Butterfly accounts for the Australian Capital Territory

A report to the Commissioner for Sustainability and the Environment

August 2019

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Suggested citation

Bond, S. and Vardon, M. 2019. Butterfly Accounts for the Australian Capital Territory: A report to the Commissioner for Sustainability and the Environment. Canberra, Australia.

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Acknowledgement

We wish to thank the volunteer surveyors for their contributions to the collection of the butterfly field data, with special mention to Steve Holliday (Australian National University) and Richard Allen. We would like to thank the reviewers of the document: Steven King (IUCN-World Conservation Monitoring Centre); Steve May and Wayne Qu (Australian Bureau of Statistics), and; Michael Mulvaney (Australian Capital Territory Government). Thanks also to Mike Booth, Jonathan Khoo, Amanda Clark and Lisa Wardlaw-Kelly from Australian Bureau of Statistics for supporting the study. We would also like to thank the London Group on Environmental Accounting for the opportunity to present part of the work at their October 2018 meeting held in Dublin, Ireland and the useful comments provided by those attending.

Access to some of the survey sites was facilitated by officers of the ACT Parks and Conservation Service.

Abstract

We present a set of novel biodiversity accounts for butterflies in the Australian Capital Territory (ACT), Australia. The accounts were prepared to assist with the preparation of the ACT State of the Environment Report, as well as ecosystem monitoring and management, and the development of ecosystem accounting within the System of Environmental Economic Accounting (SEEA). The accounts, which span four decades (1978 to 2019), identify 88 butterfly species in five families in the ACT. Of the 88 species, 63 are endemic to Australia, 69 breed in the ACT and the other 19 species are migratory or vagrants. Of the 69 breeding species, 40 are habitat specialists. Not all species were found in each year.

The accounts for the period 2014-15 to 2018-19, which are based on systematic surveys, show the number of specialist breeding species found in survey sites increasing by 10 species. Similarly, the accounts for the period 1978 to 2018 show an increase of 10 species. Of particular interest is that the number and abundance of butterfly species has increased in habitats of key concern; for example, in montane eucalypt forest and subalpine eucalypt woodland where the Montane Grass-skipper and Banks' Brown have been found. Ecosystem condition can be assessed in two general ways: condition relative to natural, or condition relative to the ecosystem services that are provided (Saner and Bordt 2016). In this paper, we take ecosystem condition to be relative to natural. Together, the accounts and the underlying data are an indication that the condition of the ecosystems surveyed is improving, probably due to the recovery of ecosystems after the extensive fires in the ACT in 2003. However, the results need to be interpreted cautiously as the number of survey sites increased over time and it is not known to what extent the survey sites represent all of the ecosystems of the ACT.

The compilation and analysis of the butterfly accounts for the ACT show that it is both possible and useful to compile species level biodiversity accounts (species accounts). A key practical aspect to emerge from the production of the accounts is that it is necessary for the SEEA to consider a range of different classifications for species accounts. In particular, it is necessary to consider more than just the threat status of species. We found, for example, that it was useful to classify species by (1) residence, (2) breeding status, (3) endemism and (4) habitat specialisation. The last provides a link to ecosystem condition accounting, with changes in the distribution and abundance of habitat specialists an indication of changes in condition.

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1. Introduction

Conservation of biodiversity is a global imperative, however achieving this is an elusive endeavor[1]. Essential to achieving conservation of biodiversity for both human and non-human benefit is to have information to enable better trade-offs between different human and environmental values (Vardon et al. 2018).

Humans have developed a number of theories, information systems and tools to assist individual and collective decision making. Key among these is the Keynes (1936) theory of employment, interest and money, which underpins economic policy and the System of National Accounts (SNA) which has evolved over 60 years: i.e. UN (1953) to EC et al. (2008). This theory and the information systems supporting the SNA (which is large) are used by governments and business in decision making. For example, the monthly meeting of the Reserve Bank of Australia, where monetary policy is reviewed and official interest rates are set[2]. Information for social systems is also important and supported by significant resources – most countries have a regular census of population, as well as employment statistics[3]. However, in comparison to economic and social information systems, the environment is poorly serviced and several environmental information deficiencies were identified recently by the Organisation for Economic Cooperation and Development (OECD) in their report on Australia[4].

Better integrated environmental, social and economic information will help to assess the effectiveness of past and current environmental policy and environmental management (Vardon et al. 2018). It will also enable the impact of possible changes to be assessed. Such information could aid the implementation of endangered species legislation, the design and management of protected area networks, pollution regulation and waste management, and unlock green growth opportunities based on the sustainable use of environmental resources.

The System of Environmental Economic Accounting (SEEA) emerged from the SNA as a response to the recognised shortcomings of traditional accounting (SEEA Central Framework, UN et al., 2014a). The development of the SEEA Central Framework was helped by the call for accounting in Agenda 21 that resulted from the 1992 Rio Conference (Vardon et al. 2016).

The best method for including biodiversity in the SEEA has been a vexing question for more than a decade. The specific call for including biodiversity values in national accounts is in [Aichi] Target 2 of the Biodiversity Strategy Plan (2011-2020) for the Convention on Biological Diversity. This call provided additional impetus for this accounting work and also coincided with the processes for elevating the SEEA Experimental Ecosystem Accounting (SEEA EEA – UN et al. 2014b) to an international statistical standard.

A number of activities and papers have addressed biodiversity accounting from theoretical and practical points of view (e.g. UNEP-WCMC 2016, Keith et al. 2017). This includes meetings convened as part of the SEEA EEA development and the London Group on Environmental Accounting that are aiming to raise ecosystem accounting to the level of an international standard[5].

[1] See, for example, Global Assessment Report on Biodiversity and Ecosystem Services: https://www.ipbes.net/news/ipbes-global-assessment-preview

[2] See Reserve bank of Australia minutes of monthly meetings: https://www.rba.gov.au/monetary-policy/rba-board-minutes/2019/

[3] See Australian Bureau of Statistics website: www.abs.gov.au

[4] See OECD (2019) OECD Environmental performance Reviews: Australia 2019: https://read.oecd-ilibrary.org/environment/oecd-environmental-performance-reviews-australia-2019_9789264310452-en

[5] See United Nations Ecosystem Accounting website: https://seea.un.org/ecosystem-accounting

Key questions for biodiversity accounting identified near the beginning of these processes (e.g. Harris 2011) were:

- What are the units of account – genes, species or ecosystems?
- Can indices of biodiversity be used as an input to ecosystem accounts?
- In what types of accounts would biodiversity be included?
- When assessing ecosystem condition using biodiversity, what reference points can be used?

The production of the SEEA EEA provided the first response to these key questions. In the SEEA EEA, there are asset accounts for biodiversity, which are one of the four thematic accounts described (the others being land, water and carbon), as well as biodiversity as an indicator of ecosystem condition. Accounts for threatened species and threatened species abundance are shown in the SEEA-EEA. The Technical Recommendations (UN 2017) in support of the SEEA EEA added additional discussion on biodiversity accounting and sources of data, but augmented or additional tables were not presented. A range of other work has shed light on both theoretical and practical issues of accounting for biodiversity and a summary of this is presented in Appendix 1.

A key on-going issue is the suitability of primary data for regular and systematic biodiversity accounts. Improving primary data sources is a vital part of the work and the challenge is to use what is available now to help create accounts, including biodiversity, that are meaningful to managers and policy.

1.1 Butterflies as indicators of biodiversity condition

Butterflies can be used as indicators of environmental condition and change, and are used by the United Kingdom where the Butterfly Monitoring Scheme is a part of the government's Official Statistics (UKBMS, 2018). Butterflies are useful indicators of biodiversity condition as they react quickly to environmental changes (Warren et al. 2001) and changes in distribution due to climate have been noted (Parmesan et al. 1999, Devictor et al. 2012). This is due to short life spans, limited dispersal ability, larval food plant specialization and close-reliance on the weather and climate[6]. In addition, unlike most other groups of insects, butterflies are well-documented, their taxonomy is understood, they are easy to recognize and there is much information on their ecology and life-histories. In the UK, the United Kingdom Butterfly Monitoring Scheme (UKBMS), launched in 2006, is part of the official statistics. In the UK, butterfly abundance data are produced annually[7], but are not yet integrated into biodiversity or ecosystem accounts.

1.2 Background to the ACT

The ACT is a relatively small (2,358 square kilometres), landlocked jurisdiction in Australia dominated by an extensive system of national parks and other reserves juxtaposed against the city of Canberra, which is Australia's national capital[8]. Local residents place a high value on environmental health and natural capital, and the ACT Government has set ambitious policy and sustainability goals to guide future development (ACT Government 2009; OCSE 2017b). These goals focus on economically, socially and

[6] United Kingdom Butterfly Monitoring Scheme: http://www.ukbms.org/Default.aspx

[7] UK Summary of changes to butterfly abundance 2017: http://www.ukbms.org/docs/reports/2017/UK%20Summary%20of%20changes%20Table%202017.pdf

[8] See "About the ACT": https://www.act.gov.au/browse/about-act

environmentally sustainable policy outcomes that align well with the United Nations Sustainable Development Goals (SDGs).

A range of threats to the environment have been identified[9] as well as specific threats to butterflies. Bond et al (2018) identified the following threats to butterflies in the ACT:

- Fire is a major threat to ACT butterflies and thought to have affected populations of Satin Azure, Banks' Brown, Silky Hairstreak and Montane Grass-skipper;
- Grazing/trampling – overgrazing by kangaroos or rabbits in the lowlands and both grazing and trampling by introduced mammals (e.g. cattle, deer, horses) in the highlands;
- Urban development – the loss of lowland eucalypt woodlands and grasslands;
- Removal of coarse woody debris – for example, by firewood collectors. These are of particular importance for Bronze Ant-blue and Small Ant-blue as their obligate attendant ant, the Coconut Ant, requires coarse woody debris for their colonies;
- Clearing of hilltop vegetation. Hilltops are important courtship and breeding sites for butterflies and loss of vegetation can result in decreased species richness;
- Climate change, especially for species specialising in subalpine habitats;
- Invasive species including European Wasps, feral honey bees, and the feral mammals mentioned above; and
- Introduced weeds like African Love Grass, wild oats and *Paspalum* (affecting, for example, Small Ant-blue, White-veined Sand-skipper, Yellow Ochre and others).

1.3 History of ACT environmental accounting work

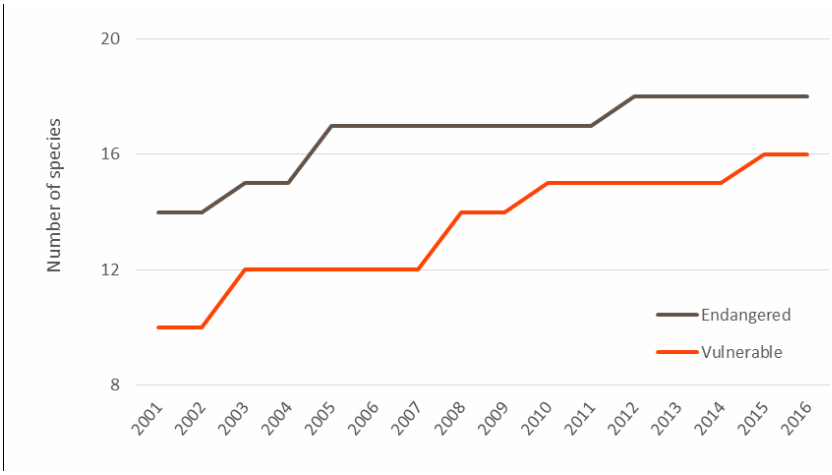
The ACT Office of the Commissioner for Sustainability and the Environment (OCSE) prepared a suite of environmental accounts as part of the 4-yearly State of the Environment (SoE) reporting (Smith et al. 2017). This was done with the assistance of the Australian Bureau of Statistics (ABS) and the Australian National University (ANU). The ABS and Bureau of Meteorology (BoM) have also prepared water accounts specifically for the ACT region (ABS and BoM 2019).

Biodiversity asset and ecosystem condition accounts were prepared by Smith et al. (2017). The ecosystem condition accounts did not include a measure of biodiversity *per se* but did include tree cover, vegetation leaf area and vegetation carbon uptake.

Biodiversity assets accounts of threatened species were prepared for 2001 to 2016 and Figure 1 summarises the accounts for each of the years. While the figure shows an increase in the number of endangered and vulnerable species, by itself it is of limited value to decision makers.

[9] See ACT State of the Environment Report 2015: http://reports.envcomm.act.gov.au/actsoe2015/the-report/index.html

Figure 1. ACT Nature Conservation Act Endangered and Vulnerable Listed Species 2001 to 2016



Source: Smith et al 2017. Data at:
http://www.environmentcommissioner.act.gov.au/__data/assets/excel_doc/0020/1106408/listed_species_account_2001-16.xlsx

Several issues may limit the usefulness of the accounts of species status in general. Firstly, listing is an administrative process that takes time, so the change in status will lag the physical change in distribution and abundance. This leads to the second point: the status of species is based on patterns in distribution and abundance that are naturally variable from year-to-year. Lastly, the likelihood of extinction risk for most species groups (i.e. birds, mammals, plants, fish, etc.) does not change appreciably from year-to-year.

In the remainder of this paper, we examine how accounts may overcome these potential limitations and report on the development of butterfly accounts for the ACT. In this, we explore how these can be used for environmental management in the ACT, as well as how the work can assist the development of ecosystem accounting via the SEEA processes.

2. Materials and methods for butterfly accounts for the ACT

2.1 Data sources and methods for accounts

To produce a species account for butterflies of the ACT, we had to construct a butterfly species list for the ACT. Kitching et al (1978) were the first to publish an initial species list of 79 butterflies; personal observations, Australian National Insect Collection (ANIC) specimens, published papers, citizen science records, and Braby (2016) helped confirm the final list of 88 species recorded for the ACT. For the purposes of this paper, butterfly species have been grouped according to taxonomy under the main Linnean groupings, with nomenclature following Braby (2016). The species list is reflected in ACT butterfly field guide (Bond et al., 2018).

Species of butterfly were also classified as:

- Breeding or non-breeding;
- Specialist or generalist;
- Resident, migrant or vagrant; and
- Endemic, non-endemic or introduced to Australia.

Breeding species were defined as butterflies that regularly breed and have established a self-sustaining population in the ACT; this typically includes residents and regular migrants. Non-breeding species includes all species which do not breed in the ACT, and species which may breed opportunistically but are unable to establish a population; this typically includes migrants and vagrants. Species for which their breeding status is unclear have been added to this category, such as the Copper Pencil-blue (*Candalides cyprotus*).

Generalists are usually common and widespread species able to survive in a range of environmental conditions. In contrast to this, specialist species are usually less common and more localised, with specific environmental conditions which need to be met for them to survive. In this paper, generalist species (or "generalists") are defined as species which must have at least two of the three following characteristics:

- A widespread distribution in the ACT;
- Three or more breeding and foraging habitats in the ACT;
- Four or more plant species, or more than one plant family, for their larval food plant preference in the ACT.

Specialist species (or "specialists"), on the other hand, must have at least two of the three following characteristics:

- A localised, very localised or restricted distribution in the ACT;
- One or two breeding and foraging habitats in the ACT;
- One, two or three plant species within the same plant family, or a preference for ant larvae, for their larval food preference in the ACT.

A good example of an ACT generalist species of butterfly is the familiar Common Brown (*Heteronympha merope*) (Fig 2.). This species occurs in every habitat type in the ACT and has cosmopolitan tastes in their larval food plant preferences, including the ability to eat introduced grasses as well native grasses; adult butterflies have the ability to go into a summer dormancy known as aestivation to survive periods of hot weather, they are able to move with great mobility through the landscape if required, have a long flight period of several months, and the females can delay laying their fertilised eggs until autumn rains trigger fresh growth in grasses for improved larval development.

Figure 2. Common Brown and Alpine Sedge-skipper (Left to right)

A good example of a specialist species of butterfly in the ACT is the Alpine Sedge-skipper (*Oreisplanus munionga*) (Fig. 2). Alpine Sedge-skippers only occur in boggy patches of subalpine eucalypt woodland and grassland and are restricted to the higher elevations; they have a localised distribution within their range and have a flight period of only one to two months. Their presence indicates that the ecosystem is in excellent condition. Alpine Sedge-skippers are thought to be highly vulnerable to climate change and inappropriate fire regimes drying out their moist habitat. Their reliance on this specific habitat is also due to the availability of their single larval food plant, the Tall Sedge (*Carex appressa*); this food plant can easily be lost through trampling and overgrazing by feral horses and cattle. This species is already listed as Endangered in the state of Tasmania.

Endemism is when a species is restricted to a defined geographic location or area, here defined as Australia, and an introduced species is when a species does not originate in Australia but has been deliberately or accidentally brought to Australia.

After the construction of species lists we had to determine the presence and abundance for these 88 species across space and time in the ACT. For this, systematic butterfly surveys were conducted in the field between 2014-15 and 2018-19. Incidental sightings were also used for determining the presence of species in the ACT.

Data was limited to butterfly species with ACT records only - neighbouring regions of New South Wales (NSW) records were also out of scope, as were moths. Sometimes diurnal moths (such as the Sun Moths, family Castniidae) are included in butterfly surveys and, due to an overlap of bioregional zones, parts of NSW to the east of the ACT (such as the Braidwood-Tallaganda region) are often considered when discussing 'ACT' Lepidoptera. Records of butterflies in the data set were of adults.

2.2 Butterfly survey method

The butterfly survey method used in the ACT field work was an adaptation of the Pollard Walk (Pollard 1977). This is a transect count designed specifically for recording adult butterflies in a scientifically robust way. The adapted transect surveys were limited to ten minutes survey time, with fixed survey boundaries of 100 metres long by 10 metres wide and unlimited height. The observer recorded the time, date, weather conditions and any other factors relevant to the site. The transect was covered at a slow walking pace, recording every identifiable adult butterfly species and their abundance. The observer walked as close as possible to the centre of the transect, and completed the 100 metre transect length within the ten minute timeframe; any butterflies observed outside of this fixed area or time were recorded as incidental records. Stopping along the transect in order to identify butterflies was permitted, but time was stopped when the observer stopped (otherwise sampling effort would be inconsistent). All identified butterfly species were recorded for presence and abundance. Individuals that were difficult to confidently identify were left off the survey, and photos were taken of problematic individuals for identification post survey.

Surveying was conducted three times at each site during the butterfly season: once during spring, once during summer and once during autumn; each survey site was fixed so that the same area was surveyed over time. Surveys were conducted from September through to May, as this is when adult butterflies are on the wing for the temperate butterfly season in the southern hemisphere. No winter surveys were conducted, although a handful of species do fly during this period.

Because surveys were aimed at detecting adult butterflies on the wing, weather was an important factor in determining survey effort. Where possible, surveys were only conducted in the following weather

conditions: when the forecast daily maximum was at or above 21°C but below 35°C, no strong winds, and no rain. These parameters were established based on previous experience in the field, where it was found that there was too little butterfly activity if these conditions were not met. It is important to note that ideal surveying conditions for the temperate zone can be different in different parts of the world - for instance, in the UK it is recommended that surveys be carried out in temperatures as low as 13°C (van Swaay et al 2015). The first snowfall or heavy frost in the mountains during autumn usually signifies the end of the flight season for most ACT butterflies, and therefore the end of the surveys for that season.

Each survey site was located within one habitat type, with all sites together providing a good representation of different habitats within the ACT. Grassland, lowland woodland, dry forest, montane forest, wet forest, montane and subalpine woodland, wetlands, urban parks/gardens and riparian habitats were all sampled across the ACT. Habitats not surveyed were *Pinus radiata* plantations, heath shrublands, agricultural land (active farms) and private suburban gardens. This was for a variety of reasons: butterflies are not usually found within pine plantations; many of the heath shrublands were physically difficult to access; and accessing farms and gardens was problematic for both practical (e.g. locked gates) and legal reasons. There may be scope in future surveys to include these habitats. In addition to different habitat types, survey sites also varied according to their topographic position in the landscape and altitude.

Site locations were also chosen based on several factors, and they were selected to try to represent a range of variables, such as different altitudes, ecosystem types, and topographies. Most of the previous records of ACT butterflies came from only a few locations, therefore this project initially aimed for improved geographic coverage of records across the ACT. Potential sites with ease of frequent access were identified, and these were selected so that a cluster of sites could be surveyed in one visit. Sites were then selected to fit the variables identified as important, with some sites included specifically to target rare and restricted species. Most survey sites were located within protected areas (Namadgi National Park, Canberra Nature Park, Tidbinbilla Nature Reserve) due to limited access to private land.

The ongoing ACT butterfly surveys were set up in 2014 as Australia's first long-term butterfly monitoring project. Survey sites consist of core sites which are surveyed every year, and supplementary sites which may not be surveyed every year. For the 2014-2019 seasons, a total of 202 sites were surveyed, with an average of 72 sites surveyed each season. In the short term, improved knowledge of butterfly presence and distribution will be gained, and in the long term, trends may be ascertained and better understood. Annex 1 and 2 detail sites, ecosystem types and years surveyed.

3. Results and butterfly accounts for the ACT

Data from the butterfly surveys are presented in Appendices 2 and 3. The appendices summarise information for all 88 species of butterflies, for all 202 survey sites, by habitat, year and season. Not every site was sampled in every year or season. These data, as well as other information, were used to construct tabular summaries and accounts, highlighting different aspects of butterfly distribution and abundance over time and space.

Table 1 presents a summary of butterfly species found at different scales at one point in time (2019). These species are grouped by state (ACT), federal and international levels of endemism, and number of introduced species. This provides an overview of the numbers of species the accounts are dealing with, and provides context. It should be noted that there are currently no butterflies listed as threatened under the ACT Nature Conservation Act (2014), however one member of the Lepidoptera is represented, with

the Golden Sun Moth (*Synemon plana*) listed as endangered in the ACT, while the ACT Scientific Committee is considering nine butterfly species for protected species listing under the Nature Conservation Act.

Table 1: Summary table of butterfly species, ACT, Australia and global (2019)

	Number of species	No. Endemic to Australia	% Endemic to Australia	No. Introduced to Australia
Global	~18,000	NA	NA	NA
Australia	408*	200	49%	3
ACT	88	63	72%	2

* Represents continental Australia only; there are 435 species including islands, and 396 confirmed resident butterfly fauna permanently established in Australia
Data sources: Braby, 2016; Canberra Nature Map, 2019; Hoskins, 2018

Table 2 also presents a further breakdown of the snapshot of ACT butterfly species present in 2019, arranged by family, showing how many species from each family are endemic to Australia. In this, it is worth noting that the ACT does not have any species only found in the ACT (i.e. every species in the ACT is found in another Australian jurisdiction). The Papilionidae ("swallowtails") are predominantly a group of tropical and subtropical butterflies; the Hesperiidae ("skippers") are usually small, often overlooked dull butterflies; the Pieridae are a group of highly mobile species, many of which are long distance migrants; the Nymphalidae in the ACT are comprised of the Satyrinae (which display a preference for shaded, grassy habitats), the Nymphalinae (a preference for sunnier habitat), and the Danainae (which are often toxic to predators); and the Lycaenidae ("blues"), which often have an association with ants.

Table 2: Butterfly species of the ACT, by family and endemism, 2019

	Native species				Introduced species	Total species
	Endemic ACT	Endemic Aust	Non-endemic Aust	Listed as threatened	Introduced Australia	
Papilionidae	0	1	5	0	0	6
Hesperiidae	0	18	0	0	0	18
Pieridae	0	4	6	0	1	11
Nymphalidae	0	15	8	0	1	24
Lycaenidae	0	25	4	0	0	29
Total	0	63	23	0	2	88

Data sources: Braby, 2016; Canberra Nature Map, 2019

Table 3 presents another alternative view of ACT butterflies for 2019, this time with a focus on classifying butterflies according to whether they breed or not in the ACT, and whether they are specialists or generalists. Among other things, this enables a link between butterfly species and ecosystem condition (i.e. the presence of a breeding specialist could be sign of a habitat in good condition). It must be remembered that the categories presented are in the context of ACT only, and that non-breeding species are exempt from the habitat specialisation categories because they do not use ACT habitats to breed in.

Table 3: Butterfly species of the ACT, by breeding status and degree of habitat specialisation, 2019

	Breeding category		Habitat specialisation	
	Breeding species*	Non-breeding species^	Generalists	Specialists
Papilionidae	3	3	2	1
Hesperiidae	18	0	6	12
Pieridae	3	8	3	0
Nymphalidae	18	6	9	9
Lycaenidae	27	2	9	18
Total	69	19	29	40

* Resident and regular migrant species

^ Migrants and vagrants; not included in classification of generalist/specialist breakdown

Data sources: Braby, 2016; Canberra Nature Map, 2019

Table 4 presents an asset account of butterfly species linking two periods in time: 1978 for the opening stock and 2019 for the closing stock. This table brings together information presented in Tables 2 and 3, with the addition of data from 1978, to pinpoint where the change over time has occurred. Tables 5-8 show accounts for the species found during the systematic surveys conducted between Spring 2014 and Autumn 2019.

Table 4: Butterfly species account for the ACT, 1978 – 2019

		Native species				Introduced species	Specialisation			
		Endemic ACT	Endemic Australia	Non-endemic Australia	Listed as threatened	Introduced Australia	Generalists~	Specialists~	NA~	Total species
Opening stock 1978		0	57	19	0	2	NA	NA	NA	78
Additions										
	Discovery of new species	0	0	0	0	0	NA	NA	NA	0
	Rediscovery of extinct species	0	0	0	0	0	NA	NA	NA	0
	Addition of species (distribution)	0	6	4	0	0	NA	NA	NA	10
	Taxonomic reclassification	0	1	0	0	0	NA	NA	NA	1
	Total	0	7	4	0	0	NA	NA	NA	11
Reductions										
	Extinction of species (Aust)	0	0	0	0	0	NA	NA	NA	0
	Loss of species (distribution)	0	0	0	0	0	NA	NA	NA	0
	Taxonomic reclassification	0	1	0	0	0	NA	NA	NA	1
	Re-evaluation of records	0	0	0	0	0	NA	NA	NA	0
	Total	0	1	0	0	0	NA	NA	NA	1
Closing stock 2019		0	63	23	0	2	29	40	19	88
Net change		0	6	4	0	0	NA	NA	NA	10

~ Cannot assign specialisation categories to 1978 data, no comprehensive measure of distribution available; vagrant and non-breeding migrant species are excluded from specialisation classification.

Data sources: Braby, 2016; Canberra Nature Map, 2019

Table 5: Butterfly species account for the ACT for endemism and introduced species, 2014 – 2019

	Native species			Introduced species	Total
	Endemic ACT	Endemic Australia	Non-endemic Australia	Introduced Australia	
2014-15	0	40	12	1	53
2015-16	0	40	12	1	53
2016-17	0	41	15	1	57
2017-18	0	51	10	1	62
2018-19	0	49	10	1	60
Net change (2014-15 to 2018-19)	0	9	-2	0	7

Data source: ACT butterfly surveys.

Table 6: Butterfly species account for the ACT, by specialisation, 2014 – 2019

	Specialisation in the ACT			Total
	Generalists	Specialists	NA	
2014-15	28	20	5	53
2015-16	28	22	3	53
2016-17	28	23	6	57
2017-18	29	32	1	62
2018-19	28	30	2	60
Net change	0	10	-3	7

Data source: ACT butterfly surveys. NA, not applicable (e.g. vagrants)

Table 7: Butterfly species account for the ACT, by breeding status, 2014 – 2019

	Breeding status in the ACT		
	Breeding	Non-breeding	Total species
2014-15	48	5	53
2015-16	50	3	53
2016-17	51	6	57
2017-18	61	1	62
2018-19	58	2	60
Net change	10	-3	7

Data source: ACT butterfly surveys.

Table 8. Selected specialist butterfly species, by number of times observed, by survey year, 2014-15 to 2018-19.

	2014-15	2015-16	2016-17	2017-18	2018-19
Alpine Sedge-skipper	1			1	5
Banks' Brown			1	5	4
Heath Ochre	1	3		2	
Montane Grass-skipper				4	
Silky Hairstreak				1	
Small Ant-blue					1
Striped Xenica	2				

Data source: ACT butterfly surveys.

4. Discussion

4.1 Butterfly diversity

Between 1978 and 2019, ten species were added to the list of butterflies found in the ACT. The species added since 1978 fall into two categories:

1. Range extensions. For vagrants and migrants, this includes the Pale Triangle (*Graphium eurpylus*), Lemon Migrant (*Catopsilia pomona*), Yellow Albatross (*Appias paulina*), Copper Pencil-blue (*Candalides cyprotus*) and for residents, this includes the Amethyst Hairstreak (*Jalmenus icilius*), Fiery Copper (*Paralucia pyrodiscus*), Flame Sedge-skipper (*Hesperilla idothea*), Small Ant-blue (*Acrodipsas myrmecophila*), White-veined Sand-skipper (*Herimosa albovenata*);
2. Taxonomic change. The Golden Ant-blue (*Acrodipsas aurata*) is a new species split from Copper Ant-blue (*Acrodipsas cuprea*); the Copper Ant-blue is subsequently absent from the ACT list.

All but one species was added by range extensions. Some of these new species, as well as species rare in 1978, have become more common and widespread over time. Much of the change in the species recorded reflects the changing landscape of Canberra. The creation of the Canberra Nature Park reserve system increased floristic diversity in what were formerly cleared sheep paddocks, with species such as the Bronze Flat (*Netrocoryne repanda*) doing so well on their larval food plant of Kurrajongs that they have upgraded from ‘a few specimens’ in 1978 to ‘fairly common’ across lowland ACT in 2019.

Another change to the landscape is urban expansion, with suburban gardens and botanical gardens now offering exotic larval food plants, enabling butterflies otherwise unlikely to be present, such as the Flame Sedge-skipper (*Hesperilla idothea*), to colonise the ACT and breed in the botanical gardens. Some of the change in this species distribution and abundance may also be driven by climate change. For example, some species formerly considered vagrant and migrant have, because of changed weather conditions and specifically milder winters, allowed species like the Tailed Emperor (*Charaxes sempronius*) to persist over winter for the first time and thereby establish resident populations.

One species that was considered difficult to find in the landscape was the Yellow Ochre, an Endangered species in Victoria, and which is also known as the Rare White-spot Skipper. It was therefore a species predicted to be rare in our surveys, but to the contrary we found that in the right habitat the Yellow Ochre was present and, while still localised, was more widespread in distribution than originally thought.

4.2 Theoretical and practical issues in producing species accounts for butterflies

The ACT has 88 butterfly species, with 70% of these endemic to Australia. The introductory summary of butterfly data places the accounts into global and regional contexts (Table 1).

Unusually for a faunal group in Australia, there are only three introduced species of butterfly in Australia, with none posing ecological threat. The species are:

- The Monarch (*Danaus plexippus*), which is thought to have arrived in the 1870s, possibly from New Caledonia, and is well-known for their spectacular migrations between Central and North America - in the ACT they are an occasional migrant;
- The Cabbage White (*Pieris rapae*), which arrived in Australia in the 1930s and has since become a pest on brassicas and canola, very common and widespread in the ACT and one of the few species which can be seen flying throughout the frosty winter months; and
- The Tawny Coster (*Acraea terpsicore*), which arrived in northern Australia in 2012 from south-east Asia and has quickly spread east to far north Queensland and as far south as central Queensland.

A species account for one point in time (2019, Table 2) shows a breakdown by family group. Table 2 shows that the Hesperiidae, Nymphalidae and Lycaenidae are important groups with several endemic species; unsurprisingly, the tropical and subtropical Papilionidae and the mobile Pieridae do not feature as strongly in the ACT.

A second species account for one point in time (again 2019, Table 3) draws out species groupings based on classifications designed to link butterfly species with ecosystem condition and climate change over time. Overwhelmingly, most of the butterflies use ACT ecosystems for breeding purposes and the ability to link species to the management of ecosystems is crucial. In this, the species accounts identify the habitats in which they occur, and this information can in turn be linked to other accounts showing habitat (i.e. ecosystem extent accounts) and land use accounts. Through this chain of accounting the government and others may be able to initiate policies and actions that both conserve butterflies and the habitats on which they depend. For example, this could be by adding underrepresented ecosystems to the protected area network. Species deemed specialists were from the Papilionidae, Hesperiidae, Nymphalidae and Lycaenidae families only.

Bringing together the data from two points in time to produce a species account can highlight changes in the dataset, as well as identifying the drivers of change, which is valuable for policy making and management. For the ACT butterflies species account, looking at two points in time forty years apart has certainly shown change, with nine new species added, plus a taxonomic change adding a 10th.

The collection of the data and the construction of the accounts has revealed an unexpectedly complex area of change over decades relevant for species accounting, namely taxonomic revisions. This has proven most noticeable in the updated scientific names of some species since 1978, such as the Meadow Argus (*Junonia villida*, formerly *Precis villida*). In the case of the Golden Ant-blue, it was described as a new species by Sands (1997), however, in 1978 this species was still considered to be the Copper Ant-blue (*Acrodipsas cuprea*, formerly *Pseudodipsas cuprea*). Another taxonomic oddity involves an occasional vagrant to the ACT, the Cycad Blue, considered *Theclinesthes miskini* in 1978, since revised to *Theclinesthes onycha*. To confuse matters, the fairly common ACT resident, the Wattle Blue, was considered *Theclinesthes onycha* in 1978 and is now *Theclinesthes miskini*. Only *Theclinesthes miskini* was recorded for the ACT in 1978, but it is likely this was the Wattle Blue rather than the Cycad Blue – the two species look very similar and can be difficult to separate.

One drawback of comparing two points in time so far apart is that significant events in between are hidden. Significantly, in 2003 extensive and intense bushfires in the ACT had a devastating impact on butterfly fauna, with the following effects:

- Suspected reduced diversity at former hotspots in Brindabella Ranges based on anecdotes and ANIC specimens;
- Some of the specialists suspected to have gone extinct from the ACT post 2003 including, Banks' Brown (rediscovered in 2017 and known from only two general locations) and Silky Hairstreak (also rediscovered 2017 known from only four locations);
- In addition, two species are suspected to have been severely impacted. These are the Montane Grass-skipper, absent from surveys until 2018, and only one prior known record since 2003, and the Satin Azure – anecdotally with slow re-colonisation of river Casuarina mistletoe.

When looking at 1978 and 2019 in isolation, the significant ecosystem disturbance and recovery in between are not evident. More comprehensive and annual and season-by-season sets of species accounts, such as those done for 2014 to 2019, would identify such changes. They would also help to address the variability in presence and abundance of butterflies and other invertebrates which fluctuate season-to-season and year-to-year according to climatic conditions. As such, the ACT butterfly surveys are a vital input to account production.

By categorising species into generalists and specialists for biodiversity accounting, surrogates for environmental condition can be developed. For instance, nominated generalists will be sufficiently widespread and abundant as to track climate change, while nominated specialists can be used as indicators for environmental condition of particular habitats and thus be used for targeted management strategies. We present a generalist butterfly species and a specialist butterfly species as case studies here.

The provision of primary data as presented and discussed here has allowed for an assessment of the suitability of such data for regular systematic biodiversity accounts. It also has implications for public policy and management of biodiversity and public areas in ACT and beyond.

4.3 Management of ecosystems

Accounting for butterflies provides a metric of ecosystem condition that can be used by government or other organisations to identify problems and guide the management of ecosystems. As part of this it hoped that the ACT butterfly species accounts will be used in the forthcoming (2019) ACT State of the Environment Report.

For butterfly conservation, the most important habitats for butterflies in the ACT are: lowland grassy box-gum woodland; wet and montane forest; wetland and riparian habitats, including high country swamps and casuarina-lined rivers; subalpine woodland; and grasslands. Different butterfly species are associated with different habitat types. Ecosystems currently listed as endangered in the ACT include: (1) Natural temperate grasslands, which are important for five specialist species, four of which are high country specialists; and: (2) Yellow Box/Red Gum Grassy Woodlands, which are important for majority of ACT species, including many specialists (e.g. Heath Ochre, Dark Purple Azure).

Some specific management actions that could be undertaken in the ACT to conserve butterflies are:

- Better management of prescribed burns (patchwork mosaic, not too hot, not too frequent), particularly for sensitive habitats like wet forest, subalpine woodlands, riparian zones - there needs to be refuges for populations;

- Protect long unburnt habitat from fire;
- Control of kangaroos and introduced mammal populations to reduce overgrazing and trampling of habitat;
- Retain and, where appropriate, add coarse woody debris into lowland woodland and forest reserves as habitat for the attendant ants of Lycaenid butterflies;
- Strategic urban development to maintain large areas of good quality lowland, woodland and grassland;
- Minimise clearing or development of hilltops;
- Be alert to any new incursions of exotic species, including invasive ants or other insects, and weeds - once identified, rapidly implement control measures; and
- Introduce a control program for European wasps, targeting sensitive butterfly areas, like high country swamps.

The management actions needed for butterfly conservation could be undertaken by a range of different agencies. In the public sector, this would obviously be the agencies of the ACT government concerned with land management and planning and national parks. In this, management of particular areas of importance to butterflies, like hilltops, could be given additional attention, while options for increasing habitats that are underrepresented in the protected area network could be examined. The information might also be of use to community groups or householders that want to promote butterflies and other species by, for example, planting vegetation (i.e. planting species used by butterflies for food or shelter). The threats to butterflies from exotic species and land management practices (e.g. on agricultural land) can also be investigated.

4.4 Moths

Two moth species deserve special consideration in the discussion of accounting for the Lepidoptera of the ACT. The first is the iconic Bogong Moth (*Agrotis infusa*). This is a well-known species to many Canberrans due to the moth's attraction to building lights as they migrate into the ACT. Bogong Moths arrive in Canberra from late September onwards from their breeding grounds in northwest New South Wales and southeast Queensland; their target is the Snowy Mountains, and as spring progresses into summer and the temperatures increase, the moths move gradually from lower to higher elevations. Once they reach the subalpine and alpine zones, they form aestivation sites in rock crevices until February when they set out to complete their return migration to their breeding grounds. Bogong Moths are an integral part of the alpine ecosystem, and are particularly important as a food resource during the breeding season for the Endangered Mountain Pygmy-Possum. Bogong Moths were also hugely significant to local Aboriginal groups, who would congregate in the high country to feast on the moths and conduct important cultural exchanges (Zborowski and Edwards, 2017).

The second is the only currently listed member of the Lepidoptera on the ACT's Nature Conservation Act (2014), the Golden Sun Moth (*Synemon plana*). This moth inhabits lowland grasslands dominated by Wallaby Grass (*Rytidosperma carphoides*) and is a flagship species for the conservation of these ecosystems within the ACT. Unusually for a moth, it flies during the day and has clubbed antennae, features more often assigned to butterflies. It flies from mid-November to early January, and the larvae feed underground for about two years before pupating into adult moths.

5. Butterfly stories

The data and accounting for butterflies prepared in this report represent an unprecedented body of technical work. However, it is also understood that the data need to be interpreted and analysed to enable non-experts to appreciate the information and how it might be used. To add such an appreciation, we have attempted to draw together information on a few species, which is presented below in Table 9, as well as in Box 1, which is a feature on the Small Ant-blue. From Table 9 it can be seen that several species have returned to the ACT after an absence since 2003, almost certainly due to the habitat changes caused by the bushfires in that year.

Table 9. Brief commentary of selected ACT butterflies

Species	**Notes**
Heath Ochre	The species is listed as Vulnerable in South Australia. It prefers mature/remnant forest and woodland and is sensitive to habitat loss and degradation. There are few records of the species in the ACT, which is a little surprising given the larval food plant (*Lomandra filiformis*) is common and widespread. A short flight season in the ACT and localised distribution may be reasons for this.
Banks' Brown	This is a fire sensitive species due to preference or possible reliance on for wet montane forest. It needs moist habitat and at immature stages is vulnerable to desiccation. It relies on soft green *Poa* grasses for larval food plants. The species has returned to the ACT after a long absence due to the 2003 bushfires. Since its return the species has been found regularly and in reasonable abundance.
Montane Grass-skipper	This is probably another species that has returned post the 2003 bushfires. There were no and then few records of the species between 2003 and 2018. Again, a preference for green *Poa* grasses for larval food plants and a reliance on montane eucalypt forest and subalpine eucalypt woodland.
Silky Hairstreak	This species has very specific habitat requirements, including particular species of eucalyptus and acacias of particular age. It also must have specific species of attendant ant, and the colony must be large enough to support the butterfly. The species is listed as Vulnerable in Victoria. There were no ACT records of the species between 2003 and 2017; it is another species influenced by the 2003 bushfires.
Striped Xenica	This species belongs to the high-country specialist genus of *Oreixenica*, so it is vulnerable to climate change. In the ACT it was seldom found in surveys and has a localised distribution. It prefers green *Poa* grasses for larval food plants and uses shrub foliage or tall grasses for roosting aggregations. It is listed as Vulnerable in SA.
Caper White	This species is a regular spring migrant to the ACT. Its numbers can fluctuate greatly from year to year, depending on the climatic conditions in their breeding grounds. Abundance is usually correlated with higher rainfall further inland.

6. Final thoughts

The development of butterfly accounts for the ACT has highlighted some of the problems with primary information on biodiversity. In particular, there are few regular, systematic surveys of species meaning that the base data needed for biodiversity accounts often has to be compiled from a variety of ad hoc data sources.

It is fortunate that systematic surveys of butterflies have been conducted over the past 5 years by a team of dedicated volunteers. This has enabled high quality data to be produced and used in the compilation of accounts. The compilation of the accounts has also shown the importance of expert knowledge of the species and their habitats. Without such knowledge the systematic surveys could not be run and the information collected could not be verified. It also enables ad hoc information to be more readily incorporated and for the survey areas to be modified to maximise the number of species that may be found.

A key feature to emerge is the need to classify species in a number of ways. While conservation status is important, a number of other classifications are useful for understanding the management needs of species, or strategies for conservation of species. In particular, classifications of species as specialists or generalists, in terms of habitat needs as well as by area of distribution and movement (e.g. resident, breeding migrant, non-breeding migrant, vagrant, etc.), is important. Having these classifications and, importantly, having them standardised (and various IUCN and CBD documents have a range of definitions that should prove useful) will enable a range of useful tables to be presented.

In the future, the species accounts will need to be integrated with the ecosystem accounting framework more generally, in both accounts of condition as well as of ecosystem services. A draft set of ecosystem condition accounts for the ACT were compiled based on remotely sensed data (Summers et al. 2018). Comparing the measures of condition obtained from the remotely sensed with those obtained from the butterfly accounts will be an important area of work. The cultural and recreation services obtained from species will also be important and an indication of this is seen in the cultural significance of the Bogong Moth to Aboriginal people.

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Appendix 1. List of biodiversity accounting papers presented at accounting meetings

Expert Meeting on Ecosystem Accounts, 5-7 December 2011, London UK.		
Charles Perrings	Biodiversity, Ecosystem Services and Wealth Accounting	https://unstats.un.org/unsd/envaccounting/seearev/meetingMay2011/bg7_CPerrings.pdf
Didier Babin	CBD and National Accounting Systems: Opportunities and Challenges	https://unstats.un.org/unsd/envaccounting/seearev/meetingMay2011/s13_DBabin.ppt
Expert Meeting on Ecosystem Accounts, 5-7 December 2011, London UK.		
J. McDonald	Key Concepts for Accounting for Biodiversity	https://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue6_Aus.pdf
E. Ivanov, R. Haines-Young, J.L. Weber	Developing a Diagnostic Species and Biotope Index for Europe	https://unstats.un.org/unsd/envaccounting/seeaLES/egm/Issue6_Ivanov.pdf
P.A. Garnåsjordet	Issue Paper on Biodiversity Accounts and Indices: Some Comments on the Difference between the Australian and Norwegian Approaches	https://unstats.un.org/unsd/envaccounting/seeaLES/egm/issue6_pag.ppt
R. Harris	Presentation of Discussant on biodiversity accounts and indexes	https://unstats.un.org/unsd/envaccounting/seeaLES/egm/Disc_issue6.ppt
Expert Meeting on Ecosystem Accounts, 16-18 May 2012, Melbourne Australia		
P.A. Garnåsjordet, J. McDonald, P. Cosier, B. ten Brink, A. Saltelli, B. Magnusson, S. Nybø, O. Skarpaas, and I. Aslaksen	Biodiversity Accounts and Indices	https://unstats.un.org/unsd/envaccounting/seeaLES/egm2/BiodiversityOP.pdf
J. McDonald, P. Gibbons, S. Bond, A. Cadogan-Cowper, J. Ovington and M. Vardon	Proposed Biodiversity Accounting in Australia	https://unstats.un.org/unsd/envaccounting/seeaLES/egm2/Biodiveristy_Aus.pdf
B. Schweppe-Kraft	Natural Capital in Germany: State and Valuation with special reference to Biodiversity	https://unstats.un.org/unsd/envaccounting/seeaLES/egm2/Biodiveristy_BSK.pdf
London Group, 12-14 November 2014, London, UK		
S. Bond, J. McDonald, M. Vardon	Experimental Biodiversity Accounting in Australia	https://unstats.un.org/unsd/envaccounting/londongroup/meeting19/LG19_16_1.pdf
M. Eigenraam, J. Chua, J. Hasker	Victorian Experimental Ecosystem Accounts	https://unstats.un.org/unsd/envaccounting/londongroup/meeting19/LG19_16_5.pdf

London Group, 17-20 October 2014, New Delhi, India		
N. Steinbach, V. Palm	Land Accounts for Biodiversity - A Methodological Study for the Allocation of Land with High Nature Values to Owners and Industries	https://unstats.un.org/unsd/envaccounting/londongroup/meeting20/LG20_3_4.pdf
C. Sbrocchi	Multiscale Environmental Asset Condition Accounts for Australia	https://unstats.un.org/unsd/envaccounting/londongroup/meeting20/LG20_3_12.pdf
Australian Bureau of Statistics	Towards Experimental Ecosystem Accounts for the Great Barrier Reef	https://unstats.un.org/unsd/envaccounting/londongroup/meeting20/LG20_3_1.pdf
London Group, 17-20 October 2015, The Hague, Netherlands		
M. Vardon, D. Lindemayer, H. Keith, S. Ferrier, P. Gibbons	Progress, Challenges and Opportunities for Biodiversity Accounting	https://unstats.un.org/unsd/envaccounting/londongroup/meeting21/Vardon%20et%20al_Biodiveristy%20Accounting%20for%20LG%20(reduced).pdf
Biodiversity Accounting based on the SEEA-Experimental Ecosystem Accounting framework, Cambridge, UK, 15th – 17th February 2016		
UNEP-WCMC (S. King, L. Wilson lead authors)	Guidance on experimental biodiversity accounting using the SEEA-EEA framework	http://wcmc.io/SEEA_EEA_Bio_Accounting
S. King, C. Brown, M. Harfoot, L. Wilson	Exploring approaches for constructing species accounts in the context of the SEEA-EEA	http://wcmc.io/Species_Accounting
London Group, 17-20 October 2016, Olso, Norway		
S. King	Biodiversity Accounting	https://unstats.un.org/unsd/envaccounting/londongroup/meeting22/F_30.pdf
1st Policy Forum on Natural Capital Accounting for Better Decision Making, 22-23 November 2017, The Hague, The Netherlands		
M. Vardon, S. King, D. Juhn, S. Bass, P. Burnett, C. Manuel Rodriguez, S. Johansson	The Aichi Targets and Biodiversity Conservation – The Role of Natural Capital Accounting	https://www.wavespartnership.org/sites/waves/files/kc/WAVES%20report%20final%20version%20%20%281%29.pdf
London Group, 17-20 October 2017, San Jose, Cost Rica		
S. King, M. Eigenraam	Accounting for ecosystem and biodiversity related themes in Uganda	https://seea.un.org/sites/seea.un.org/files/lg23_accounting_for_ecosystem_and_biodiversity_related_themes_in_uganda.pdf
M. Vardon, R. Harris	Review of ecosystem condition indicators	https://seea.un.org/sites/seea.un.org/files/lg23_review_of_ecosystem_condition_indicators_vardon-harris.pdf

2nd Policy Forum on Natural Capital Accounting for Better Decision Making, 22-23 November 2017, The Hague, The Netherlands			
R. Portela, M. Alam, C. Schneider, D. Juhn	Ecosystem accounting for water and biodiversity policies: Experience from a pilot project in Peru	https://www.wavespartnership.org/sites/waves/files/images/10.%20Ecosystem%20accounting%20for%20water%20and%20biodiversity%20policies.pdf	
S. King, M. Eigenraam, C. Obst, M. Vardon, D. Juhn	Revisiting the role of natural capital accounting for biodiversity conservation - Discussion and a case study from Uganda	https://www.wavespartnership.org/sites/waves/files/images/11.%20Revisiting%20the%20role%20of%20natural%20capital%20accounting%20for.pdf	
Forum of Experts in SEEA Experimental Ecosystem Accounting, 18 – 20 June 2018, Long Island, USA			
S. Ferrier	The Role of Biodiversity Indicators in Condition Measurement	https://seea.un.org/sites/seea.un.org/files/documents/Forum_2018/s12_area_2_ferrier_-_seea-eea_expert_forum.pdf	

Appendix 2. ACT Butterfly species (N=88) – number of sites present by season and year

Note: Includes records from systematic survey only; figure is number of surveys in which butterfly was present

Year	2014-15			2015-16			2016-17			2017-18			2018-19		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
Macleay's Swallowtail	10	6			1		4	1		15	6	8	23		1
Blue Triangle															
Pale Triangle															
Orchard Swallowtail		6			3			1		1	8	3		6	3
Chequered Swallowtail				1				1							
Dainty Swallowtail		11		1	6	2	2	4	6	6	8	5	1	13	8
Bronze Flat		4			5			2			2			2	
Heath Ochre	1			3						2					
Montane Ochre	4			1			2			11	1		4	3	
Yellow Ochre	1			1						2			1		
Orange Ochre		1			1			1		1	3			2	
Montane Grass-skipper											4				
Two-brand Grass-skipper			2		1	1			2	1	17	6		12	
Two-spotted Grass-skipper				1	1					1	1		1		
Barred Skipper		1	1		1				2		4	1		1	2
Banded Grass-skipper												1			1
Dingy Grass-skipper							1				1				
Bright Shield-skipper		1			2			3			1				
Alpine Sedge-skipper			1								1			4	1
Flame Sedge-skipper														1	
Varied Sedge-skipper														3	
White-veined Sand-skipper															

Year	2014-15			2015-16			2016-17			2017-18			2018-19		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
White-banded Grass-dart		1	1	1					1	1				1	
Greenish Grass-dart	1	6	3		4	1	2	1			3			1	
White Migrant							6								
Lemon Migrant															
Small Grass-yellow	2		1		1	1	3	1						1	
Cabbage White	28	59	17	17	19	3	12	10	6	36	49	14	11	25	25
Narrow-winged Pearl-white															
Yellow Albatross															
Caper White	6	3		3			13			8			2	5	
Spotted Jezebel	2	13	1	5	15	2	4	5	6	7	14	7		7	6
Scarlet Jezebel															
Imperial Jezebel	1	6	2	3	3		3	1	1	3	3	5	1	1	3
Black Jezebel		1													
Blue Tiger		1													
Lesser Wanderer	1						2								
Monarch															
Common Crow															
Glasswing								1							
Australian Painted Lady	30	13	6	19	23	2	39	22	1	37	15	18	41	19	12
Yellow Admiral	10	6	1	4	9		30	13	2	14	9		5	9	6
Meadow Argus	6	48	30	11	18	4	20	18	3	4	35	45	5	34	57
Varied Eggfly															
Tailed Emperor	1	5			3	2		3	6	1	8	7		4	7
Striped Xenica		1	1												
Orange Alpine Xenica											9			7	

Year	2014-15			2015-16			2016-17			2017-18			2018-19		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
Silver Xenica		1	11						4		4	11		11	4
Spotted Alpine Xenica		5			11			3			7	5		11	1
Small Alpine Xenica			3									7			3
Forest Brown													2		
Bright-eyed Brown		5			5			3			11	1		14	
Common Brown	18	54	27	9	41	3	3	22	25	16	49	67	2	42	59
Shouldered Brown		12	17		8	4		4	14		48	35		23	22
Spotted Brown		1				1			2		6	5		2	3
Banks' Brown									1			5			4
Solander's Brown					2			3	1		3				1
Ringed Xenica		4	1		7	1		11	1	1	19	4		12	1
Marbled Xenica		38	9	1	26	4		19	12	1	58	44		39	20
Bronze Ant-blue															
Golden Ant-blue		2		1	2	1		1	1	1	3		1	4	2
Small Ant-blue														1	
Chequered Copper		6	1	1	3	1	1	2			3	4		5	2
Fiery Copper					2			3			3	1		2	
Bright Copper	3	6	1	2	4		1	4		6	9	2	10	5	3
Yellow Jewel		1			1			1			1				
Moonlight Jewel							1	1		1			1	3	
Satin Azure	2	4		2	1	1	2		1	3	2	1			2
Dark Purple Azure								1	1		3			1	3
Broad-margined Azure	2	10		4	5	2	1	3	3	5	2	5	1	4	5
Southern Purple Azure					1						1	1		1	1
Stencilled Hairstreak					2			3	3		3	3		10	2

Year	2014-15			2015-16			2016-17			2017-18			2018-19		
Season	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
Imperial Hairstreak		6		1	3			4			3	2		5	
Amethyst Hairstreak		7		1	1			4			3	1		2	1
Silky Hairstreak										1					
Dark Pencil-blue															
Copper Pencil-blue															
Varied Dusky-blue	2	4		1	4		3	3	1		3	1	5	4	1
Blotched Dusky-blue		1		1	1		2		1	1	1	1	1	2	2
Rayed Blue	1				1		3			6			10		
Two-spotted Line-blue	2	3		2	3		3	12	1		4	3		5	
Montane Heath-blue		2			7			1			19			10	
Fringed Heath-blue	5	9		5	11			5		4	5			8	
Cycad Blue															
Wattle Blue				1					1		1			1	2
Saltbush Blue	1	8	3		5	2	1	1			1	2	1	4	8
Long-tailed Pea-blue		3		1		2	11	1	1	4	3	3			
Common Grass-blue	46	84	37	17	40	5	33	34	8	52	90	58	26	91	41
Total species	25	44	23	30	44	21	28	42	30	32	52	37	22	50	37
Total visits present	186	469	177	121	313	45	208	237	118	253	570	392	155	483	325

Appendix 3. ACT Butterfly survey sites (N=202) by habitat types and year surveyed

ALL SITES	Habitat type	2014-15	2015-16	2016-17	2017-18	2018-19
ANBG RF1	Urban park garden	X	X	X	X	X
ANBG RF2	Urban park garden	NS	NS	NS	X	X
ANBG RF3	Urban park garden	NS	NS	NS	X	X
ANBG DB1	Urban park garden	NS	NS	NS	X	X
ANBG DB2	Urban park garden	NS	NS	X	X	X
ANBG DB3	Urban park garden	NS	NS	NS	X	X
ANBG2	Urban park garden	X	NS	NS	NS	NS
ANBG3	Urban park garden	X	X	NS	NS	NS
Blackfellows Gap1	Subalpine and montane woodland	NS	NS	NS	X	NS
Blackfellows Gap2	Subalpine and montane woodland	NS	NS	NS	X	NS
Blackfellows Gap3	Subalpine and montane woodland	NS	NS	NS	X	NS
Black Mtn1	Dry forest	X	X	X	X	X
Black Mtn2	Dry forest	X	NS	NS	X	X
Black Mtn3	Dry forest	X	X	NS	NS	NS
Black Mtn4	Dry forest	NS	NS	NS	X	X
Blun Flat1	Montane forest	X	NS	NS	NS	X
Blun Flat2	Montane forest	X	NS	NS	NS	X
Blun Flat3	Montane forest	X	NS	NS	NS	X
Boboyan Trig1	Montane forest	NS	NS	NS	NS	X
Boboyan Trig2	Subalpine and montane woodland	NS	NS	NS	NS	X
Boboyan Trig3	Subalpine and montane woodland	NS	NS	NS	NS	X
Bogong Ck1	Grassland	NS	NS	NS	X	X
Bogong Ck2	Grassland	NS	NS	NS	X	X
Bogong Ck3	Grassland	NS	NS	NS	X	X
Bulls Head1	Urban park garden	X	X	NS	NS	NS
Burnt Hill1	Subalpine and montane woodland	NS	NS	NS	X	X
Burnt Hill2	Subalpine and montane woodland	NS	NS	NS	X	X
Burnt Hill3	Subalpine and montane woodland	NS	NS	NS	X	X
Cas Sands1	Lowland woodland riparian	X	NS	NS	X	X
Cas Sands2	Lowland woodland riparian	X	X	X	X	X
Cas Sands3	Lowland woodland riparian	X	X	X	X	X
Condor Ck1	Montane forest riparian	NS	X	X	NS	NS
Corin Rd3	Montane forest	X	NS	NS	NS	NS
Dry Gahnia 1	Subalpine and montane woodland	NS	X	X	X	NS
Dry Gahnia 2	Subalpine and montane woodland	NS	NS	NS	X	NS
Dry Gahnia 3	Subalpine and montane woodland	NS	NS	NS	X	NS
Gibr Ck1	Montane forest	X	NS	NS	X	X
Gibr Ck 2	Montane forest	NS	NS	NS	X	X
Gibr Ck 3	Montane forest	NS	NS	NS	X	X
Gibr Falls1	Montane forest riparian	X	X	NS	X	X
Gibr Falls2	Montane forest riparian	X	X	X	X	X
Gibr Falls3	Montane forest	X	X	NS	NS	NS

ALL SITES	Habitat type	2014-15	2015-16	2016-17	2017-18	2018-19
Gibr Falls4	Montane forest riparian	NS	NS	NS	X	X
Ginini Flats1	Subalpine and montane woodland	NS	NS	NS	X	X
Ginini Flats2	Subalpine and montane woodland	NS	NS	NS	X	X
Ginini Flats3	Subalpine and montane woodland	NS	NS	NS	X	X
Ginini Flats4	Wetlands	NS	NS	NS	X	X
Ginini Flats5	Wetlands	NS	NS	NS	X	X
Ginini Flats6	Wetlands	NS	NS	NS	X	X
Glendale1	Montane forest riparian	NS	NS	X	X	X
Glendale2	Montane forest riparian	NS	NS	NS	X	X
Glendale3	Montane forest riparian	NS	NS	NS	X	X
Gooroo Trig1	Lowland woodland	NS	NS	X	X	X
Gooroo Trig 2	Lowland woodland	NS	NS	NS	X	X
Gooroo Trig 3	Lowland woodland	NS	NS	NS	X	X
Gooroo Grass Sl1	Grassland	X	X	X	X	X
Gooroo Grass Sl2	Grassland	NS	NS	NS	X	X
Gooroo Grass Sl3	Grassland	NS	NS	NS	X	X
Gooroo Dam1	Lowland woodland riparian	NS	NS	X	X	X
Gooroo Dam2	Lowland woodland riparian	NS	NS	NS	X	X
Gooroo Dam3	Lowland woodland riparian	NS	NS	NS	X	X
Gooroo Grass Fl1	Grassland	X	X	X	X	X
Gooroo Grass Fl2	Grassland	NS	NS	NS	X	X
Gooroo Grass Fl3	Grassland	NS	NS	NS	X	X
Gooroo Wdld1	Lowland woodland	X	X	X	X	X
Gooroo Wdld2	Lowland woodland	NS	NS	NS	X	X
Gooroo Wdld3	Lowland woodland	NS	NS	NS	X	X
Gun Hill1	Dry forest	X	NS	NS	NS	NS
Honeys Ck1	Montane forest	X	NS	NS	NS	NS
Jerra Wetld1	Urban park garden	X	NS	NS	NS	NS
Kroo Ck2	**Montane forest riparian**	X	NS	X	X	X
Kroo Ck 1	Montane forest	NS	NS	NS	X	X
Kroo Ck 3	Montane forest	NS	NS	NS	X	X
Long Flat Wetland1	Wetlands	NS	NS	NS	X	X
Long Flat Wetland2	Wetlands	NS	NS	NS	X	X
Long Flat Wetland3	Wetlands	NS	NS	NS	X	X
Long Flat Wdld1	Subalpine and montane woodland	NS	NS	NS	X	X
Long Flat Wdld2	Subalpine and montane woodland	NS	NS	NS	X	X
Long Flat Wdld3	Subalpine and montane woodland	NS	NS	NS	X	X
Long Flat Forest1	Montane forest	NS	NS	NS	X	X
Long Flat Forest2	Montane forest	NS	NS	NS	X	X
Long Flat Forest3	Montane forest	NS	NS	NS	X	X
Molonglo G1	**Dry forest riparian**	X	X	X	X	X
Molonglo G2	**Dry forest riparian**	X	X	X	X	X
Molonglo G3	**Dry forest riparian**	X	X	X	X	X

ALL SITES	Habitat type	2014-15	2015-16	2016-17	2017-18	2018-19
Mt Aggie1	Montane forest	X	NS	NS	NS	NS
Mt Aggie2	Subalpine and montane woodland	X	X	X	X	X
Mt Aggie3	Subalpine and montane woodland	X	NS	NS	X	X
Mt Aggie4	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Ainslie1	Dry forest	X	X	X	X	X
Mt Ainslie2	Dry forest	X	X	X	X	X
Mt Ainslie3	Dry forest	X	X	NS	NS	NS
Mt Ainslie4	Dry forest	NS	NS	NS	X	X
Mt Clear1	Grassland	X	X	X	X	X
Mt Clear2	Grassland	NS	NS	NS	X	X
Mt Clear3	Grassland	NS	NS	NS	X	X
Mt Coree1	Subalpine and montane woodland	NS	NS	NS	NS	X
Mt Coree2	Subalpine and montane woodland	NS	NS	NS	NS	X
Mt Coree3	Subalpine and montane woodland	NS	NS	NS	NS	X
Mt Franklin1	Subalpine and montane woodland	X	NS	NS	NS	NS
Mt Gingera Summit1	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Gingera Summit2	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Gingera Summit3	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Gingera Woodland1	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Gingera Woodland2	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Gingera Woodland3	Subalpine and montane woodland	NS	NS	NS	X	X
Mt Ginini1	Subalpine and montane woodland	X	X	X	X	X
Mt Ginini2	Subalpine and montane woodland	X	X	X	X	X
Mt Ginini3	Subalpine and montane woodland	X	X	X	X	X
Mt Majura Summit1	Lowland woodland	NS	NS	X	X	X
Mt Majura Summit2	Lowland woodland	NS	NS	NS	X	X
Mt Majura Summit3	Lowland woodland	NS	NS	NS	X	X
Mt Majura Waterfall1	Lowland woodland	NS	NS	X	X	X
Mt Majura Waterfall2	Lowland woodland	NS	NS	NS	X	X
Mt Majura Waterfall3	Lowland woodland	NS	NS	NS	X	X
Mt Majura Track1	Lowland woodland	NS	NS	X	X	X
Mt Majura Track2	Lowland woodland	NS	NS	NS	X	X
Mt Majura Track3	Lowland woodland	NS	NS	NS	X	X
Mt Painter1	Lowland woodland	X	X	NS	X	X
Mt Painter2	Grassland	X	X	NS	X	X
Mt Painter3	Grassland	X	X	NS	X	X
Mt Pleasant1	Lowland woodland	X	NS	NS	NS	NS
Mt Stromlo	Urban park garden	X	NS	NS	NS	NS
Mull Flat Grass1	Grassland	X	NS	NS	NS	X
Mull Flat Grass2	Grassland	NS	NS	NS	NS	X

ALL SITES	Habitat type	2014-15	2015-16	2016-17	2017-18	2018-19
Mull Flat Grass3	Grassland	NS	NS	NS	NS	X
Mull Flat Heath1	Lowland woodland	X	NS	NS	NS	X
Mull Flat Heath2	Lowland woodland	NS	NS	NS	NS	X
Mull Flat Heath3	Lowland woodland	NS	NS	NS	NS	X
Mull Flat Forest1	Lowland woodland	X	NS	NS	NS	X
Mull Flat Forest2	Lowland woodland	NS	NS	NS	NS	X
Mull Flat Forest3	Lowland woodland	NS	NS	NS	NS	X
Naas Valley1	Subalpine and montane woodland	NS	NS	NS	X	X
Naas Valley2	Subalpine and montane woodland	NS	NS	NS	X	X
Naas Valley3	Subalpine and montane woodland	NS	NS	NS	X	X
Naas Valley4	Subalpine and montane woodland	NS	NS	NS	X	X
Naas Valley5	Subalpine and montane woodland	NS	NS	NS	X	X
Naas Valley6	Subalpine and montane woodland	NS	NS	NS	X	X
NVC1	Lowland woodland	X	NS	NS	NS	X
NVC2	Lowland woodland	NS	NS	NS	NS	X
NVC3	Lowland woodland	NS	NS	NS	NS	X
Orroral Valley1	Montane forest riparian	NS	NS	X	X	X
Orroral Valley2	Montane forest riparian	NS	NS	NS	X	X
Orroral Valley3	Montane forest	NS	NS	NS	X	X
Picc Circ1	Subalpine and montane woodland	X	X	NS	NS	X
Picc Circ2	Subalpine and montane woodland	X	NS	NS	NS	X
Picc Circ3	Montane forest	X	NS	NS	NS	X
Pinnacle1	Dry forest	NS	NS	NS	NS	X
Pinnacle2	Dry forest	NS	NS	NS	NS	X
Pinnacle3	Dry forest	NS	NS	NS	NS	X
Point Hut Xing1	Urban park garden	X	NS	NS	NS	NS
Red Hill1	Urban park garden	X	NS	X	NS	X
Red Hill2	Urban park garden	NS	NS	NS	NS	X
Red Hill3	Lowland woodland	NS	NS	NS	NS	X
Red Hill4	Lowland woodland	NS	NS	NS	NS	X
Red Hill5	Lowland woodland	NS	NS	NS	NS	X
Red Hill6	Lowland woodland	NS	NS	NS	NS	X
Rendezvous Ck1	Montane forest	NS	NS	NS	X	X
Rendezvous Ck2	Montane forest	NS	NS	NS	X	X
Rendezvous Ck3	Montane forest	NS	NS	NS	X	X
Shan Mtn1	Montane forest	X	NS	NS	NS	NS
Shan Mtn2	Montane forest	NS	X	NS	NS	NS
Smokers Gap1	Wetlands	X	X	X	X	X
Smokers Gap2	Montane forest	X	NS	NS	NS	NS
Smokers Gap3	Montane forest	X	NS	NS	NS	NS
Smokers Gap4	Wetlands	NS	NS	NS	X	X
Smokers Gap5	Wetlands	NS	NS	NS	X	X
Smoker's Gap CP1	Wetlands	NS	NS	NS	NS	X

ALL SITES	Habitat type	2014-15	2015-16	2016-17	2017-18	2018-19
Smoker's Gap CP2	Subalpine and montane woodland	NS	NS	NS	NS	X
Smoker's Gap CP3	Wetlands	NS	NS	NS	NS	X
Stockyard1	Subalpine and montane woodland	X	X	NS	X	X
Stockyard2	Wetlands	X	X	NS	X	X
Stockyard3	Subalpine and montane woodland	X	X	NS	X	X
Tidbin Black Flat1	**Montane forest riparian**	X	X	X	X	X
Tidbin Black Flat2	Montane forest	NS	NS	NS	X	X
Tidbin Black Flat3	Montane forest	NS	NS	NS	X	X
Tidbin Heath2	Montane forest	NS	X	X	X	X
Tidbin Heath1	Montane forest	NS	NS	NS	X	X
Tidbin Heath3	Montane forest	NS	NS	NS	X	X
Tidbin WF1	Wet forest	X	NS	NS	X	X
Tidbin WF2	Wet forest	NS	NS	NS	X	X
Tidbin WF3	Wet forest	NS	NS	NS	X	X
Tidbin3	Montane forest	X	NS	NS	NS	NS
Tugg Hill1	Lowland woodland	X	X	X	X	X
Tugg Hill2	Lowland woodland	X	X	X	X	X
Tugg Hill3	Lowland woodland	X	X	X	X	X
Uriarra Xing1	Lowland woodland	X	NS	NS	NS	NS
Warks Rd1	Wet forest	NS	X	X	X	X
Warks Rd2	Wet forest	NS	NS	NS	X	X
Warks Rd3	Wet forest	NS	NS	NS	X	X
Warks Rd4	Wet forest	NS	NS	NS	X	X
Warks Rd5	Wet forest	NS	NS	NS	X	X
Warks Rd6	Wet forest	NS	NS	NS	X	X
Warks Rd7	Wet forest	NS	NS	NS	X	X
Warks Rd8	Wet forest	NS	NS	NS	X	X
Warks Rd9	Wet forest	NS	NS	NS	X	X
Yankee Hat1	Grassland	NS	NS	X	X	X
Yankee Hat2	Grassland	NS	NS	NS	X	X
Yankee Hat3	Grassland	NS	NS	NS	X	X
Yerrabi Tk1	Wetlands	X	X	X	X	X
Yerrabi Tk2	Wetlands	NS	NS	NS	X	X
Yerrabi Tk3	Wetlands	NS	NS	NS	X	X