on the patterns of GSM in context of the vegetation patterns which will inform ecological grazing management. The key conclusions from this year's survey are:

- GSM distribution and abundance seems to be greatly reduced this year, which may be in part due a shift back to dry and heatwave conditions.
- There seems to be little link between the floristic species composition at the transects and GSM pattern. This is in part due to the current low number of transects where GSM are recorded, though there are significant relationships between many specific vegetation factors and GSM presence or abundance.
- Thresholds and consistent predictors are revealing themselves, and these consistently seem to be native vegetation cover and height, and Wallaby and Spear grass species richness and cover (i.e. *Austrostipa* spp. height 30-80 cm, Wallaby grass species richness of 1-3; *Rytidosperma* spp. cover 5-40%); Future monitoring may concentrate on more intensively sampling patches of native vegetation where GSM consistently occur over the multiple years of survey.
- Though some of the relationships between the environmental factors and GSM abundance are linear, as the data is accumulated, there seem to be intermediate ranges of which GSM are associated. These intermediate patterns are typical in ecology where the extremes (very high or very low cover abundance for example) are not suitable for species. This suggests that the grazing patterns that might be suitable for GSM will be intermediate also – neither too high nor too low – and the relationship with weather pattern will be critical. For example, if dry conditions are predicted or prevail, grazing might have to be reduced in order to prevent native vegetation cover declining below the thresholds identified above.
- Currently outcomes relating directly to grazing effects for this project cannot be met, as the differing grazing management regimes of the CMP and OMP are yet to commence. It is recommended that this is instigated as soon as practicable.
- The third summer sample (i.e. 2014/15) will be important, as it will provide a third time point in the current survey series that will help clarify the trend and trajectory in GSM and vegetation patterns. This will allow us to evaluate and refine the monitoring approach, which is an important component of the adaptive monitoring program.

One alteration to the monitoring should be considered for the upcoming surveys. The correspondence of the spring 2013 vegetation data to the 2013/14 GSM survey was poor. It may be wise to concentrate the vegetation survey effort to summer only and reinstate the vegetation survey to the full 90 transects. Some GSM were recorded on transects where no vegetation data was collected (due to the reduction to 74 transects), which means valuable data on determinants of GSM presence was missing. Further to this, it might be more valuable to include rapid surveys for key vegetation variables (i.e. Spear and Wallaby grasses) on the transects in the grazing paddocks, throughout the year, in order to provide data for the grazing management. This will require further review and discussion with MWC, and is probably best undertaken in summer 2014/15 when the first full review of the data and monitoring is planned.

This survey is the second phase of the monitoring and we can make some further comments regarding the preliminary outcomes required for the project:

- Enable informed decisions on best practice ecological grazing management in the context of a conservation regime aimed at protecting the habitat of GSM.

  The adaptive monitoring framework and revised monitoring array seems to present a successful means to make informed decisions on best practice ecological grazing, though to date the grazing management program has not been fully realised and analysis of the relationship between grazing, vegetation and GSM patterns is not possible.

- Provide guidance for an ongoing ecological grazing regime of sheep and cattle, including optimum stocking rates and times for the various management zones of the property in order to maintain and enhance habitat for the local populations of GSM.

  As the grazing management program is yet to be clearly defined and articulated, the link between grazing management, vegetation pattern and GSM cannot be clearly articulated. The instigation of this program is critical to understanding the link between grazing and GSM, and the development of an ecological grazing regime.

- Measureable triggers for movement of stock to other management zones at various times of the year and measureable triggers for removing stock altogether.

  The preliminary data have provided some measurable trigger points and thresholds, regarding vegetation cover and species richness, namely the importance of native vegetation height, cover, and Rytidosperma and Austrostipa cover and species richness, and it seems that these factors will form the core component of the triggers for ecological grazing management.

- Will contribute to the broader body of knowledge about ecological grazing regimes and their influence on grassland habitat for GSM.

  A manuscript has been submitted to Austral Ecology (Appendix D), and was asked to be resubmitted after some reanalysis of the data. After the third summer of sampling for the current monitoring (i.e. summer 2014/15) a further publication will be prepared regarding the relationships and patterns between GSM abundance and the detailed vegetation sampling.

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Appendices

Appendix A – Species List

Scientific Name	Common Name	Summer 2012/13	Spring 2013	Summer 2013/14
Acaena echinata	Sheep's Burr	Y	Y	Y
Acaena spp.	Sheep's Burr			Y
**Acetosella vulgaris*	Sheep Sorrel	Y	Y	Y
**Agrostis capillaris*	Brown-top Bent	Y		
Agrostis spp.	Bent Grass	Y		
**Aira cupaniana*	Quicksilver Grass			Y
**Aira elegantissima*	Delicate Hair-grass	Y		
**Aira* spp.	Hair Grass	Y		Y
Amphibromus nervosus	Common Swamp Wallaby-grass	Y		
Amphibromus spp.	Swamp Wallaby-grass	Y		
**Anthoxanthum odoratum*	Sweet Vernal-grass	Y		Y
**Aphanes arvensis*	Parsley Piert		Y	
**Arctotheca calendula*	Cape Weed	Y	Y	Y
Austrostipa densiflora	Dense Spear-grass	Y		Y
Austrostipa rudis var. *rudis*	Veined Spear-grass	Y		Y
Austrostipa scabra subsp. *falcata*	Rough Spear-grass	Y		
Austrostipa scabra subsp. *scabra*	Rough Spear-grass	Y		Y
Austrostipa spp.	Spear-grass	Y	Y	
**Avena barbata*	Bearded Oat			Y
**Avena fatua*	Wild Oat	Y		
**Avena* spp.	Oat	Y		Y
Bothriochloa macra	Red-leg Grass	Y		
**Briza minor*	Lesser Quaking-grass	Y		
**Bromus diandrus*	Great Brome	Y		Y
**Bromus hordeaceus* subsp. *hordeaceus*	Soft Brome	Y	Y	Y
**Bromus madritensis*	Madrid Brome			Y
**Carex divisa*	Divided Sedge	Y	Y	Y
**Centaurium erythraea*	Common Centaury	Y		
**Centaurium* spp.	Centaury	Y		
Chloris truncata	Windmill Grass	Y		
**Cirsium vulgare*	Spear Thistle	Y	Y	Y
Convolvulus angustissimus subsp. *angustissimus*	Blushing Bindweed	Y		
Crassula decumbens	Spreading Crassula		Y	
**Cynodon dactylon* var. *dactylon*	Couch	Y		Y
**Cynosurus echinatus*	Rough Dog's-tail	Y		Y

Scientific Name	Common Name	Summer 2012/13	Spring 2013	Summer 2013/14
**Dactylis glomerata*	Cocksfoot	Y	Y	Y
Desmodium varians	Slender Tick-trefoil	Y		Y
Dichelachne spp.	Plume Grass			Y
Elymus scaber	Common Wheat-grass	Y		Y
Epilobium billardierianum subsp. *cinereum*	Grey Willow-herb	Y		Y
Epilobium hirtigerum	Hairy Willow-herb	Y		
Epilobium spp.	Willow Herb		Y	
Eragrostis brownii	Common Love-grass			Y
**Erodium moschatum*	Musk Storks-bill		Y	
Eucalyptus camaldulensis	River Red-gum	Y		
Eucalyptus polyanthemos	Red Box	Y		
Euphorbia drummondii	Flat Spurge	Y		Y
**Festuca arundinaceae*	Tall Fescue		Y	Y
Geranium spp.	Crane's Bill	Y	Y	Y
Glycine tabacina	Variable Glycine	Y		Y
**Holcus lanatus*	Yorkshire Fog	Y	Y	Y
**Hordeum leporinum*	Barley-grass	Y		
**Hordeum marinum*	Sea Barley-grass	Y		Y
**Hordeum murinum* s.l.	Barley-grass	Y		Y
**Hordeum* spp.	Barley-grass	Y		Y
Hypericum gramineum spp. agg.	Small St John's Wort	Y		
**Hypericum perforatum* subsp. *veronense*	St John's Wort	Y		Y
**Hypochaeris radicata*	Flatweed	Y	Y	Y
Juncus amabilis	Hollow Rush	Y		Y
Juncus australis	Austral Rush	Y		
Juncus bufonius	Toad Rush	Y		Y
Juncus flavidus	Gold Rush			Y
Juncus gregiflorus	Green Rush			Y
Juncus pallidus	Pale Rush			Y
Juncus planifolius	Broad-leafed Rush		Y	
Juncus sarophorus	Broom Rush			Y
Juncus spp.	Rush	Y	Y	Y
Juncus subsecundus	Finger Rush	Y		Y
Lachnagrostis filiformis s.l.	Common Blown-grass			Y
Lachnagrostis spp.	Hair Grass			Y
**Lolium perenne*	Perennial Rye-grass			Y
**Lolium rigidum*	Wimmera Rye-grass	Y		
**Lolium* spp.	Rye Grass	Y	Y	Y
Lomandra filiformis	Wattle Mat-rush	Y	Y	Y

Scientific Name	Common Name	Summer 2012/13	Spring 2013	Summer 2013/14
**Lophopyrum ponticum*	Tall Wheat-grass			Y
**Lotus angustissimus*	Slender Bird's-foot Trefoil	Y		Y
**Lotus corniculatus* subsp. *corniculatus*	Bird's-foot Trefoil	Y		
**Lotus* spp.	Trefoil	Y	Y	Y
Luzula meridionalis var. *densiflora*	Common Woodrush	Y		
**Lysimachia arvensis*	Pimpernel	Y	Y	
Lythrum hyssopifolia	Small Loosestrife			Y
**Malva* spp.	Mallow		Y	
Microlaena stipoides var. *stipoides*	Weeping Grass	Y	Y	Y
Oxalis exilis	Shady Wood-sorrel			Y
Oxalis perennans	Grassland Wood-sorrel	Y	Y	Y
Oxalis spp.	Wood Sorrel	Y	Y	Y
**Paspalum dilatatum*	Paspalum		Y	Y
**Phalaris aquatica*	Toowoomba Canary-grass	Y		Y
**Phalaris minor*	Lesser Canary-grass	Y		Y
**Phalaris* spp.	Canary Grass		Y	
Pimelea curviflora	Curved Rice-flower		Y	
Pimelea humilis	Common Rice-flower			Y
Pimelea spp.	Rice Flower	Y		
**Poa annua*	Annual Meadow-grass		Y	
Poa labillardierei var. *labillardierei*	Common Tussock-grass			Y
**Polygonum aviculare* s.l.	Prostrate Knotweed			Y
**Polypogon monspeliensis*	Annual Beard-grass			Y
Pteridium esculentum	Austral Bracken	Y		
**Romulea rosea*	Onion Grass	Y	Y	Y
**Rubus fruticosus* spp. agg.	Blackberry			Y
Rumex brownii	Slender Dock	Y		Y
**Rumex crispus*	Curled Dock			Y
Rumex spp.	Dock	Y	Y	Y
Rytidosperma caespitosa	Common Wallaby-grass	Y		Y
Rytidosperma duttonianum	Brown-back Wallaby-grass	Y		Y
Rytidosperma eriantha	Hill Wallaby-grass	Y		Y
Rytidosperma laevis	Smooth Wallaby-grass	Y		
Rytidosperma penicillatum	Weeping Wallaby-grass	Y		
Rytidosperma pilosa	Velvet Wallaby-grass	Y		Y
Rytidosperma racemosum var. *racemosum*	Slender Wallaby-grass	Y		Y
Rytidosperma setaceum var. *setaceum*	Bristly Wallaby-grass	Y		Y

Scientific Name	Common Name	Summer 2012/13	Spring 2013	Summer 2013/14
Rytidosperma spp.	Wallaby Grass	Y	Y	
Schoenus apogon	Common Bog-sedge	Y	Y	
**Setaria parviflora*	Slender Pigeon Grass	Y		
**Sonchus asper* s.l.	Rough Sow-thistle	Y		
**Sonchus oleraceus*	Common Sow-thistle	Y	Y	Y
**Taraxacum* spp.	Dandelion		Y	
Themeda triandra	Kangaroo Grass	Y	Y	Y
**Tribolium acutiflorum* s.s.	Crested Desmazeria	Y		
**Tribolium* spp.	Desmazeria			Y
**Trifolium angustifolium* var. *angustifolium*	Narrow-leaf Clover			Y
**Trifolium arvense* var. *arvense*	Hare's-foot Clover	Y	Y	Y
**Trifolium campestre* var. *campestre*	Hop Clover	Y		Y
**Trifolium dubium*	Suckling Clover			Y
**Trifolium fragiferum* var. *fragiferum*	Strawberry Clover			Y
**Trifolium glomeratum*	Cluster Clover	Y		
**Trifolium repens* var. *repens*	White Clover		Y	Y
**Trifolium* spp.	Clover	Y	Y	Y
Unknown Poaceae	Unknown Poaceae	Y	Y	Y
**Vulpia bromoides*	Squirrel-tail Fescue	Y	Y	Y
**Vulpia muralis*	Wall Fescue	Y		Y
**Vulpia myuros* subsp. *myuros*	Rat's-tail Fescue	Y		
**Vulpia* spp.	Fescue	Y		Y

Appendix B – Mann-Whitney U non-parametric GSM presence/absence analysis

	All data				Summer 12/13				Summer 13/14				Spring 13/14			
Factors	Z	p-value	Present	Absent	Z	p-value	Present	Absent	Z	p-value	Present	Absent	Z	p-value	Pres-ent	Absent
Aspect																
Elevation (m)	-2.25	0.024	219.4 (5.6)	234.4 (2.7)					2.34	0.019	205.3 (8)	231.5 (3.7)	2.30	0.020	1.6 (0)	1.6 (0.2)
Mean height (cm)													-1.81	0.069	5.2 (1.6)	10.0 (4.2)
Austrostipa height (cm)	2.84	0.005	43.8 (4.2)	28.7 (2.9)	1.69	0.091	41.7 (4.8)	34.9 (4.6)	-2.30	0.021	49.5 (8.4)	23.3 (3.7)				
Rytidosperma spp height (cm)																
Biomass mean	2.17	0.030	12.5 (0.4)	10.9 (0.3)	2.17	0.030	13.2 (0.4)	11.1 (0.5)					2.30	0.020	11.9 (1.7)	15.0 (5.5)
Bare ground mean (%)																
Introduced forbs (%)	2.33	0.020	0 (0)	0.2 (0.1)												
Introduced graminoids (%)									-1.89	0.059	5.3 (2.4)	6.0 (1.3)				
Native forbs (%)	-2.11	0.035	0.5 (0.1)	0.5 (0)												
Native graminoids (%)	1.78	0.075	35.9 (3.6)	49.1 (2.5)					-1.86	0.064	49.3 (6.8)	55.8 (3.2)				
Unknown Poaceae (%)					-1.66	0.097	27.9 (3.3)	27.1 (2.8)								
Austrostipa cover (%)	2.33	0.020	6.2 (1.3)	3.4 (0.6)												
Austrostipa R	2.05	0.040	0.8 (0.1)	0.5 (0)												
Austrostipa densiflora	2.89	0.004	0.1 (0)	0 (0)	2.90	0.004	0.2 (0.1)	0 (0)								
Austrostipa rudis	1.76	0.079	5.5 (1.2)	3.3 (0.6)												
Austrostipa scabra subsp. scabra																
Austrostipa scabra subsp. falcata																
Austrostipa spp.	2.05	0.040	0.5 (0.5)	0 (0)												
Rytidosperma spp cover (%)	3.45	0.001	14.4 (2.9)	8.4 (1.1)					-2.87	0.004	16.6 (7.7)	6.4 (1.5)				
Rytidosperma spp R	3.83	0.000	1.8 (0.1)	1.1 (0)	2.62	0.009	1.9 (0.1)	1.3 (0.1)	-2.13	0.033	1.6 (0.2)	0.9 (0)				

	All data				Summer 12/13				Summer 13/14				Spring 13/14			
Factors	Z	p-value	Present	Absent	Z	p-value	Present	Absent	Z	p-value	Present	Absent	Z	p-value	Pres-ent	Absent
Rytidosperma caespitosa	2.01	0.045	2.5 (1.3)	1.6 (0.7)	1.73	0.084	2.6 (1.7)	0.8 (0.3)								
Rytidosperma duttonianum																
Rytidosperma eriantha	3.54	0.000	1.2 (0.7)	0 (0)	2.35	0.019	0.8 (0.7)	0 (0)	-3.16	0.002	2.1 (1.8)	0 (0)				
Rytidosperma laevis																
Rytidosperma penicillatum	2.31	0.021	0.4 (0.1)	0.2 (0.1)												
Rytidosperma pilosa									-2.07	0.039	0.5 (0.3)	0.3 (0.2)				
Rytidosperma racemosum																
Rytidosperma setaceum	3.38	0.001	4.7 (1.6)	0.7 (0.2)	2.86	0.004	6.5 (2.1)	1.4 (0.5)								
Rytidosperma spp.																
Themeda triandra	-2.08	0.037	7.0 (2.2)	13.5 (1.6)	-2.52	0.011	2.0 (0.9)	9.2 (2.0)					-1.78	0.074	0 (0)	0.1 (0.1)
Microlaena stipoides	2.92	0.003	1.9 (1.3)	0 (0)	2.85	0.004	2.7 (1.8)	0 (0)								
Elymus scaber																

Appendix C – Generalised linear models

	All data					Summer 12/13					Summer 13/14					Spring 13/14				
Factors	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**
Landscape model																				
Intercept	1	2.109	0.645	10.688		3	2.357	0.684	11.869		54	15.436	3.622	18.159		49	15.649	3.697	17.916	0.000
Elevation (m)		-0.010	0.003	11.083	0.001		-0.006	0.003	4.043	0.007		-0.094	0.021	20.851	0.000		-0.095	0.021	20.602	0.000
Aspect												0.017	0.004	20.538	0.000		0.018	0.004	20.379	0.000
Height model																				
Intercept	14	0.531	0.194	7.496		14	1.091	0.201	29.542		9	-2.743	0.642	18.276		20	0.812	0.781	1.081	
Mean height (cm)		-0.382	0.054	49.925	0.000		-0.430	0.065	43.084	0.000							-2.068	0.714	8.388	0.004
Austrostipa height (cm)		0.032	0.004	76.296	0.000		0.024	0.004	37.056	0.000		0.052	0.019	7.278	0.007		0.111	0.030	13.286	0.000
Rytidosperma spp height (cm)							0.023	0.009	6.278	0.012							-0.287	0.136	4.489	0.034
Biomass model																				
Intercept	3	-1.443	0.331	18.978	0.000	6	-0.955	0.383	6.226											
Biomass mean		0.116	0.025	20.682	0.000		0.114	0.029	15.907	0.000										
Cover model																				
Intercept	31	0.232	0.345	0.453		24	0.528	0.334	2.497		37	-3.378	0.772	19.146						
Bare ground (%)		0.041	0.008	24.618	0.000		0.038	0.008	23.875	0.000										
Introduced forbs (%)		0.054	0.007	59.489	0.000		0.045	0.007	41.238	0.000		-0.427	0.162	6.993	0.008					
Introduced graminoids (%)		0.057	0.025	4.976	0.026		-0.032	0.008	16.731	0.000										
Native forbs (%)		-0.034	0.007	27.609	0.000							0.107	0.025	19.038	0.000					
Native graminoids (%)		-0.536	0.084	40.589	0.000		-0.475	0.103	21.204	0.000										
Wallaby grass cover model																				
Intercept	14	-0.869	0.624	1.936		34	-1.646	0.314	27.544		13	-2.372	0.483	24.105						
Rytidosperma spp cover (%)							0.063	0.008	68.116	0.000										
Rytidosperma spp R		0.523	0.224	5.455	0.020		1.001	0.133	56.423	0.000		0.697	0.268	6.780	0.009					
Rytidosperma caespitosa							-0.353	0.090	15.288	0.000										
Rytidosperma eriantha							0.599	0.216	7.714	0.005		0.106	0.053	3.932	0.047					

	All data					Summer 12/13					Summer 13/14					Spring 13/14				
Factors	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**	**%**	**Est**	**SE**	**Wald**	**P**
Rytidosperma penicillatum							-0.445	0.149	8.896	0.003										
Rytidosperma racemosum							-0.061	0.012	25.961	0.000										
Rytidosperma setaceum		0.061	0.012	27.463	0.000															
Spear grass species model																				
Intercept	39	-1.800	0.245	54.059		46	-1.295	0.284	20.798		5	-1.894	0.391	23.474		14	-1.811	0.296	37.480	
Austrostipa cover (%)		-0.050	0.016	9.995	0.002		1.871	0.215	75.507	0.000							0.144	0.032	19.805	0.000
Austrostipa spp R		1.935	0.199	94.127	0.000		-0.072	0.018	16.594	0.000		0.875	0.430	4.147	0.042					
Austrostipa densiflora		0.585	0.174	11.272	0.001		0.607	0.179	11.433	0.001										
Austrostipa scabra subsp. *scabra*																				
Austrostipa spp.																				
Other native grasses model																				
Intercept	20	0.258	0.098	6.938		2	0.624	0.100	38.781											
Elymus scaber		-0.021	0.008	7.909	0.005															
Microlaena stipoides		0.034	0.012	7.782	0.005															
Themeda triandra		-1.511	0.454	11.071	0.001		-0.031	0.012	7.295	0.007										

Appendix D – Draft publication submitted to *Austral Ecology*

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Annual variation in a population of the critically endangered Golden Sun Moth Synemon plana in a conservation reserve in south-eastern Australia

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Annual variation in a population of the critically endangered Golden Sun Moth *Synemon plana* in a conservation reserve in south-eastern Australia

Short title: Golden Sun Moth annual variation

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ABSTRACT

The loss and modification of grassland ecosystems globally is significant, and there has been a concomitant decline in its biodiversity. For critically endangered species, such as the Golden Sun Moth *Synemon plana*, the management of grazing to perpetuate its preferred habitat is one essential management activity. In this study we review the ecological pattern of three years of survey data at a conservation reserve in south-eastern Australia and use this data to design a new monitoring program to inform a grazing management. We found Golden Sun Moth spatial distribution and abundance dramatically declined from a peak in extent and abundance from 2008-09 to 2011-12 due to a shift from drought to above average rainfall. Auto-regressive correlative models indicated that a northerly aspect and elevation were key predictors of abundance over time; over time distribution shifted from wet to dry locations in the landscape. We conclude that: long-term changes in weather patterns significantly affect local distribution over time; local populations and distribution are more variable than previously considered for the species; and self-evidently long term monitoring is essential for understanding the population dynamics of threatened species. We stratified a new sampling array of permanently marked transects based on a combination of factors of elevation, aspect and dominant vegetation (16 treatment combinations) and included specific data collection methods for plant composition and structure, to assess grazing effects on native species (*Rhytidosperma* spp.) known to be significant for Golden Sun Moth life history.

INTRODUCTION

The loss and modification of natural grassland ecosystems due to increasing and intensifying agriculture, livestock grazing and urbanisation is a significant global conservation issue (Ceballos*, et al.* 2010). In south-eastern Australia, temperate grassland and grassy woodland communities have been reduced to <4% of their original extent, which has caused a dramatic reduction in biodiversity in these ecosystems, especially for smaller vertebrates and invertebrates associated with dense ground cover and endemic grassland plants (Dorrough*, et al.* 2012).

Prior to European settlement, grassland ecosystem function in Australia is likely to have been maintained by a combination of periodic intense disturbance such as fire (Benson and Redpath 1997) and more frequent but less dramatic disturbance such as grazing by native macropods (Dorrough*, et al.* 2004). Modification of these historic disturbance regimes has resulted in notable impacts on native flora and fauna (Gilmore*, et al.* 2008;Kutt*, et al.* 1998;Lunt*, et al.* 2007), though the extent of the effect depends on the frequency of the disturbance (Collins*, et al.* 1995). Species responses also depend on how closely a species has adapted to exploit niches that are changed by disturbance such as grazing (Milchunas*, et al.* 1988) or evolutionary history of the plants (i.e. native or introduced) and any preadaptation to disturbance (McIntyre and Lavorel 1994). In addition, livestock grazing can change predator-prey relationships within grassland systems, which can secondarily affect total abundance of birds, reptiles and invertebrates (Pringle*, et al.* 2007).

Grazing can play a valuable role in maintaining biodiversity. This is well-documented on continents where vegetation has evolved under heavy grazing pressure (Davidson*, et al.* 2010;Goheen*, et al.* 2010) but is less understood in Australian ecosystems where the domestic stock have been relatively recently introduced (Lunt*, et al.* 2007). The Golden Sun Moth *Synemon plana* is listed as critically endangered in Australia and is distributed in south-eastern native temperate grasslands particularly where there is a high density of wallaby grasses (e.g. *Rytidosperma* spp.) (DEWHA 2009). As with other grassland biota, the major threat to Golden Sun Moth is the supplanting of their preferred habitat (native tussock species and structure) by vigorous exotic pasture grasses introduced for livestock grazing, nutrient enrichment and pasture cultivation (DEWHA 2009;O'Dwyer and Attiwill 2000). Although there are other factors, such as climate and landscape position, that determine Golden Sun Moth presence (DEWHA 2009), grazing is considered an important management tool (DEC 2007;DSE 2004). The challenge is that there is no single grazing regime is suitable across multiple years and a flexible strategy is required. Thus, long-term ecological studies are critical to evaluate the response of fauna to disturbances over time, the causes of this change, and therefore, how management should be altered (Lindenmayer and Likens 2009;Youngentob*, et al.* 2013).

In this paper we examine the annual variation in a population of a threatened grassland-dependant species, the Golden Sun Moth from 2009 to 2012. These surveys were designed to initially monitor the annual presence and broad distribution of this species on a conservation offset property. We review this data and investigate: (i) what are the key landscape and environmental factors that determine the location and abundance of Golden Sun Moth in the study area and do they match our current understanding of this species ecology; and (ii) is there any variation in pattern of distribution annually, and how might this information help us design a better survey regime into the future. The results of this survey will inform a revised monitoring program that will provide more refined information for manipulation of livestock grazing as the primary land management tool for the species.

METHODS

Study area

The Sheoak property is located approximately 3 kilometres south of Yea, in the Central Victorian Uplands Bioregion, central Victoria, Australia (Fig. 1). The region has a Mediterranean climate, with an average rainfall of 640 mm (Yea weather station) that falls predominantly within winter and spring (http://www.bom.gov.au/ accessed 5/11/2012). The study area is located on lower slopes of gently undulating hills (37.21º S, 145.42º E), with elevations ranging from 200-300 m a.s.l. The study area is characterised by derived grasslands that formerly supported woodland vegetation dominated by River Red Gum (*Eucalyptus camaldulensis*) prior to clearing over 100 years ago. Grasslands were variably dominated by native Spear grasses (*Austrostipa* spp.) and Wallaby grasses (*Rytidosperma* spp.), and the introduced taxa, Brome grasses (*Bromus* spp.), Yorkshire Fog (*Holcus lanatus*), Barley grasses (*Hordeum* spp.) and Rye grasses (*Lolium* spp).

The property was set aside for conservation purposes in early 2008 by Melbourne Water Corporation (MWC), mainly to manage populations of the critically endangered Golden Sun Moth. Approximately half of the site will be managed in the future in accordance with an approved native vegetation offsets package (Offset Management Plan area) where grazing would be removed. The other half is to be managed under a Conservation Management Plan, where grazing would be manipulated to protect the threatened species' values. Grazing has yet to be removed from any portion of the property.

Golden Sun Moth surveys

Surveys for the Golden Sun Moth were undertaken on Sheoak between November and January of 2008/09, 2009/10, 2010/11 and 2011/12, using the methods based on the Significant Impact Guidelines for the Critically Endangered Golden Sun Moth (*Synemon plana*) (DEWHA 2009). Surveys were conducted in the peak flying period (November to January) when there was evidence of emergence and breeding. As per the guidelines, surveys were undertaken in the warmest part of the day between 10 am and 2 pm when temperatures were above 20 degrees Celsius, and when cloud cover and wind were minimal (Gibson and New 2007;Greenville*, et al.* 2012). The surveys comprised two groups of two people walking continuous transects over the property over a two-day period on four separate occasions. The pairs of survey personal walk at a steady pace 5 m apart scanning for flying male Golden Sun Moths, or females, which are flightless, on the ground. Each pair of observers walked for four hours between 10 am and 2 pm for each survey day, so each annual survey comprised of 64 hours of observation. Data on Golden Sun Moth abundance were collected for every 100 m segment, with the start and end point, and start and end time, recorded on GPS. Every half hour, cloud, wind and temperature was recorded, to ensure ambient weather were within the recommended survey conditions.

The first Golden Sun Moth surveys on the property in 2008/09 focussed on only a small portion of the property in the north-east. Subsequent surveys in the summers of 2009/10, 2010/11 and 2011/12 covered the entire Sheoak property. No vegetation or habitat data were recorded along these transects, as the intent was simply to map abundance and distribution.

For the analysis conducted in this study, annual transect locations were then mapped and using a 100 x 100 m grid for the Sheoak property, we were able to identify for each grid square if Golden Sun Moth was present or absent, and then calculate a measure of relative abundance. As the 100 m transect segments were unstructured, we used the following rules: (i) if transects where Golden Sun Moth were recorded intersected two grid squares, presence was recorded for each grid square; and (ii) for abundance, if transects where Golden Sun Moth were recorded intersected two grid squares, the proportion of the abundance recorded was assigned to each grid square according to the proportion of the transect in each grid square.

Environmental data

In Victoria Golden Sun Moth populations generally occur at elevations between 95 m and 406 m, and in sloping sites (at 3º or less), particularly those with a northerly aspect, and as such there seems to be a relationship between Golden Sun Moth presence, soil moisture and temperature (DSE 2004). Suitable habitat is generally native temperate grasslands, and open grassy woodlands where the ground layer is dominated by *Rytidosperma* spp. (Wallaby Grasses) (Gilmore*, et al.* 2008;O'Dwyer and Attiwill 2000). Therefore we used three broad measures of these variables – elevation (as a surrogate of moisture), aspect and extent of native vegetation – to examine what environmental factors predicted the distribution of the species.

Environmental spatial data was generated for the 100 x 100 m grid squares. We used the central point of each grid to estimate elevation (in meters) and aspect (as degrees) via a 100 m resolution digital elevation model (www.geodata.com.au). For vegetation we used mapping undertaken for the Sheoak Biodiversity Management Strategy (DSE 2004). In this mapping, native vegetation was defined as vegetation where greater than 25% of the understorey vegetation cover was native. Using this mapping we calculated the proportion of native vegetation in each grid square. To map general climate variation over the eyars of survey, we downloaded the monthly rainfall totals over the period of the past surveys (2009-2013) for Yea from the Bureau of Meteorology (www.bom.gov.au/climate/averages).

Analysis

We examined the variation in Golden Sun Moth abundance in each grid surveyed for each year separately and then all years (as frequency of occurrence in grid) in relation to elevation, aspect and native vegetation cover and all combinations of interaction. As our data is presented as grids, and the spatial distribution of the Golden Sun Moth in and across years may be spatially auto-correlated, we undertake regression analysis that takes spatial dependence into account. We used mixed models (REML) module in GenStat Version 16, and in particular the Spatial Model – Irregular Grid option. This method uses an auto-regressive correlative model that considers the location of the data points in relation to neighbouring points and how these change the further one moves away from each data point. Each grid is given an X and Y coordinate, and we used power-distance model (auto-regressive order 1 equivalent) for an irregular grid (given the study area is not completely square). We use a city block distance measure and an anisotropic form of the model. The grid square number is used as the random term, and the fixed effects are elevation, aspect and native vegetation cover. Variance components are estimated using maximum likelihood for the fixed effects and dispersion components, and approximate empirical Bayes estimates of the random effects and significance of the fixed effect was assessed via the Wald statistic (Payne, *et al.* 2010).

We recognise that the annual distribution of the species is spatially dependent on the previous years' distribution. However as the flying season for the Golden Sun Moth is a distinct short summer period lasting only 2-3 months, we examined the data on an annual basis in order to investigate whether the determinants of distribution of the Golden Sun Moth are consistent over each year (i.e. the landscape position) or whether they change.

Though we have undertaken the main analysis via regression, the previously published data on landscape distribution of the species, suggests north versus south, wetter versus dry and native versus non-native environmental factors determine the species distribution. Therefore, for illustrative purposes we want to show whether there is a consistent pattern in mean abundance over time in grid squares that represent one or the other of these factors. We plotted the mean and standard error of Golden Sun Moth abundance for each contrast of the environmental factors. Elevation is split into two categories (run-on areas or lower slopes and run-off areas or upper slopes). Each grid square was classified as upper or lower, depending on the dominant proportion (i.e. <50%, > 50%) of each category in each. Similarly for aspect, the grids were classified as either predominantly north or south facing, also by proportion of aspect in each grid square. Finally vegetation was classified as native or non-native via the dominant proportion of mapped native or non-native vegetation in the grid square.

RESULTS

We found that throughout the period of Golden Sun Moth surveys there was a peak in relative extent and abundance in 2009-2008 (Table 1), towards the end an exceptional period of drought in Victoria lasting over 10 years. The proportion of grid squares surveyed with Golden Sun Moth present, and total abundance, declined rapidly over this period from 2008-09 to 2011-12 (Table 1) and this coincided with the onset of drought breaking rains and above-average monthly rainfall (Fig. 2).

The spatial distribution of Golden Sun Moth changed markedly over the three survey periods of 2009-2010 to 2011-2012 (ignoring 2008-2009 when only a small area was surveyed). The total area where the species was recorded declined substantially from 74% of the property area to 19% of the property area (Fig. 3, Table 1). There was a similar decrease in size of largest patch of continuous Golden Sun Moth presence recorded (156 ha to 18 ha) with the smallest patch being only 2 ha (Table 3). In 2009-2010 the distribution of the Golden Sun Moth across the property was continuous (i.e. one large interconnected patch) and this reduced to seven very small patches in 2011-2012, with the largest distance between patches in this survey period being 400 m (Fig. 3, Table 1).

The mixed spatial autoregressive models of Golden Sun Moth abundance for each year alone indicated subtle shifts in the predictive variables (Table 2). In 2009-10 aspect and elevation (and their interaction) were the only significant predictor variables ($P<0.1$), and then in 2010-11 only elevation was, though the direction of the estimate changed from negative to positive (Table 2). In the year 2011-2012 aspect was strongly predictive of Golden Sun Moth abundance. Using the frequency of occurrence in each grid square over the entire survey periods from 2009-2012, aspect and the interaction between vegetation type and aspect and aspect and elevation, were highly significant (Table 2).

The coarse patterns of change in Golden Sun Moth abundance across dominant aspect (north, south), elevation (lower, upper) and vegetation type (native, non-native) indicates that Golden Sun Moth abundance was generally higher in north facing sites, and sites with more native vegetation; however, from 2009-10, to the following two years of survey, the location of the highest abundance of Golden Sun Moth shifted from lower slopes (wet areas) to the upper slopes (dry areas) (Fig. 4, Table 3).

DISCUSSION

In this study we found that the landscape determinants of Golden Sun Moth distribution and abundance were typical of what were previously reported for the species, for example, the strong effect of aspect and the interaction between aspect and vegetation type and elevation (Brown*, et al.* 2012;Gilmore*, et al.* 2008;O'Dwyer and Attiwill 2000). However, there were also unexpected changes in landscape position over time caused by annual changes in weather patterns, long-term climate conditions, and by inference the moisture content and temperature of the soil, which are considered influential on the species' presence (DSE 2004). Due to the retrospective nature of analysis, we could only examine the change in distribution and abundance according to broad landscape variables, but our results indicated that there is a degree of spatial autocorrelation in the distribution, and contraction of the distribution, of the Golden Sun Moth at out site. Despite this, the northerly aspect is a key determinant of higher abundance. Over the multiple years of survey, even with the significant shift in elevation of distribution, the interaction with aspect suggests that populations move, but in locations associated with native vegetation on more northerly facing slopes.

Annual and seasonal variation in weather patterns and longer term decadal cycles of *La Nina* and *El Nino* can have a significant effect on fauna abundance and distribution (Holmgren*, et al.* 2001). For invertebrates with short breeding and life cycles, the timing and onset of warming temperature and rainfall events can influence migration, emergence and breeding (Dempster 1983;Gregg*, et al.* 1994). For the Golden Sun Moth, temperature controls emergence (DEWHA 2009), and the spatial distribution at our study site suggests an interaction of exposure and slope, and by proxy, the local soil moisture and temperature conditions might be significant for their breeding ecology. Long-term changes in weather cycles coupled with habitat modification have a significant effect on distribution, abundance and typical breeding synchronicity of moths and butterflies in other locations worldwide (Visser and Holleman 2001;Warren*, et al.* 2001). There is limited evidence of the effect of long-term changes in weather patterns on Golden Sun Moth distribution and abundance, but annual declines, linked to wetter and drier years have been previously identified in sites in western Victoria (Brown*, et al.* 2012). Our study, which focussed on a single site over four years, provided clear evidence that there is annual variation in small-scale spatial distribution and abundance and these changes can be substantial. The shift from very dry (long-term rainfall deficit and El Nino climate patterns) to very wet weather (severe and rapid shift to La Nina) seems to have caused Golden Sun Moth to shift from run-off (i.e. nominally wetter) to run-on (i.e. nominally drier) locations in the landscape, and decrease in area of occurrence. This shift may not represent actual movement, but changed survivorship of pupae, reduction in ovi-position sites and the emergence of larvae, which can survive in situ from 2-3 years (Brown*, et al.* 2012), all of which will be linked to local scale vegetation, soil moisture and ambient seasonal temperatures. Changes in distribution and survivorship with respect to changing weather patterns also has implications for the species under a changing annual climate (Warren*, et al.* 2001).

Previous reports of Golden Sun Moth local movement and dispersal suggest that adult males will not fly more than 100 m from suitable habitat, and that populations separated by distances greater than 200 m can be isolated (Clarke and O'Dwyer 2000). The implication is that sites where Golden Sun Moth persist are small (Clarke and O'Dwyer 2000) and can become isolated or extinct very easily, through limited colonisation and genetic flow between populations (Clarke and Whyte 2003). In this study, though our analysis was coarse using 1 ha grid squares, we found that there was a maximum distance of 400 m between patch areas over all the years of survey, but a shifting size and distribution of the total number of patches from one effectively large continuous distribution to a few small sites. This suggests that at Sheoak, the Golden Sun Moth may form a meta-population, where over multiple years there is changing dispersal and survivorship based on available habitat and extrinsic factors, but a substantial degree of interaction in the population over time (Menéndez and Thomas 2000). We do not have any fine-scale distribution or genetic evidence to support the notion of a meta-population at this site, and locations from the extreme ends of the property might be isolated via indistinct habitat barriers such as areas of extensive introduced grasses. This suggests that manipulation of grazing regimes, the management focus of this monitoring program, will be a key conservation tool to maintain Golden Sun Moth here, as it is for other threatened butterfly and moth species globally (Pöyry*, et al.* 2005).

Another feature of our results was the interaction between aspect and elevation when frequency data for all years was considered. Aspect, in particular a more northerly aspect, and shifts in landscape location (elevation) were consistent predictors of distribution in abundance and distribution over each year. However the lack of a clear association with vegetation, suggests that the mapping scale might have been too coarse to define an association, or that contiguous locations to existing Golden Sun Moth locations was more important than a suitable environment. However other studies monitoring vegetation change in highly disturbed grassland restoration plots over the same period and in the same location (Jellie*, et al.* 2013), indicated there was a rapid and significant increase in introduced tussock grass cover, a non-preferred habitat arrangement for Golden Sun Moth when grazing was excluded, and this was only exacerbated by the onset of drought-breaking rain. Plant productivity and growth can respond rapidly to increased rainfall (Nippert*, et al.* 2006), with the above average rainfall at the study site likely to have affected grass structure, density and biomass, and therefore Golden Sun Moth abundance, in parallel with changes in subsurface moisture and lower annual temperatures (Brown*, et al.* 2012). The increase in introduced grasses over the period of study may have combined to reduce available native habitat, and hence the lack of association between Golden Sun Moth locations and areas previously mapped as predominantly native grassland.

The outcomes of our study has provided a solid background to design a new monitoring program at the property, and we subsequently (in 2013) we stratified a new sampling array of permanently marked transects based on a combination of factors of elevation, aspect and dominant vegetation, resulting in 16 treatment combinations. Given the lack of association between extent of native vegetation in the results in this study, and knowledge that the relationship of wallaby grasses (*Rhytidosperma* spp.) to Golden Sun Moth ecology (DEWHA 2009) emphasise the need to collect transect specific data on plant composition and structure. The significant spatial variation in Golden Sun Moth over the four years of our survey indicates future work needs to encompass the entire site, including locations that might seem to provide less suitable habitat. Finally there are a number of conclusions that can be made regarding the changing patterns in Golden Sun Moth distribution over time that we recorded at the Sheoak property. First, and despite the caveat regarding the lack of floristic data for the Golden Sun Moth locations, long-term weather patterns associated with the landscape array can interact to significantly affect local distribution over time. On-going monitoring will reveal important, fine scale data regarding determinants of Golden Sun Moth persistence and distribution over time, and in response to management on the site. Second, our data provide an interesting counterpoint to conclusions that Golden Sun Moth has been known to persist in very small areas (Greenville*, et al.* 2012) and suggest that distribution can change quite markedly over time on a local scale. Third, and somewhat self-evidently, the variability in the data has implications for single surveys to identify presence and absence of conservation significant species, especially with one hampered by a very restricted activity and breeding period (DEWHA 2009). This suggests that annual sampling over a number of seasons is important (Brown*, et al.* 2012).

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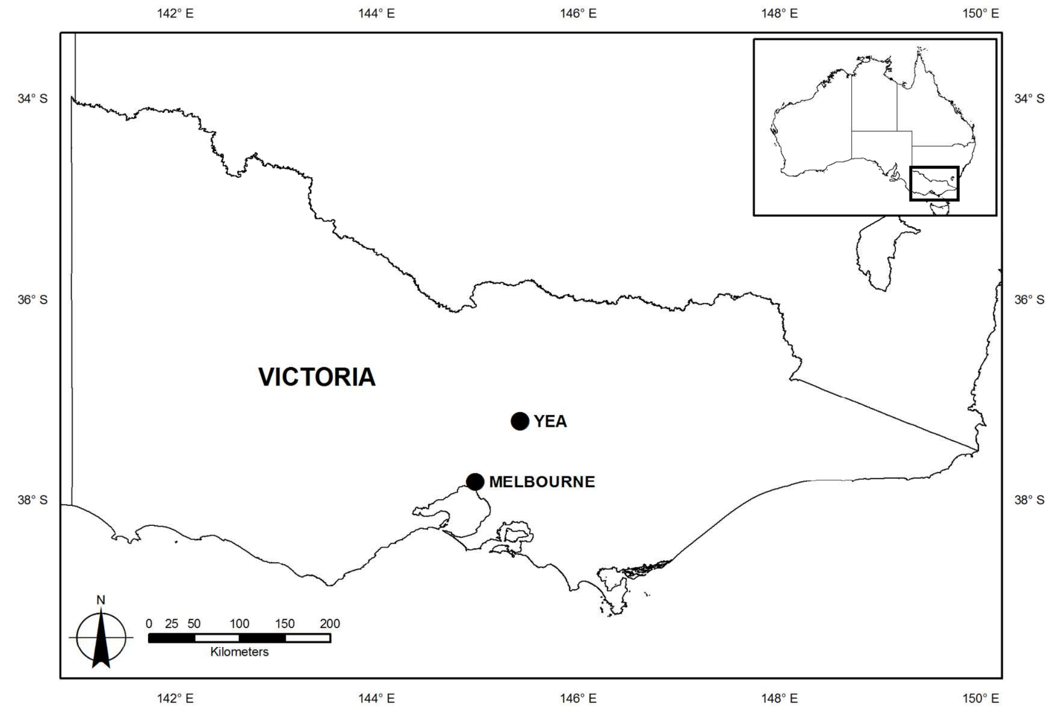
Figure 1. Location of the study near Yea, south-east Australia.

Figure 2. The variation in rainfall and Golden Sun Moth abundance from 2008 to 2012. Crosses and dashed line represents the monthly rainfall and the solid diamonds extent of distribution (see Table 3) for each year of survey.

Figure 3. The presence of Golden Sun Moth at Sheoak Station on an annual basis (a-d). Dark squares represent presence, white squares are absence and hashed squares indicate no survey. (e) Represents frequency over the four year period, with hashed squares meaning no survey, white squares 0% and black squares 100%.

Figure 4. The variation in total Golden Sun Moth abundance for the years of survey, 2009-10, 2010-11, 2011-12 for (a) aspect, (b) landscape position and (c) dominant vegetation. The central point is the mean, and the whiskers are standard error.

Figure 1.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144° E
146° E
148° E
150° E
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36° S
38° S
VICTORIA
YEA
MELBOURNE
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0 25 50 100 150 200
Kilometers

474 **Figure 2.**

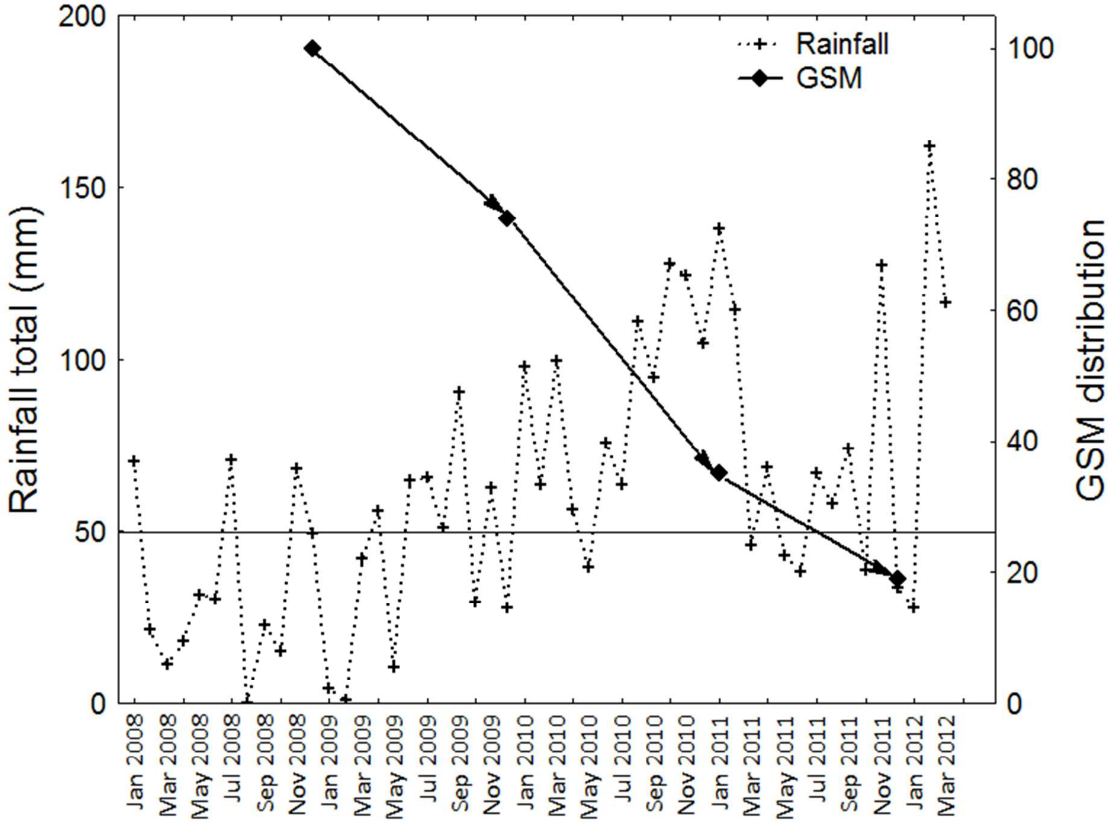

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Figure 3.

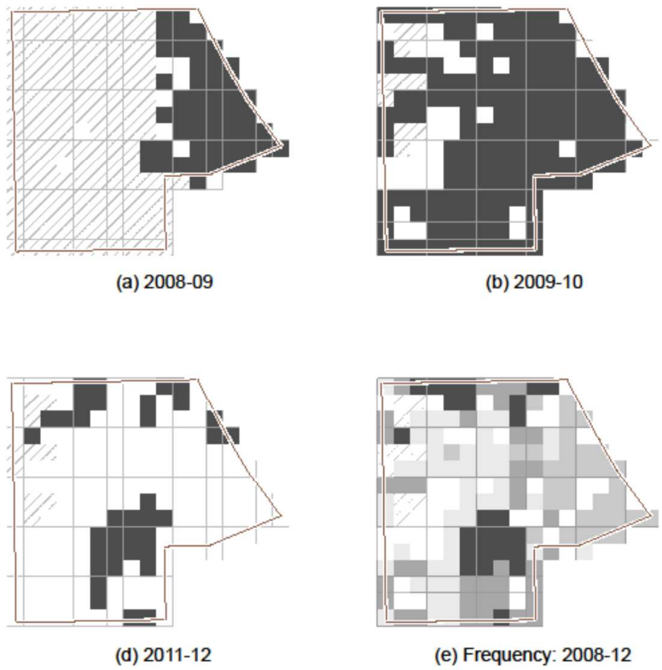

Figure 4.

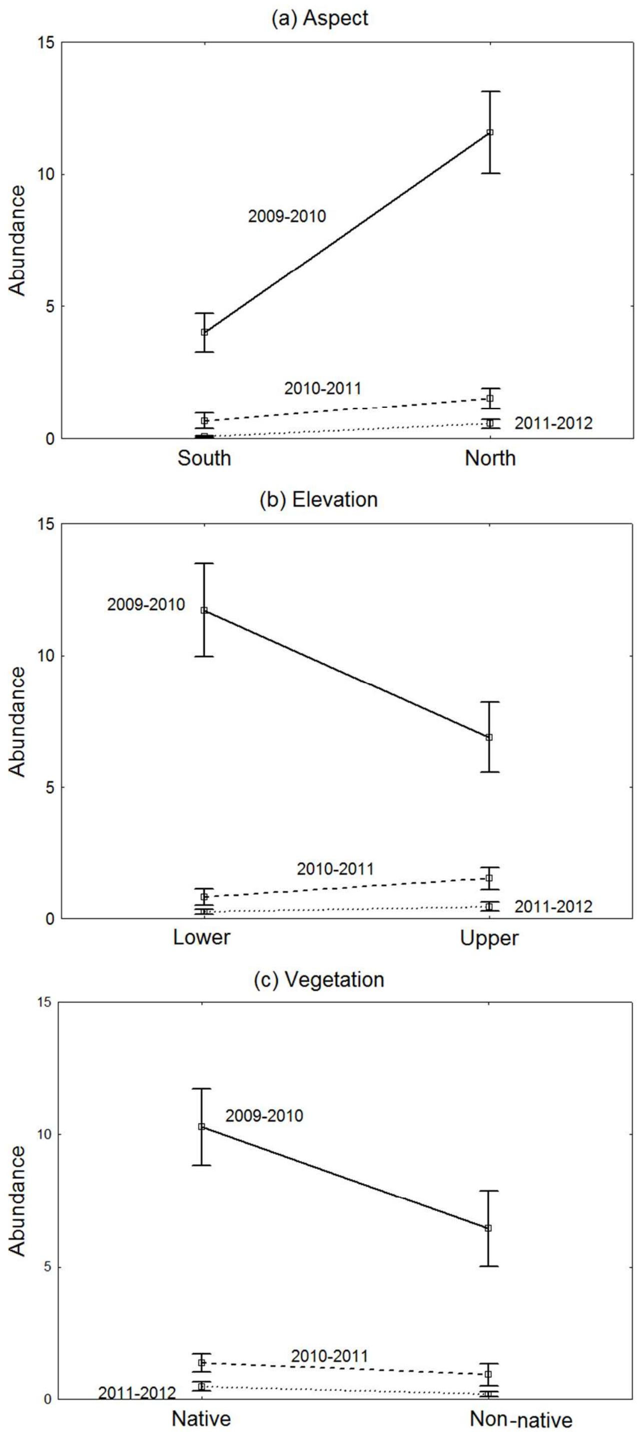
(a) Aspect
Abundance
15
10
5
0
2009-2010
2010-2011
2011-2012
South
North
(b) Elevation
Abundance
15
10
5
0
2009-2010
2010-2011
2011-2012
Lower
Upper
(c) Vegetation
Abundance
15
10
5
0
2009-2010
2010-2011
2011-2012
Native
Non-native

Table 1. The variation in Golden Sun Moth distribution for the survey years 2008-09 to 2011-2012. **No. grids** is the total number of grids on the property, **No. surveyed** is total number surveyed for that year, **No. present** is the total grids the moth was present, **Proportion** is the area of the property with moths present, **Abundance** is the total moth numbers recorded in that season of survey, **No. patches** is the number of discrete unconnected grids patches with moth present, **Largest /Smallest** is the largest / smallest discrete patch without grid sides touching, **Mean** the mean patch size and **Range** shortest distance (m) is the smallest to largest distance between all the patches. Patches with only corners touching are considered separate patches, but separated by a distance of 0 m.

Year	No. grids	No. surveyed	No. present	Proportion	Abundance	No. patches	Largest (ha)	Smallest (ha)	Mean (ha)	Range shortest distance (m)
2008-2009	51	51	51	100%	1172	2	50	1	25.5	0
2009-2010	224	209	156	74%	2474	1	156	156	156.0	0
2010-2011	224	209	74	35%	442	9	25	2	3.0	0-200
2011-2012	224	194	37	19%	169	7	18	2	2.9	0-400

Table 2. The results of the mixed models (spatial autoregressive) examining the relationship between Golden Sun Moth abundance in each grid and elevation, aspect and native vegetation cover. Data for each year was tested individually, and then all years using frequency of occurrence in grid. The estimate is the direction of the effect, Wald is the test statistic and p is the significance level.

Factor	**2009-10**			**2010-2011**			**2011-2012**			**2009-2012**		
	Estimate	**Wald**	**p**	**Estimate**	**Wald**	**p**	**Estimate**	**Wald**	**p**	**Estimate**	**Wald**	**p**
Vegetation	-0.085	0.32	0.572	-0.012	0.11	0.744	-0.004	0.007	0.796	-0.093	0.31	0.575
Aspect	0.048	8.43	**0.004**	0.005	2.42	0.121	0.004	8.62	**0.004**	0.045	10.12	**0.002**
Elevation	-0.058	3.14	**0.078**	0.015	3.55	**0.061**	-0.004	1.50	0.223	-0.051	2.34	0.127
Vegetation x Aspect	0.037	2.68	0.103	0.007	1.79	0.182	0.002	1.01	0.315	0.044	3.29	**0.071**
Vegetation x Elevation	0.088	1.99	0.159	0.020	2.04	0.154	0.001	0.08	0.783	0.093	2.20	0.140
Aspect x Elevation	-0.001	11.18	**<0.001**	-0.001	0.007	0.778	-0.001	1.51	0.221	-0.001	10.91	**0.001**
Vegetation x Aspect x Elevation	-0.001	1.02	0.315	0.001	0.007	0.787	-0.001	0.03	0.853	-0.001	0.62	0.431

Table 3. The mean (and standard error) of Golden Sun Moth abundance for the years of survey, 2009-10, 2010-11, 2011-12, and all surveys combined (2009-2012) for aspect (north or south), elevation (upper run-off areas, lower run-on areas) and vegetation (>25% vegetation is native, <25% native is non-native). Bold indicates the higher values for each comparison, but only for factors that were significant for that year, as identified in the generalised linear modelling.

Year	**North**	**South**	**Lower slope**	**Upper slope**	**Native**	**Non-native**
2009-2010	**11.6 (1.6)**	4.1 (0.7)	**11.7 (1.8)**	7.0 (1.4)	**10.4 (1.5)**	6.4 (1.4)
2010-2011	**1.5 (0.4)**	0.7 (0.3)	0.8 (0.3)	**1.5 (0.4)**	**1.4 (0.4)**	0.9 (0.4)
2011-2012	**0.5 (0.2)**	0.1 (0.1)	0.3 (0.1)	**0.5 (0.2)**	0.5 (0.2)	0.2 (0.1)
2009-2012	**13.1 (1.7)**	4.3 (0.8)	**12.1 (1.8)**	8.3 (1.5)	**11.6 (1.6)**	6.9 (1.5)

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