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The use of the biodiverse parasitoid Hymenoptera (Insecta) to assess arthropod diversity associated with topsoil stockpiled for future rehabilitation purposes on Barrow Island, Western Australia

Nicholas B. Stevens, Syngeon M. Rodman, Tamara C. O'Keeffe and David A. Jasper.

Outback Ecology (subsidiary of MWH Global), 41 Bishop St, Jolimont, Western Australia 6014, Australia.
Email: Nick.Stevens@mwhglobal.com

ABSTRACT – This paper examines the species richness and abundance of the Hymenoptera parasitoid assemblage and assesses their potential to provide an indication of the arthropod diversity present in topsoil stockpiles as part of the Topsoil Management Program for Chevron Australia Pty Ltd Barrow Island Gorgon Project. Fifty six emergence trap samples were collected over a two year period (2011 and 2012) from six topsoil stockpiles and neighbouring undisturbed reference sites. An additional reference site that was close to the original source of the topsoil on Barrow Island was also sampled. A total of 14,538 arthropod specimens, representing 22 orders, were collected. A rich and diverse hymenopteran parasitoid assemblage was collected with 579 individuals, representing 155 species from 22 families. The abundance and species richness of parasitoid wasps had a strong positive linear relationship with the abundance of potential host arthropod orders which were found to be higher in stockpile sites compared to their respective neighbouring reference site. The species richness and abundance of new parasitoid wasp species yielded from the relatively small sample area indicates that there are many species on Barrow Island that still remain to be discovered. This study has provided an initial assessment of whether the hymenoptera parasitoid assemblage can give an indication of arthropod diversity. However, further work would still be required to more robustly establish the use of the hymenoptera parasitoid assemblage as indicators of arthropod diversity.

KEYWORDS: abundance, diversity, bioindicator, emergence trap, baseline monitoring, parasitic wasps

INTRODUCTION

The abundance and ubiquity of insects, with an estimated 8.5 million species worldwide (Stork 1999), mean they are vital contributors not only to global biodiversity but to ecosystem functioning. Insects fulfil functional roles as herbivores, decomposers, predators and parasitoids (regulating populations of other insects), pollinators and seed dispersers. They contribute to the cycling of nutrients, the maintenance of soil structure and fertility and provide a major prey source for other animals (Schoenly et al. 1991). The intrinsic role of insects in the environment means single taxa or assemblages of taxa or functional groups can potentially be useful biological indicators (bioindicators) in reflecting environmental conditions, ecological responses to impacts, or biodiversity within an area (Botes et al. 2006, McGeoch 1998, 2007, McGeoch et al. 2002, Morrison et al. 2012, Rainio and Nimela 2003). The use of an appropriately developed bioindicator can provide a more efficient means of evaluating an ecosystem, by reducing the impracticalities associated with attempting to collect and identify the entire biodiversity present.

Of all the insect orders, the Hymenoptera (ants, bees, wasps and sawflies) are involved in the largest number of interactions with other organisms, including plants, in an ecosystem (La Salle and Gauld 1993). The Hymenoptera are one of the five largest orders of insects, along with the Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs) and Lepidoptera (moths and butterflies), and comprise a significant proportion of arthropod diversity in most terrestrial habitats with over 115,000 species described worldwide (Stevens et al. 2007). In

Australia there are approximately 8,000 described species with a conservative estimate of 44,000 species actually present (Austin et al. 2004, Gaston and Hudson 1994).

Within the Hymenoptera, the parasitoid wasp superfamilies form the most speciose assemblage that occur throughout a broad range of habitats in arid to semi-arid, temperate to tropical environments, including freshwater and intertidal zones (Naumann 1991, Quicke 1997, Stephens and Stevens 2005). Parasitoid wasps play key roles in the functioning of natural and agricultural ecosystems by regulating arthropod populations (La Salle and Gauld 1993). Parasitoids lay their eggs into or onto other insects (most commonly targeting the egg or juvenile stages) as well as other arthropods such as spiders and, less frequently, ticks. Once the egg laid by a parasitoid wasp hatches, the wasp larva then feed on the host to complete development, resulting in the death of the host. The high trophic level of parasitoid Hymenoptera as specialised predators within the arthropod community, often with high levels of host specificity, has made them ideal biological control agents of a large range of agricultural and horticultural pest insects (La Salle and Gauld 1993). It has only been in relatively recent times that the potential use of parasitoid wasps as indicators of arthropod diversity and community structure has begun to be developed and evaluated. Studies have shown that the abundance and diversity of parasitoid wasp species can provide a more reliable indication of overall arthropod diversity than any other group (Anderson et al. 2011, Jensen 1997, Stephens 2005). Further to this, the composition of parasitoid taxa and respective functional groups present have the potential to provide insights into the responses of the soil, grassland and litter associated invertebrates to various agro-ecosytem management practices, impacts of weed invasion into native ecosystems, and reforestation initiatives (Anderson et al. 2011, Jensen 1997, Maeto et al. 2009, Stephens 2005).

The preliminary examination of the arthropod diversity presented here, has been conducted as part of the Topsoil Management Program for Chevron Australia Pty Ltd Barrow Island Gorgon Project. The Gorgon Project involves the development of the Greater Gorgon natural gas fields with the construction of a liquefied natural gas (LNG) plant on Barrow Island. The Topsoil Management Program forms a component of the Post-Construction Rehabilitation Plan, a regulatory requirement for the Gorgon Project. The program provides guidelines and recommendations for the handling and storage of topsoil on Barrow Island including ongoing monitoring to measure stockpiled topsoil viability and stability. The overall objective of the topsoil monitoring program was to measure and report on the biological value and stability over time of the stockpiles of topsoil that had been removed as part of the construction process to be used for future rehabilitation efforts. Topsoil is a vital part of an ecosystem; its physical, chemical and biological characteristics interact to provide a medium to support plant growth and regeneration, which in turn supports other components of the ecosystem (Allen et al. 2002, Bowen et al. 2005). An application of topsoil can greatly enhance the rate and success of rehabilitation of cleared or disturbed land (Jasper 2007, Bowen et al. 2005). A criterion of the Post-Construction Rehabilitation Plan for evaluating rehabilitated areas is to assess the re-colonisation of invertebrate fauna. Therefore, the assessment of the arthropod fauna, particularly insects, as part of the Topsoil Management Program will not only contribute to the long-term monitoring of the biological value of the topsoil stockpiles but will also contribute to evaluating arthropod re-colonisation of rehabilitated areas in the future.

To provide a more efficient means of assessing the arthropod fauna as part of the topsoil monitoring program, the parasitoid hymenopteran assemblage was selected *a priori* as a potential biological indicator of arthropod diversity based on the fulfilment of certain criteria outlined in McGeoch (1998) and McGeoch (2007). On Barrow Island, the Hymenoptera has been found to be the most species-rich insect order present, with 373 species recorded, 263 of which were parasitoid hymenopterans (Callan et al. 2011). More recent surveys by the Curtin University Entomology group have increased the Barrow Island Hymenoptera species count to 448 species, including 314 parasitoid taxa (PaDIL 2012). An objective of the study that is presented here was to assess whether the parasitoid hymenopteran species richness and abundance collected will provide a reliable indication of the greater arthropod diversity present in both stockpiles of topsoil and adjacent undisturbed topsoil.

MATERIALS AND METHODS

Barrow Island is Western Australia's second largest Island located 1,300 km north of Perth and 56 km north-west of the Pilbara coastline. The island is a nature reserve and experiences an arid to sub-tropical climate with tropical cyclonic activity commonly influencing the Island's rainfall, bringing sporadic and intense rainfall events usually from January to April (Australian Natural Resources Atlas 2007; Bureau of Meteorology 2012).

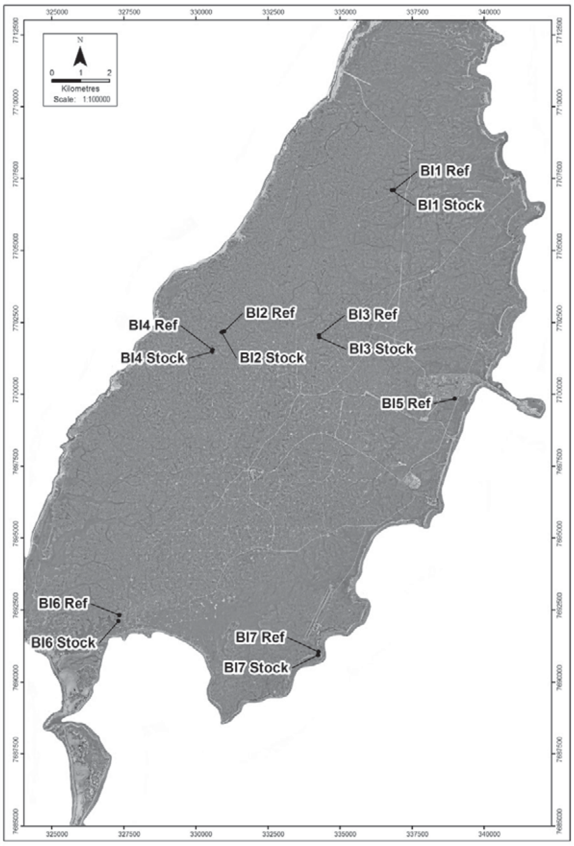

FIGURE 1 Location of the stockpile and reference sites sampled by emergence traps on Barrow Island.

STUDY SITES

Collection was carried out in 2011 and 2012 on topsoil stockpiles at six locations on Barrow Island (Figure 1). Undisturbed reference sites were sampled within 10 to 50 metres of each of the stockpile locations. The undisturbed reference site Barrow Island 5 (BI5) is as close as is accessible to the original location of the topsoil source (Figure 1).

The original vegetation complexes of the sourced topsoil included flats and limestone vegetation complexes, both of which are dominated by *Triodia* species, as is much of the island (Chevron 2005). Soil chemical and physical attributes were broadly similar for all stockpiles, with low soil organic carbon (< 1%) neutral to alkaline pH and low nutrient contents. Due to differences in soil stripping techniques, some stockpiles (BI1) contain substantial amounts of dead *Triodia.* This is the result of vegetation being included with the soil when it is removed, rather than being cleared prior to topsoil removal. Stockpiles at BI2, and BI7 were formed in 2012 and BI4 was re-worked in 2011, hence, these stockpiles were not sampled in 2011.

SAMPLING METHOD

Emergence traps (Figure 2) were used to sample known hymenopteran parasitoid host arthropod groups, Araneae and Insecta, which emerged from the soil or litter within the trap before migrating upwards towards the light and into the collection jar, as per Stephens (2005). This method of collecting emerging invertebrates has not been used on Barrow Island previously and we would expect a different subset of fauna to be collected. Each emergence trap consisted of a fabric tent that allowed air, light and rainfall to enter, so that the microhabitat remained consistent with the outside environment. The traps have a square base 50 cm wide; therefore, each emergence trap covered an area of 0.25 m^2. The base was secured to the ground using tent pegs and a collection jar was attached to the opening of the conical top of the tent. The collection jar was filled with propylene glycol which preserves any specimens until they can be sorted and transferred to ethanol for longer preservation times. The collection jar was secured to a metal post that was implanted in the ground. The distance from the soil surface to the connection of the tent to the collection jar was 80 cm. The emergence traps (three per site) were arranged so as to maximise the diversity of microhabitats sampled, by placing the traps on stockpile peaks and troughs, soils with both high and low organic matter, and cleared and vegetated areas.

During 2011 and 2012 a total of 56 emergence traps were deployed: 23 traps in April 2011; and 33 traps in March 2012 (Table 1). Both collection periods coincided with the late wet season on

TABLE 1 Sample effort undertaken at reference and stockpile emergence trap sites in 2011 and 2012.

Site	2011 Reference	2011 Stockpile	2012 Reference	2012 Stockpile
BI1	3	5	3	5
BI2	–		1	2
BI3	3	3	2	3
BI4	-		2	3
BI5	3	–	3	–
BI6	3	3	2	3
BI7	–		2	2
Overall	12	11	15	18
2011 Total	23		2012 Total	33

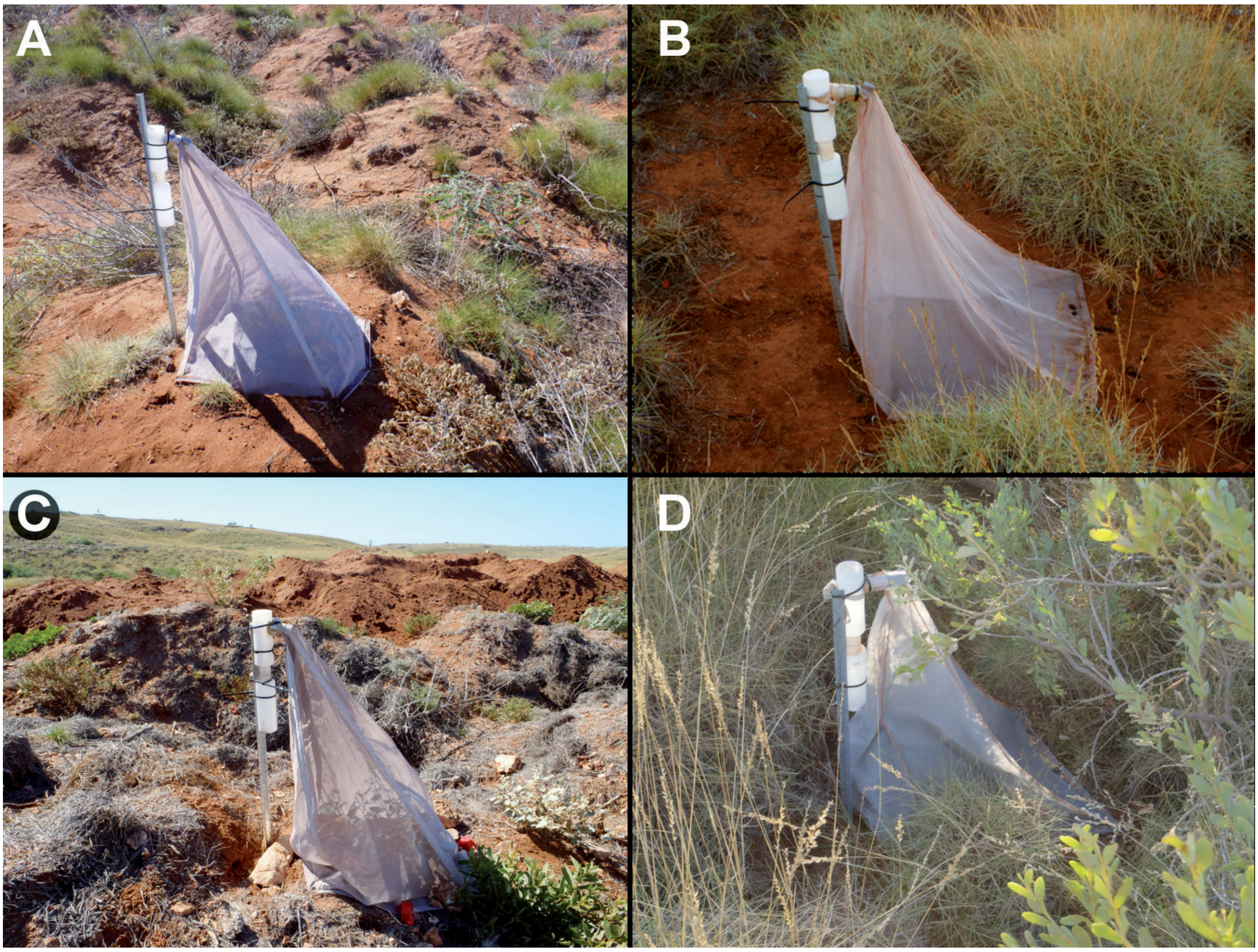

FIGURE 2 Representative emergent trap site images: A) A28 Em1; B) PER EmR2; C) Q31 Em1; D) LNG Flats EmR2

Barrow Island. Traps remained in the field for approximately eight weeks. After this time, the collection jar samples were couriered to the Outback Ecology laboratory in Perth for sorting. Preserved samples were sorted manually under Leica MZ6, MZ7.5 and M80 stereomicroscopes. Sorting was conducted by Syngeon Rodman and Nicholas Stevens. Once sorted in the laboratory, specimens were preserved in 100% ethanol. Identifications were undertaken by Nicholas Stevens and Syngeon Rodman. Hymenopteran identification resources used included hard copy (Bou ek 1988, Naumann 1991) and electronically published literature (Stevens et al. 2007).

Emergence traps are designed to sample various arthropod taxa associated with the topsoil such as Arachnida, Entognatha, Myriapoda, and Insecta. All arthropods were identified to order and abundance of each recorded. The arthropod groups collected were classified as either known (all insect orders and Araneae) or unknown (all other orders) to include hosts of parasitoid Hymenoptera.

Parasitoid Hymenoptera (including live prey, nest provisioning wasps) were mainly identified to family and, where feasible, lower taxonomic levels. All parasitoid wasps were morphotyped and aligned with Curtin University Barrow Island species and morphospecies (http://www.padil.gov.au/barrow-island). Species and morphospecies not present in the Curtin University Barrow Island collection were assigned Outback Ecology Services (OES) morphotype designations. Voucher material of OES species is housed at Outback Ecology, with remaining material housed at Curtin University Entomology Laboratory, and the Western Australian Museum.

RESULTS

ORDER LEVEL

The 56 emergence traps collected a total of 14,538 arthropod specimens, representing 22 orders during the surveys. Collembola made up the vast majority (61%) (Table 2). The five most species-rich and biologically-diverse insect orders, Coleoptera,

TABLE 2 Invertebrate abundance, diversity and distributions recorded from reference ('ref') and stockpile ('stock') emergence traps in 2011 and 2012.

Taxon	BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
Arachnida																
Acarina	205	124	15	82	58	40	16	30	433	32	60	31	4	284	846	1130
Araneae	26	82	1	17	15	22	9	24	56	37	46	4	8	128	219	347
Pseudoscorpionida	2				1		1		5			1		2	8	10
Malocostraca																
Isopoda		3			5			1	2		12			1	22	23
Chilopoda																
Chilopoda	2	2		5	1		1	1		1		3	1		17	17
Diplopoda																
Diplopoda					1		4								5	5
Gastropoda																
Gastropoda												1			1	1
Entognatha																
Collembola	535	1085	100	800	615	2467	300	215	1460	445	422	225	250	3838	5081	8919
Insecta																
Blattodea	7	1		1	6		1	1	3	2	3	2		3	24	27
Coleoptera	8	143		19	12	173	4	35	10	4	118	1	82	417	192	609
Dermaptera												1			1	1
Diptera	23	234		50	46	54	6	85	145	34	180	6	8	407	464	871
Embioptera									4					1	3	4
Hemiptera	18	15	1	3	28	37	4	15	40	28	104	2	4	193	106	299
Isoptera		1							1						2	2
Lepidoptera	2	11		5	2	17		51	93	4	78	1	4	108	160	268
Mantodea		1			1				1						3	3
Orthoptera	6	7		2	2		4		5	1	5			3	29	32
Psocoptera	6	42		80	2	159		52	1	7	15		2	40	326	366
Thysanoptera	2	5			1	1	1		1	2	6			12	7	19
Zygentoma		3						1			1			3	2	5
Hymenoptera: *Non-parasitic*																
Formicidae	58	135	4	50	75	54	14	135	153	123	90	69	41	230	771	1001
Hymenoptera: *Parasitic*	39	83	6	9	39	52	26	36	71	56	120	13	29	223	356	579
Total Abundance	939	1977	127	1123	910	3076	391	682	2484	776	1260	360	433	5893	8645	**14538**

Diptera, Hemiptera, Hymenoptera and Lepidoptera were all well represented, each by more than 100 individuals, as well as the less speciose insect order Psocoptera. The more speciose arachnid orders, Acarina and Araneae, were also well represented with the collection of over 100 individuals each. The remaining 13 orders recorded were not collected in as large an abundance (Table 2).

There was an overall increase in the number of invertebrates captured in 2012 (8,645) compared to 2011 (5,893) consistent with the increased number of emergence traps deployed (10 additional traps in 2012). Invertebrate densities for 2011 (1025 individuals / m^2) were comparable to 2012 densities (1048 individuals / m^2). Diptera, Hymenoptera and Psocoptera were collected in higher abundances in 2012 and represented a larger proportion of the invertebrate fauna collected compared to the 2011 survey. Conversely, both Coleoptera and Hemiptera were collected in lower abundance in 2012 and represented a smaller proportion of the invertebrate fauna collected compared to the 2011 survey. The diversity of orders represented in the 2012 sampling was greater than for 2011. Orders represented in 2012 but not in 2011 were Chilopoda, Diplopoda, Gastropoda, Dermaptera, Isoptera, and Mantodea (Figure 3A; Table 2).

HYMENOPTERA PARASITOIDS

The emergence traps collected an abundant and diverse hymenopteran parasitoid assemblage with 579 individuals, representing 155 species from 22 families, collected in the 2011 and 2012

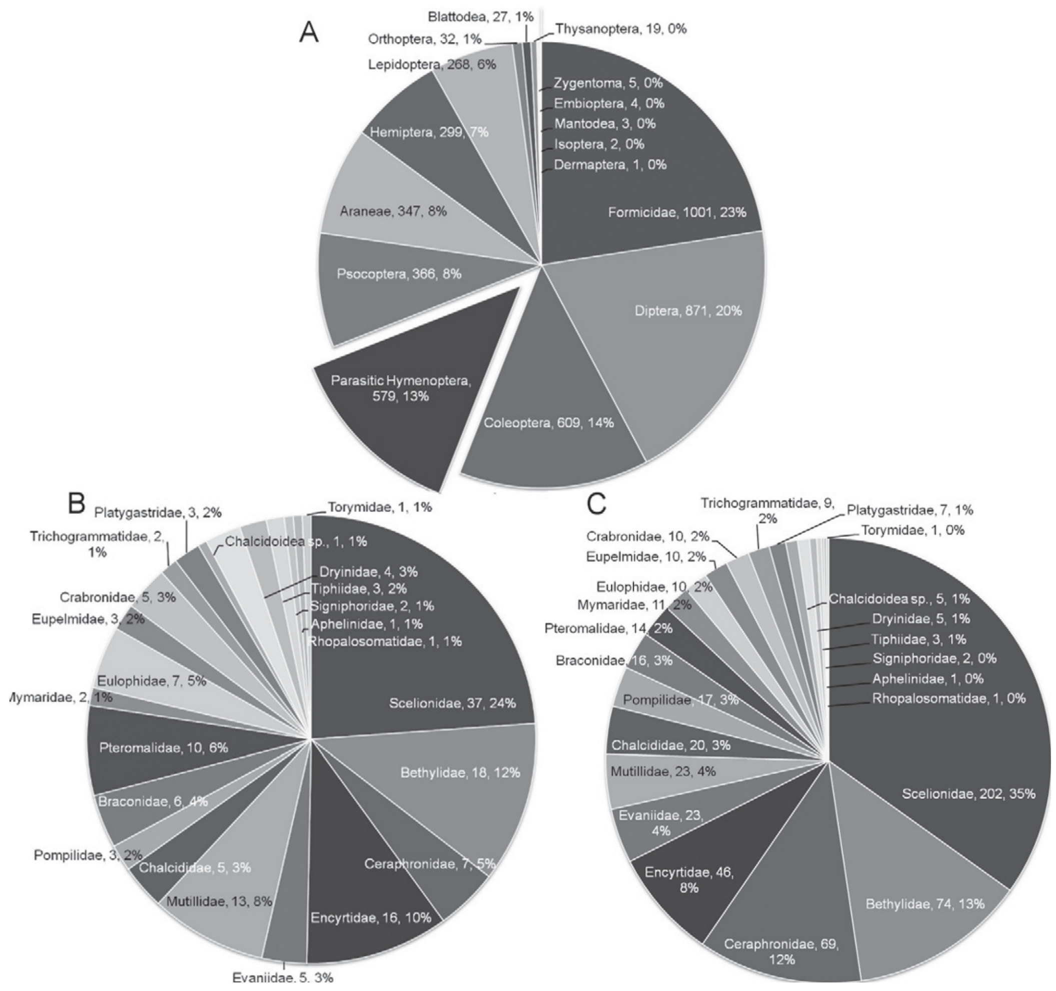

FIGURE 3 Invertebrate taxa collected in the 2011 and 2012 emergence trap survey; A) Abundance of parasitoid Hymenoptera and other arthropod groups known to be hosts for parasitoid wasps; B) Number of species per Family and percent contribution to over-all diversity of parasitiod Hymenoptera; C) Number of individuals collected per Family and percent contribution to over-all abundance of parasitoid Hymenoptera.

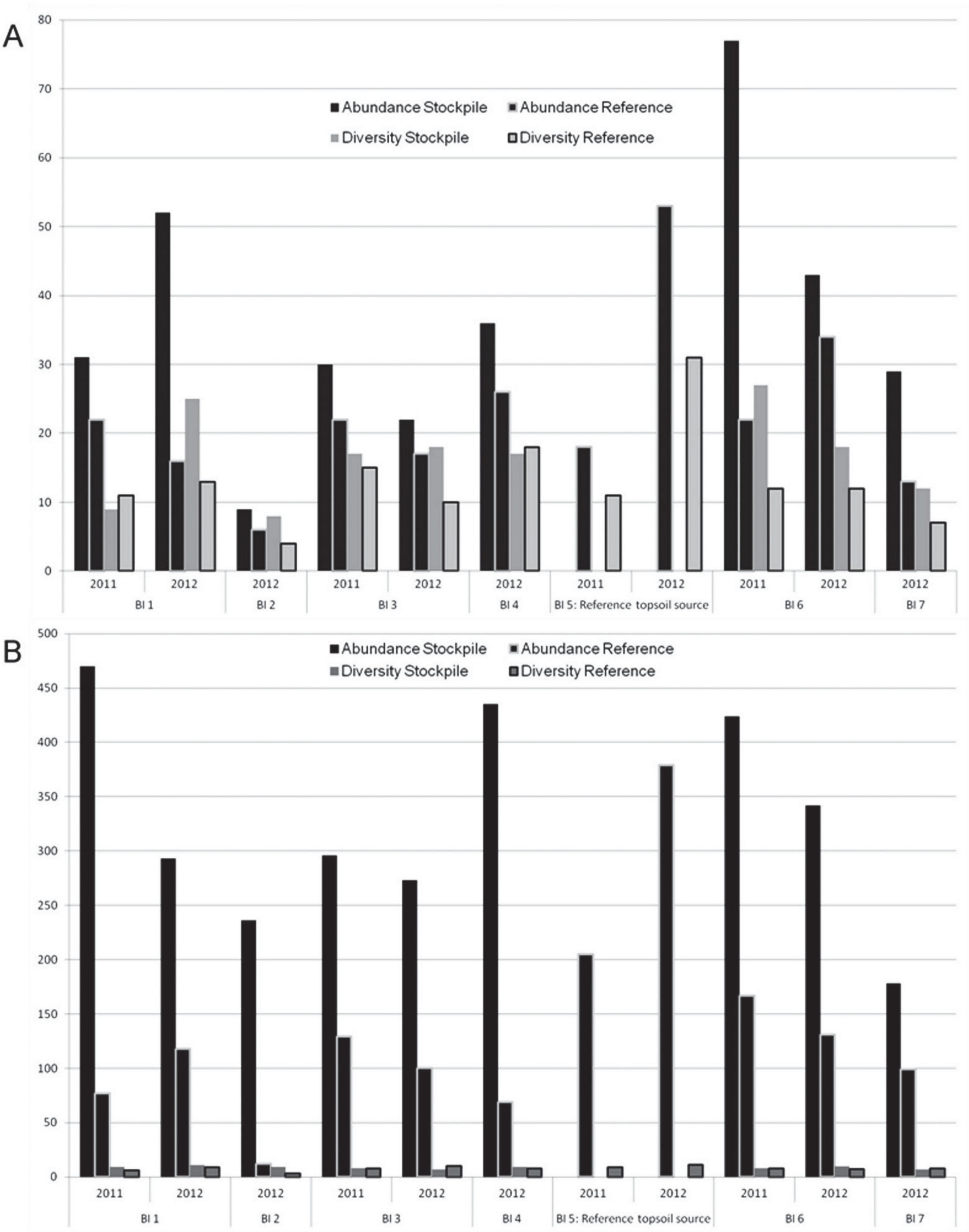

FIGURE 4 Stockpile versus corresponding reference site invertebrate taxa abundance and diversity recorded in the 2011 and 2012 emergence trap survey; A) Parasitoid Hymenoptera abundance and species diversity; B) Order level abundance and diversity of arthropod groups known to be hosts of parasitoid wasps.

survey period (Appendix 1). Of the 155 species of Hymenoptera parasitoids recorded, 84 (54.2 %) could not be matched to a species from the Curtin University Barrow Island collection. The majority of hymenopteran parasitoid species (97) were represented by two or fewer specimens. Only thirteen (8.4 %) of the parasitoid species were represented by more than 10 individuals. In 2011, 23 emergence traps collected 223 individuals, representing 71 species from 16 families. The 2011 density of parasitoid wasp specimens and species recorded was 38.8 and 12.1 per square metre, respectively. In 2012, 33 emergence traps collected 356 individuals, representing 104 species from 21 families. The 2012 density of parasitoid wasp specimens and species recorded was 43.2 and 12.6 per square metre, respectively. Only 20 (13%) parasitoid species were collected in both the 2011 and 2012 surveys.

The abundance of parasitoid Hymenoptera was found to have a large positive linear correlation with the abundance of specimens from potential host arthropod orders (Pearson's Correlations: r = 0.85) and with the potential host order level diversity (r = 0.69). The species richness of parasitoid Hymenoptera was also found to have a large positive linear correlation with the abundance of specimens from potential host arthropod orders (r = 0.81) and with the potential host order level diversity (r = 0.72). Throughout each survey the abundance of parasitoid wasps was consistently higher in stockpile sites compared to their respective neighbouring reference site (Figure 4A). This trend was also reflected by the abundance of potential host orders present (Figure 4B). The species richness of parasitoid Hymenoptera was also generally greater in stockpile sites compared to their respective neighbouring reference site, with only two exceptions to the trend recorded. These were from BI1 in 2011 and BI4 in 2012 (Figure 4A). The density of parasitoid wasp specimens and species recorded at stockpile sites was 45.4 and 19.9 per square metre, respectively. This was compared to the lower density of specimens and species recorded at reference sites which was 26.52 and 14.07 per square metre, respectively. Overall, BI6 stockpile had the highest abundance (120 individuals) and species richness (44 species) of any site, twice the abundance and species richness of its neighbouring reference site. This trend was also highlighted in the BI7 stockpile in 2012, which had more than double the abundance and nearly twice the species richness of the BI7 reference site (Appendix 1). This is likely in response to the higher abundance of a number of the main host invertebrates, particularly Coleoptera that comprised nearly half the abundance of the main host groups in the stockpile with 82 individuals collected, compared to one individual in the reference site (Table 1).

Of the 155 parasitoids species recorded, 61 (39.4%) species were collected from stockpile sites only, 59 (38.1%) species were from reference sites only, with only 35 species (22.6%) found to occur in both reference and stockpile sites (Appendix 1). Two stockpile sites (BI7 and BI2) did not share any species with their corresponding reference sites. This trend of few species shared between reference and stockpile site at these stockpiles was evident in both the 2011 and 2012 survey. Some of the more abundant species were collected from several sites, both stockpile and reference, with some sites separated by more than 15 km. Numerous species of Scelionidae in particular, were collected in three or more sites and not limited to occurring in only reference or stockpile sites. Scelioninae sp. 16 and Scelioninae sp. 21 occurred in over five sites, both stockpile and reference, including the most northern and southern sites. *Fabriogenia* sp. 3 and two Evaniids (*Acanthinevania* sp. 2 and Evaniidae sp. OES5) were also collected from several sites throughout the island (Appendix 1).

There was also a marked variability of the parasitoid wasp assemblages between years, particularly so for BI5 reference site. Reference site BI5 recorded the highest abundance (53) and species richness (31) of all stockpile and reference sites sampled in 2012 (Figure 4A). However in 2011, the abundance (18) and species richness (11) recorded from the BI5 reference site was lower than all of the other reference sites sampled with the exception of the species richness recorded from BI1 reference site (11).

The most abundant and species rich hymenopteran parasitoid family was the Scelionidae with 202 individuals collected, representing 37 species (Figure 3B and C, Figure 5). Thirty one of the scelionid species collected belonged to the subfamily Scelioninae with the other scelionid subfamily, Telenominae, represented by only six species and 35 individuals (Appendix 1). The Bethylidae was the second most abundant parasitoid wasp family with 74 individuals collected, representing 18 species. Bethylidae were collected in greater species richness (11) and abundances (44) in 2011 compared to 2012 (10 species represented by 30 individuals). The Ceraphronidae was the third most abundant but the sixth most diverse family recorded with 69 individuals, representing 7 species (Figure 3B and C). The family had similar species richness and abundances in both 2011 and 2012. The Encyrtidae was another well represented parasitoid family with 46 individuals collected, representing 16 species (Figure 3B and C, Appendix 1). The five families not represented in 2011 that were collected in the 2012 survey were Aphelinidae, Dryinidae, Mymaridae, Rhopalosomatidae and Signiphoridae (Appendix 1, Figure 6).

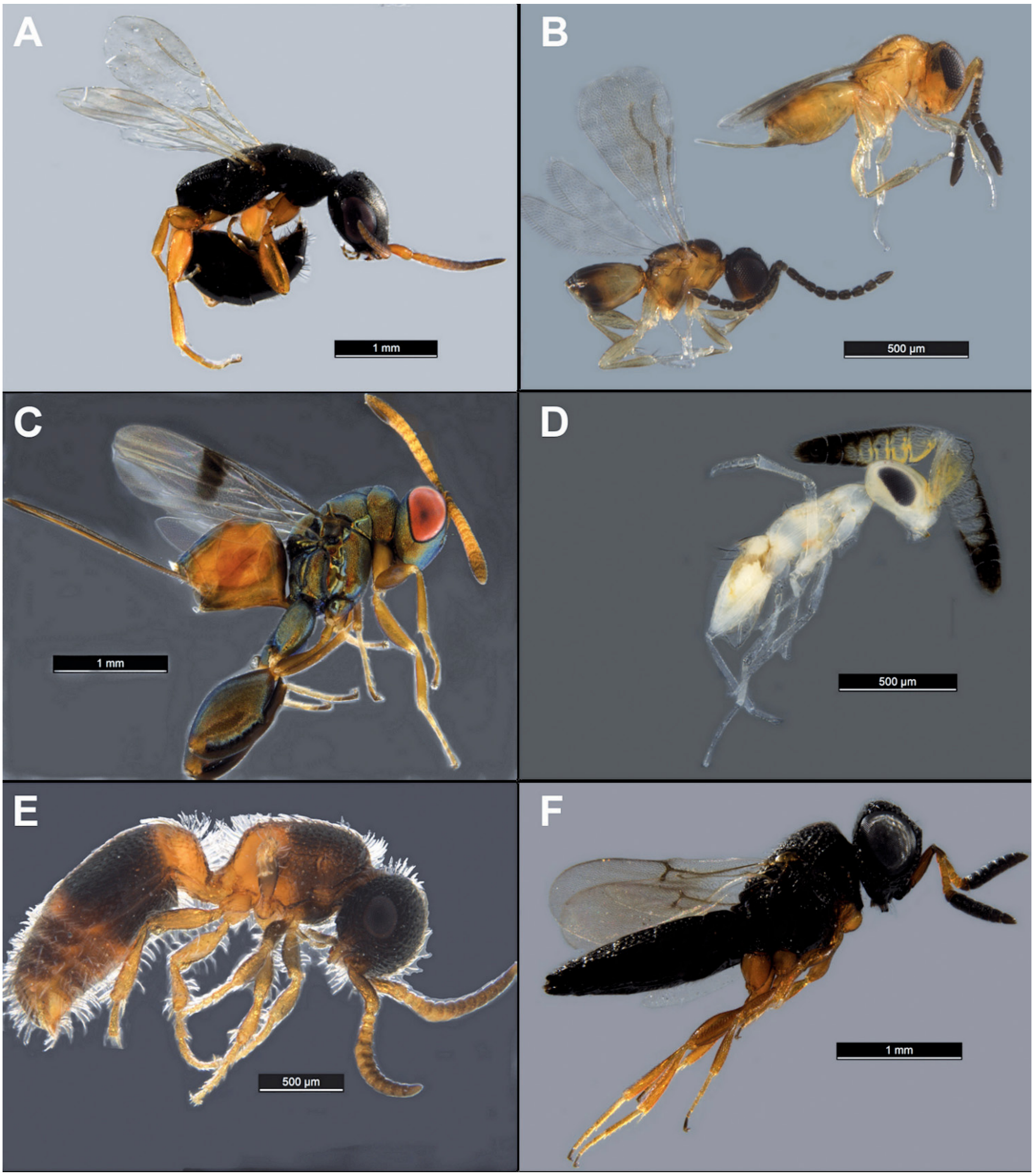

FIGURE 5 Representative parasitic Hymenoptera images: A) Bethylidae – Epyrinae sp. OES8; B) Female (top) and male (bottom) Ceraphronidae sp. 17; C) Torymidae sp. OES6; D) Encyrtidae sp. OES5, E) Mutillidae sp. 24; F) Scelionidae – *Oxyscelio* sp. OES1.

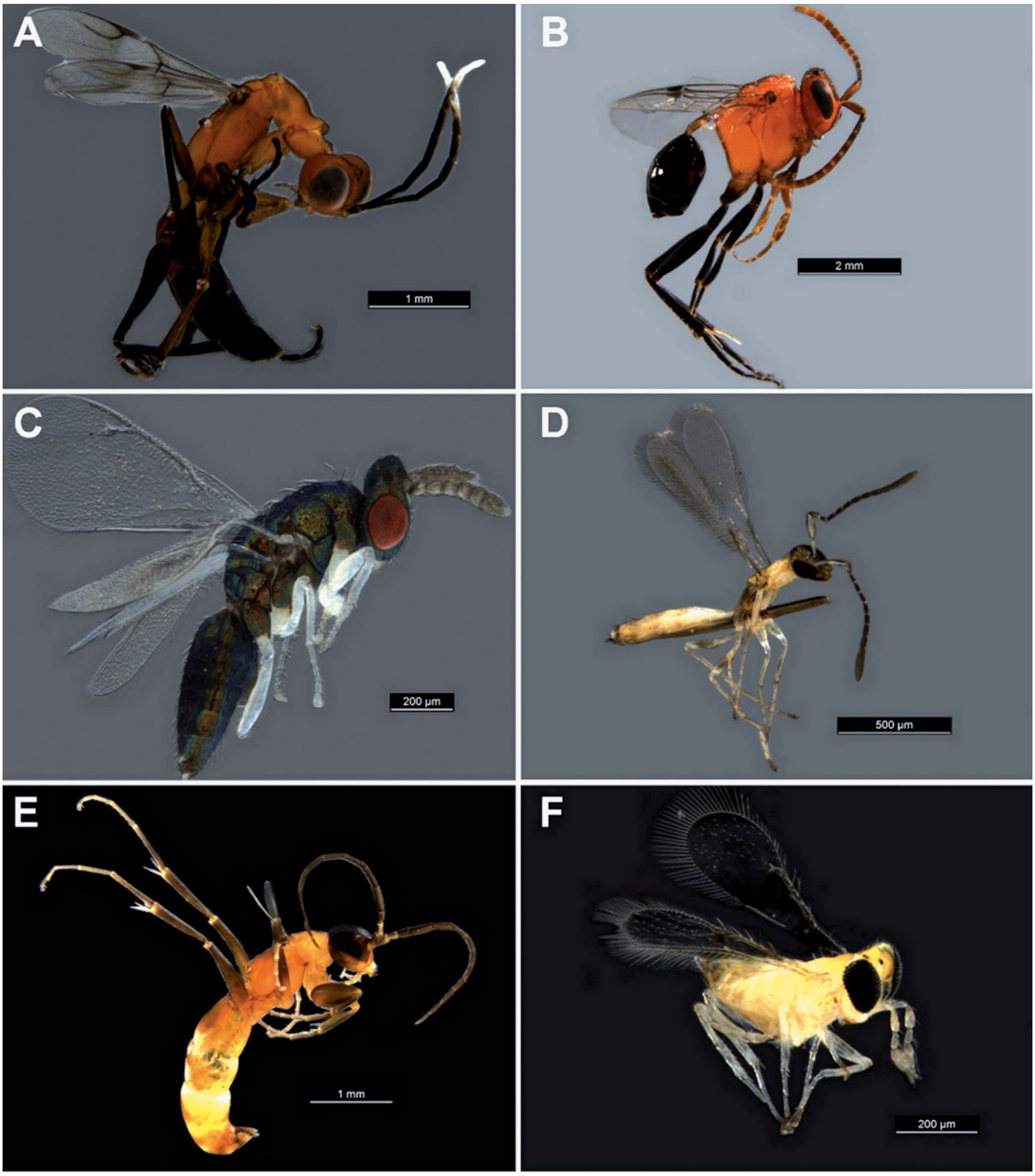

FIGURE 6 Representative parasitic Hymenoptera images: A) Dryinidae – Dryininae sp. OES1; B) Evaniidae sp. OES5; C) Eulophidae sp. 6; D) Mymaridae – Gonatocerinae sp. OES2 sp. OES5, E) Rhopalosomatidae – *Olixon* sp. 2; F) Trichogrammatidae sp. OES2.

The most abundant species recorded was Ceraphronidae sp. 17 with 42 individuals collected. Ceraphronidae sp. 10 was also collected in relatively high abundances with 16 individuals collected. Nine of the 13 most abundant species were scelionids. An encyrtid (Encyrtidae sp. 5) and a pompilid (*Fabriogenia* sp. 3) were also recorded with more than 10 individuals. There were 72 parasitic wasp species, representing 46.5% of wasp taxa recorded, known from a single specimen only. The proportion of singletons was similar for both 2011 and 2012. Some families, such as Eulophidae, Pteromalidae and Mutillidae, were mostly represented by singleton species. Less species diverse families, such as Aphelinidae, Signiphoridae, Rhopalosomatidae and Tiphiidae were only represented by singleton species (Appendix 1, Figure 6).

DISCUSSION

The initial monitoring reported here provided a baseline for the arthropod diversity associated with the topsoil stockpiles as well as positively indicating the potential of parasitoid wasps to be further developed as diversity indicators. As per the procedural steps in developing bioindicators (McGeoch 1998, MeGeoch 2007), further investigation and testing is required to more robustly establish the relationship between the abundance and species richness composition of the parasitoid wasp assemblage (or components thereof) and the diversity of other potential host taxa in the context of the monitoring program. The parasitoid Hymenoptera were demonstrated to be efficient tools for monitoring of the variations in diversity of arthropod assemblages in agricultural grasslands in Ireland (Anderson et al. 2011). In addition to the potential of parasitoid Hymenoptera to be bioindicators of biodiversity, there exists the potential for them to be effective ecological indicators. The use of functional groups in assessing parasitoid wasp assemblages indicated that there were measurable relationships between the habitat disturbance and components of the indicator group (Maeto et al. 2009, Stephens 2005). Further development of the theoretical biodiversity and ecological indicator potential of parasitoid Hymenoptera could provide efficient means of not only evaluating the influence and biological performance of topsoil stockpiling in the context of this monitoring program, but could be extended to assessing soil management and land rehabilitation programs in general.

The findings from the first two years of monitoring of the topsoil stockpiles have shown that the emergence traps are an efficient means of sampling soil associated arthropods in an arid environment that is characterised by a relatively thin natural soil layer. Previous studies that demonstrated the effectiveness of emergence traps in sampling soil and litter associated invertebrates occurred in more mesic environments that possessed much deeper topsoil profiles (Jensen 1997, Stephens 2005). The diversity and abundance of invertebrates yielded from a pooled area of 14 square metres was remarkable and indicates that there are many native species on Barrow Island that still remain to be discovered. This was clearly evident by the high number of new parasitoid wasp species collected each year. Further sampling will most likely uncover more species previously unknown to Barrow Island. Future work will involve getting these previously unrecorded wasp species listed on PaDIL as well as further investigation of the distributions of parasitoid species already recorded by the Curtin University Entomology Group.

The degree of endemicity present in the Barrow Island parasitoid wasp fauna remains largely unknown as few studies have been undertaken involving the Pilbara wasp fauna. A recent morphological study of Barrow Island *Elasmus* (Hymenoptera: Eulophidae) species found only one of the eleven species recorded to be potentially endemic to the island as it had not been recorded previously from mainland Australia or neighbouring islands (Gunawardene and Taylor 2012). However, it is not known how well this example reflects the situation for other parasitoid taxa present on Barrow Island. Three of the four species of *Olixon* (Hymenoptera: Rhopalosomatidae) described from the neighbouring mainland displayed relatively widespread distributions in the Pilbara (Krogmann et al. 2009) but comparisons with *Olixon* specimens collected from Barrow Island have not yet occurred. Further comparisons of the Barrow Island parasitoid wasp fauna with corresponding mainland taxa, incorporating molecular analyses where possible, would be required to provide any certainty in determining the endemism of the parasitoid wasp fauna of Barrow Island.

There are a number of factors that are likely to have contributed to the consistent trend of topsoil stockpiles hosting a greater abundance and species richness of parasitoid wasps compared to their respective neighbouring reference sites. A factor may have been the creation of more optimal habitat with the concentration of topsoil providing an increase in available resources (such as vegetative matter) compared to the naturally thin soil profile present on Barrow Island. The optimisation of the habitat may have been further augmented by the source of the topsoil for stockpiling. Topsoil was taken from near BI 5 which lies lower in the landscape on Barrow Island and has a higher clay and silt content compared to stockpile reference sites that are situated higher up in the island landscape. The abundance and species richness of parasitoid hymenoptera recorded from the topsoil source reference site BI5 indicate that it is a relatively productive habitat naturally. Disturbance is also recognised as an important element contributing to the diversity of a community with hypotheses stating that intermediate or moderate levels of disturbance promote higher species richness than low or high levels of disturbance (Hobbs and Huenneke 1992, Petraitis et al. 1989, Szentkiralyi and Kozar 1991). The disturbance caused by the creation of the stockpiles did increase the plant diversity with many native ruderal species quickly establishing on the stockpiles. The increase in plant diversity may in turn have provided greater abundance and diversity of resources for parasitoid wasp hosts. It is likely that the interaction of a number of factors are contributing to the patterns observed but empirically qualifying and quantifying these factors would be difficult and would require additional experimental investigation.

It is important to note that the findings presented here represent the results of an initial invertebrate monitoring program and not a more extensive research project. A preliminary multivariate assessment (the results of which have not been presented here) indicated there was a strong temporal influence among the results. This further highlights the importance of establishing a longer term monitoring program that can enable longer term trends to emerge from amongst the biological 'noise' that reflects the natural temporal and spatial variation present in the environment under investigation. To more robustly assess the use of parasitoid hymenoptera as indicators of arthropod diversity and evaluate the potential trends among sites using multivariate analysis would require a greater number of replications which is outside the scope of this soil invertebrate monitoring program.

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APPENDIX 1 Parasitoid Hymneoptera abundance, species diversity and distribution recorded from reference ('ref') and stockpile ('stock') sites in 2011 and 2012. Morphospecies names with OES denote species not present in Curtin University Barrow Island species and morphospecies collection (http://www.padil.gov.au/barrow-island).

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
CERAPHRONOIDEA																	
Ceraphronidae:	Ceraphronidae sp. 2						1								1		1
	Ceraphronidae sp. 4											1				1	1
	Ceraphronidae sp. 5					3	3								6		6
	Ceraphronidae sp. 8			2												2	2
	Ceraphronidae sp. 10		15				1								16		16
	Ceraphronidae sp. 12						1								1		1
	Ceraphronidae sp. 17		22						10	3		7				42	42
CHALCIDOIDEA																	
	Chalcidoidea sp. OES1	2									3				5		5
Aphelinidae:	Aphelinidae sp. OES1													1		1	1
Chalcididae:	Chalcididae sp. OES5											1			1		1
	Chalcidinae sp. 3											1			1		1
	Chalcididae sp. 4						2					4			6		6
	Chalcididae sp. 5								3			6	1		6	4	10
	Chalcididae sp. 6				2											2	2
Encyrtidae:	Encyrtidae sp. OES1	1				1					3				5		5
	Encyrtidae sp. OES2	3				1					2	1			5	2	7
	Encyrtidae sp. OES3									1					1		1
	Encyrtidae sp. OES5					2				1					1	2	3
	Encyrtidae sp. OES6									1					1		1
	Encyrtidae sp. OES7									4						4	4

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Encyrtidae sp. OES8									1						1	1
	Encyrtidae sp. OES9									1						1	1
	Encyrtidae sp. OES10									2						2	2
	Encyrtidae sp. OES11									1						1	1
	Encyrtidae sp. OES12													1		1	1
	Encyrtidae sp. OES13													1		1	1
	Encyrtidae sp. OES14							1								1	1
	Encyrtidae sp. OES15	1														1	1
	Encyrtidae sp. 5	1	4		1	4				3						13	13
	Encyrtidae sp. 7		1			1						1				3	3
Eulophidae:	Eulophidae sp. OES1										1				1		1
	Eulophidae sp. OES2											3			3		3
	Eulophidae sp. OES4									1					1		1
	Eulophidae sp. OES5						1									1	1
	Eulophidae sp. 6				1											1	1
	Eulophidae sp. 7								1							1	1
	Tetrastichinae sp. OES3											2			2		2
Eupelmidae:	Eupelmidae sp. OES1						2			1	1				2	2	4
	Eupelmidae sp. OES2	1				1							3		2	3	5
	Eupelmidae sp. 10											1				1	1
Mymaridae:	Gonatocerinae sp. OES1						2			1		1				4	4
	Gonatocerinae sp. OES2						1					6				7	7
Pteromalidae:	Pteromalidae sp. OES2											1			1		1
	Pteromalidae sp. OES3					1						1			2		2
	Pteromalidae sp. OES4					1									1		1
	Pteromalidae sp. OES5					1									1		1

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Pteromalidae sp. OES6					1									1		1
	Pteromalidae sp. OES7						1								1		1
	Pteromalidae sp. OES8						4								4		4
	Pteromalidae sp. OES9						1								1		1
	Pteromalidae sp. OES10							1								1	1
	Pteromalidae sp. OES11					1										1	1
Signiphoridae:	Signiphoridae sp. OES1													1		1	1
	Signiphoridae sp. 1							1								1	1
Torymidae:	Torymidae sp. OES6							1								1	1
Trichogrammatidae:	Trichogrammatidae sp. OES1											7			7		7
	Trichogrammatidae sp. OES2						1					1				2	2
CHRYSIDOIDEA																	
Bethylidae:	Bethylidae sp. OES1										3				**3**		3
	Bethylidae sp. OES2		3				2				1	1			7		7
	Bethylinae sp. 2									2					2		2
	Bethylinae sp. 13									1					**1**		1
	Bethylinae sp. 15											7			7		7
	Epyrinae sp. OES2		1				1					2			3	1	4
	Epyrinae sp. OES8								2							**2**	2
	Epyrinae sp. 1						3								3		3
	Epyrinae sp. 2		2													2	2
	Epyrinae sp. 10										2				**2**		2
	Epyrinae sp. 12		1						2		1	1		1		6	6
	Epyrinae sp. 14		1						1	1		2		3		8	8
	Epyrinae sp. 18	7	1												**8**		8

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Epyrinae sp. 19		1							2		3		1	6	1	7
	Epyrinae sp. 20	1				1	1								2	1	3
	Pristocerinae sp. OES5									1		1				**2**	2
	Pristocerinae sp. OES6							1								1	1
	Pristocerinae sp. OES7					3		2	1							6	6
Dryinidae:	Bocchinae sp. OES1									1	1					2	2
	Bocchinae sp. OES2											1				1	1
	Dryininae sp. OES1									1						1	1
	Dryininae sp. 7										1					1	1
EVANIOIDEA																	
Evaniidae:	Acanthinevania sp. 2		1						1	3	5				1	9	10
	Evaniidae sp. OES2											1			1		1
	Evaniidae sp. OES3						1		1			1			1	2	3
	Evaniidae sp. OES4		1							1		3	3			8	8
	Evaniidae sp. OES5									1						1	1
ICHNEUMONOIDEA																	
Braconidae:	Braconidae sp. OES1										1				1		1
	Braconidae sp. OES3											1			1		1
	Braconidae sp. OES4									2					2		2
	Braconidae sp. 14		1													1	1
	Cheloninae sp. OES2						2					7			9		9
	Cheloninae sp. 8						2									2	2
PLATYGASTROIDEA																	
Platygastridae:	Inostemma sp. 1									4						4	4
	Platygastridae sp. OES1				1							1			1	1	2

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Platygastrinae sp. 11									1						1	1
Scelionidae:	*Ceratobaeus* sp. OES15						2		1			2				5	5
	Ceratobaeus sp. 15	1													1		1
	Ceratobaeus sp. 29						1	1		2					2	2	4
	Ceratobaeus sp. 38									1						1	1
	Idris sp. OES20		4							3		5				12	12
	Mirobaeoides sp. 39								1							1	1
	Odontocolus sp. OES16		1												1		1
	Oxyscelio sp. OES1						1					1				2	2
	Oxyscelio sp. 2											1			1		1
	Scelioninae sp. OES 10	1	2				5	1			1	2			7	5	12
	Scelioninae sp. OES11					3				1					4		4
	Scelioninae sp. OES12					1									1		1
	Scelioninae sp. OES21		1									1				2	2
	Scelioninae sp. OES22	1		1					1							3	3
	Scelioninae sp. OES23						1									1	1
	Scelioninae sp. OES24				1		1									2	2
	Scelioninae sp. OES25		2													2	2
	Scelioninae sp. OES26													13		13	13
	Scelioninae sp. OES27												1			1	1
	Scelioninae sp. 1		2			3	1		1	1	8				4	12	16
	Scelioninae sp. 4	2						1								3	3
	Scelioninae sp. 11						1			1	3				1	4	5
	Scelioninae sp. 15									7						7	7
	Scelioninae sp. 16	1	7			1			2			5		2	7	11	18
	Scelioninae sp. 21	1		2		2	1	1	6				1			14	14

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Scelioninae sp. 28						2					13			15		15
	Scelioninae sp. 30	1														1	1
	Scelioninae sp. 31						1			1						2	2
	Scelioninae sp. 32								1							1	1
	Scelioninae sp. 33		1			1		2			1	9			6	8	14
	Scelioninae sp. 35	1												1		2	2
	Telenominae sp. OES1									1						1	1
	Telenominae sp. OES2				1											1	1
	Telenominae sp. 9											1			1		1
	Telenominae sp. 18										1					1	1
	Telenominae sp. 25	5	1							4	10	1			12	9	21
	Telenominae sp. 27	1	1					1			7					10	10
SPHECOIDEA																	
Crabronidae:	Crabronidae sp. OES1		1					2				1			1	3	4
	Crabronidae sp. OES2							1		2						3	3
	Crabronidae sp. OES3													1		1	1
	Crabronidae sp. 22		1													1	1
	Lyroda sp. 1									1						1	1
VESPOIDEA																	
Pompilidae:	Ctenostegus sp. 1			1				1								2	2
	Fabriogenia sp. 3	3	1			2		4		1			3		3	11	14
	Turneromyia sp. 8											1			1		1
Mutillidae:	Mutillidae sp. OES1	1													1		1
	Mutillidae sp. OES2						1								1		1
	Mutillidae sp. OES3		1							1						2	2

Taxon		BI 1 Ref	BI 1 Stock	BI 2 Ref	BI 2 Stock	BI 3 Ref	BI 3 Stock	BI 4 Ref	BI 4 Stock	BI 5 Ref	BI 6 Ref	BI 6 Stock	BI 7 Ref	BI 7 Stock	Total 2011	Total 2012	Overall
	Mutillidae sp. OES4					1				1						2	2
	Mutillidae sp. 7					3									3		3
	Mutillidae sp. 8							3								3	3
	Mutillidae sp. 9									1						1	1
	Mutillidae sp. 13	1													1		1
	Mutillidae sp. 16				1									3		4	4
	Mutillidae sp. 21		1													1	1
	Mutillidae sp. 22		1												1		1
	Mutillidae sp. 24								1							1	1
	Mutillidae sp. 25				1		1									2	2
Rhopalosomatidae:	Olixon sp. 2												1			1	1
Tiphiidae:	Tiphiidae sp. OES1	1													1		1
	Tiphiidae sp. OES2	1														1	1
	Tiphiidae sp. 15							1								1	1
Total Abundance		39	83	6	9	39	52	26	36	71	56	120	13	29	223	356	**579**
Total Species Diversity		23	30	4	8	23	33	18	17	42	20	44	7	12	71	104	**155**