Conservation of the Graceful Sun-moth (*Synemon gratiosa*)

Findings from the 2010 Graceful Sun-moth surveys and habitat assessments across the Swan, South West and southern Midwest Regions

Interim report

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Cover photos: Coastal heathland habitat of the graceful sun-moth (*Synemon gratiosa)* at Kangaroo Point, Cervantes, taken by Andrew Williams. Graceful sun-moth (inset, x2 magnification) taken by David Pike.

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This report highlights preliminary results for the *Conservation of graceful sun-moth habitat* project, determined by basic analysis and field observation, for the year 2010. This interim report should not be quoted or used as final results for the *Conservation of graceful sun-moth habitat* program. Publications based on detailed analyses using comprehensive statistical methods will be published in subsequent reports. This and associated reports will be available on the DEC website at www.dec.wa.gov.au.

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Executive Summary

Surveys of the graceful sun-moth were carried out in 2010 in the Swan, South West and southern Midwest Regions by DEC staff, volunteers and environmental consultants. Data were compiled from all of these sources and used to generate the information in this report. This project aimed to:

- Determine the distribution and habitat requirements of the graceful sun-moth;
- Identify key habitat for conservation;
- Re-assess the conservation status of the graceful sun-moth, should any substantial changes to its distribution be found;
- Assess the effectiveness of current survey prescriptions for detecting the graceful sun-moth; and
- Make recommendations for conservation actions.

The 2010 graceful sun-moth surveys have shown the species to range well beyond its previously known distribution in *Banksia* woodland of the Swan region, into the coastal parts of the northern South West and southern Midwest Regions (Appendix 1). Graceful sun-moth counts were up to 5 times higher in coastal heathland compared to *Banksia* woodland. Four repeat surveys appear adequate for detection of the graceful sun-moth in coastal heathland habitat, with the potential for this to be reduced. However, survey guidelines for *Banksia* woodland will need to be revised.

Preliminary analysis has shown that the graceful sun-moth remains within the “endangered” category of the IUCN (2008) criteria for listing under state legislation, despite the range extension. A formal nomination based on the new distribution data is being prepared for assessment by the Western Australian Threatened Species Scientific Committee.

Data collected will be analysed in the future to generate predictive habitat suitability models to allow assessment of site suitability in the absence of a graceful sun-moth survey. These out-of-season habitat assessments will be used to determine if a site requires a targeted graceful sun-moth survey to be carried out during the peak flying season (late February through to early April).

Priorities for future research include creation of habitat suitability models for both coastal heathland and *Banksia* woodland habitat types, targeted graceful sun-moth surveys and habitat assessments in the Midwest Region north to Kalbarri. Habitat data obtained to date are insufficient to determine the site-based characteristics required by the graceful sun-moth in *Banksia* woodland habitat, with further habitat assessments required across the known graceful sun-moth range. A population genetics study is also required to determine population structure and to determine minimum viable population and habitat sizes.

In lieu of data specific to the graceful sun-moth, we have adopted the significant impact guidelines developed for the Critically Endangered golden sun-moth (DEWHA 2009a) as useful model for significant impact assessment. These guidelines should be adopted for the graceful sun-moth in the interim, until sufficient species-specific data become available. Mitigation measures for graceful sun-moth sites should also be modeled around those outlined for the golden sun-moth.

1. Introduction

The graceful sun-moth (*Synemon gratiosa* Westwood 1877, family Castniidae) is a day-flying moth endemic to south-west Western Australia. Prior to this study, the graceful sun-moth was only known from remnants of native vegetation between Mandurah and Neerabup within the greater Perth metropolitan region. Historical records of the graceful sun-moth showed that its distribution had declined substantially as a result of habitat loss for housing, industry and agriculture (Burbidge 2004). In 1997 the graceful sun-moth was listed as declared rare fauna under the *WA Wildlife Conservation Act 1950* due to its small range, the lack of any known sub-populations in protected areas, and the ongoing loss of existing habitat through land clearing. This listing was based on expert opinion, which was an accepted assessment method at that time, although this method has since been superseded and the current listing process uses standard criteria (i.e. IUCN Standards and Petitions Working Group 2008). In 2009 the species was also listed as Endangered under the Commonwealth *EPBC Act 1999* (Threatened Species Scientific Committee 2008), using the IUCN criteria. The reasons for listing the graceful sun-moth as a threatened species were that it had a restricted geographic distribution, small area of occupancy, and the remaining sub-populations were severely fragmented and in continuing decline.

The Castniidae is a small family of day-flying moths considered to be of Gondwanan origin, as it is restricted to the Neotropical, Australian and Oriental regions (Holloway et al. 2001; Douglas 2003b). The larvae of Castniidae feed only on monocotyledons, and are usually restricted to one or a few closely-related host plants. For most purposes, their biology, ecology and behavior can be considered identical to that of butterflies, a more thoroughly studied group. The Australian species (collectively known as “sun-moths”) are all placed in the single genus *Synemon* (Doubleday), containing approximately 45 species, of which about half are currently undescribed (Common 1990; Edwards 1997a, 1997b). Several species are endangered, and many more are poorly known, with the group’s taxonomy requiring revision (ACT Government 1998; Douglas 2003a, 2004; Marriott 2004).

Information is sparse on the biology and ecology of sun-moths, but the general life history has been documented as follows (Common & Edwards 1981; Douglas 2003b). As adults, sun-moths are thought to have relatively brief lives of approximately four to ten days, depending on the species (Douglas & Marriott 2003). All species are active during daylight, and many will not fly except in bright sunshine. The adults of some species have reduced mouthparts and do not feed, relying on nutrients stored during the larval stage to sustain them through their adult lives. Female sun-moths mate and commence egg-laying soon after emergence from the pupal stage, using a long, retractable ovipositor to deposit eggs beneath the soil, at or near the base of their larval host plants. After hatching, the larvae tunnel within or beside the roots or rhizomes of the host plant, on which they feed. Prior to pupation the larva constructs a vertical, silk-lined tunnel to just below the soil surface from which the empty pupal case protrudes after the adult moth has emerged. In general it is not known how long sun-moths take to complete their life cycles, but *Synemon magnifica* is known to take 2 to 3 years to complete development, and *S. jcaria*, the closest relative of the graceful sun-moth, may have a 2 year life-cycle (Common & Edwards 1981; E. D. Edwards ANIC pers. comm., M. R. Williams, A. A. E. Williams and N. Willers DEC pers. obs.).

Prior to 2009, the graceful sun-moth had only been recorded in *Banksia* woodland containing the monocotyledon *Lomandra hermaphrodita* (Asparagaceae). In early 2009, new populations of the graceful sun-moth were located in coastal heathland associated with *Lomandra maritima,* a species closely related to the original host plant *L. hermaphrodita. Lomandra maritima* is abundant in coastal vegetation between Binningup and Shark Bay, so the discovery of this new host plant meant it was possible that additional habitat and populations of graceful sun-moth may be found.

Like other organisms, many species of butterflies and day-flying moths are increasingly dependent on remnant vegetation for survival, especially in urbanised areas (Ruszczyk & De Araujo 1992; Connor et al.

2002; Newland 2003). The threats to conservation of these taxa are generally the same as for other fauna: habitat destruction or alteration; changes to management practices; isolation of remnant habitat; pollution and use of chemical insecticides and herbicides; climate change; and over-collecting or trade in specimens (New 1991; Pollard & Yates 1993; Beaumont & Hughes 2002). In Australia, several studies have documented the conservation status of individual butterfly taxa (Kitching & Dunn 1999; Braby 2000; Sands & New 2002; New 2009). These studies cite the lack of systematic surveys in conservation reserves as the major impediment to establishing the conservation status of many species. Information about the habitat resources needed (e.g. density of host plants) to conserve remnant populations of day-flying moths is also required (Garden et al. 2006). Other than the studies of Williams (2008; 2009) and Willers (unpublished) there have been no targeted, systematic surveys of the graceful sun-moth. Williams (2009) examined habitat remnants, all of which contained apparently suitable *Banksia* woodland habitat, but located only six graceful sun-moth populations. These studies were restricted to the Perth metropolitan area and sampled few sites in coastal heathland, which have only recently been found to be important breeding habitat.

Typically, it is the requirements of the immature life stages that define habitat quality for insects, and the importance of host plant density for butterflies and day-flying moths has been demonstrated both in Western Australia and elsewhere (Dennis et al. 2004; Dover et al. 2008; Williams 2010). Because of this obligate dependence on suitable plants for breeding, the distribution of the host plants determines the potential habitat. The larvae of the graceful sun-moth feed on only two closely-related mat-rushes, *Lomandra hermaphrodita* (C. R. P. Andrews) C. A. Gardner, and *L. maritima* T. S. Choo (E. D. Edwards pers. comm., M. R. Williams, A. A. E. Williams and T. Gamblin DEC *pers. obs*.). The reliance of the graceful sun-moth on these two species of host plants means that much of the potential habitat occurs in areas proposed for future urban and other development, particularly in the coastal and sub-coastal parts of the greater Perth metropolitan region. This created an urgent need to better clarify the habitat and distribution of the species to help minimize potential conflict between the conservation of the graceful sun-moth and proposed development.

This project was funded by the Department of Environment and Conservation (DEC) to carry out additional surveys to better delimit the occupied range of both the host plants and the graceful sun-moth, and to assess the species habitat requirements.

This project focused on areas where the host plants occur, and in particular on areas within conservation estate. The project aimed to:

- Determine the distribution and habitat requirements of the graceful sun-moth;
- Identify key habitat for conservation;
- Re-assess the conservation status of the graceful sun-moth, should any substantial changes to its distribution be found;
- Assess the effectiveness of current survey prescriptions for detecting the graceful sun-moth; and
- Make recommendations for conservation actions.

This interim report documents the results of the first year of the study, provides a preliminary analysis of the data collected, and outlines priorities for future research.

2. Methods

The graceful sun-moth distribution and habitat data used in this report were collected by specialist DEC research and operational staff, community volunteers, and environmental consultants. Full details of the graceful sun-moth survey and habitat assessment methodologies are given by Bishop et al. (2009), and are briefly outlined below.

2.1. Site selection

Potential survey sites were identified based on historic records of the graceful sun-moth and distribution of the host plants, with priority placed on areas within DEC conservation estate. Specimens of the graceful sun-moth are held in institutional collections at the Western Australia Museum (WAM), Western Australian Department of Agriculture (WADA, now the Department of Agriculture and Food), Queensland Museum (QM) and the Australian National Insect Collection (ANIC), with additional records from a recent survey of butterflies and day-flying moths in Perth's urban bushland remnants (Williams 2009). Records of the *Lomandra* spp. host plants and its density within various vegetation types were determined from DEC databases and consultation with N. Gibson (DEC). This enabled a list of potential sites to be determined, which were then prioritized on the basis of their level of protection. Conservation reserves within DEC estate were given the highest priority, followed by sites listed in the Bush Forever version 2 report (Department of Environmental Protection 2000). Sites where the graceful sun-moth had been previously recorded, and sites with potentially suitable habitat but where the graceful sun-moth was thought to be absent (to provide discriminatory power in determining habitat requirements) were also included. Environmental consultants conducting standard environmental impact assessments of sites within potential graceful sun-moth habitat were requested to undertake surveys using standard methodology, so that the resultant data could also be incorporated into this study.

After the first few weeks of surveys, graceful sun-moths were being recorded in the northernmost coastal sites (i.e. in the region near Wilbinga) and it seemed probable that the species may be found further north than previously thought. It also seemed possible to identify anticipated coastal habitat based on landform and vegetation. A decision was made to amend the original survey plan to include coastal sites in the northern Swan and southern Midwest Region. These surveys were exploratory in nature, with a limited number of surveys in conservation reserves containing potentially suitable habitat.

2.2. Graceful sun-moth surveys

At each site, a 10m wide fixed-route transect was established to sample across vegetation and habitat types, including features known to be suitable flight areas for the graceful sun-moth (Pollard & Yates 1993; Williams 2008; Bishop et al. 2009). Sites were surveyed on several occasions (typically 3-4 times) in suitable weather conditions between mid February and early April, when adult graceful sun-moths are detectable in the field (Bishop et al. 2009). Where possible, transects followed existing paths to minimize any impact of trampling or other disturbance on the vegetation.

During initial surveys in coastal heathland sites it was realized that graceful sun-moths tended to be more numerous on dune ridges and so where possible these were incorporated into survey transects. The transect length at each site was dependent on remnant area, with the aim of achieving a minimum sampling fraction of 2.5%, with considerably higher sampling fractions in small remnants and areas proposed for clearing (Williams 2008). Based on the golden sun-moth survey prescription (DEWHA 2009a, 2009b) and previous studies, a series of repeated surveys (typically 4, at approximately weekly intervals) were prescribed on the basis that such a survey regime was estimated to provide >95% confidence in detecting species presence at a site (Williams 2009). As noted above, in addition to the standard surveys

method, one-off searches of suitable habitat between Leeman and Kalbarri were conducted, with the aim of locating graceful sun-moth populations and to identify suitable sites for future surveys.

Large remnants, such as National Parks and Nature Reserves (NPs and NRs, >1,000 ha), were surveyed using 2-3 widely separated transects (>3km apart), and each of these transects was treated as a separate site. In moderately large sites (>300 ha), multiple transects were also used but these were combined and treated as a single site.

Prior to commencement of each transect, standard details were recorded. This included:

- Date;
- Number and identity of observers;
- Weather conditions: air temperature, cloudiness, wind speed and direction; and
- Start time.

During the walk transect, details of each graceful sun-moth sighting were recorded. This included:

- Number of graceful sun-moths seen;
- GPS coordinates;
- Wind speed; and
- Cloudiness.

At completion of each transect survey, finish time was recorded, to quantify the density of individuals seen at each site (i.e. number of individuals / hour). All graceful sun-moth sightings were recorded and added to the DEC Fauna Survey Database (and available at http://naturemap.dec.wa.gov.au/).

2.3. Habitat assessment

At each site, characteristics thought to potentially affect graceful sun-moth presence and abundance were assessed:

- Density (number or cover) of host plants;
- Vegetation condition, based on a standard rating system ("Bush Forever", Government of Western Australia 2000);
- Vegetation structure and composition, and extent of bare ground;
- Area of remnant bushland; and
- Soil type.

Habitat assessments can be carried out any time of the year, including prior to the graceful sun-moth flying period and can then be used to assist in design of survey transects.

2.4. Volunteers

Community groups and volunteers were contacted and invited to undertake surveys within areas identified as potential habitat, or in sites of particular interest to them. On-site training in survey methods was provided. Where possible, depending on the expertise and availability of the individual volunteers, habitat assessments were also undertaken.

2.5. Environmental consultants

Many areas of potential graceful sun-moth habitat occur on private landholdings that may in future be cleared for urban or other developments. Private landholders that propose to clear land typically engage environmental consultants to assess any environmental impact that may result from vegetation clearing or other activities. Environmental consultants involved in this assessment process were contacted and provided with training in survey methods, requested to undertake both graceful sun-moth surveys and habitat assessments within areas identified as potential habitat, and asked to provide the results in a format consistent with that of DEC and the volunteers.

2.6. Trial identification of anticipated habitat by desktop analysis

During the survey it became apparent that, in the coastal heathland sites, the graceful sun-moth was strongly associated with the Quindalup parabolic dune systems. On a trial basis, anticipated graceful sun-moth habitat in coastal heathland was mapped based on the occurrence of similar environmental features to occupied sites. This mapping is not suitable for release as it was a preliminary exercise in habitat identification and requires further refinement. These inferences were essentially subjective, based on an assessment of soil types, landforms and vegetation mapping, using the following features:

- Presence of landforms and vegetation types consistent with those occurring in sites occupied by the graceful sun-moth; and
- Areas of remnant vegetation of a size equal or greater than that of sites known to be currently or previously occupied by the graceful sun-moth

As with any desktop analysis, the trial mapping requires ground-truthing to confirm graceful sun-moth habitat suitability and occupancy. Mapping anticipated habitat provides information about the representation of graceful sun-moth habitat across tenure.

We were unable to complete this mapping exercise in *Banksia* woodland habitat due to the lack of recognisable, characteristic habitat features. Identifying the habitat features driving graceful sun-moth distribution in *Banksia* woodland is a priority for future research.

3. Results

3.1 Survey effort

Surveys and searches were carried out across the Swan , the northern South West and southern Midwest Regions, between the Leschenault Peninsula (33° 14’ S) and the mouth of the Murchison River (27° 43’ S). A total of 83 sites were surveyed within the study region: 43 in coastal heathland and 40 in *Banksia* woodland (Table 1; Appendix 2). Over 90 volunteers and 30 DEC staff participated in surveys. Not all sites initially identified as potential habitat could be surveyed, due to lack of resources, or insufficient time to obtain the necessary permissions. Ten previously recorded localities could not be relocated because of imprecise locality details, but in many of those instances no remnant vegetation remained in the area. In terms of total area assessed, survey coverage was greatest by DEC staff and volunteers (48 km^2 of potential habitat assessed), and a further 26 km^2 was surveyed by environmental consultants (Table 1). The DEC survey focused on existing conservation areas with a larger area of coastal heathland habitat surveyed than *Banksia* woodland. Approximately similar numbers of sites were surveyed in formal conservation reserves, although there was a focus on conservation reserves in the coastal heathland habitat.

Table 1: Survey effort area (km^2 & number of sites) by habitat type and survey group

Group	*Banksia* woodland (km^2) [# sites]	Coastal heathland (km^2) [# sites]	Total (km^2) [# sites]
DEC staff and volunteers	18.9 [23]	29.1 [22]	48.0 [45]
Environmental consultants	7.4 [17]	18.6 [21]	26.0 [38]
Total	**26.3 km^2 [40]**	**47.7 km^2 [43]**	**74.0 km^2 [83]**

3.2 Distribution and habitat

Of the total 74 km^2 surveyed, 42.6 km^2 was found to be occupied by the graceful sun-moth (Table 2). The graceful sun-moth was recorded at 43 sites (52% of those surveyed), of which 34 were new locality records and 9 confirmed existing sites (Appendix 3). The species was not relocated at 13 previously recorded localities, including most of the historical sites. The range of the species extended from near Binningup, in the south, to Coolimba Rd, 8km north of Leeman, in the north (Appendix 4). Thus the total linear extent of the graceful sun-moth was approximately 380 km, although the two sites at the extremes of the range (Binningup and Coolimba Rd) are disjunct from the main range, which was confined to the Swan Coastal Plain between Preston Beach and Jurien Bay, an extent of 300 km. There are other disjunctions in the range, most notably where urban development between Mandurah and Perth has resulted in the loss of large areas of habitat, and also in the north of the range where the habitat is less continuous as a result of clearing for agriculture.

The majority of sites where the graceful sun-moth was detected were in coastal heathland. This is partly a result of more coastal heathland habitat (47.7 km^2) being surveyed, compared with 26.3 km^2 of *Banksia* woodland habitat. It is also apparent from the numbers of graceful sun-moths recorded in the two habitat types (both total numbers and sightings per hour) that the graceful sun-moth is more visible (up to 5 times) in the coastal heathland habitat and hence more detectable (Figure 1).

Within coastal heathland, the graceful sun-moth was found predominantly on the upper slopes and ridges of secondary parabolic sand dunes, where *Lomandra maritima* was locally abundant. In *Banksia* woodlands, there was no obvious microhabitat preference, although males were encountered more frequently on tracks or in open areas.

Table 2: Area of habitat occupied by graceful sun-moth (km^2 & number of sites) by habitat type and tenure.

Protection level (tenure)	*Banksia* woodland Area occupied [# sites]	Coastal heathland Area occupied [# sites]	TOTAL Area occupied [# sites]
Reserves with Conservation purpose	0.1 km^2 [1]	23.7 km^2 [12]	23.8 km^2 [13]
Sites with some protection (non-DEC Bush Forever, Local gov. reserves, UCL etc)	3.6 km^2 [6]	1.5 km^2 [6]	5.0 km^2 [12]
Non-protected sites	1.8 km^2 [4]	12.0 km^2 [14]	13.8 km^2 [18]
TOTAL area occupied	5.5 km^2 [11]	37.2 km^2 [32]	42.6 km^2 [43]

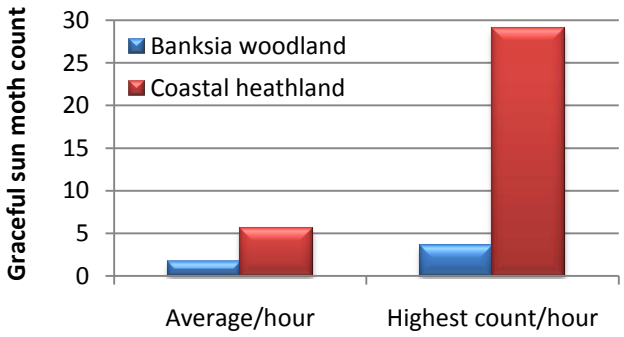

Figure 1: Observed abundance of the graceful sun-moth, by habitat type, based on March 2010 survey data

Anticipated graceful sun-moth habitat in coastal heathland

The coastal heathland habitat of the graceful sun-moth (i.e. the parabolic secondary Quindalup dune systems) has been mapped on a trial basis, but ground-truthing is required to confirm occupancy, suitability of habitat and determine host plant density. The majority of anticipated coastal heathland habitat, 42.4 km² (56%), is found in non-protected sites, with only 30.1 km² (39%) within dedicated conservation reserve (Table 3).

Table 3: Anticipated additional graceful sun-moth habitat area (km^2) by tenure from trial desktop analysis

Protection level (tenure)	*Banksia* woodland Area occupied	Coastal heathland Area occupied
Reserves with Conservation purpose	Insufficient data to estimate	30.1 km^2
Sites with some protection (non-DEC Bush Forever, Local gov. reserves, UCL etc)	Insufficient data to estimate	3.9 km^2
Non-protected sites	Insufficient data to estimate	42.4 km^2
TOTAL area anticipated habitat	Insufficient data to estimate	76.4 km^2

Further analysis of the habitat data may provide additional information on which features most strongly drive graceful sun-moth distribution, in particular for habitat where *L. hermaphrodita* is the host plant. Ideally this analysis may provide capacity to identify probable graceful sun-moth habitat by habitat assessment, valuable for a species that is detectable for only a few weeks each year.

3.3 Key habitat for conservation

A large proportion of habitat both known and anticipated to be occupied by the graceful sun-moth is severely fragmented. Many sites, including some with the highest numbers and density of the graceful sun-moth, were private landholdings and are, or may be, subject to proposals for future clearing. The largest loss of habitat in the past has been due to urbanization within the greater Perth area, from approximately 10km south of Yanchep to Dawesville. Thirty-two of the known 43 graceful sun-moth sites (Table 4) are located in habitat remnants in this region, with extreme fragmentation of these relictual populations. The areas of these remnants was typically small (1 – 290 ha), with most <20ha. Other anticipated habitat within the range has been lost due to agriculture and the creation of townsites, notably between the Preston Beach townsite and Yalgorup NP, from Yanchep to the Two Rocks townsite, and at several sites north of Wilbinga. The graceful sun-moth occurred in several major conservation reserves: Yalgorup NP, Yanchep NP, Wilbinga, and the contiguous reserves Nilgen NR, Wanagarren NR, Nambung NP and Southern Beekepers NR.

3.4 Conservation status

From these survey results the extent of occurrence was 2015 km^2. Total area of occupancy was 42.6 km^2, with a further 76.3 km^2 of coastal heathland adjudged to be anticipated habitat but with graceful sun-moth presence currently unconfirmed (Table 2).

We were unable to relocate the graceful sun-moth at 6 sites (~9 km^2) where it had been recorded in the last 20 years. These include Kings Park, Whiteman Park, Landsdale Rd bushland BF 199, Decourcey Bushland BF 328, Gumblossum Reserve at Quinns Rocks and one privately owned site. The loss of

historical sites is probably far greater, and habitat lost due to past land clearing grossly underestimated, as the historical distribution of the graceful sun-moth is poorly known.

Area of occupancy in private landholdings was 15.1 km^2, with a further 42.4 km^2 of private land adjudged to be anticipated habitat in coastal heathland.

Eleven sites (25.6%) can be considered viable sub-populations, as they occur in DEC estate where habitat is continuous and in suitable condition. The remaining 32 sites are potentially threatened by future urban development, or are severely fragmented and at risk of extinction (Table 4).

Table 4: Proportion of known graceful sun-moth sites by tenure

Site status	# sites
In conservation reserve[1]	11 (25.6%)
Threatened by proposed development	14 (32.5%)
Severely fragmented and at risk of extinction	18 (41.9%)
TOTAL # of occupied sites	**43 sites**

[1]Two sites in Yanchep NP are threatened by the proposed Mitchell Freeway extension

Some previously known sub-populations of the graceful sun-moth were not relocated. The locality descriptions of ten of the early records (of 24 previously known records) were not precise enough to identify their exact locations (Table 5). In many cases a significant amount of clearing has occurred in the intervening period and so they are presumed extinct.

Table 5: Historical sites unable to be relocated and considered extinct

Locality	Tenure	Last recorded sighting	Habitat type
"Applecross"	Unknown	1951	*Banksia* woodland
"Crawley"	Unknown	1935	unknown
"Fremantle"	Unknown	1935	unknown
"Jandakot"	Unknown	1969	*Banksia* woodland
"Mandurah"	Unknown	1984	unknown
"Naval Base"	Unknown	unknown	Coastal heathland
"Sorrento"	Unknown	1971	Coastal heathland
"Swan River"	Unknown	unknown	unknown
"Swanbourne"	Unknown	1976	Coastal heathland
"Wanneroo"	Unknown	1985	*Banksia* woodland

3.5 Detectability and survey methods

The density of the graceful sun-moth varied considerably between sites, between sampling occasions within individual sites, and in response to weather conditions (Fig. 1 p.12, Appendix 3 and data not shown). There was also some evidence of a latitudinal gradient in graceful sun-moth counts, with declining numbers observed north of Yanchep NP. This may have been due to the weather conditions encountered at the northern sites (i.e. Nilgen Nature Reserve, Wanagarran Nature Reserve, Nambung National Park, Southern Beekeepers Nature Reserve and Coolimba Road). At these northern sites the "observability window" was often limited to a short period during the middle of the day when weather conditions were sufficiently warm for graceful sun-moths to fly. By comparison, less windy conditions with extended warm to hot periods at southern localities increased the time during which graceful sun-moths could be observed. We also inferred that the ability of observers to detect the graceful sun-moth varied considerably, as there were marked differences in density between some sites in very close proximity (data not shown). To (partly) account for variation in observed abundance, we tabulated the peak density at each site as an index of abundance and habitat suitability (Fig. 1, Appendix 3). A more detailed analysis of the detectability and density of the graceful sun-moth will be conducted in the future.

4. Discussion

4.1 Distribution and habitat

The extent of occurrence of the graceful sun-moth and its area of occupancy (2015 km^2 and 42.6 km^2) were found to be substantially greater than the previous known values of 230 km^2 and 18 km^2, respectively. If habitat anticipated to be occupied by graceful sun-moth is included, the area of occupancy may be as high as 119 km^2. However, the accuracy of the anticipated habitat mapping requires verification through ground truthing. The previously recorded distribution, from Mandurah to Neerabup (90 km linear extent), appears to represent a sampling bias around the Perth metropolitan area, and this study extended the range by almost 300 km. The distribution extends the full length of the Swan Coastal Plain, from Binningup in the south to Leeman in the north, but within this area the sub-populations are severely fragmented, with several natural and human-caused disjunctions.

Natural fragmentation of habitat results from the graceful sun-moth's narrow habitat preference for coastal heathland on secondary coastal sand dunes, where variations in soil and vegetation types produce a mosaic of occupied and unoccupied habitat at small spatial scales. Superimposed upon this natural pattern there has been a substantial loss of habitat through past clearing of native vegetation, exacerbating fragmentation and restricting the majority of sub-populations to small, isolated, relictual habitat remnants. Possible future loss of sub-populations on private land, where there is a potential threat from land clearing, may further reduce the area of occupancy and further increase fragmentation.

Some sub-populations in conservation reserves are also subject to potential threats: for example, both sub-populations in Yanchep NP are likely to be impacted by extension of the Mitchell freeway, which would result in loss of occupied habitat, fragmentation of the existing sub-populations, and disturbance through the likely introduction of weeds, increased pollution, and more frequent fires. Nonetheless, several graceful sun-moth sub-populations occur in large existing or proposed conservation reserves, notably Yalgorup NP, Wilbinga, and a group of contiguous reserves between Nilgen and Cervantes.

In addition to substantial differences in abundance between habitat types, a latitudinal gradient in graceful sun-moth abundance was apparent, with fewer individuals recorded per unit area or per hour of survey in sites north of Yanchep. This may be linked to variable detectability determined by weather

conditions, habitat quality, *Lomandra* density or suitability for breeding, but this gradient requires confirmation.

The disjunctions in the distribution of the graceful sun-moth, and substantial differences in abundance between the two habitat types where it occurs, raise the issue of genetic variation within the taxon. Obvious questions are whether the outlying sub-populations at each end of the range (Binningup, Coolimba Road), and the sub-populations in *Banksia* woodlands, show any genetic differentiation from the main range. For example, the voucher specimens from Binningup show consistent morphological differences from other graceful sun-moth specimens found across the range, which may reflect genetic differences (Figures 2, 3, 4). Similarly, genetic variation within the main range needs to be determined. The extent of inbreeding within the many small relictual sub-populations should also be investigated to assist in determining the future viability of these sub-populations.

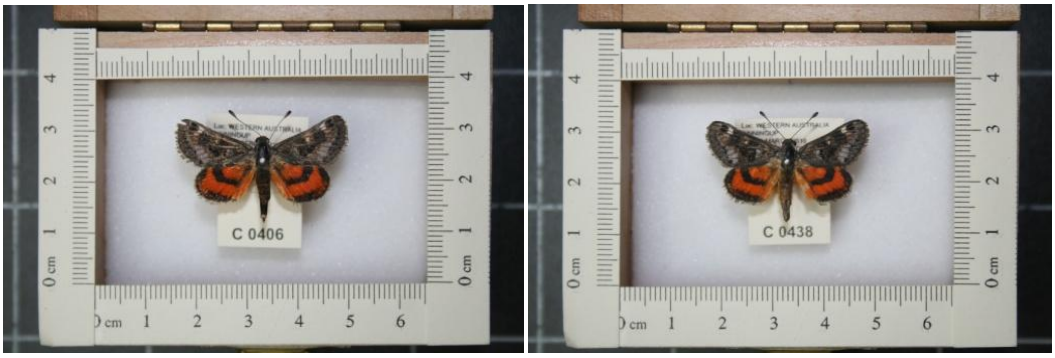

Figure 2: Examples of Binningup graceful sun-moth specimens (♀♀) with characteristic dark banding on the hind wings apparently unique to this sub-population

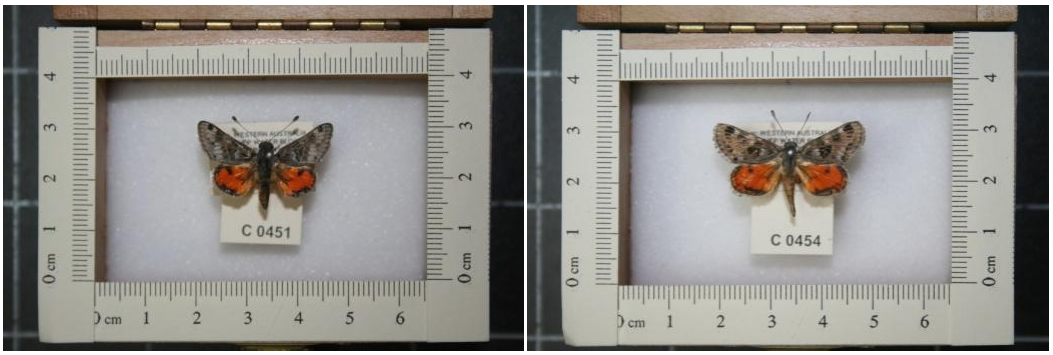

Figure 3: Examples of Yanchep NP ('Water Block') graceful sun-moth specimens (♂ and ♀)

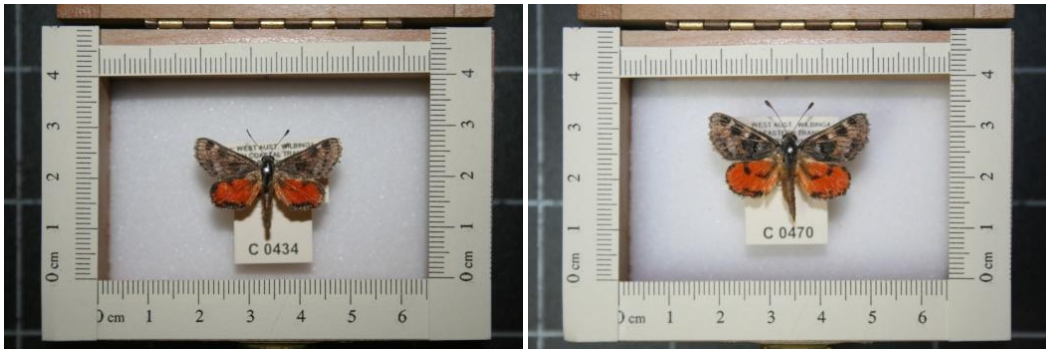

Figure 4: Examples of Wilbinga graceful sun-moth specimens (♀♀)

4.2 Key habitat for conservation

Of the anticipated habitat, 34.1 km^2 occurs in conservation estate and other reserves, although much is in small habitat fragments of unknown viability. Because DEC staff and volunteers targeted conservation estate and other reserves, there was a bias in area of occupied habitat found in conservation reserves. The area of occupancy data (based on confirmed habitat) show that only 11 of 43 (25.6%) graceful sun-moth sub-populations are in secure reserves. The majority of the remaining sub-populations, both known and anticipated, were within coastal heathland habitat. This appears to be the core habitat, with *Lomandra maritima* being the principal host plant. Sub-populations occurring in *Banksia* woodlands, and breeding on the other host plant *L. hermaphrodita*, are severely fragmented and restricted to small bushland remnants within the Perth metropolitan area. Of these remaining habitats, Warwick and Koondoola bushlands contain the largest sub-populations (in terms of area) and should be a priority for conservation. Graceful sun-moth was unable to be relocated in either Kings Park or Whiteman Park, which are two of the largest *Banksia* woodland remnants in the Perth metropolitan area (320ha and 1550ha respectively). This suggests that either factors other than fragmentation influence survival (potentially vegetation condition) or that survey effort was inadequate.

Of eight recently-occupied sites surveyed in both this study and in 2003-2005 by Williams (2009) (Errina Road, Koondoola, Shenton Park, Warwick, Marangaroo, Landsdale, Sir Fredrick Samson, and Wandi bushlands), the first four were recorded as having graceful sun-moths present on both surveys, and the other four produced inconsistent results. As Williams (2009) sampled on only two occasions during the flight period, the present study would have produced more accurate results, so the failure to detect the graceful sun-moth in Landsdale and Marangaroo bushlands during this study is a cause for concern. Several sub-populations in the Perth metropolitan region have apparently become locally extinct in recent times (<20 yr): DeCourcey, Flynn Drive, Landsdale, Neerabup, Whiteman Park, Gumblossom, and over longer time frames in the past: Kings Park, and presumably at Applecross, Crawley, Fremantle, Jandakot, Mandurah, Naval Base, Sorrento, Swanbourne and Wanneroo.

Insufficient information exists to determine the minimum patch size required for a viable graceful sun-moth population. The species is able to persist for many years in some small areas, particularly in coastal heathland sites (<2 ha), such as at Madana and Maritana Parks. Comparative to *Banksia* woodland, sites that are viable in the long term are likely to be smaller in this habitat type, because of the much higher density of individuals. The graceful sun-moth also shows some preference for vegetation that is in very good or better condition (Williams 2010). A preliminary estimate of minimum patch size could be made using the data from this study, but will require refinement after developing a habitat suitability model, and after assessment of inbreeding is such small reserves. Genetic analysis will also assist in determining minimum viable population sizes in each habitat type.

4.3 Conservation status

Given the substantial changes in both extent of occurrence and area of occupancy, we assessed the conservation status of the graceful sun-moth against IUCN Criteria (IUCN Standards and Petitions Working Group 2008) (summarized in Table 6) . With the data currently available, conservation status could only be assessed using Criterion B 'Geographic Range', although further analysis should also enable future assessment against criterion A3 'Reduction in population size'.

The species still qualifies for the *endangered* category for both extent of occurrence and area of occupancy. The sub-populations of the graceful sun-moth are considered severely fragmented, with most of the individuals found in small and relatively isolated sub-populations at risk of extinction, with limited recolonisation potential (IUCN Species Survival Commission 2001). Initial state listing in 1997 was based

on expert opinion, and a formal nomination will be prepared and submitted to the Western Australian Threatened Species Scientific Committee for verification of this conservation status.

A large proportion of extant graceful sun-moth sub-populations (14 sites, 32%) are facing immediate threats from proposed developments. Only 26% (11 sites) are considered to have long term viability as they occur in DEC estate, and in habitat patches that are relatively continuous and in suitable vegetation condition.

Fragmentation must be assessed at a scale appropriate to the biological isolation of the species being considered (IUCN Standards and Petitions Working Group 2008). The graceful sun-moth has poor dispersal capabilities and is therefore easily isolated, with little or no potential to disperse between the remnant habitat patches that are now severely fragmented as a result of urbanization, agriculture and other land use changes.

Decline of the graceful sun-moth is expected, with projected reductions in:

- extent of occurrence (with possible loss in the near future of the southernmost sub-population at Binningup);
- area of occupancy (which may be reduced in the near future with the projected loss of several sub-populations in areas proposed for clearing);
- area, extent and quality of habitat (as above, with associated habitat degradation and further fragmentation); and
- number of locations or sub-populations (as above)

Table 6: Comparison of the graceful sun-moth geographical data against IUCN criterion B (IUCN Standards and Petitions Working Group 2008).

Anticipated results for the graceful sun-moth (GSM) are highlighted, with relevant information in parentheses.

B. Geographic range in the form of either B1 (extent or occurrence) AND/OR B2 (area or occupancy)			
	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence	< 100 km²	< 5,000 km² **(GSM~ 2015km²)**	< 20,000 km²
B2. Area of occupancy	< 10 km²	< 500 km² **(GSM ~ 43km²)**	< 2,000 km²
and 2 of the following 3:			
(a) severely fragmented or # locations **(GSM ~ most individuals are found in small and relatively isolated sub-populations)**	= 1	≤ 5	≤ 10
(b) continuing decline in: (i) extent of occurrence **(GSM ~ may be reduced in the near future, as a resulting of proposed clearing at Binningup).** (ii) area of occupancy **(GSM ~ may be reduced in the near future with the projected loss of several sub-populations in areas proposed for clearing).** (iii) area, extent and/or quality of habitat **(GSM ~ as above, with associated habitat degradation and further fragmentation).** (iv) number of locations or sub-populations **(GSM ~ as above)**			
(c) extreme fluctuations in any of (i) extent of occurrence, (ii) area of occupancy, (iii) number of locations or sub-populations and (iv) number of mature individuals. **(GSM ~ insufficient data)**			

4.4 Detectability and survey methods

There was a substantial difference in graceful sun-moth detection rates between *Banksia* woodland and coastal heathland habitats, probably as a consequence of differing abundances between these habitat types (Williams 2010). This difference is a cause of concern, as the current survey prescription (Bishop et al. 2009) within *Banksia* woodland may be inadequate to reliably detect the species when it is present. Clearly, the different habitat types require different survey effort.

In comparison with the critically endangered golden sun-moth (*Synemon plana* Walker), the graceful sun-moth is substantially less abundant at a local scale. A detailed study recorded golden sun-moth counts of 87 individuals/ha (range 52 – 120) and 52 individuals/hr (range 32 – 72) (Gibson & New 2007). These figures are known to be substantial underestimates for two reasons (DEWHA 2009a). Firstly, female golden sun-moths rarely fly, and males for only short distances, substantially reducing the detection rate of adults. Secondly, the survey was conducted outside of the peak flying period. The lifespan of the golden sun-moth is thought to be as short as two – four days, whereas our limited data (not shown) suggest that the graceful sun-moth lives in excess of one week. Thus the graceful sun-moth should have a considerably higher detection rate than the golden sun moth, as both sexes fly and are more active, and adults are present within a site for longer. Recorded counts of the graceful sun-moth (average 5 individuals/hr, peak 29/hr) indicate that the count of graceful sun-moth is always considerably less, and in several sites orders of magnitude less, than that of the golden sun-moth. Thus survey methods used for the golden sun-moth are unlikely to be adequate for the graceful sun-moth. A mark recapture study would enable calibration of transect counts with true abundance.

Resurvey of some sites known to be previously occupied by the graceful sun-moth failed to find any specimens during the 2010 survey season. For both habitat types this may be due to local extinction as a result of habitat degradation, or changes in the abundance or palatability of food plants. Where habitat has remained relatively intact (e.g. Whiteman Park, Kings Park) failure to detect the graceful sun-moth may also be a function of inadequate survey effort. For example, the graceful sun-moth was recorded in Shenton Park bushland in 2004 and then not seen again until March 2010, despite being surveyed several times during the intervening 5 years. Survey guidelines specific to *Banksia* woodland sites are being revised to enhance detection. The number of surveys necessary in *Banksia* woodland will increase, potentially requiring up to 8 repeat surveys within a season. Data is currently being analysed and the new survey prescription will be released in time for the 2011 survey season. Survey effort at coastal heathland sites will remain unchanged, with 4 repeat surveys required for detection of graceful sun-moth.

4.5 Recommendations for conservation actions

The potential for a significant impact on a listed threatened species will depend on:

- the intensity, duration, magnitude and geographic extent of the impact;
- the sensitivity, value and quality of the environment on and around the site;
- the cumulative effect of on-site, off-site, direct and indirect impacts, and
- presence of this and other matters of national environmental significance (DEWHA 2009a).

Table 7 outlines the significant impact guidelines for the graceful sun-moth.

Table 7: Significant impact guidelines for the graceful sun-moth.

Ecological element affected	Impact threshold	Comment
Large or contiguous habitat area (>10 ha)	Habitat loss, degradation or fragmentation >0.5 ha	Habitat is a similar or connected area within which the graceful sun-moth is found during surveys or known from records. The function of the area may include, but is not limited to: feeding, breeding, dispersal.
Small or fragmented habitat area (<10 ha)	Any habitat loss, degradation or fragmentation	Small areas of habitat are more likely to suffer significant impacts from loss, degradation and fragmentation than larger areas. The limited dispersal ability of the graceful sun-moth means habitat areas separated by >200 m are effectively isolated and should be considered as separate habitat areas. Extremely small, isolated and degraded habitat patches (e.g. <0.25 ha) may support populations of graceful sun-moth but are unlikely to contribute to the overall ecological health of the species.
Habitat connectivity	Fragmentation of a population through the introduction of a barrier to dispersal	Barriers to dispersal could include: breaks in habitat of >200 m; structures that prohibit movement (e.g. buildings, solid fences)

A conservation advice statement is currently being prepared by the Nature Conservation Division of DEC. This document will outline management actions for implementation on sites where graceful sun-moth have been located.

4.6 Research priorities

The level of genetic differentiation, if any, between the sub-populations that breed on different host plants, and the level of genetic variation within the main population in coastal and sub-coastal sites between Binningup and Leeman, requires clarification. Genetic techniques are routinely used in conservation programs to both assess the level of genetic diversity within and among sub-populations and also as a tool for understanding past and present evolutionary and demographic processes. The results of such analyses are able to provide conservation managers with estimates of how much variation is present within each sub-population and how and where that variation is partitioned both within and among sub-populations. Such information can assist in the identification of sub-populations that are a priority for the conservation of genetic diversity within the species, and contribute to its overall conservation management. A genetic study to address the questions of genetic structure across the distribution and to determine any difference between the sub-populations that breed on different host plants is needed urgently. Genetic analysis will also assist in determining minimum viable population sizes in each habitat type.

Further detailed surveys are needed to better delimit the occupied range of both the host plants and the graceful sun-moth, and to better assess the graceful sun-moth habitat requirements. These will also be needed to ground-truth the habitat suitability model once it is completed. Repeated surveys at key sites identified in 2010 (e.g Yalgorup NP, Yanchep NP and Nilgen NR) will enable annual variation in abundance to be assessed.

A quantitative habitat suitability model should be developed once the habitat assessments are completed. The large number of sites surveyed and the fraction of occupied sites (~50%) should provide good

discriminatory power. Determining potential habitat in *Banksia* woodland requires additional study, as the low detectability of the graceful sun-moth in such sites makes development of a habitat suitability model more difficult in this habitat type. The proposed extension of the Mitchell freeway through or adjacent to the two localities in Yanchep NP, may provide an opportunity to undertake an experimental assessment of the impacts of land clearing and fragmentation on graceful sun-moth populations.

Greater survey effort is likely to be required in *Banksia* woodland habitats, and possibly less in coastal heathland, although changes to survey regimes may impair comparisons between years and sites. A review of the survey prescription, based on a detailed analysis of the detection rates in different habitat types, should be undertaken.

As coastal and near-coastal populations of the host plant *Lomandra maritima* are now known to occur at Kalbarri National Park, surveys should also be undertaken there to assess the suitability of that habitat for graceful sun-moths.

Further research is required to resolve gaps in knowledge of the biology of the graceful sun-moth. Mark-recapture studies in particular could assist in determining adult lifespan and population size, and may be used to calibrate the relationship between transect counts and actual population size (see Collier et al. 2008).

Experimental translocations of adult graceful sun-moths and the larval host plants should be attempted into suitable sites identified in this study. This will determine if translocation is a viable option for mitigating the impact of any future clearing of graceful sun-moth habitat.

5. Recommendations

A formal assessment of the conservation status of the graceful sun-moth at state level, using all possible IUCN criteria (IUCN Standards and Petitions Working Group 2008), should be prepared to supersede the past assessment based on expert opinion.

A consolidated conservation strategy for the graceful sun-moth should be developed based on the findings presented in this interim report, after obtaining and collating the comments of volunteers and environmental consultants who participated in the 2010 surveys, and undertaking any additional analyses necessary to better identify site-based habitat factors that predict graceful sun-moth presence.

To determine if graceful sun-moth counts are indicative of true abundance, a calibration (mark- recapture) study should be conducted. If transect counts prove to be indicative of true abundance, the graceful sun-moth can then be assessed against the relevant IUCN criteria regarding population reduction.

6. Conclusion

In order to reach a more comprehensive understanding of the conservation needs of the graceful sun-moth, additional habitat assessments are required across the range, particularly in *Banksia* woodland habitat, using refined survey methods. Genetic analyses are urgently needed to assist in determining the genetic variability and structure of remaining populations, to enable assessment of the conservation priority of sub-populations within the distribution of the species, and to inform estimates of minimum viable population and patch sizes. Similarly, a mark-recapture study would provide invaluable information on graceful sun-moth population sizes, dispersal capabilities, survival rates and other demographic parameters to assist conservation planning. The results of these actions, when completed, will be included in a future report.

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Volunteers

Marjorie Apthorpe	Vanessa Clarke	Jason Johnson	David Mickle	Quinns Rocks Primary School	Jill Stryk
Jan Bant	Jane Clarkson	Janine Keuhs	Brian Morgan	Julie Raines	Louise Tomlin
Geoff Barrett	Julia Coggins	Chrystal King	Sarah Murphy	Kate Reading	Jo Tregonning
Anne Bellman	Abbie Crawford	Peter Kiss	Lyndon Mutter	Alice Reaveley	Geri Treloar
James Best	Lisa Cuthbert	Kirsten Knox	Amy Mutton	Margaret Redfern	Jeff Turpin
Pete Beswick	Jess Davis	Rae Kolb	Mike Norman	Juanita Renwick	Colin Walker
Karen Bettink	Tegan Douglas	Janine Kuehs	Anna Nowicki	Ellie Ridley	Sean Walsh
Daniel Boase-Jelenik	Margaret Ellerton	Tanja Lambe	Craig Olejnik	John Riley	Andy Webb
Brett Brenchley	Caren Elliot	Georgina Lambert	Jeremey Owen	Phyllis Robertson	Mike Webster
Kate Brown	Bek Esszig	Margaret Larke	Grazyna Paczkowska	Liesl Rohl	James Widenbar
Jacklyn Buchanan	Fiona Felton	Caron Macneall	Grace Patorniti	Lyn Rowland	Craig Wilson
Fiona Bujok	Christine Fleay	Jacqui Maguire	Lyn Phillips	Leigh Sage	Sonya Wilson
Kathleen Butler	Ryan Glowacki	Michi Maier	Chris Phillips	Marco Serra	Marc Wohling
Claire Caldeira	Melissa Hoskins	Claudia Marchhart	Kristian Pollock	Geraldine Shaw	Heather Woodley
Judith Carter	Katherine Howard	Sharon McArthur	Tanya Porter	Loretta Shillinglaw	Alan Wright
Simon Caunter	John Hudson	Sue McCormack	Jim Prince	Tracy Sonneman	Mal Wright
Patrick Cavalli	Kelby Jennings	Nina McLaren	Jeremy Quartermaine	Daniella Stott	Renata Zelinova

Environmental Consultants

Bamford Consulting Ecologists	Ecoscape	Phoenix Environmental Sciences
Cardno	ENV	RPS
Coffey Environments	ERM Australia	Syrinx Environmental
EcoLogical	Greg Harewood	Western Wildlife

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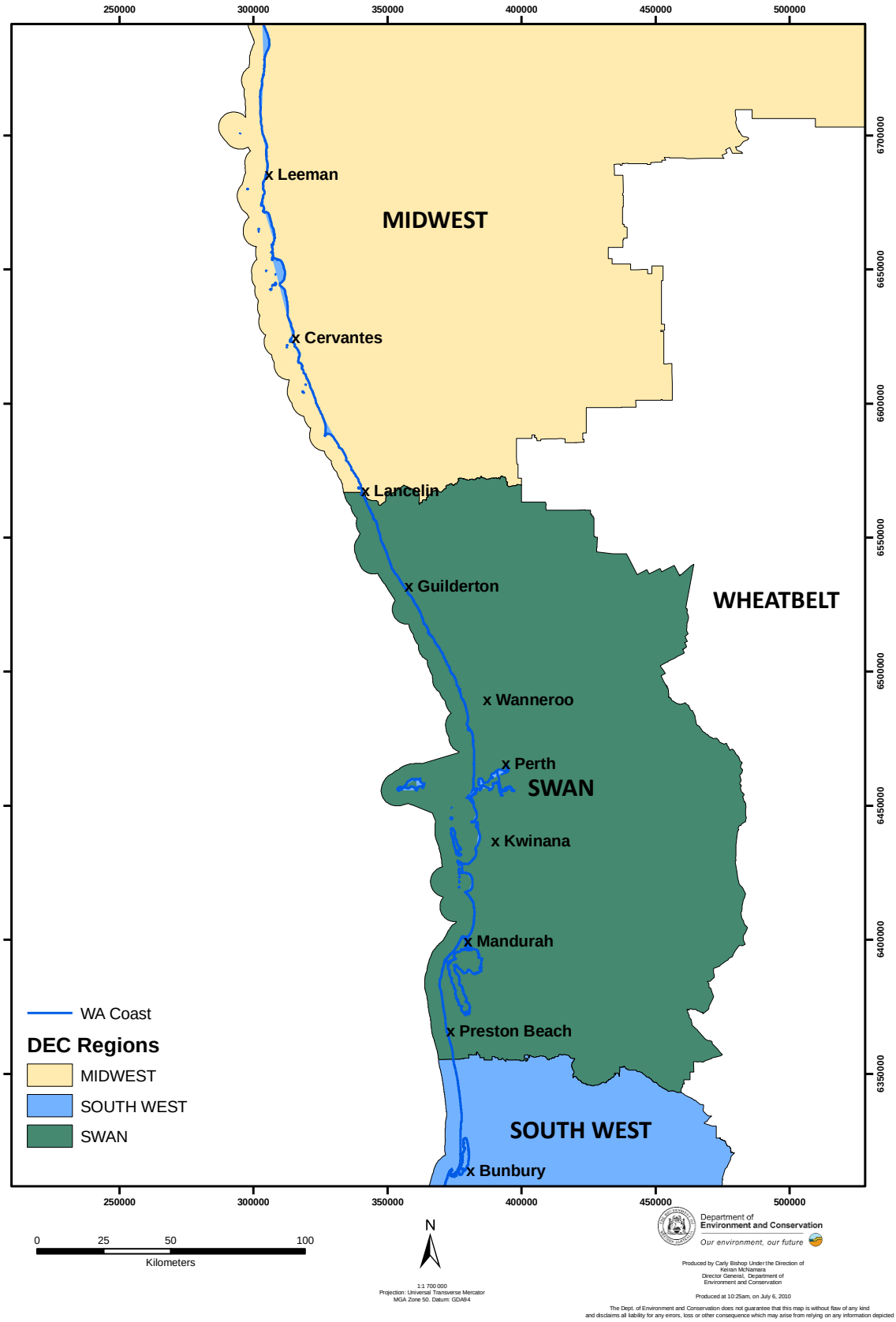
APPENDIX 1: Location of the Swan, South West and Midwest DEC Regions



APPENDIX 2: Sites surveyed for the graceful sun-moth by DEC staff, volunteers, and environmental consultants.

Note: Data for sites assessed by environmental consultants has been summarized, as confidentiality of some data was requested.

Site name	Site type	Vegetation type	Site area (ha)	Surveyed by
Baldivis Childrens Forest, Baldivis	Recreation reserve	*Banksia* woodland	49	Volunteers
Cottonwood Bushland, Dianella BF043	Bush forever	*Banksia* woodland	11	Volunteers
Decourcey Bushland, Marangaroo BF328	Bush forever	*Banksia* woodland	33	DEC
Harry Sandon Bushland, Attadale BF226	Bush forever	*Banksia* woodland	4.2	Volunteers
Hillview Bushland, Bentley	Recreation reserve	*Banksia* woodland	0.7	DEC and volunteers
Kensington Bushland, Kensington BF048	Bush forever	*Banksia* woodland	9.1	DEC and volunteers
Kings Park BF317	Bush forever	*Banksia* woodland	321	DEC
Landsdale Rd Bushland, Landsdale BF199	Bush forever	*Banksia* woodland	16	Volunteers
Neerabup NP	DEC estate	*Banksia* woodland	541	DEC
Paganoni Swamp, Karnup BF395	Bush forever	*Banksia* woodland	2	Volunteers
Star Swamp, Waterman BF204	Bush forever	*Banksia* woodland	60	Volunteers
Swanbourne Bushland, Swanbourne BF389	Bush forever	*Banksia* woodland	32	DEC and volunteers
Wal Hughes Park, Attadale	Recreation reserve	*Banksia* woodland	1.5	Volunteers
Whiteman Park BF304	Bush forever	*Banksia* woodland	367	DEC
Yanchep NP (Rydges extension)	DEC estate	*Banksia* woodland	1	DEC
Yanchep NP (Yeal Swamp Rd)	DEC estate	*Banksia* woodland	73	DEC
Shenton Bushland, Shenton Park BF218	Bush forever	*Banksia* woodland	20	Volunteers
Sir Frederick Samson Park, Samson BF059	Recreation reserve	*Banksia* woodland	13	Volunteers
Bushland adjacent to Wandi NR, Wandi BF347	DEC estate	*Banksia* woodland	93	DEC and volunteers
Warwick Open Space, Warwick, BF202	Bush forever	*Banksia* woodland	58	Volunteers
Reid Highway bushland, Malaga/Marangaroo BF385	Bush forever	*Banksia* woodland	48	Volunteers
Errina Rd bushland, Alexander Heights BF493	DEC estate	*Banksia* woodland	8.5	DEC
Koondoola Regional bushland, Koondoola BF201	Bush forever	*Banksia* woodland	124	Volunteers
Bold Park, City Beach BF312	Bush forever	Coastal heathland	362	DEC and volunteers
Gumblossum Reserve, Quinns Rocks	Recreation reserve	Coastal heathland	4	Volunteers
Neerabup NP (Lone Tree Hill)	DEC estate	Coastal heathland	25	DEC
Woodman Point, Coogee BF341	Bush forever	Coastal heathland	1	Volunteers
Yalgorup NP (southern site)	DEC estate	Coastal heathland	51	DEC
Madana Park, Kallaroo	Recreation reserve	Coastal heathland	3	Volunteers
Porteous Park, Sorrento	Recreation reserve	Coastal heathland	1	Volunteers
Nambung NP (Kangaroo Point)	DEC estate	Coastal heathland	95	DEC
Beekeepers NR	DEC estate	Coastal heathland	250	DEC
Southern Beekeepers NR	DEC estate	Coastal heathland	250	DEC

Site name	Site type	Vegetation type	Site area (ha)	Surveyed by
Whitfords Ave bushland, Craigie BF303	Bush forever	Coastal heathland	4	DEC and volunteers
Maritana Bushland, Craigie	Recreation reserve	Coastal heathland	3	Volunteers
Yanchep NP ("Water Block")	DEC estate	Coastal heathland	54	DEC
Coolimba Rd (8km N of Leeman)	Recreation reserve	Coastal heathland	131	DEC
Wilbinga (south coast)	DEC estate	Coastal heathland	48	DEC
Wanagarran NR	DEC estate	Coastal heathland	719	DEC
Nilgen NR	DEC estate	Coastal heathland	490	DEC
Wilbinga (north east)	DEC estate	Coastal heathland	40	DEC
Wilbinga (north coast)	DEC estate	Coastal heathland	119	DEC
Cawarra Reserve, Craigie	Recreation reserve	Coastal heathland	4	Volunteers
Yanchep NP (Pipidinny Rd)	DEC estate	Coastal heathland	96	DEC
Yalgorup NP (White Hills Rd)	DEC estate	Coastal heathland	164	DEC
Various private sites (1)	17	*Banksia* woodland	741	Environmental consultants
Various private sites (2)	21	Coastal heathland	1857	Environmental consultants
TOTALS	**83 sites surveyed**		**7398 ha surveyed**	

APPENDIX 3: Records of the graceful sun-moth and density of host plants from the 2010 surveys

Site name	First record	Number of individuals recorded	Peak density (#/hr)	*Lomandra maritima* cover (%)	*Lomandra hermaphrodita* density (plants/m^2)
Bushland adjacent to Wandi NR, Wandi BF347	2010	2	1	absent	unknown
Errina Rd bushland, Alexander Heights BF493	2004	7	4	absent	0.18
Koondoola Regional bushland, Koondoola BF201	2002	unknown	unknown	absent	0.75
Reid Highway bushland, Malaga/Marangaroo BF385	2010	unknown	unknown	absent	unknown
Shenton Bushland, Shenton Park BF218	2004	1	1	unknown	unknown
Sir Frederick Samson Park, Samson BF059	2010	1	1	unknown	unknown
Warwick Open Space, Warwick, BF202	2003	3	3	unknown	unknown
Beekeepers NR	2010	5	5	5.1	absent
Cawarra Reserve, Craigie	2009	32	11	unknown	unknown
Coolimba Rd (8km N of Leeman)	2010	8	8	unknown	unknown
Madana Park, Kallaroo	2009	1	1	unknown	unknown
Maritana Bushland, Craigie	2009	6	3	unknown	unknown
Nambung NP (Kangaroo Point)	2010	2	1	5.4	absent
Nilgen NR	2010	11	6	5.2	absent
Porteous Park, Sorrento	2008	1	1	unknown	unknown
Preston Beach Reserve 22091	2010	54	15.4	unknown	absent
Southern Beekeepers NR	2010	5	5	5.1	absent
Wanagarran NR	2010	10	2	unknown	unknown
Whitfords Ave bushland, Craigie BF303	2009	5	4	unknown	unknown
Wilbinga (north coast)	2010	18	5	28.8	absent
Wilbinga (north east)	2010	12	2	14.2	absent
Wilbinga (south coast)	2010	9	4	25	absent
Yalgorup NP (White Hills Rd)	2010	56	10	18	absent
Yalgorup NP (central site)	2010	57	19	15.1	absent
Yanchep NP ("Water Block")	2010	6	4	16.8	absent
Yanchep NP (Pipidinny Rd)	2010	46	10	24.6	absent
Consultant sites (*Banksia* woodland)	2010	28	2 to 3	-	-
Consultant sites (Coastal heathland)	2010	746	3 to 29	-	-
TOTALS (All data)	**NA**	**1132 GSM records**	**NA**	**5.8 to 28.1 % cover**	**0.18 to 0.75 plants per m2**

APPENDIX 4: Graceful sun-moth sites (presence and absence) across the Swan, South West and southern Midwest Regions. Data for sites assessed by environmental consultants has been excluded, as confidentiality of some data was requested.