2

Methods

Database

The data compiled for this atlas were stored and managed in a dedicated relational database, using Microsoft Access, developed by the Northern Territory Flora and Fauna Division, and is now publicly available through the *Atlas of Living Australia* (www.ala.org.au). The database was constructed specifically to manage invertebrate data collected from targeted field surveys of threatened species, faunal inventories and incidental observations. The structure of this database is shown in Figure 1. The fields were organised into six tables, of which the three most relevant are the taxon table, the site table and the incidental table. Descriptions of some of the more critical fields used to capture data are summarised in Table 1.

The total number of species records assembled for this project was 23,885, of which 13,146 (55 per cent) were observations, 8,110 (34 per cent) specimens and 2,629 (11 per cent) literature. The spatial and temporal data collected for each species consisted of five main sources: vouchered specimens (S), specimens netted and released (N), photographs (P), field observations (O) and scientific literature (L) (Table 1). For the purposes of this work, codes N, P and O were combined into a single category, 'Observation'. Vouchered specimens consisted of specimens in museum collections and in most cases these are registered with an accession number. The majority of specimens are registered in the Museum and Art Gallery of the Northern Territory (NTM), the Northern Territory Economic Insect Collection (NTEIC) and the Australian National Insect Collection (ANIC). Some additional museum data were sourced through the *Atlas of Living Australia*, particularly for material that has been registered and databased in the South Australian Museum (SAM), Museum Victoria (NMV) and Australian Museum (AM).

A 'species record' was defined as a unique site–date occurrence for a particular species. Sites were defined as point localities more than 1 km apart (i.e. the spatial precision from the centre of the point was 500 m) and locations were defined as areas more than 10 km apart. For example, if 10 species were observed at a site (e.g. Lameroo Beach, the Esplanade, Darwin, Northern Territory) and then the same 10 species were observed at another nearby site, more than 1 km away but less than 10 km distant (e.g. East Point Reserve, Darwin, Northern Territory), on the same day (e.g. 1 January 2000), that would comprise a total of 20 species records from one location representing two sites.

Geocoordinates of all spatial records were first transformed to decimal degrees if required and then plotted using ArcMap, ArcGIS 10.3 Esri. Our dataset consisted of 4,352 spatial records (i.e. unique sampling sites), which are shown in

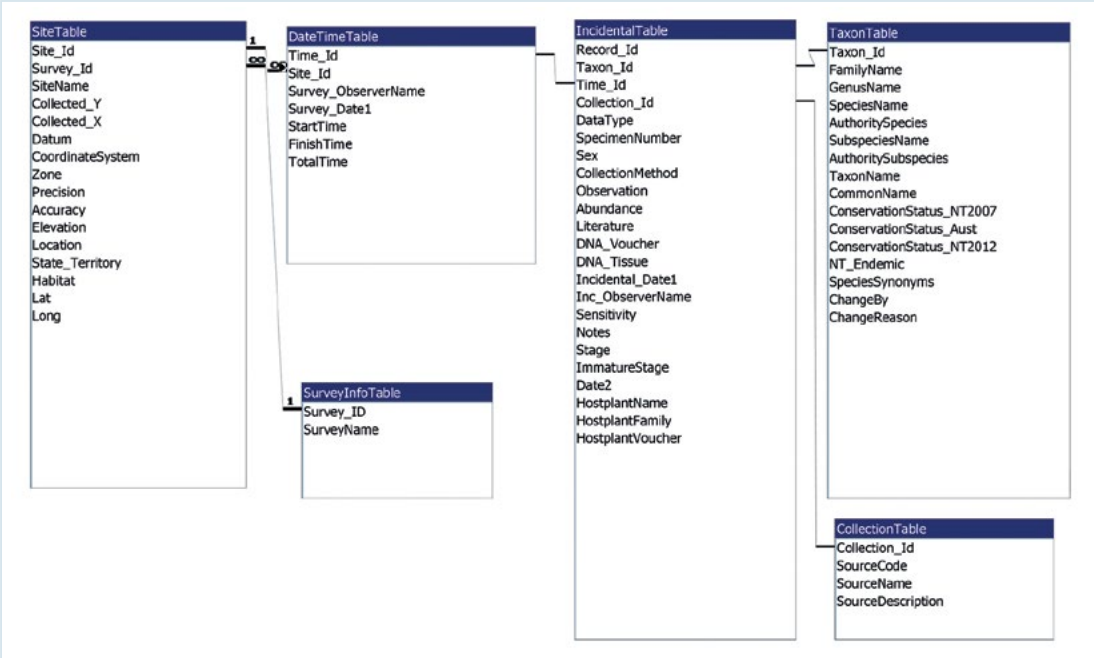
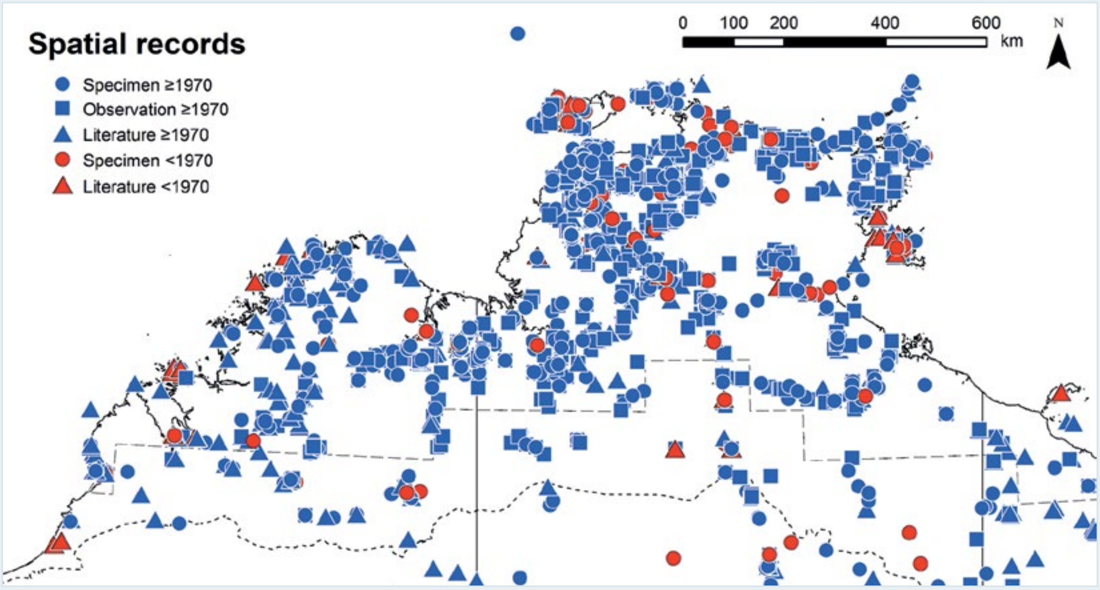


Figure 1 Structure and relations of the database used to manage species records
Source: Prepared by the authors.



Map 4 Geographical distribution of spatial records (unique sampling sites) within the study region (n = 4,352)
Source: Prepared by the authors.

Map 4. The distribution of these spatial records shows that most areas within the study region have been sampled, but to varying extents. For instance, there is a strong bias in sampling towards urban areas, such as around the city of Darwin in the north-western corner of the Top End. In contrast, there are fewer sites from the semi-arid and arid zones towards the southern boundary of the study region. Some areas have been very sparsely sampled, such as eastern Arnhem Land, the Barkly Tableland, the Tanami Desert and the Great Sandy Desert.

Excluded records

During the course of compiling an inventory of butterflies and diurnal moths for the study region, a number of records came to our attention that required scrutiny or clarification. Several of these records have already been removed from the inventory following detailed investigation and analysis (see Meyer et al. 2006; Braby 2008a, 2012b, 2014a). These records were excluded because they were deemed to be in error, comprising taxonomic misidentifications (determination errors) or mislabelling (transcription errors), or there was considerable doubt regarding their authenticity, with insufficient evidence provided to substantiate them. Thus, we do not recognise the following 10 species from the study region: *Pachliopta liris*, *Oriens augustulus*, *Pseudoborbo bevani*, *Pelopidas agna*, *Telicota ancilla*, *Telicota mesoptis*, *Deudorix diovis*, *Theclinesthes onycha*, *Theclinesthes serpentatus* and *Leptotes plinius*. In the case of *Telicota ancilla* (for the subspecies *T. ancilla baudina*), the taxon proved to be a junior synonym of *T. augias krefftii* (Braby 2012b).

Table 1 Descriptions of some of the critical fields used to capture species data, with an example provided to illustrate how data were coded for an individual species record

Field name	Description	Example
Taxon table		
FamilyName	Name of family	Papilionidae
GenusName	Name of genus	*Protographium*
SpeciesName	Name of species	*leosthenes*
AuthoritySpecies	Authority of species	(Doubleday 1846)
SubspeciesName	Name of subspecies	*geimbia*
AuthoritySubspecies	Authority of subspecies	(Tindale 1927)
TaxonName	Genus_species_subspecies	*Protographium leosthenes geimbia*
CommonName	Common name	Kakadu Swordtail
Site table		
SiteName	Site code name or number	
Collected_Y	Y coordinates (latitude or northing)	12.84262ºS
Collected_X	X coordinates (longitude or easting)	132.81895ºE
Datum	WGS84, GDA94 or AGD66	WGS84
CoordinateSystem	Dd = decimal degrees, DMS = degrees, minutes, seconds, DMm = decimal minutes, or E_N (easting and northing)	Dd
Zone	Only when projected coordinate system is used (E_N)	
Precision	Radius from point: 5 m, 10 m, 50 m, 100 m, 250 m, 500 m	250 m
Accuracy	Error in point reading	
Elevation	Elevation (m)	50 m
Location	Description of location name	Kakadu National Park, Nourlangie Rock, Nanguluwur Art site
State_Territory	NT, WA, Qld	NT

Field name	Description	Example
Habitat	Vegetation community	Monsoon vine thicket at base of sandstone cliff
Lat	Mapping Y coordinates converted to latitude in Dd with GDA94 or WGS84	–12.84262
Long	Mapping X coordinates converted to longitude in Dd with GDA94 or WGS84	132.81895
Incidental table		
DataType	S = specimen, O = observation, L = literature, N = netted and released, P = photograph	S
SpecimenNumber	Museum repository/private collection and voucher number of specimen collected	NTM I005572
Sex	M = male, F = female	F
CollectionMethod	Sweep net, hand, light trap, etc.	Hand
Literature	Author (year)	
Date1	Day/month/year	20 December 2009
ObserverName	Initials and surname	M. F. Braby
Notes	Early stages, adult behaviour numbers collected etc.	6 larvae, various instars, collected from LFP growing at base of escarpment
Stage	A = adult, I = immature	I
ImmatureStage	E = egg, L = larva, P = pupa	L
Date2	Date of adult emergence for reared specimen	8 January 2010
HostplantName	Name of genus and species of larval food plant	*Melodorum rupestre*
HostplantFamily	Name of family of larval food plant	Annonaceae
HostplantVoucher	Herbarium repository and voucher number of plant specimen	M. F. Braby 200, DNA

Data analysis

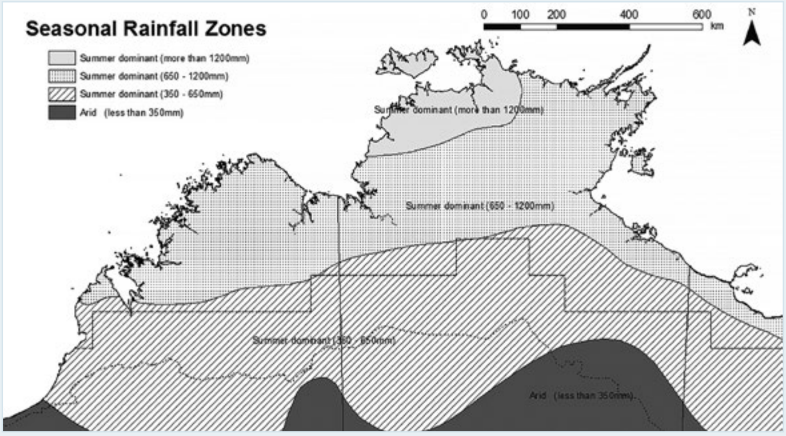
Geographic range

The geographic range (Maps 6–8) of each butterfly and diurnal moth species was estimated directly from the distribution of spatial records or inferred by combining these records with those of larval food plant(s) or attendant ant. The geographic ranges were generated using a rule set based on the minimum distances between distribution records and, where applicable, the larval food plant or attendant ant data. Records for larval food plants included both known and putative species; however, only native food plant records were plotted.

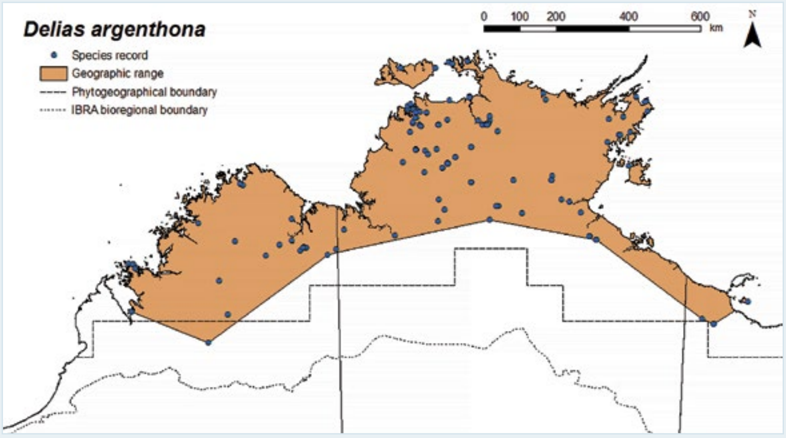
For each species, several criteria were used to create polygons to estimate the geographic range and determine whether ranges were continuous or disjunct. Based on the distances between spatial records, distributions were classified as continuous or disjunct, with continuous distributions incorporated into range polygons and disjunct distributions surrounded by an arbitrary buffer of 15 km so they could be clearly discerned in the range maps. The method is broadly similar to the α-hull recommended by the IUCN Standards and Petitions Subcommittee (2016) for estimating the extent of occurrence (EOO) of a taxon, but with some notable differences, as follows.

Continuous distribution

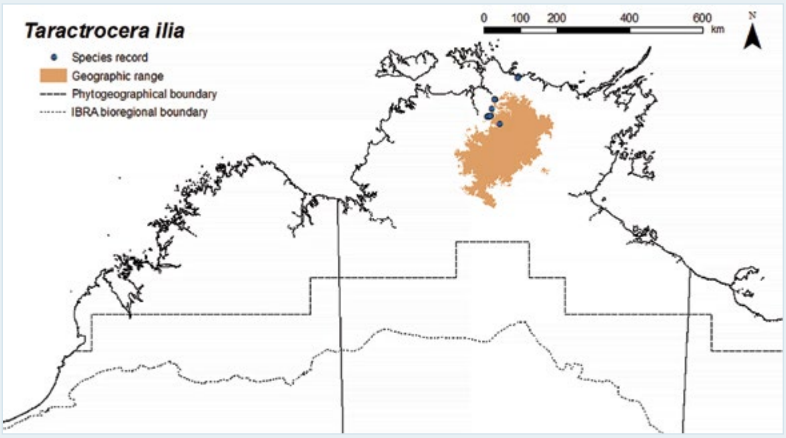
Distribution records were included in the polygon only if they were located within a specified distance of one another or had intervening larval food plant records. Thus, the distribution was considered to be continuous when spatial records within the geographic range were 200 km apart, with or without intervening larval food plant records, or 200–500 km apart, but only with intervening



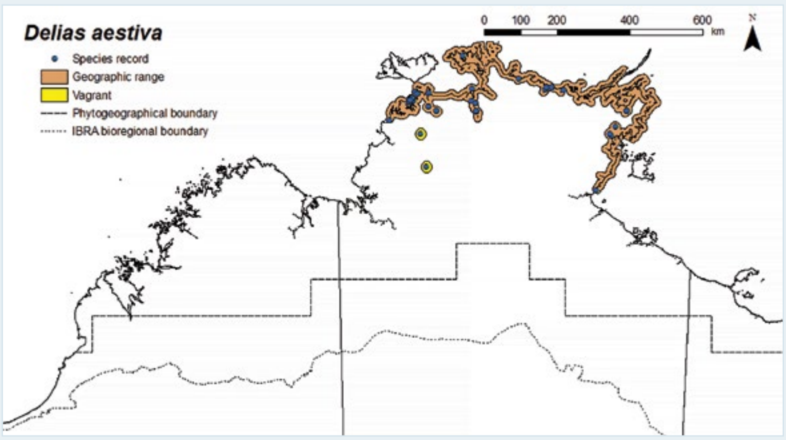
Map 5 Seasonal rainfall zones of northern Australia
Source: After Gaffney (1971).



Map 6 Example of the method used to estimate geographic range: *Delias argenthona*, a species with a continuous distribution, as inferred from distribution records and larval food plant data
Source: Prepared by the authors.



Map 7 Example of the method used to estimate geographic range: *Taractrocera ilia*, a narrow-range endemic restricted to the Arnhem Land Plateau
Source: Prepared by the authors.



Map 8 Example of the method used to estimate geographic range: *Delias aestiva*, a species normally restricted to coastal habitats (mangrove), but with two inland non-breeding records (vagrants)
Source: Prepared by the authors.

larval food plant records. These distances were chosen as a conservative estimate for how far a species may disperse in the presence or absence of larval food plants. Distribution records that fell outside these thresholds were considered to be disjunct (see below). However, there was a sampling bias in the study region (for butterflies and diurnal moths and their larval food plants) related both to the distance from major urban centres and to seasonal rainfall zones (Map 5), with comparatively few distribution records from the remote semi-arid and arid zones (< 700 mm mean annual rainfall). Thus, to adjust for this sampling bias, different distance rule sets were applied to records from the lower rainfall zones with intervening larval food plant data (Table 2).

In addition, seven other criteria based on particular idiosyncrasies of the data or geography were applied to estimate the geographic range for continuous distributions. First, for those species for which the larval food plant was unknown, distribution records were included in the polygon when the distance between them was less than 500 km. Second, marine areas were excluded from polygons and the distance rule sets were not applied across marine gaps, such as gulfs. Third, if a species occurred on any of the larger islands (Bathurst, Melville, Groote or Mornington), the whole island was included in the geographic range. However, if a species had not been recorded from an island, the island was excluded from the geographic range, even if the larval food plant was present and it fell within the polygon. Fourth, areas near the coast (i.e. within 150 km of the coastline) and nearby small islands that fell outside the line joining two distribution records were included in the geographic range, but only if the larval food plant was present or if the butterfly would be expected to occur in the intervening area based on expert opinion. Fifth, for species known to be restricted to particular geological elements—for example, the sandstone plateau of western Arnhem Land—the geological element was used to delimit the geographic range (Map 7). It should be noted that the eastern part of the sandstone plateau of western Arnhem Land is difficult to access and hence there is a paucity of larval food plant (and butterfly/diurnal moth) data from this remote area. Sixth, for species restricted to coastal habitats (e.g. mangroves, saltmarsh), a 10 km wide buffer was applied along the coastline and along mangrove/saltmarsh-lined watercourses between distribution records to estimate the geographic range (Map 8). Finally, for widespread species known to occur throughout the central arid zone, poorly sampled areas such as the south-eastern corner of the study region were included in the geographic range, despite the absence of distribution records.

Disjunct distribution

Distribution records were considered to be disjunct or isolated when the closest points were separated by 200 km or more and there were no intervening larval food plant records, or when the closest points were separated by more than 500 km and there were intervening larval food plant records. However, as noted above, different distance rule sets were applied to the lower rainfall areas of the semi-arid and arid zones (Table 2) to account for the low sampling effort in the southern half of the study region.

Disjunct or isolated distribution records may represent: 1) resident breeding populations, 2) vagrant individuals or 3) temporary range expansions. Disjunct resident breeding populations comprising a single isolated point, or a small cluster of points, outside the main distribution were included in the geographic range with a 15 km buffer. However, often we were not able to distinguish whether the disjunction was a natural one due to an inhospitable area (e.g. absence of breeding habitat) between two resident breeding populations or simply due to low sampling effort in the intervening area. Vagrant individuals or temporary breeding populations outside the normal breeding range were not included in the geographic range size calculations, and were buffered in a contrasting colour (yellow) to indicate their exclusion from the natural geographic range (Map 8).

Endemism

Taxa restricted to the study region are referred to as endemics. We distinguished three types of endemics according to their geographic

Table 2 Threshold criteria used to determine the inclusion of butterfly and diurnal moth distribution records in the continuous range polygon with intervening larval food plant records according to mean annual rainfall zones

Seasonal rainfall zone	Distance between spatial records (km)
Summer dominant rainfall zone (≥ 700 mm)	≤ 500
Summer dominant rainfall, semi-arid zone (350–700 mm)	≤ 750
Arid zone (≤ 350 mm)	≤ 1,000

Note: See also Map 5.

range size. Taxa that had small geographical range sizes (≤ 40,000 sq km) were categorised as 'narrow-range endemics', whereas those that had exceedingly small distributions (≤ 10,000 sq km) were classified as 'short-range endemics' following the definition of M. S. Harvey (Harvey 2002; Harvey et al. 2011). Taxa with slightly larger ranges (40,000–100,000 sq km) were considered 'restricted'. The 40,000 sq km threshold for narrow-range endemism was chosen because this is the maximum extent of the Arnhem Land Plateau—an area that supports numerous endemic plants (Woinarski et al. 2006) and invertebrates (Andersen et al. 2014).

Relative abundance

Seasonal trends in relative abundance throughout the year were graphed for each species. Relative abundance was estimated from data pooled across the species' range based on the number of temporal records for each month. For our purposes, a temporal record was defined as the occurrence on a particular date (time) at a given site (space) irrespective of the number of adults recorded or time spent at the site. As noted above, the spatial precision of sites was set to a 500 m radius from its central point—that is, a minimum distance of 1 km was used to distinguish two adjacent sites sampled on the same day. Only species with more than 25 temporal records were plotted, along with two highly seasonal species, Genus 1 sp. 'Sandstone' and *Periopta ardescens*, which had 21 and 23 temporal records, respectively.

The dataset comprised 4,603 temporal records (i.e. unique sampling dates); however, there was substantial seasonal variation, with April having the most records and three times more than September, which had the least (Figure 2). This seasonal difference reflects a bias in sampling effort when surveys or field collections are generally undertaken: April heralds the end of the wet season, when areas become increasingly accessible and insect activity for many species is at its greatest, whereas September coincides with the end of the dry season, when conditions are dry and hot and insect activity is considerably reduced. Hence, more surveys have been carried out in the late wet season than in the late dry season. Thus, to minimise the effect of this seasonal bias in sampling on interpretation of seasonal patterns, we applied a correction factor to adjust for the variation in sampling effort for each month, calculated as follows: correction factor = 616 / n, where 616 is the maximum number of temporal records in April and n is the total number of temporal records in the month (see Table 3).

Table 3 Correction factor used to estimate relative abundance for each month to account for seasonal variation in sampling effort (the number of temporal records)

Month	Number of records	Correction factor
January	392	1.571
February	394	1.563
March	484	1.273
April	616	1.000
May	524	1.176
June	450	1.369
July	388	1.588
August	327	1.884
September	206	2.990
October	312	1.974
November	270	2.282
December	240	2.567

Note: For seasonal variation in the number of temporal records, see Figure 2.

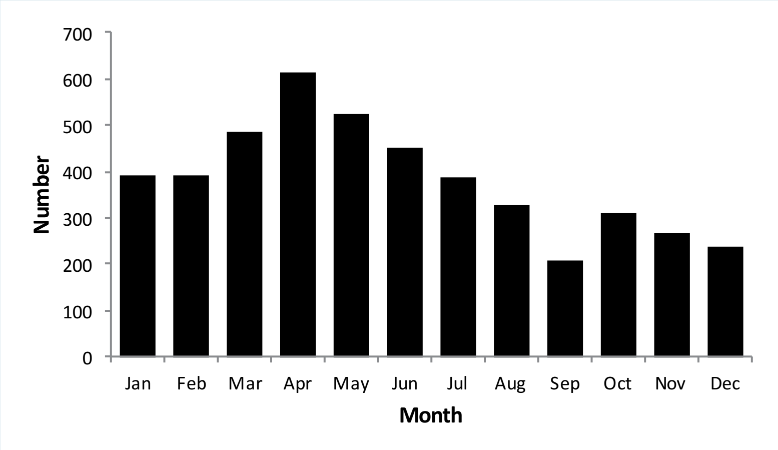


Figure 2 Seasonal variation in the number of temporal records (unique sampling dates) within the study region (*n* = 4,603)
Source: Prepared by the authors.

Nomenclature

Scientific nomenclature for butterflies largely follows Braby (2010b, 2011b, 2016a), while that for moths follows Nielsen et al. (1996). The recent proposal to place the species *Mycalesis sirius* in the genus *Mydosama* (Kodandaramaiah et al. 2010; Aduse-Poku et al. 2015) is followed. Nomenclature for plants follows the *Australian Plant Census* (2017) and FloraBase (2017). We have also included nine undescribed species of diurnal moths (from the families Castniidae, Zygaenidae, Geometridae, Erebidae and Noctuidae) and five undescribed subspecies of butterflies (from the families Hesperiidae, Pieridae and Lycaenidae). Formal descriptions of these taxa are currently in preparation (M. F. Braby, unpublished data).

The taxonomic status of the pierid *Elodina tongura* (Pipeclay Pearl-white), which is endemic to the Top End, requires comment. It is closely related to *E. walkeri* and may be a junior synonym of that species. *Elodina tongura* was originally described by Tindale (1923) as a subspecies of *E. perdita*, based on 16 specimens collected from Groote Eylandt and Winchelsea and Woodah islands, in the Northern Territory, in the wet season between February and April. However, De Baar and Hancock (1993) and De Baar (2004) treated *E. tongura* as a separate species, considering it to be closely allied to *E. walkeri*, which was reinstated by De Baar and Hancock (1993) as a species distinct from *E. perdita*. The type locality of *E. walkeri* is Darwin (Edwards et al. 2001). De Baar (2004) indicated that *E. walkeri* and *E. tongura* are sympatric in the Darwin region and possibly elsewhere in coastal areas of the Northern Territory, and alluded to differences in adult size, the shade of the yellow basal patch on the underside of the forewing and length of the vesica of the male phallus to distinguish the two species. In contrast, Braby (2000) regarded *E. tongura* as a junior synonym of *E. walkeri* based on examination of the syntypes, an extensive series of other material and an unpublished geographical study of the male genitalia. It was concluded that many of the character differences (e.g. adult size, yellow basal flash on the underside of the forewing, the presence of a dark apical patch on the underside of the forewing and the shape of the forewing apex) vary seasonally; thus, the validity of *E. tongura* as a distinct taxon was considered very doubtful. In the present work, we have therefore not recognised *E. tongura* until a thorough taxonomic study of the complex is undertaken.

Common names for butterflies follow Braby (2016a); however, most of the diurnal moths do not have standard common names, although some genera do have group names—for example, 'sun-moth' for *Synemon*. Hence, we have proposed common names for all species of moths, including the names for three species of sun-moths recently given by Williams et al. (2016).

Species accounts

Distribution

For each species, the geographical distribution of records, along with those of its native and/or putative larval food plant(s), is presented. For some species of Lycaenidae that are obligately attended by ants or are ant predators—notably, *Liphyra brassolis*, *Acrodipsas* spp., *Hypochrysops* spp., *Arhopala* spp. and *Hypolycaena phorbas*—the spatial distribution of the ant is also included.

Data for known and putative larval food plants were extracted from *Australia's Virtual Herbarium* (2017). For each plant species, records were vetted using the following procedure. Records were first removed if they were flagged as being of uncertain identity, cultivated, had more than 10 km uncertainty in the coordinates, had no coordinates or were outside the study region by more than one degree of latitude or longitude. The remaining records were then examined spatially and compared against benchmark publications—Liddle et al. (1994) for the Northern Territory and FloraBase (2017) for Western Australia—to identify obvious outliers. Where outliers were detected, the record was examined for potential errors such as mismatches between location and coordinates, and then either deleted or corrected if such an error was detected.

Data for ants were obtained either from the *Atlas of Living Australia* (for *Oecophylla smaragdina*) or from specimens curated in the Tropical Ecosystems Research Centre (TERC) and the ANIC (for *Froggattella kirbii* and *Papyrius* spp.).

For each butterfly and diurnal moth, spatial records were divided into two periods: historical (before 1970) and contemporary (1970 onwards). There were two reasons for this approach. First, prior to 1970 there was comparatively little collecting effort in the study region and a similarly low level of reporting in the scientific literature. Second, locality data for specimens collected before 1970 were rarely, if ever, georeferenced with latitude and longitude; it was not until detailed topographic maps (employing the AGD66 datum) became widely available in the late 1960s and early 1970s that professional entomologists started to routinely include geographic coordinates on their label data. Hence, plotting for historical records almost invariably has low precision and large spatial errors. For example, Tindale (1923) was stationed on Groote Eylandt—an island measuring approximately 70 km by 50 km—for almost a year (June 1921 – May 1922) and published a detailed list of the 52 species he recorded, which included temporal data on the months during which specimens were collected. However, Tindale (1923: 349) mentioned the actual place of capture in the text for only one species: 'female [*Liphyra brassolis*] flew to a light at 8.30 p.m. on a sultry night, in my camp at Yetiba'. For the others, precise locations were not given. Thus, plotting most of Tindale's records for Groote Eylandt with any level of precision is problematic. In this case, we have assigned and plotted all records to 'Yedikba' (Yetiba) (14.079°S, 136.457°E), approximately 25 km south of Alyangula, because this is the only site where we can be certain Tindale was stationed, but the spatial error of such records may well be more than 10 km.

Where multiple data points had the same geographic coordinate, we plotted the contemporary records (≥ 1970, blue symbols) over historic records (< 1970, red symbols) to emphasise more recent occurrences. Thus, for some species historical records may not always be clearly visible in the distribution maps.

Comparison of the spatial distribution of a butterfly or diurnal moth species with its larval food plant(s) required exploration of possible reasons for discrepancies where differences arose. For example, a species may be more widespread than its larval food plant because: 1) the adult regularly disperses outside its breeding area (i.e. the non-breeding distribution is wider than the breeding distribution); 2) the species has additional food plants that have not yet been reported (i.e. knowledge of the breeding area is incomplete); or 3) the food plant may be underreported and is in fact more widespread than herbarium records indicate. Conversely, a species may be less widespread than its larval food plant because: 1) the species' distribution may be limited by factors other than the food plant, such as climate; 2) breeding populations of the species may be limited to areas where the food plant occurs above a threshold density or where the extent of the breeding habitat is above a critical minimum size; or 3) the species' distribution may be underreported and thus our knowledge of it is incomplete.

Excluded data

A number of spatial records were found to be erroneous or doubtful. These records are listed for the relevant species and the data are excluded from the distribution maps. Braby (2000, 2012b, 2014a) and Braby and Zwick (2015) have previously discussed the reliability of some of these records.

Habitat

The habitats listed for each species refer to breeding habitats—that is, where the species completes its life cycle from egg to adult and where the particular larval food plants grow. Habitats were based largely on natural vegetation types and structural classification according to the *National Vegetation Information System* (Executive Steering Committee for Australian Vegetation Information 2003), together with topographic features and climatic factors. The adult stage of butterflies and diurnal moths may also use other habitats for feeding (e.g. nectar resources) and mating (e.g. landmarks such as hilltops); however, for most species in the study region, these habitats were not well known and thus are generally not reported in this work.

Larval food plants

The known larval food plants, both native and non-native species, are summarised for each species based on records published in the scientific literature and our own unpublished observations. Where multiple food plants were used, comments on any apparent preferences are noted. If the larval food plant had not been recorded from the study region, we listed the food plant reported from adjacent areas—usually northern Queensland. In most cases, these putative larval food plant records were derived from Braby (2000, 2016a), although in some cases we referred to the primary literature source.

Attendant ants

The larvae, and to some extent pupae, of many Lycaenidae are attended by ants to various degrees. In this work, these ant–lycaenid associations are grouped into five categories: 1) those species not attended by ants; 2) those species usually unattended, but very occasionally attended by a few ants; 3) those species attended by a few ants from several genera in a facultative association; 4) those species constantly attended by many ants of a specific species or genus in an obligate association; and 5) those species that are dependent on ants as a food source in a myrmecophagous association. Ant associations are based primarily on information collated by Eastwood and Fraser (1999) and Braby (2000), combined with subsequent records published in the scientific literature and our own unpublished observations.

Seasonality

For each species, the broad adult flight period and patterns of seasonal changes in relative abundance are given. Additional information on breeding, incidence of the immature stages (eggs, larvae and pupae), number of generations completed annually and incidence of dormancy are also provided where known. A phenology chart showing monthly temporal records of the immature stages is also presented for each species. These charts are necessarily incomplete, but are provided for two reasons: 1) to give an approximation of when the various stages are present during the year; and 2) to highlight knowledge gaps in recording of the life cycle stages. For instance, for some species there are very few or no available temporal data on the incidence of their eggs, larvae or pupae. Migration records are also summarised where this has been reported.

Breeding status

The breeding status of each species was determined, noting whether it was: 1) a resident, in that the species breeds regularly and is permanently established in the study region; 2) an immigrant, in which the species breeds temporarily within the study region and then vacates it on a regular basis; 3) a visitor, in that the species does not breed within the study region, but regularly occurs within its boundaries; or 4) a vagrant, in which the species does not breed and only occasionally or rarely enters the study region, usually in very small numbers. Resident species include those that are nomadic—that is, the population occurs regularly within the study region, but at any given location breeding is temporary.

Conservation status

The conservation status of each species was evaluated according to the IUCN Red List criteria (IUCN 2001; IUCN Standards and Petitions Subcommittee 2016). Although these criteria are designed for global taxon assessments, they can be applied to subsets of global data at different geographical scales (e.g. national, regional or local levels). In this work, we determined the conservation status at the regional level—that is, the status of each species within the study region. Only taxa (species, subspecies) that are endemic to the region qualify for global assessment. For taxa that occur outside the study region—either elsewhere in Australia or outside Australia—the Red List category may differ substantially from the global assessment because we have evaluated only a small subset of the geographic range. For these nonendemic, extralimital taxa we therefore followed IUCN guidelines for the application of Red List criteria to assess populations at the regional level (IUCN 2012). Under these regional criteria, taxa that are introduced, vagrants or rare immigrants (i.e. populations that breed occasionally during favourable conditions, but do not become permanently established) or have recently colonised the region and are currently expanding their range outside the region should not be assessed and are accordingly categorised as Not Applicable (NA).

It should be noted that taxa may be listed as threatened under IUCN criteria because they have small population sizes (criteria C and D) and/or marked population declines (criterion A). However, these parameters are generally unknown for butterflies and diurnal moths in northern Australia; thus, our conservation assessments focused mostly on those distributional parameters (criterion B) for which information is more readily available. Indeed, criterion B is the primary Red List criterion used for status evaluation of butterflies globally (Lewis and Senior 2011), and it has previously been used to assess the conservation status of butterflies in Australia (Braby and Williams 2016).

The EOO, a component of IUCN Criterion B1, was used to evaluate whether a taxon belonged in a threatened category (IUCN Standards and Petitions Subcommittee 2016). Taxa were first sorted according to their geographic range size (based on the calculations described above; see 'Data analysis') to determine whether they fell within or close to the threshold of 20,000 sq km to potentially qualify for a threatened category (i.e. Vulnerable). The initial sorting produced a short list of 34 taxa (i.e. with distributions of < 40,000 sq km), which were then scrutinised in more detail to determine the EOO, number of locations or extent of fragmentation and any other known conservation issues such as evidence of decline and/or threatening processes. The EOO was calculated (in square kilometres) using minimum convex polygons or convex hulls in ArcMap, ArcGIS 10.3 Esri Projected Coordinate System: GDA 1994 Australia Albers. Areas of unsuitable habitat (e.g. ocean) within the minimum convex polygon were also included in the area calculation. Based on this information, IUCN Red List categories were then allocated to each of the 34 taxa.

For taxa for which the EOO could not be estimated, because they were known from only one or two sites, the area of occupancy (AOO) was used as an alternative method of assessment. The AOO is a component of IUCN Criterion B2, and the most common approach is to calculate the area of distribution from range-wide occurrences (grid cells) (Gaston and Fuller 2009). However, this method proved unsatisfactory because of the low spatial resolution of the grid cells employed across the study region (100 km x 100 km = 10,000 sq km) (Braby et al., unpublished data). We therefore used spatial buffering for these locality records (with the buffer set to 15 km) in conjunction with habitat suitability where this was known. The spatial buffering is not an actual estimate of the AOO, but rather an indication that these species are currently known to have exceedingly small geographic range sizes within the study region. That is, these taxa are likely to fall below the threshold of 2,000 sq km to potentially qualify for a threatened category (i.e. Vulnerable) under IUCN Red List criteria.

For taxa assessed as Data Deficient (DD), but which are of conservation interest because they may qualify as Near Threatened (NT) once adequate data are available, we have followed Bland et al. (2017), who recommended that justification tags be assigned to identify knowledge gaps and help prioritise reassessments. For example, lack of information could arise because there are few records or historical records only, there is uncertainty about locations or distribution, or there are uncertain threats or uncertain taxonomy. The actions needed for these taxa are also provided.

Although listing undescribed taxa on the IUCN Red List is discouraged—for example, as Least Concern (LC) or DD (see IUCN Standards and Petitions Subcommittee 2016)—the guidelines do allow for taxa to be evaluated provided there is certainty that the species are being or are about to be described; this is certainly the case for the putative butterfly subspecies and agaristine diurnal moth species that we have assessed (M. F. Braby, unpublished data).

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