Ecological strategies of pl(ant)s: toward a world-wide worker economic spectrum for ants

Heloise Gibb, Tom R. Bishop, Lily Leahy, Catherine L. Parr, Jean-Philippe Lessard, Nathan J. Sanders, Jonathan Z. Shik, Javier Ibarra-Isassi, Ajay Narendra, Robert R. Dunn, & Ian J. Wright

Appendices

Appendix S1: Web of Science search terms used in generating Figure 1

Plant ecological strategies: Abstract: "ecological strateg$" OR "ecology strateg$" OR "trait syndrome$" AND "plant$" OR "vegetation" AND "trait$" NOT "microb$" OR "bacteria$" OR "fung$" OR animal$" OR "insect$" OR "mammal$" OR "bird$" OR "reptile$" OR "amphibian$" OR "fish$" OR "spider$" OR "ant" OR "beetle$" OR "coral$"

Animal ecological strategies: Abstract: "ecological strateg$" OR "ecology strateg$" OR "trait syndrome$" AND "animal$" OR "insect$" OR "mammal$" OR "bird$" OR "reptile$" OR "amphibian$" OR "fish$" OR "spider$" OR "ant" OR "beetle$" OR "coral$" AND "trait$" NOT "microb$" OR "bacteria$" OR "fung$" OR "plant$" OR "vegetation"

Plant traits: Abstract: "plant trait$" OR "vegetation trait$" NOT "microb$" OR "bacteria$" OR "fung$" OR animal$" OR "insect$" OR "mammal$" OR "bird$" OR "reptile$" OR "amphibian$" OR "fish$" OR "spider$" OR "ant" OR "beetle$" OR "coral$"

Animal traits: Abstract: "animal trait$" OR "insect trait$" OR "mammal trait$" OR "bird trait$" OR "reptile trait$" OR "amphibian trait$" OR "fish trait$" OR "spider trait$" OR "ant trait$" OR "beetle trait$" OR "coralt rait$" NOT "microb$" OR "bacteria$" OR "fung$" OR "plant$" OR "vegetation"

Plant trait space: Abstract: "trait space$" OR "morphospace" AND "plant$" OR "vegetation" AND "trait$" NOT "microb$" OR "bacteria$" OR "fung$" OR animal$" OR "insect$" OR "mammal$" OR "bird$" OR "reptile$" OR "amphibian$" OR "fish$" OR "spider$" OR "ant" OR "beetle$" OR "coral$"

Animal trait space: Abstract: "trait space" OR "morphospace" OR AND "animal$" OR "insect$" OR "mammal$" OR "bird$" OR "reptile$" OR "amphibian$" OR "fish$" OR "spider$" OR "ant" OR "beetle$" OR "coral$" AND "trait$" NOT "microb$" OR "bacteria$" OR "fung$" OR "plant$" OR "vegetation"

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Appendix S2: Methods for Box 2

The core data of our analysis came from *GlobalAnts*, a twin database of ant functional traits (Parr *et al.* 2017) and local abundances (Gibb *et al.* 2017) from across the globe. The trait database contained information on 14 morphological traits from 4564 ant species and morphospecies. We selected nine traits that were available for at least 50% of the species: head length, mandible length, hind femur length, eye width, clypeus length, interocular distance, scape length, pronotum width and head width. We used a series of algorithms to error check the data and corrected obvious typographic errors but otherwise removed erroneous or suspicious values. All traits for the minor worker caste were averaged within species, within study. We assumed that intraspecific variation was small relative to the range of interspecific differences that this dataset captures – this is likely to be true at local scales for ant morphological variation (Gaudard, Robertson & Bishop 2019).

We chose nine raw morphological variables to calculate eight traits for analysis. We used head length as a proxy for overall size and calculated 7 shape traits. These shape traits were relative eye size, relative leg length (hind femur), head elongation, relative mandible length, relative antennae length (scape), relative clypeus length, and relative interocular distance. Most were calculated by diving the raw variable by head length. Exceptions were head elongation (head length ÷ head width = head elongation. Where low values are wide and round heads and high values are narrow and long heads) and relative interocular distance (interocular distance ÷ head width = relative eye position. Where high values are laterally positioned eyes on the side of the head and low values are dorsally positioned, front facing eyes). Ants with no eyes were given a raw eye width of 0 and a raw interocular distance equal to their head width. These traits are commonly used in ant trait studies and are thought to reflect trophic position, hunting strategy, and the various ways that ants move through their environments.

We removed species with less than six of the nine raw traits, and gap-filled missing values (14% of species-by-trait combinations were missing) using random forest imputation (Stekhoven & Bühlmann 2012). We included time-calibrated phylogenetic information (Nelsen, Ree & Moreau 2018), in the form of phylogenetic eigenvectors calculated at the genus-level, as additional predictors in the imputation to account for phylogenetic signal in the trait values (Diniz-Filho *et al.* 2012; Penone *et al.* 2014). These size and shape traits were $\log_{10}+1$ transformed, scaled, and centred before a Euclidean distance matrix was calculated from them. We then applied a principal component analysis (PCA) to this trait distance matrix.

We then used principal component analysis (PCA) to summarise variation in worker ant size and shape. We used two methods to decide how many principal component dimensions to retain for further analysis: (1) all dimensions with eigenvalues greater than the mean eigenvalue, the Kaiser-Guttman criterion, and (2) the redundancy testing procedure proposed by Dray (2008). These methods suggested retaining three and five dimensions, respectively. We compromised and retained four.

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We collated a series of independent datasets from the literature on ant ecology and evolution with which to compare against our trait space.

Clade age: We used a time-calibrated phylogeny (Nelsen, Ree & Moreau 2018) to estimate the crown age of each genus in millions of years before the present.

Arboreality: We used the genus-level dataset published by Lucky *et al.* (2013) which describes which habitat strata different ant genera most commonly live in. These data are ordinal categories, and we transformed them into a numeric variable ranging from 0 (subterranean) to 2 (arboreal).

Trophic position: Blanchard and Moreau (2017) provide a dataset of species level trophic positions. The authors scored species as herbivorous, omnivorous, or predacious. We converted these categories into a numeric variable (herbivorous = 0, predacious = 2) and calculated an average at the genus-level for our analysis.

Foraging strategy: We extracted information on ant foraging strategies from Lanan (2014). Lanan (2014) grouped the various foraging strategies of ants into three categories of increasing complexity. Solitary foraging strategies are the simplest. Group foraging strategies, whereby there is some physical or chemical coordination between workers, are of intermediate complexity. Chemical mass recruitment strategies are the most complex and use a range of short or long-term trail networks, volatile pheromones, and raiding behaviours. We converted these ordinal categorical foraging strategy data into a numeric variable for analysis. The original dataset is presented on a per species basis. We summed the number of entries in each foraging category for each genus and took the most common strategy as the strategy for the genus overall.

Liquid feeding behaviour: Lanan (2014) also provide data on feeding preferences. We extracted data on liquid feeding behaviour via extrafloral nectaries, floral nectar and honeydew from trophobiont mutualists. Genera with recorded liquid feeding behaviour were scored 1, and those with no records of liquid feeding behaviour were scored 0.

To understand how each of the original morphological traits was linked to the PC axes, we calculated the Pearson correlation between each original trait and each PC axis. We also calculated the percentage contribution of each trait to each axis according to the formula:

$$\text{Contribution \%} = \frac{(\text{VL} \times \text{PCsd})^2 \times 100}{\sum(\text{VL} \times \text{PCsd})^2}$$

Where VL represents the variable loading of each trait on a given axis and PCsd represents the standard deviation of the scores on a given axis. We made these calculations based on the species level trait data and PC axes.

Finally, we correlated each axis to each independent ecological variable, calculating Pearson's correlation coefficients (Table S2).

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Table S2: Correlations or contributions of the morphological traits and independent traits to the computed principal component axes.

		Contribution of trait to PC axes			
Trait	Trait description	Axis 1	Axis 2	Axis 3	Axis 4
Head length	Size	8.57	13.08	21.72	1.95
Relative mandible length	Mandibles	3.87	22.37	34.06	2.21
Relative hind femur length	Legs	27.56	0.01	2.22	6.27
Relative eye width	Eyes	14.02	3.00	13.81	20.56
Head length ÷ head width	Head elongation	6.00	23.61	2.54	35.29
Relative clypeus length	Clypeus	6.19	15.87	21.62	17.15
Relative scape length	Antennae	24.02	0.05	0.26	15.01
Relative interocular distance	Eye position	9.77	22.01	3.77	1.56

		Pearson's correlation between traits and PC axes			
Head length	Size	0.46	0.45	0.48	0.12
Relative mandible length	Mandibles	0.34	-0.58	0.59	0.14
Relative hind femur length	Legs	0.89	0.02	0.15	-0.24
Relative eye width	Eyes	0.63	0.22	-0.37	0.41
Head length ÷ head width	Head elongation	-0.41	0.61	0.16	-0.53
Relative clypeus length	Clypeus	0.43	-0.50	-0.46	-0.36
Relative scape length	Antennae	0.84	-0.02	0.04	-0.35
Relative interocular distance	Eye position	-0.55	-0.59	0.20	-0.11

		Pearson's correlation between traits and PC axes			
	Age	-0.15	-0.04	0.05	-0.14
	Trophic level	-0.25	-0.08	0.36	-0.03
	Foraging complexity	0.11	0.33	-0.29	0.31
	Arboreality	0.29	0.50	-0.46	0.21
	Liquid feeding	0.37	0.18	-0.38	-0.07