



<b>Title</b>	<b>Ants in the city, a preliminary checklist of Formicidae (Hymenoptera) in Macau, one of the most heavily urbanized regions of the world</b>
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# Ants in the city, a preliminary checklist of Formicidae (Hymenoptera) in Macau, one of the most heavily urbanized regions of the world

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**ABSTRACT.** Macau is a small territory in South East China and one of the most densely populated regions in the world. Previous studies on insect groups have shown that a relatively diverse, yet specific, fauna could still survive in this region. However, to this point, studies on the myrmecofauna of Macau are scarce and to date no species checklist exists. Here, we present the first checklist of Macanese ant species by combining results from recent ant surveys using hand-collections and Winkler extractors with published records. During the surveys, 82 species and morphospecies belonging to 37 genera and 8 subfamilies have been collected, with 37 species representing new records for Macau, including an interesting new record of an undescribed *Leptanilla* species, the second record of the Leptanillinae subfamily for South East China. To date, Macanese ants comprise 105 species/morphospecies and 8 subspecies, after the removal of dubious records present in the literature (though some misidentifications may remain). While still likely incomplete, these results represent the most comprehensive list of ants for Macau, and a baseline for future research on ant diversity in heavily urbanized environments and for understanding the potential consequences of urbanization on native and non-native diversity in Asia.

**Keywords:** Ants, Checklist, Exotic Species, Macao, Diversity Survey, Urban Ecosystems.

## INTRODUCTION

Globally, urban development has been constantly expanding; in one analysis, by 2050, 70% of the global human population is expected to live within cities leading to an increase of urbanized areas (Seto *et al.* 2013). In this context, understanding what role urban habitats can play to maintain a certain level of biodiversity and which species are present in these environments is key to future ecology and conservation.

Located in the subtropical part of China, Macau Special Administrative Region (SAR) (22.2°N, 113.5°E) lies on the south west side of the Pearl River mouth, and is a small territory of 30.4 km<sup>2</sup>, encircled within the Chinese province of Guangdong. Similar to several cities in South China, Macau has experienced rapid urban development over the past decades and as of 2017 its population density is the highest in the world with 20,166 inhabitants per km<sup>2</sup>: 2.5 and 3 times higher than Singapore and Hong Kong respec-

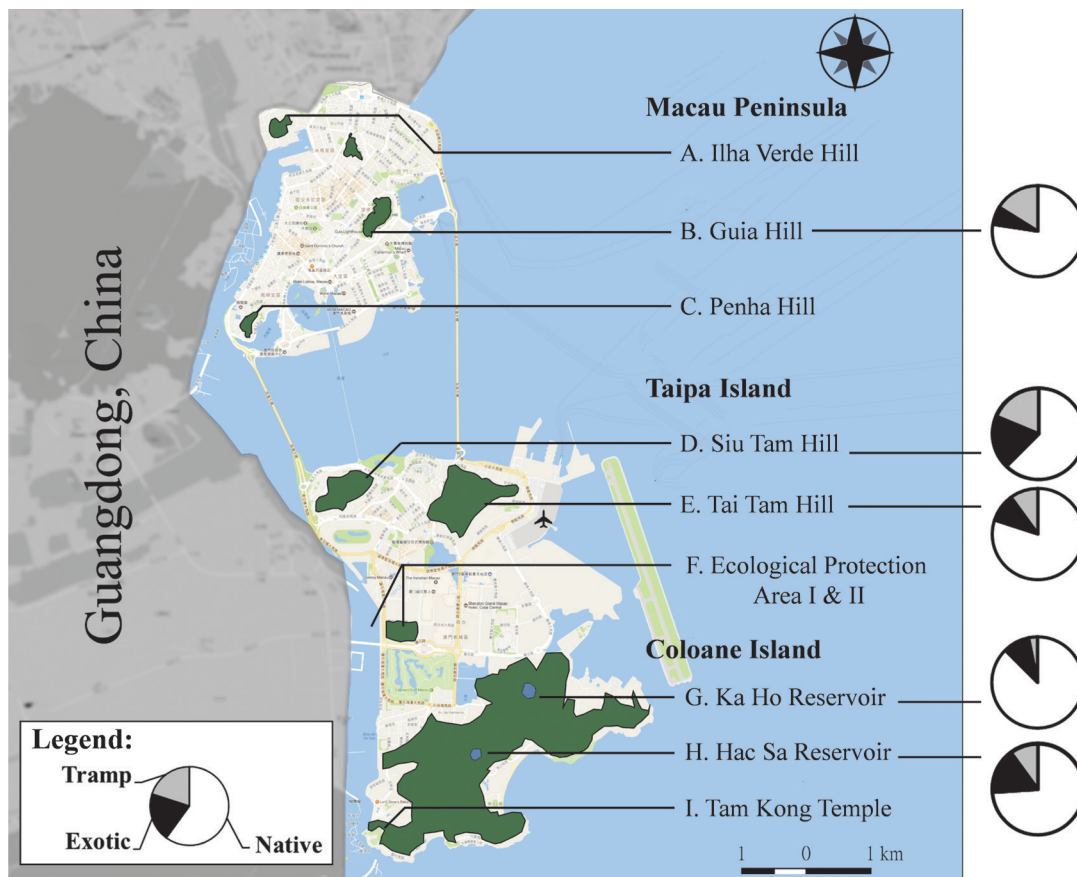
tively (Information Services Department Hong Kong Special Administrative Region Government 2015; United Nations 2015; Statistics and Census Service 2017). Historically, Macau consisted of a peninsula connected to Guangdong, and of two islands: Coloane Island (8.07 km<sup>2</sup>) and Taipa Island (7.6 km<sup>2</sup>). Over the past decades, important land reclamation over the ocean has led to the merging of Coloane and Taipa Islands together. Despite this important urbanization and land changes, a few “natural” areas and parks have been preserved. For example, Ka Ho and Hac Sa Reservoirs on Coloane Island are freshwater-wetland ecological zones, and areas of these two reservoirs are regulated for the conservation purpose of an endemic moss *Fissidens macaoensis* (Zhang & Hong 2011) and an endemic mosquito *Toxorhynchites macaoensis* (Ribeiro 1997).

Regarding the Macanese insect fauna, several groups like butterflies and moths (Lepidoptera) (Easton & Pun 1997a, b), water beetles (Coleoptera) (Jäch & Easton 1998), stink bugs (Homoptera) (Easton & Pun 1999), mosquitoes, sandflies, and blackflies (Diptera) (Ou 2001) or again damselflies (Zygoptera) (Wilson & Xu 2007) have been previously surveyed in Macau, but other major taxonomic groups that compose the Macanese biodiversity are still poorly known, including ants (Formicidae). Yet, understanding ant diversity and species composition is important. For instance, within an urban matrix composed of a diversity of habitats, even small natural patches of natural habitats can still support high species diversity of ants (Menke *et al.* 2011; Guénard *et al.* 2015), while on the other hand non-native or habitat disturbance specialist species can represent a significant portion of the myrmecofauna within the habitats (Guénard *et al.* 2015). Moreover, as ants represent a dominant group among arthropods and show sensitivity to environmental changes in relation to disturbance, they can represent a good bioindicator across different habitats and help in monitoring their respective ecological values (Andersen *et al.* 2002; Del Toro *et al.* 2012).

To the best of our knowledge, no specific checklist or sampling has been realized to characterize ant diversity in Macau, and only sporadic records have been reported in the literature. To date, the most comprehensive list of ants

of Macau was provided in the 1920's in a series of articles by the American myrmecologist William Morton Wheeler, and embedded with other records for various parts of China (Wheeler 1921, 1928, 1930). A few other records from Macau were reported or cited in various taxonomic revisions on Chinese or Asian ants (Xu 2003; Eguchi 2008). Over the past two decades, several records of Macau ants were included within Chinese species checklists, yet with no or little specific sampling efforts for this territory (e.g. Wu 1941; Chapman & Capco 1951; Tang *et al.* 1995; Zhou 2001; Fellowes 2006; Hua 2006; Guénard & Dunn 2012; Ran & Zhou 2011, 2012, 2013); and existing records of Macanese ants were not included in a checklist of ants in Guangdong (Zhao *et al.* 2009). Despite these limited efforts and the small area that Macau represents, two species and subspecies of ants have been described on the basis of specimens collected there, namely *Carebara capreola laeviceps* (Wheeler, 1928) and *Crematogaster macaoensis* Wu & Wang 1995, with this latter recorded from other Chinese provinces as well (Guénard & Dunn 2012; antmaps.org 2017). The subspecies *C. capreola laeviceps* is endemic to Macau, however as no recent work has examined the taxonomic validity of this species, the possibility that this species represents a synonym should not be excluded. In addition, most historical records were reported without specific collecting locations in Macau and without habitat information, which limits the understanding of the distribution of these species. As a result, knowledge on Macanese ants is at this point limited, and in order to establish a landmark allowing improved future work on ant diversity and conservation on this territory, a first species checklist is currently needed.

Here, we present the results of a preliminary ant survey conducted in the main natural habitats of Macau. We then establish the first comprehensive species checklist of Macanese ants based on newly collected materials and published records. This checklist may benefit knowledge of the ants from Macau and South-East China, and provide detailed information for future studies. In addition, the discussion on ant community of each study site is also presented to provide insights on the effects of urbanization on ants.



**Fig. 1.** Map of Macau SAR presenting the sampling locations (modified after Google Map 2017). Pie charts represent the ant composition in native (white), tramp (grey) and exotic species (black) for the sites with the most complete sampling effort.

## MATERIALS AND METHODS

The main sampling sites were located on Guia Hill on the Macau Peninsula, Tai Tam Hill and Siu Tam Hill on Taipa Island and Ka Ho and Hac Sa Reservoirs on Coloane Island (sampling locations shown on Figure 1). Field work was conducted from July to August 2015, July to August 2016, January 2017 and July to August 2017. It should be noted that sampling effort among the different sites was not standardized and more effort was applied on sites located on Coloane Island, to deliberately target more natural and mature habitats preserved on this island rather than the urbanized and isolated habitats present on Taipa Island and Macau Peninsula. In 2015, a total of 23 field sessions were realized; in each of

them we surveyed for about five hours using hand collection; in 2016 and 2017, a total of fourteen field sessions were realized, again for about five hours using hand collection but coupled with the use of a Winkler extractor, this latter being an efficient method to collect cryptobiotic ants present in the leaf litter as well as ground dwelling ants (Bestelmeyer *et al.* 2000). In addition, some specimens collected in diverse locations of Macau were generously provided by Mr Martinho G. Oxalá and Mr Chi-Yui Lei.

For hand collection, we searched for ants visually with a specific focus on the ground, under rocks, in rotten wood (breaking it open), and on tree trunks with the help of an insect aspirator. For Winkler extractor sampling, six litres of sifted leaf litter (abundantly decomposed organic

materials) were collected within each site and chosen to maximize the number of micro-habitats sampled and thus ant diversity (Ward 2000). Leaf litter was dried in a Winkler extractor for seven days. All collected specimens were preserved in 75% ethanol before being point mounted and later processed for identification. All specimens of this study were deposited in the Insect Biodiversity and Biogeography Laboratory at the University of Hong Kong.

### Taxonomic changes and updates

Regarding previous records, taxonomic updates and changes were incorporated into our results and followed taxonomic information available in AntCat.org (2017). Voucher specimens from previous records in the literature were not deposited in Macau or did not have specific voucher specimens (Wu 1941; Tang *et al.* 1995; Zhou 2001; Xu 2003; Hua 2006), which prevented us from

examining these records. Thus, to identify potential dubious records, we used information on species' known distributions available on antmaps.org (Janicki *et al.* 2016; Guénard *et al.* 2017) and in the literature. Here we retained the subspecies level to reflect the lack of recent taxonomic revisions in several genera, with some of the current subspecies representing potential valid species in the future. On the other hand, if these subspecies are later on synonymized with other known species, this would allow to easily adopt future taxonomic changes.

### RESULTS

A total of 82 valid species and morphospecies, belonging to 37 genera and from 8 subfamilies, were collected during this survey, including 37 newly recorded species for Macau, which now

**Table 1.** Collection sites of this study with details on location and collection methods used (including GPS coordinate, attitude, size of habitat, sampling times and methods such as H. = Hand collection, W. = Winkler extractor). The last column (right) present the ant diversity retrieved at each site, as well as the number of exotic and tramp species.

Code	Location	GPS coordinate	Attitude (m)	Size (ha)	Sampling sessions	Methods	Total species (exotic, tramp)
A	Ilha Verde Hill	22.2116 °N, 113.5374°E	55	4.3	1	H. + W.	3 (1,0)
B	Guia Hill	22.1983 °N, 113.5511 °E	64	16.4	10	H. + W.	31 (2,5)
C	Penha Hill	22.1833 °N, 113.5319 °E	37	5.3	1	H.	3 (1,1)
D	Siu Tam Hill	22.1608 °N, 113.5466 °E	75	26	4	H. + W.	29 (4,0)
E	Tai Tam Hill	22.1575 °N, 113.5650 °E	104	77.9	4	H.	16 (3,3)
F	Ecological Protection Area I & II	22.1406 °N, 113.5544 °E	0	55	1	H.	11 (3,3)
G	Ka Ho Reservoir	22.1244 °N, 113.5672 °E	93	177.6	6	H. + W.	32 (3,1)
H	Hac Sa Reservoir	22.1344 °N, 113.5725 °E	65	264.7	8	H. + W.	50 (8,5)
I	Tam Kong Temple	22.1138 °N, 113.5500 °E	11	4	2	H.	5 (2,1)

**Table 2.** Species recorded during previous studies (extracted from Guénard & Dunn 2012; antmaps.org 2017) and the current study. Single asterisk in front of species name shows new records from Macau. Also with notes (e.g. tramp and exotic species). The collecting methods (H. = Hand collection, W. = Winkler extractor) for each species records are provided.

Species	Earliest record	This study	Notes	Methods
<b>AMBLYOPONINAE</b>				
[1 genus, 1 species]				
<i>Stigmatomma rothneyi</i> (Forel, 1900)	Wheeler 1928	√		H. + W.
<b>DOLICHODERINAE</b>				
[5 genera, 9 species; 2 morphospecies]				
<i>Chronoxenus wroughtonii</i> (Forel, 1895)	Tang <i>et al.</i> 1995			
<i>Chronoxenus wroughtonii formosensis</i> (Forel, 1913)	Hua 2006			
<i>Chronoxenus dalyi</i> (Forel, 1895)	Wheeler 1928			
<i>Chronoxenus walshi</i> (Forel, 1895)	Hua 2006			
<i>Dolichoderus taprobanae</i> (Smith, 1858)	Wheeler 1928			
<i>Dolichoderus</i> sp. mo01 [cf. <i>sibiricus</i> Emery, 1889]		√		H.
<i>Ochetellus glaber</i> (Mayr, 1862)	Wheeler 1928	√	Tramp	H.
* <i>Tapinoma indicum</i> Forel, 1895		√		H. + W.
<i>Tapinoma melanocephalum</i> (Fabricius, 1793)	Wheeler 1921	√	Tramp	H.
<i>Tapinoma</i> sp. mo01 [nr. <i>melanocephalum</i> (Fabricius, 1793)]		√		H. + W.
<i>Technomyrmex brunneus</i> Forel, 1895	Tang <i>et al.</i> 1995	√	Tramp	H. + W.
<b>DORYLINAE</b>				
[1 genus, 1 species]				
* <i>Ooceraea biroii</i> (Forel, 1907)		√	Tramp	H.
<b>FORMICINAE</b>				
[8 genera, 23 species; 7 morphospecies]				
* <i>Acropyga acutiventris</i> Roger 1962		√		H.
<i>Acropyga sauteri</i> Forel, 1912	Wheeler 1928			
<i>Acropyga</i> sp. mo02		√		H. + W.
<i>Anoplolepis gracilipes</i> (Smith, 1857)	Wheeler 1928	√	Exotic	H. + W.
<i>Camponotus albosparsus</i> Bingham, 1903	Wheeler 1928			
* <i>Camponotus lighti</i> Wheeler, 1927		√		H.
<i>Camponotus mitis</i> (Smith, 1858)	Wheeler 1928	√		H. + W.
* <i>Camponotus nicobarensis</i> Mayr, 1865		√		H. + W.
<i>Camponotus parius</i> Emery, 1889	Wheeler 1921	√		H. + W.
* <i>Camponotus vitiosus</i> Smith, 1874		√		H. + W.
<i>Camponotus variegatus</i> (Smith, 1858)	Hua 2006		Tramp	
<i>Camponotus variegatus dulcis</i> Dalla Torre, 1893	Wheeler 1928	√		H. + W.
<i>Camponotus variegatus proles</i> Emery, 1925	Wu 1941			

Species	Earliest record	This study	Notes	Methods
<i>Camponotus</i> sp. mo01 [cf. <i>mitis</i> (Smith, 1858)]		√		H.
<i>Colobopsis</i> sp. mo01 [nr. <i>nipponica</i> Wheeler, 1928]		√		H.
<i>Colobopsis</i> sp. mo02 [nr. <i>vitrea</i> Smith, 1860]		√		H.
<i>Lepisiota rothneyi watsonii</i> (Forel, 1894)	Wheeler 1921			
<i>Nylanderia amia</i> (Forel, 1913)	Wheeler 1928	√	Tramp	H. + W.
<i>Nylanderia bourbonica</i> (Forel, 1886)	Hua 2006		Tramp	
<i>Nylanderia indica</i> (Forel, 1894)	Wheeler 1928			
<i>Nylanderia vividula</i> (Nylander, 1846)	Hua 2006		Exotic	
<i>Nylanderia yerburyi</i> (Forel, 1894)	Wheeler 1928	√		H.
<i>Nylanderia</i> sp. mo01		√		H. + W.
<i>Nylanderia</i> sp. mo02 [nr. <i>vividula</i> (Nylander, 1846)]		√		H. + W.
<i>Nylanderia</i> sp. mo03 [cf. <i>birmana</i> (Forel, 1902)]		√		H.
<i>Paraparatrechina sauteri</i> (Forel, 1913)	Hua 2006			
<i>Paratrechina longicornis</i> (Latreille, 1802)	Wheeler 1928	√	Exotic	H. + W.
* <i>Polyrhachis demangei</i> Santschi, 1910		√		H.
<i>Polyrhachis dives</i> Smith, 1857	Tang <i>et al.</i> 1995	√		H. + W.
* <i>Polyrhachis illaudata</i> Walker, 1859		√		H. + W.
<b>LEPTANILLINAE</b>				
[1 genus; 1 morphospecies]				
<i>Leptanilla</i> sp. mo01		√		W.
<b>MYRMICINAE</b>				
[12 genera, 40 species; 9 morphospecies]				
* <i>Cardiocondyla minutior</i> Forel, 1899		√	Tramp	H.
<i>Carebara capreola</i> (Wheeler, 1927)	Xu 2003			
<i>Carebara capreola laeviceps</i> (Wheeler, 1928)	Wheeler 1928			
<i>Carebara diversa</i> (Jerdon, 1851)	Wheeler 1921			
* <i>Carebara diversa laotina</i> (Santschi, 1920)		√		H.
* <i>Carebara zengchengensis</i> (Zhou, Zhao & Jia, 2006)		√		H. + W.
<i>Carebara</i> sp. 2 BG [nr. <i>melasolena</i> (Zhou & Zheng, 1997)]		√		H. + W.
<i>Carebara</i> sp. mo02		√		H. + W.
<i>Crematogaster biroi</i> Mayr, 1897	Wheeler 1928			
<i>Crematogaster dohrni artifex</i> Mayr, 1879	Wheeler 1928			
* <i>Crematogaster ferrarii</i> Emery, 1888		√		H.
<i>Crematogaster macaoensis</i> Wu & Wang, 1995	Wheeler 1928			
* <i>Crematogaster quadriruga</i> Forel, 1911		√		H. + W.
* <i>Crematogaster rogenhoferi</i> Mayr, 1879		√		H. + W.
<i>Meranoplus</i> sp. mo01 [sp. nr. <i>bicolor</i> (Guérin-Méneville, 1844)]		√		H. + W.

Species	Earliest record	This study	Notes	Methods
* <i>Monomorium floricola</i> (Jerdon, 1851)		√	Tramp	H.
* <i>Monomorium pharaonis</i> (Linnaeus, 1758)		√	Exotic	W.
<i>Monomorium</i> sp. mo01		√		H. + W.
* <i>Myrmecina sinensis</i> Wheeler, 1921		√		W.
* <i>Pheidole tumida</i> Eguchi, 2008		√		H. + W.
<i>Pheidole fervens</i> Smith, 1858	Eguchi 2008	√	Tramp	H. + W.
<i>Pheidole hongkongensis</i> Wheeler, 1928	Eguchi 2008	√		H. + W.
<i>Pheidole indica</i> Mayr, 1879	Wheeler 1928		Tramp	
<i>Pheidole megacephala</i> (Fabricius, 1793)	Eguchi 2008	√	Exotic	H. + W.
* <i>Pheidole nodus</i> Smith, 1874		√		H. + W.
* <i>Pheidole ochracea</i> Eguchi, 2008		√		H. + W.
<i>Pheidole taipoana</i> Wheeler, 1928	Eguchi 2008			
<i>Pheidole parva</i> Mayr, 1865	Eguchi 2008	√		H. + W.
<i>Pheidole</i> sp. mo01		√		H.
* <i>Recurvidris recurvispinosa</i> (Forel, 1890)		√		H. + W.
<i>Solenopsis geminata</i> Buren, 1972	Wheeler 1928	√	Exotic	H.
<i>Solenopsis invicta</i> (Fabricius, 1804)	Hua 2006	√	Exotic	H. + W.
* <i>Solenopsis jacoti</i> Wheeler, 1923		√		H. + W.
* <i>Strumigenys emmae</i> (Emery, 1890)		√	Exotic	H. + W.
* <i>Strumigenys exilirhina</i> Bolton, 2000		√		H. + W.
<i>Strumigenys membranifera</i> Emery, 1869	Wheeler 1928		Exotic	
* <i>Strumigenys minutula</i> Terayama & Kubota, 1989		√		H. + W.
* <i>Strumigenys nepalensis</i> Baroni Urbani & De Andrade, 1994		√		H. + W.
<i>Strumigenys silvestrii</i> Emery, 1906	Chapman and Capco 1951		Exotic	
<i>Sylophopsis</i> sp. mo01 [nr. <i>sechellensis</i> (Emery, 1894)]		√		H. + W.
* <i>Tetramorium bicarinatum</i> (Nylander, 1846)		√	Tramp	H. + W.
* <i>Tetramorium kraepelini</i> Forel, 1905		√	Tramp	H. + W.
<i>Tetramorium lanuginosum</i> Mayr, 1870	Wheeler 1928	√	Tramp	H. + W.
* <i>Tetramorium nipponense</i> Wheeler, 1928		√		H.
* <i>Tetramorium parvispinum</i> (Emery 1893)		√		H. + W.
* <i>Tetramorium simillimum</i> (Smith, 1851)		√	Exotic	H.
<i>Tetramorium</i> sp. 1BG ( <i>obesum</i> group Bolton, 1976)		√		H. + W.
<i>Tetramorium</i> sp. mo02		√		H. + W.
<i>Tetramorium</i> sp. mo03 [cf. <i>wroughtonii</i> (Forel, 1902)]		√		H. + W.



Species	Earliest record	This study	Notes	Methods
<b>PONERINAE</b>				
[11 genera, 17 species; 2 morphospecies]				
<i>*Anochetus risii</i> Forel, 1900		√		H.
<i>Bothroponera rubiginosa</i> (Emery, 1889)	Wheeler 1928			
<i>Brachyponera luteipes</i> (Mayr, 1862)	Wheeler 1928		Tramp	
<i>Brachyponera obscurans</i> (Mayr, 1862)	Wheeler 1928	√		H. + W.
<i>Diacamma rugosum</i> (Le Guillou, 1842)	Hua 2006			
<i>Diacamma rugosum anceps</i> Matsumura & Uchida, 1926	Wheeler 1928			
<i>Diacamma</i> sp. mo01		√		H. + W.
<i>Ectomyrmex astutus</i> (Smith, 1858)	Zhou 2001			
<i>*Ectomyrmex leeuwenhoekii</i> (Forel, 1886)		√		H.
<i>*Euponera pilosior</i> Wheeler, 1928		√		H. + W.
<i>Euponera sharpi</i> Forel, 1901	Wheeler 1928			
<i>Harpegnathos venator</i> (Smith, 1858)	Zhou 2001	√		H. + W.
<i>Harpegnathos venator rugosus</i> (Mayr, 1862)	Wheeler 1928			
<i>*Hypoponera exoecata</i> (Wheeler, 1928)		√		H. + W.
<i>Hypoponera</i> sp. mo01		√		H. + W.
<i>*Leptogenys chinensis</i> (Mayr, 1870)		√		H.
<i>Leptogenys peuqueti</i> (André, 1887)	Wheeler 1928	√		H. + W.
<i>*Odontoponera denticulata</i> (Smith, 1858)		√		H. + W.
<i>Pseudoneoponera rufipes</i> (Jerdon, 1851)	Wheeler 1930	√		H. + W.
<b>PSEUDOMYRMECINAE</b>				
[1 genus; 1 species]				
<i>*Tetraoponera allaborans</i> (Walker, 1859)		√		H. + W.

includes a total of 105 species and 8 subspecies (Table 2). Among these, 11 species can be considered exotic or potentially exotic to Macau, and 15 species are known as tramp species.

The highest diversity in Macau was found on two sites of Coloane Island, Hac Sa and Ka Ho Reservoirs, in which 50 and 32 species were collected respectively, inclusive of a significant number of exotic and tramp species (Table 1 & Figure 1). The Guia Hill on the Macau Peninsula and Siu Tam Hill on Taipa Island presented similar levels of species richness as well as the presence of several exotic and tramp species. While the other sites sampled had much lower species diversity, exotic or tramp species

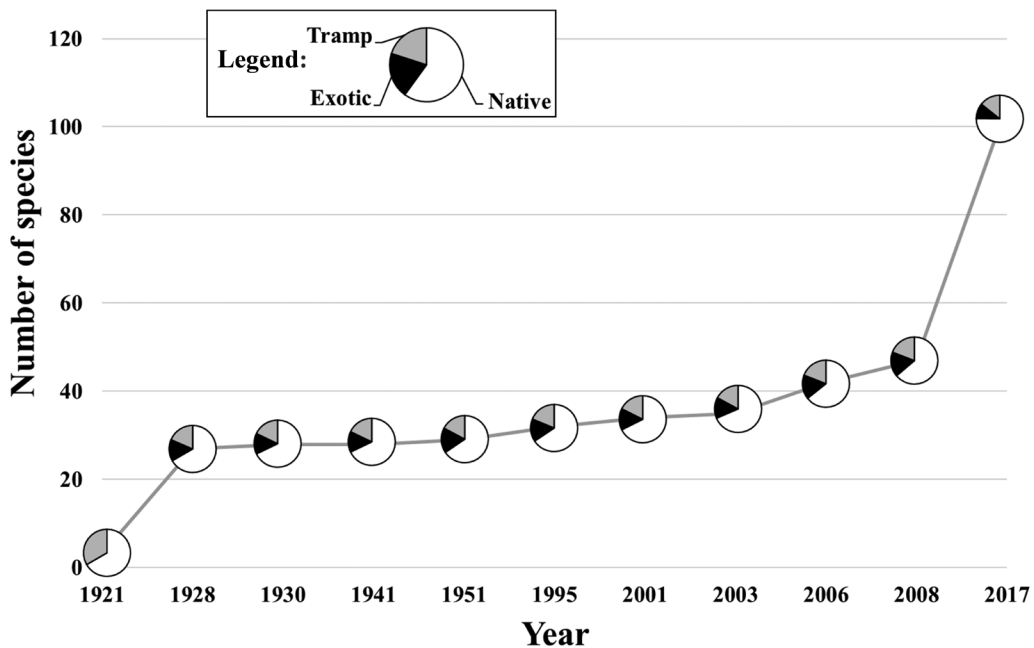
were commonly collected (Table 1 & Figure 1). It should be noted that the sampling effort across sites was not standardized, and thus comparison between sites should carefully consider this point.

Four species previously reported in Macau, *Formica exsecta*, *Technomyrmex albipes*, *Tetramorium guineense* and *Tetramorium tsushimae*, are provisionally excluded from the Macanese ant fauna until further confirmation as these records represent distribution anomalies in Macau relative to the rest of their global distribution (antmaps.org 2017); they have not been collected in this study nor could they be confirmed from voucher specimens. Notes on the four dubious records: (1) *Formica exsecta* is distributed in re-

gions of temperate climate. Therefore, *F. exsecta* should not occur in Macau, and we consider the record doubtful. (2) Although *Technomyrmex albipes* is a successful tramp species and spread easily, we have not collected this species. Moreover this species has often been misidentified in the past and is part of a group known to be difficult to identify (Bolton 2007), and previous records of *T. albipes* in East Asia most likely represent records of *T. brunneus* which was commonly collected in this study. (3) *Tetramorium guineense* is restricted to the Afrotropical region (Hita Garcia *et al.* 2010). The record from Macau, presented by Wheeler (1928), does not contain enough information on the specimen diagnosis or description to confirm its presence and no new specimen was collected in this study. Moreover, previous records of *T. guineense* from Macau most likely represent records of *T. bicarinatum* which was commonly collected in this study, and has been incorrectly reported as *T. guineense* in many locations around the world (Wetterer 2009). (4) Records of *T. tsushimae* are based on previous records of *T. caespitum jacoti* and *T. caespitum*

*jacoti annectens* by Wheeler (1928), which are now considered primary synonyms of *T. tsushimae*. Species of the genus *Tetramorium* are particularly difficult to identify in Asia and these species are regularly misidentified. However, *T. tsushimae* is primarily a temperate-distributed species and its presence in the subtropical climate of Macau can be considered doubtful.

Figure 2 presents the accumulation of Macanese ant species records through time, which currently includes a total of 105 species and 8 subspecies based on literature records and newly collected material (Figure 2 and Appendix 1). The sharp increase following this survey is noticeable and demonstrates the incomplete knowledge on Macanese ants for both native and exotic species. The majority of the species newly recorded in the Macanese myrmecofauna are considered native, but it should be noted that newly recorded exotic species have also been reported recently. Two notorious invasive species, *Solenopsis invicta*, native to South America (first recorded by Hua 2006), and *Pheidole megacephala*, native to Africa (first recorded by



**Fig. 2.** Accumulation of Macanese ant species knowledge based on literature records and this study. Pie charts present the ant composition in native (white), tramp (grey) and exotic species (black) for each time period (details presented in appendix 1).

Eguchi 2008), represent recent introductions and seem now widespread in Macau based on their multiple occurrences in the recent survey. Here, *Strumigenys emmae*, native to the Australasian region, is for the first time recorded in Macau. We also report the first record of *Ooceraea biroi*. While this species could be native to Macau, its exact native range is uncertain and this species is known to have successfully colonized various regions around the world: Taiwanese and Japanese islands, Pacific islands, Caribbean islands, Malagasy islands and Christmas Island (Australia). Both species possess cryptobiotic habits and live within the leaf litter and soil. The records of *Monomorium pharaonis* and *Tetramorium similimum*, both native from the Afrotropical region, represent new records for Macau. Other notorious exotic species first recorded nearly 90 years ago (e.g. *Anoplolepis gracilipes*, *Paratrechina longicornis* and *Solenopsis geminata*) were still commonly encountered in Macau.

The comprehensive species checklist of Macanese ants is shown in Table 2, in addition to collecting methods used for each species (when information is available).

### Checklist of species collected in this study

\* indicates newly recorded species from Macau.

#### AMBLYOPONINAE [1 genus; 1 species]

##### *Stigmatomma rothneyi* (Forel, 1900)

**Material examined.** Guia Hill, 9.VIII.2015, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker and 1 male, CM Leong leg.

#### DOLICHODERINAE [4 genera; 4 species, 2 morphospecies]

##### *Dolichoderus* sp. mo01 [cf. *sibiricus* Emery, 1889]

**Material examined.** Hac Sa Reservoir, 29.VII.2015, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 1 worker, CM Leong leg.

##### *Ochetellus glaber* (Mayr, 1862)

**Material examined.** Guia Hill, 28.VII.2015, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 3 workers, CM Leong leg.

##### \**Tapinoma indicum* Forel, 1895

**Material examined.** Siu Tam Hill, 5.VIII.2015, 1 worker, CM Leong leg. Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg. Ilha Verde Hill, 25.I.2017, 1 dealate queen, CM Leong leg.

##### *Tapinoma melanocephalum* (Fabricius, 1793)

**Material examined.** Guia Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 2 workers and 1 dealate queen, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 1 worker, B Guénard leg.

##### *Tapinoma* sp. mo01 [nr. *melanocephalum* (Fabricius, 1793)]

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker, CM Leong leg.

##### *Technomyrmex brunneus* Forel, 1895

**Material examined.** Guia Hill, 13.VII.2015, 1 worker, CM Leong leg.; Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker, CM Leong leg.

#### DORYLINAE [1 genus, 1 species]

##### \**Ooceraea biroi* (Forel, 1907)

**Material examined.** Tai Tam Hill, 25.VIII.2016, 1 worker, MG Oxalá leg.

#### FORMICINAE [7 genera; 14 species, 7 morphospecies]

##### \**Acropyga acutiventris* Roger 1962

**Material examined.** Guia Hill, 24.VII.2015, 1 dealate queen, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 dealate queen, CM Leong leg.;

Hac Sa Reservoir, 29.VII.2017, 1 dealate queen and 7 workers, CM Leong leg. Hac Sa Reservoir, 2.VIII.2017, 4 dealate queens and 7 workers, B Guénard leg.

***Acropyga* sp. mo02**

**Material examined.** Hac Sa Reservoir, 29.VII.2017, 3 workers, CM Leong leg.

***Anoplolepis gracilipes* (Smith, 1857)**

**Material examined.** Hac Sa Reservoir, 7.VIII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, CM Leong leg.

**\**Camponotus lighti* Wheeler, 1927**

**Material examined.** Tai Tam Hill, 29.VII.2015, 1 major, CM Leong leg.; Tam Kong Temple, 30.VII.2015, 1 minor, CM Leong leg.; Tam Kong Temple, 31.VII.2015, 1 minor, CM Leong leg.; Penha Hill, 6.VIII.2015, 1 minor, CM Leong leg.; Guia Hill, 9.VIII.2015, 1 minor, CM Leong leg.

***Camponotus mitis* (Smith, 1858)**

**Material examined.** Siu Tam Hill, 18.VII.2015, 1 minor and 1 major, CM Leong leg.; Hac Sa Reservoir, 31.VII.2015, 1 minor, CM Leong leg.; Siu Tam Hill, 31.VII.2015, 1 minor, CM Leong leg.; Hac Sa Reservoir, 7.VIII.2015, 2 majors, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 dealate queen, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 2 minors and 1 major, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 minor and 2 majors, CM Leong leg.

**\**Camponotus nicobarensis* Mayr, 1865**

**Material examined.** Hac Sa Reservoir, 7.VIII.2015, 1 minor and 1 major, CM Leong leg.; Tai Tam Hill, 30.IX.2015, 1 minor, CY Lei leg.; Ka Ho Reservoir, 14.VII.2016, 1 major, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 major, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 minor, CM Leong leg.

***Camponotus parius* Emery, 1889**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 2 media, B Guénard leg.

***Camponotus variegatus dulcis* Dalla Torre, 1893**  
**Material examined.** Guia Hill, 20.VIII.2016, 1 minor, CM Leong leg.

**\**Camponotus vitiosus* Smith, 1874**

**Material examined.** Siu Tam Hill, 13.VII.2016, 3 minors, MG Oxalá leg. Guia Hill, 20.VIII.2016, 1 minor, CM Leong leg.

***Camponotus* sp. mo01 [cf. *mitis* (Smith, 1858)]**

**Material examined.** Siu Tam Hill, 12.X.2015, 1 minor, CY Lei leg.

***Colobopsis* sp. mo01 [nr. *nipponica* (Wheeler, 1928)]**

**Material examined.** Tai Tam Hill, 5.VIII.2015, 1 minor, CM Leong leg.

***Colobopsis* sp. mo02 [nr. *vitrea* Smith, 1860]**

**Material examined.** Siu Tam Hill, 5.VIII.2015, 1 minor, CM Leong leg.

***Nylanderia amia* (Forel, 1913)**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 1 worker, B Guénard leg.

***Nylanderia yerburyi* (Forel, 1894)**

**Material examined.** Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.

***Nylanderia* sp. mo01**

**Material examined.** Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.; Hac Sa Reservoir, 3.X.2015, 1 worker, CY Lei leg.; Ka Ho Reservoir, 13.X.2016, 1 worker, CY Lei leg.

***Nylanderia* sp. mo02 [nr. *vididula* (Nylander, 1846)]**

**Material examined.** Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

***Nylanderia* sp. mo03 [cf. *birmana* (Forel, 1902)]**

**Material examined.** Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.

***Paratrechina longicornis* (Latreille, 1802)**

**Material examined.** Hac Sa Reservoir, 29.VII.2015, 1 worker, CM Leong leg.; Tam Kong Temple, 30.VII.2015, 1 worker, CM Leong leg.; Penha Hill, 6.VIII.2015, 2 workers, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 2 workers, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 1 worker, CM Leong leg.

**\**Polyrhachis demangei* Santschi, 1910**

**Material examined.** Ka Ho Reservoir, 23.VIII.2015, 1 worker, CM Leong leg.

***Polyrhachis dives* Smith, 1857**

**Material examined.** Hac Sa Reservoir, 22.I.2017, 1 worker, CM Leong leg.

**\**Polyrhachis illaudata* Walker, 1859**

**Material examined.** Ka Ho Reservoir, 11.VII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Tai Tam Hill, 02.VIII.2017, 1 worker, B Guénard leg.

**LEPTANILLINAE [1 genus; 1 morphospecies]*****Leptanilla* sp. mo01**

**Material examined.** Ilha Verde Hill, 25.I.2017, 5 workers, CM Leong leg.

**MYRMICINAE [12 genera; 30 species, 9 morphospecies]****\**Cardiocondyla minutior* Forel, 1899**

**Material examined.** Tai Tam Hill, 2.VIII.2017, 2 workers, B Guénard leg.

**\**Carebara diversa laotina* (Santschi, 1920)**

**Material examined.** Tai Tam Hill, 02.VIII.2017, 50 workers, B Guénard leg.

**\**Carebara zengchengensis* (Zhou, Zhao & Jia, 2006)**

**Material examined.** Ka Ho Reservoir, 11.VII.2015, 1 minor, CM Leong leg.; Siu Tam Hill, 18.VII.2015, 1 minor and 1 major, CM Leong leg.; Siu Tam Hill, 31.VII.2015, 1 minor and 1 major, CM Leong leg.; Ka Ho Reservoir, 31.VII.2015, 1 minor, 1 major and 1 supermajor, CM Leong leg.; Tai Tam Hill, 25.IX.2015, 1 minor and 2 majors, CY Lei leg.; Ka Ho Reservoir, 14.VIII.2016, 1 minor and 1 major, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 2 minors, 2 majors and 1 supermajor, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2016, 1 minor, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 minor, 1 major and 1 supermajor, CM Leong leg.

***Carebara* sp. 2 BG [nr. *melasolena* (Zhou & Zheng, 1997)]**

**Material examined.** Guia Hill, 18.VIII.2016, 3 minors, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 major, CM Leong leg.

***Carebara* sp. mo02**

**Material examined.** Guia Hill, 15.VII.2015, 1 minor, CM Leong leg.; Siu Tam Hill, 18.VII.2015, 1 minor, CM Leong leg.

**\**Crematogaster ferrarii* Emery, 1888**

**Material examined.** Hac Sa Reservoir, 29.VII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2015, 1 worker, CM Leong leg.

**\**Crematogaster quadriruga* Forel, 1911**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.

**\**Crematogaster rogenhoferi* Mayr, 1879**

**Material examined.** Tai Tam Hill, 29.VII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 31.VII.2015, 1 worker, CM Leong leg.; Siu Tam Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Tai Tam Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Tai Tam Hill, 20.VIII.2015, 1 worker, CM Leong leg.; Tai Tam Hill, 25.IX.2015, 2 workers, Lei CY leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 2 workers, CM Leong leg.

***Meranoplus* sp. mo01 [nr. *bicolor* (Guérin-Méneville, 1844)]**

**Material examined.** Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

**\**Monomorium floricola* (Jerdon, 1851)**

**Material examined.** Penha Hill, 6.VIII.2015, 1 worker, CM Leong leg.

**\**Monomorium pharaonis* (Linnaeus, 1758)**

**Material examined.** Hac Sa Reservoir, 29.VII.2017, 1 worker, CM Leong leg.

***Monomorium* sp. mo01**

**Material examined.** Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

**\**Myrmecina sinensis* Wheeler, 1921**

**Material examined.** Hac Sa Reservoir, 29.VII.2017, 1 worker, CM Leong leg.

***Pheidole fervens* Smith, 1858**

**Material examined.** Hac Sa Reservoir, 9.I.2017, 1 minor, CM Leong leg.

***Pheidole hongkongensis* Wheeler, 1928**

**Material examined.** Guia Hill, 18.VIII.2016, 1 minor, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 major and 1 minor, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 29.VII.2017, 1 major and 2 minors, CM Leong leg.

***Pheidole megacephala* (Fabricius, 1793)**

**Material examined.** Guia Hill, 28.VII.2015, 2 minors, CM Leong leg.; Hac Sa Reservoir, 29.VII.2015, 2 minors, CM Leong leg.; Tam Kong Temple, 30.VII.2015, 1 major, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 major and 1 minor, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 1 major and 1 minor, CM Leong leg.; Ilha Verde Hill, 25.I.2017, 1 minor and 1 major, CM Leong leg.; Tai Tam Hill, 2.VIII.2017, 13 workers, B Guénard leg.

**\**Pheidole nodus* Smith, 1874**

**Material examined.** Guia Hill, 15.VII.2015, 2 minors, CM Leong leg.; Tam Kong Temple, 30.VII.2015, 1 minor, CM Leong leg.; Ka Ho Reservoir, 1.VI.2016, 1 worker, 1 dealate queen and 1

male, CY Lei leg.; Hac Sa Reservoir, 20.VIII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 12 workers, B Guénard leg.

***Pheidole parva* Mayr, 1865**

**Material examined.** Hac Sa Reservoir, 21.VIII.2015, 2 minors, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 2 minors, B Guénard leg.; Guia Hill, 20.VIII.2016, 2 majors and 1 minor, CM Leong leg.

**\**Pheidole ochracea* Eguchi, 2008**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 2 minors, B Guénard leg.

**\**Pheidole tumida* Eguchi, 2008**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 minor, CM Leong leg.; Hac Sa Reservoir, 29.VII.2017, 2 minors, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 minor, CM Leong leg.

***Pheidole* sp. mo01**

**Material examined.** Ecological Protection Area I & II, 12.I.17, 1 minor, CM Leong leg.

**\**Recurvidris recurvispinosa* (Forel, 1890)**

**Material examined.** Siu Tam Hill, 1 worker, 26.VIII.2016, CM Leong leg.

***Solenopsis geminata* (Fabricius, 1804)**

**Material examined.** Hac Sa Reservoir, 7.VIII.2015, 1 alate queen and 2 males, CM Leong leg.; Hac Sa Reservoir, 21.VIII.2015, 1 worker, CM Leong leg.

***Solenopsis invicta* Buren, 1972**

**Material examined.** Siu Tam Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Tai Tam Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Hac Sa Reservoir, 8.VIII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 1 worker, CM Leong leg.

**\**Solenopsis jacoti* Wheeler, 1923**

**Material examined.** Hac Sa Reservoir, 29.VII.2017, 2 workers, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 2 workers, CM Leong leg.

**\**Strumigenys emmae* (Emery, 1890)**

**Material examined.** Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 dealate queen, CM Leong leg.; Tai Tam Hill, 02.VIII.2017, 1 worker, B Guénard leg.

**\**Strumigenys exilirhina* Bolton, 2000**

**Material examined.** Hac Sa Reservoir, 29.VII.2017, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 2 workers, CM Leong leg.

**\**Strumigenys minutula* Terayama & Kubota, 1989**

**Material examined.** Hac Sa Reservoir, 20.VIII.2016, 1 dealate queen, CM Leong leg.; Hac Sa Reservoir, 29.VII.2017, 1 dealate queen, CM Leong leg.; Ka Ho Reservoir, 20.VIII.2016, 1 worker, MG Oxalá leg.

**\**Strumigenys nepalensis* Baroni Urbani & De Andrade, 1994**

**Material examined.** Hac Sa Reservoir, 1 worker, 20.VIII.2016, CM Leong leg.

***Sylophopsis* sp. mo01 [nr. *sechellensis* (Emery, 1894)]**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 2 workers, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

**\**Tetramorium bicarinatum* (Nylander, 1846)**

**Material examined.** Guia Hill, 24.VII.2015, 1 worker, CM Leong leg.; Tam Kong Temple, 30.VII.2015, 1 worker, CM Leong leg.; Guia Hill, 5.VIII.2015, 1 worker, CM Leong leg.; Hac Sa Reservoir, 3.X.2015, 1 worker, CY Lei leg.; Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Ka Ho Reservoir, 20.VIII.2016, 1 worker, MG Oxalá leg.; Guia Hill, 27.VIII.2016, 2 workers, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 1 worker, CM Leong leg.

**\**Tetramorium kraepelini* Forel, 1905**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 3 workers, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2016, 1 worker, CM Leong leg.

***Tetramorium lanuginosum* Mayr, 1870**

**Material examined.** Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 2 workers, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 4 workers, B Guénard leg.; Tai Tam Hill, 02.VIII.2017, 1 worker, B Guénard leg.

**\**Tetramorium nipponense* Wheeler, 1928**

**Material examined.** Ka Ho Reservoir, 20.VIII.2016, 1 worker, MG Oxalá leg.

***Tetramorium parvispinum* (Emery, 1893)**

**Material examined.** Ka Ho Reservoir, 14.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 2 workers, CM Leong leg.

Note that the specimens are similar to the type of *Tetramorium parvispinum formosae* Forel 1912, now considered a junior synonym of *Tetramorium parvispinum*, with a distinct and large trapezoidal cell present just on the antero-dorsal position of eyes.

**\**Tetramorium simillimum* (Smith, 1851)**

**Material examined.** Hac Sa Reservoir, 2.VIII.2017, 4 workers, B Guénard leg.

***Tetramorium* sp. 1BG (*obesum* group Bolton, 1976)**

**Material examined.** Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 4 workers, B Guénard leg.

***Tetramorium* sp. mo02**

**Material examined.** Siu Tam Hill, 26.VIII.2016, 1 dealate queen, CM Leong leg.

***Tetramorium* sp. mo03 [cf. *wroughtonii* (Forel, 1902)]**

**Material examined.** Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

**PONERINAE** [10 genera; 10 species, 2 morpho-species]

**\**Anochetus risii* Forel, 1900**

**Material examined.** Ka Ho Reservoir, 20.VIII.2016, 1 worker, MG Oxalá leg.

***Brachyponera obscurans* (Mayr, 1862)**

**Material examined.** Guia Hill, 18.VII.2016, 1 worker, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker, CM Leong leg.; Ecological Protection Area I & II, 12.I.2017, 2 workers, CM Leong leg.

***Diacamma* sp. mo01**

**Material examined.** Siu Tam Hill, 31.VII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 2 workers, CM Leong leg.; Guia Hill, 18.VII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 worker, CM Leong leg.

**\**Ectomomyrmex leeuwenhoekii* (Forel, 1886)**

**Material examined.** Tai Tam Hill, 26.VIII.2016, 3 workers, MG Oxalá leg.; Hac Sa Reservoir, 29.VII.2017, 1 worker, CM Leong leg.

**\**Euponera pilosior* Wheeler, 1928**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 29.VII.2017, 1 alate gyne, CM Leong leg.; Hac Sa Reservoir, 2.VIII.2017, 1 worker, B Guénard leg.

***Harpegnathos venator* (Smith, 1858)**

**Material examined.** Hac Sa Reservoir, 7.VIII.2015, 1 worker, CM Leong leg.; Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 worker, CM Leong leg.

**\**Hypoponera exoecata* (Wheeler, 1928)**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 2 workers, CM Leong leg.; Hac Sa Reservoir, 20.VIII.2016, 1 worker, CM Leong leg.; Siu Tam Hill, 26.VIII.2016, 1 worker, CM Leong leg.

***Hypoconerops* sp. mo01**

**Material examined.** Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.

**\**Leptogenys chinensis* (Mayr, 1870)**

**Material examined.** Tai Tam Hill, 25.IX.2015, 1 worker, CY Lei leg.

***Leptogenys peuqueti* (André, 1887)**

**Material examined.** Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.; Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 20.VIII.2016, 1 worker, CM Leong leg.; Guia Hill, 27.VIII.2016, 1 worker and 1 male, CM Leong leg.; Hac Sa Reservoir, 29.VII.2017, 1 worker, CM Leong leg.

**\**Odontoponera denticulata* (Smith, 1858)**

**Material examined.** Guia Hill, 15.VII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 23.VIII.2015, 1 worker, CM Leong leg.; Tai Tam Hill, 29.VII.2015, 1 worker, CM Leong leg.; Siu Tam Hill, 25.IX.2015, 1 worker, CY Lei leg.; Siu Tam Hill, 12.X.2015, 1 worker, CY Lei leg.; Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.; Guia Hill, 18.VIII.2016, 1 worker, CM Leong leg.; Hac Sa Reservoir, 9.I.2017, 1 worker, CM Leong leg.

Note that although some specimens of *O. denticulata* were mentioned by Leong *et al.* (2017) for comparing the sculpture variation of *O. denticulata* in Asia, the formal record for Macau is firstly provided in this study.

***Pseudoneoponera rufipes* (Jerdon, 1851)**

**Material examined.** Hac Sa Reservoir, 7.VIII.2015, 1 worker, CM Leong leg.; Ka Ho Reservoir, 14.VII.2016, 1 worker, CM Leong leg.

**PSEUDOMYRMECINAE** [1 genus; 1 species]

**\**Tetraoponera allaborans* (Walker, 1859)**

**Material examined.** Guia Hill, 27.VIII.2016, 1 worker, CM Leong leg.



## DISCUSSION

Here, we present the first ant survey specific to Macau, with results providing new data for 82 species/morphospecies from 37 genera in 8 subfamilies. More than 2/5 (37 species) of the species collected represent new species records from Macau, which brings the known Macanese myrmecofauna to 105 species and 8 subspecies (Table 2); with this checklist summarizing literature records collected for nearly a century and excluding potential dubious records. While during this period the urbanization of Macau has increased, and it cannot be excluded that some of the species previously collected in Macau are now locally extinct, the results presented here suggest the presence of a diverse ant fauna in Macau. This is particularly interesting as Macau is a small region (30.4 km<sup>2</sup>) with the highest human population density globally, and with most of its natural habitats small and highly fragmented within the urban matrix. For comparison, and with the limitations due to climatic differences, the myrmecofauna of Macau is probably as diverse as the myrmecofauna found in Oregon (110 species; 254,806 km<sup>2</sup>) or South Korea (112 species; 100,210 km<sup>2</sup>), both regions being several thousands of times larger than Macau (data from antmaps.org 2017, Guénard *et al.* 2017). While the results presented here should be perceived as preliminary, nonetheless, they provide a basal framework for future research on Macanese ant fauna and can be informative to measure potential extinction and introduction rates of ants in the region.

Typical of heavily urbanized environments (McKinney 2008; Guénard *et al.* 2015), the proportion of species considered either as exotic or tramp species was high. Here, nearly a quarter of the species collected (19/82; 23.2%) belong to one of these two categories, with eight species considered exotic (Table 2), *Anoplolepis gracilipes*, *Monomorium pharaonis*, *Paratrechina longicornis*, *Pheidole megacephala*, *Solenopsis geminata*, *Solenopsis invicta*, *Strumigenys emmae*, *Tetramorium simillimum* and eleven other species considered tramp species: *Cardiocondyla minutior*, *Monomorium floricola*, *Nylanderia amia*, *Ochetellus glaber*, *Ooceraea biroi*, *Pheidole fervens*, *Tapinoma melanoceph-*

*alum*, *Technomyrmex brunneus*, *Tetramorium bicarinatum*, *Tetramorium kraepelini*, *Tetramorium lanuginosum*. Exotic species prevalence is particularly high in Macau as shown by their presence in all sites sampled in this study. Moreover, within the best sampled sites tramp or exotic species represented a significant portion of the myrmecofauna (Fig. 1), consistent with McKinney's (2008) speculation of a high proportion of non-native and habitat disturbance specialist species retrieved within heavily urbanized environments. Finally, several of the exotic species collected are considered among the world's worst invasive alien species (*Anoplolepis gracilipes*, *Pheidole megacephala* and *Solenopsis invicta*: Lowe *et al.* 2000) which could result in problems for local biodiversity conservation (Holway *et al.* 2002). Our results also indicate that new exotic species can be detected in Macau. However, at this point, it is unclear if these species represent recent species introductions or much older establishment that has been missed until now due to the limited extent and nature of sampling. Nonetheless, measures to control establishment of new exotic species through trading activities should be considered as potential new invaders present in the Asia/Pacific region (e.g. *Linepithema humile*, *Wasmannia auropunctata*) could establish populations in Macau (antmaps.org 2017).

The array of sampling methods used in this study is likely insufficient to capture the full spectrum of the Macanese myrmecofauna, e.g. no arboreal or subterranean traps being used, which might in the future allow the collection of new species. Yet, the use of Winkler extractors within this study, a collecting method used infrequently in South East China, has enhanced the collection of cryptobiotic ant species, including within urban habitats. For instance, in 2015, 37 species/morphospecies from 23 genera were collected using only hand collection over 26 sampling sessions; while in 2016 and 2017, 68 species/morphospecies from 37 genera were collected from a combination of both hand collections and Winkler extractors over 14 sampling sessions. Particularly, the use of Winkler extractors has allowed the collection of four species of *Carebara* (formerly *Oligomyrmex*), one *Myrmecina* species, four *Strumigenys* species, one *Sylophopsis* species, two *Hypoponera* species and a new record

of the rarely collected subfamily Leptanillinae, the second record for South East China with the first recently reported from Hong Kong (Wong & Guénard 2016c). This survey represents a starting point for future myrmecological research in Macau. However future studies are needed in particular to improve taxonomic knowledge to delimit and identify current morphospecies, with some representing new species (e.g. *Leptanilla* species; Leong *et al.* submitted); and to complete the survey of Macanese ants through the use of a wider range of sampling methods. For instance, the use of complementary and efficient methods such as arboreal, subterranean and pitfall traps are likely to provide new records for Macau and potentially to Guangdong province. Recently, the use of subterranean pitfall traps and Winkler extractors in Singapore, another heavily urbanized city of South East Asia, has allowed the recent collection of three new ant species (Wong & Guénard 2016a, b, c) and the discovery of the species of *Leptanilla* suggests that similar outcomes might be possible.

Based on current knowledge, the diversity of Macanese ants is comparable to that of other diverse groups such as 145 moths and 74 butterflies (Lepidoptera; Easton & Pun 1997a, b), and significantly higher than the 37 stinkbugs (Homoptera; Easton & Pun 1999), 35 mosquitoes (Diptera; Ou 2001), 25 water beetles (Coleoptera; Jäch & Easton 1998) or 7 damselflies (Zygoptera; Wilson & Xu 2007) recorded thus far. Although it should be noted that further inventory in some of these groups (e.g. moths, Odonata), as for ants, is probably necessary, the high taxonomic and ecological diversity of ants observed within an urban matrix combined with the presence of numerous native and non-native disturbance specialists should encourage their use as a bioindicator in Macau and other urbanized regions of Asia; in particular if coupled with studies within more pristine habitats in the region to determine composition changes following urbanization. Finally, future studies should focus on the distribution and potential ecological impacts of the tramp and exotic species observed in the ant community surveyed, as most of the ecological impacts of these species on the regional native fauna and flora are still unknown and should be investigated in the future to benefit our knowledge on urbanized habitats within Asia.

In summary, although Macau is small and highly urbanized, the need for biodiversity inventory and the protection of the few natural terrestrial habitats left is important as these might still host a diverse fauna, including some species of peculiar importance (e.g. *Leptanilla* species). To enhance our knowledge of the Macanese myrmecofauna and guide the dilemmas of urban development, future studies should include comprehensive collecting methods, further study on these morphospecies, and ecological impacts of tramp and exotic species.

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## ASIAN MYRMECOLOGY

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## APPENDIX

**Appendix 1.** Summary of the accumulation of species known from Macau over time with details on the number of reported native, tramp and exotic species.

First record	Species			Subspecies	Total
	Native species	Tramp species	Exotic species		
Wheeler 1921	2	1	0	1	4
Wheeler 1928	18	5	4	5	32
Wheeler 1930	19	5	4	5	33
Wu 1941	19	5	4	6	34
Chapman and Capco 1951	19	5	5	6	35
Tang <i>et al.</i> 1995	21	6	5	6	38
Zhou 2001	23	6	5	6	40
Xu 2003	24	6	5	6	41
Hua 2006	27	8	7	7	49
Eguchi 2008	30	9	8	7	54
Present study 2017	79	15	11	8	113