



No matter where you are, ants (Hymenoptera: Formicidae) get attention when it is warm

Antonio C.M. QUEIROZ, Icaro WILKER, Chaim J. LASMAR, Elisa MOUSINHO, Carla R. RIBAS & Eduardo VAN DEN BERG

Abstract

Google Trends® (GT) can show us how social trends vary in time and space through real-time data. In this study, we aimed to investigate spatial and temporal patterns of variation observed in interest in the search term “ants” and their related variables across the globe. We collected GT data from 20 countries within a 13-year time frame, with 156 monthly values corresponding to search-relative interest (values related to the search interest concerning the highest peak of popularity for a certain term within a certain period). After that, we correlated the average of relative interest per country (constancy of interest) with demographic data and ant diversity and the relative interest in “ants” among countries. The inter- and intra-annual variations in the relative interest in the search term “ants” were also evaluated. After that, we listed related queries and made clusters with related topics collected from each country. We observed that: (I) the constancy of interest in the term “ants” is correlated with higher internet access and higher ant-genera diversity; (II) countries with a closer location, and in the same hemisphere, have similar trends in relative interest independently of their languages; (III) the relative interest in “ants” increased over the years and during warmer months (signaling seasonality). Besides, it is noticed that (IV) there is a high demand for information about ant control. Finally, we found that (V) historic, cultural, and linguistic similarities among countries also influence the search patterns for “ants”. These results can help researchers to gain insight into the psychology of the ordinary Google searcher and reveal the typical perception of ants. They also direct, among others, grant writing, framing research, and choosing research directions and guide eventual public outreach activities. We know myrmecologists need no convincing why ants are interesting and ecologically important, but most people only think about ants when they are annoying them and how to get rid of these animals. Thus, the early months of the warmer seasons would be the best time frame for promotional activities on the benefits of ants. Based on these findings, we suggest: 1) publishing information related to ants during warmer months, highlighting positive aspects of ants; 2) stimulating science education for children and teenagers in myrmecological holiday camps; 3) developing apps focused on providing information about ants, among other actions.

Key words: Ant diversity, Google Trends, internet search, people’s interests, seasonality.

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Introduction

Ants are diverse and widespread across the globe, but the general population is less interested in them than expected, given their importance to ecosystems and, conse-

quently, for humanity (HÖLLDOBLER & WILSON 1990, ELIZALDE & al. 2020). However, as we can see in music, movies, paintings, folklore, novels (ANTWIKI 2020, ELIZALDE

& al. 2020), and ceremonies of native peoples (e.g., the rite of passage into adulthood in the Brazilian Amazon, see BOTELHO & WEIGEL 2011), ants do not go unnoticed, as they are part of our daily life and imagination.

People's interests and contact with ants vary around the globe. In Western cultures, the general aversion against insects (BASSET & LAMARRE 2019), which also includes ants, is commonly associated with allergic reactions and discomfort caused by stings and bites (DAY & al. 2004). The negative reinforcement of the perception of ants is due, for example, to the recurrent media coverage of the economic (LARD & al. 2002, HÖLLEDOBLER & WILSON 2011) or health damage (RHOADES & al. 1989, FOWLER & al. 1993, HADDAD & al. 2005) they can cause. Outside of the Euro-American view, many cultures do not see ants as enemies, but sometimes allies in medicine or food provision (SILVESTRE & SAUDA NETO 2020). However, how the nonscientific community views the ecological benefits provided by ants has been poorly studied. Ants provide environmental services (e.g., seed dispersal, biological control, nutrient cycling) that result directly and indirectly in human well-being (DEL TORO & al. 2012, ELIZALDE & al. 2020). Moreover, ants also serve as a food and medicinal resource for many people in different continents (SRIVASTAVA & al. 2009, GAHUKAR 2011, RASTOGI 2011, ELIZALDE & al. 2020, SILVESTRE & SAUDA NETO 2020). In this context, due to the number of environmental services ants can provide, and the high chance of visualization and interaction with these organisms, people's perception of ants becomes an interesting object of study.

Nowadays, a large part of the scientific and nonscientific information is available on the internet. This is not different when it comes to ants (see Antwiki, AntWeb, Antmaps, and other initiatives; FISHER & WARD 2002, SHATTUCK & al. 2014, JANICKI & al. 2016, GUÉNARD & al. 2017). The spread of the internet around the world was accompanied by the development of a collective environment for sharing knowledge and experiences in an accessible way. Furthermore, the internet has revolutionized scientific communication by increasing the speed and dissemination of information (CUENCA & TANAKA 2005). Despite this fact, little is known about how people from different backgrounds use the internet to express their interest in ants. Additionally, little is discussed concerning the kind of information about ants that is accessed on the internet. Thus, we need this background to strategize disclosure actions and increase the disclosure of ant benefits in peaks of interest. Besides, scientists need to engage with citizens and collectively disseminate science also focusing on ant benefits for a broad audience at the right time.

Google Trends® (GT) is a tool that detects events in Real Life (IRL), with free-access data that reflect the interest of users in search terms of the Google search engine, the most popular on the internet (SULLIVAN 2013, DAVIES 2018). Therefore, GT is a promising tool for conducting surveys for the social analysis of people's relative interest in a particular search term. In recent years, this tool has been used to collect and analyze data that serve to assess patterns in

some areas of the biological sciences such as ecology, conservation, biological control, medicine, and epidemiology (CHO & al. 2013, NGHIEM & al. 2016, CERVELLIN & al. 2017, TROUMBIS 2017, BRODEUR & al. 2018, DAVIES & al. 2018).

We aimed to investigate patterns of spatial and temporal variation in the relative interest in the search term "ants", verify the utility of GT as a tool for understanding people's interest in this term, and plan actions addressed to the non-scientific audience based on this information. For this purpose, we asked the following questions: I) Does the constancy of interest in the term "ants" vary in space (among countries) due to demographic indicators and / or ant biodiversity? II) Do the tendencies of increasing and decreasing in relative interest in the term "ants" occur synchronously in different countries from the same hemisphere and regardless of their languages? III) How does the relative interest in the term "ants" vary over time (annually and monthly)? IV) Which aspects are related to GT Top Related Queries (TRQ), for the term "ants"? V) How are countries clustered according to GT Top Related Topics (TRT), for the term "ants"?

In these scenarios, we expected to find: *I)* correlation between the constancy of interest in the term "ants" and aspects of the countries' demographics (i.e., size of the population and internet access) and / or the greater diversity of ants (BOUSQUET & al. 2017, SHIPLEY & BIXLER 2017); *II)* higher synchronicity on tendencies of increasing and decreasing in relative interest among countries located in similar latitude bands (as VALDIVIA & al. 2010); *III)* a greater relative interest in the term over the years with the popularization of the internet and the use of the Google search engine (BOUSQUET & al. 2017), as well as in the warmer months of the year, reflecting the greater activity of ants (WOLDA 1978, 1988); *IV)* aspects related to negative features and biological control of ants (ALONSO 2009) are the most associated and searched on Google; *V)* countries with similar social features and geographic location presenting similar TRT related to "ants" (FISHER 2009, HAN & al. 2015). Finally, based on our findings, we suggested education and public outreach activities focused on demystifying ants as the "bad bugs" as they have tremendous importance for the ecological functioning and life on earth.

Material and methods

Data collection and analyses: Data were collected on GT, searching the term "ants" within the period from January 2007 to December 2019 (13 years). The searches were filtered for 20 countries (Fig. 1), with different languages around the globe, in which 156 monthly records were collected (values corresponding to relative interest during our sampling period of each month for 13 years; these records are numbers that represent "search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term"). To standardize the data and unitize bias across terms and to search the same term in different

Tab. 1: Summary of 20 countries that we search for the relative interest in the search term “ants”. We listed one official language (*the official language or the most used language in the country on the internet in 2007), code (ISO 3166-1 alpha-3, used in this study), population, population with access to internet (%), gross domestic product (GDP) and GDP per capita in US Dollars (USD\$), territory (km²) from: WORLD BANK (2020), GOOGLE (2020) and number of ant genera and number of ant species from ANTWIKI (2020).

| Official Language* | Country | Code | Pop. (in Millions) | Pop. with Internet (%) 2017 | GDP (in Billions) (USD\$) | GDP per capita (USD\$) | Area (in Millions) (km ²) | Ant genera | Ant species |
|--------------------|--------------|------|--------------------|-----------------------------|---------------------------|------------------------|---------------------------------------|------------|-------------|
| English | Australia | AUS | 24.60 | 86.55 | 1,430.00 | 57,373.69 | 7.692 | 110 | 1,623 |
| English | Canada | CAN | 36.71 | 92.70 | 1,710.00 | 46,232.99 | 9.980 | 26 | 131 |
| English | India | IND | 1,350.00 | 32.00 | 2,720.00 | 2,009.98 | 3.290 | 106 | 843 |
| English | Nigeria | NGA | 195.88 | 42.00 | 397.30 | 2,028.18 | 0.924 | 40 | 123 |
| English | Utd. Kingdom | GBR | 66.02 | 90.42 | 2,860.00 | 42,943.90 | 0.242 | 27 | 80 |
| English | Utd. States | USA | 325.15 | 87.27 | 20,540.00 | 62,794.59 | 9.830 | 79 | 793 |
| French | France | FRA | 66.99 | 80.50 | 2,780.00 | 41,463.64 | 0.644 | 36 | 174 |
| German | Germany | DEU | 82.93 | 84.39 | 3,950.00 | 47,603.03 | 0.357 | 26 | 132 |
| Indonesian | Indonesia | IDN | 267.66 | 32.34 | 1,040.00 | 3,893.60 | 1.900 | 127 | 1,534 |
| Italian | Italy | ITA | 60.43 | 63.08 | 2,080.00 | 34,483.20 | 0.301 | 38 | 186 |
| Japanese | Japan | JAP | 126.53 | 91.73 | 4,970.00 | 39,289.96 | 0.377 | 68 | 288 |
| Portuguese | Angola | AGO | 29.78 | 14.34 | 105.80 | 3,432.39 | 1.240 | 37 | 165 |
| Portuguese | Brazil | BRA | 209.29 | 67.47 | 1,870.00 | 8,920.76 | 8.510 | 112 | 1,499 |
| Portuguese | Mozambique | MOZ | 29.67 | 20.77 | 14.72 | 498.96 | 0.801 | 80 | 282 |
| Portuguese | Portugal | PRT | 10.30 | 73.79 | 240.70 | 23,407.91 | 0.092 | 33 | 113 |
| Russian | Russia | RUS | 144.48 | 76.01 | 1,660.00 | 11,288.87 | 17.100 | 38 | 316 |
| Spanish | Argentina | ARG | 44.27 | 74.29 | 519.90 | 11,683.95 | 2.780 | 76 | 592 |
| Spanish | Colombia | COL | 49.07 | 62.26 | 331.00 | 6,667.79 | 1.140 | 98 | 891 |
| Spanish | Mexico | MEX | 129.16 | 63.85 | 1,220.00 | 9,673.44 | 1.970 | 101 | 1,081 |
| Spanish | Spain | ESP | 46.59 | 84.60 | 1,420.00 | 30,370.89 | 0.506 | 45 | 292 |

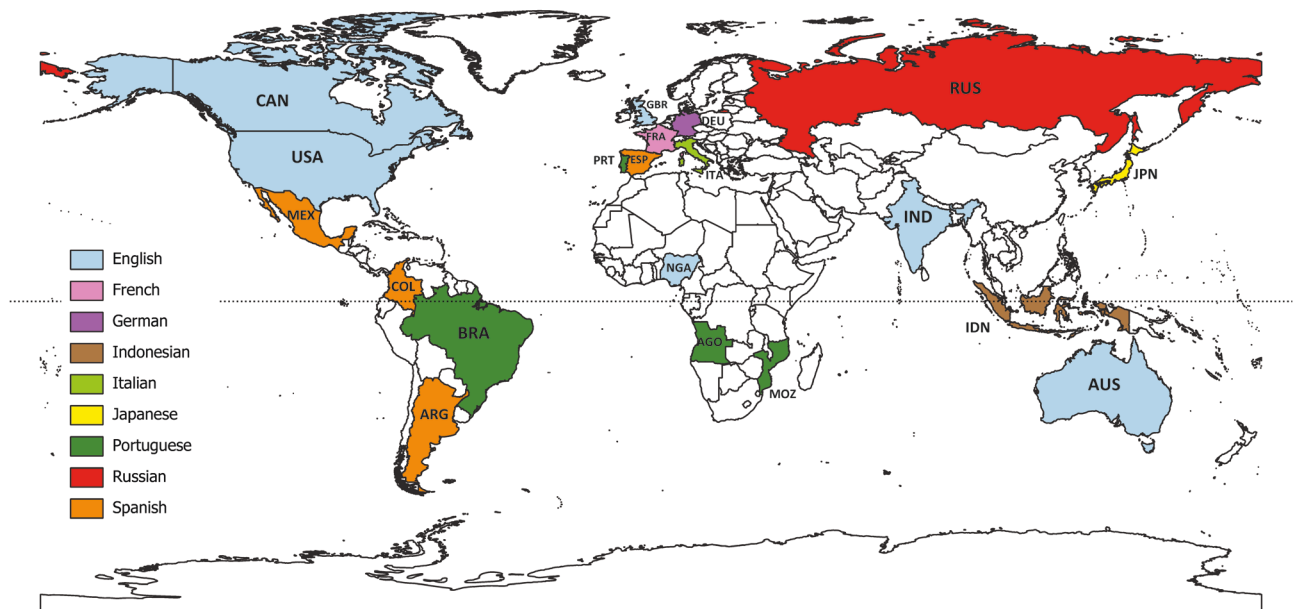


Fig. 1: Analyzed countries. We collected data for this study for the highlighted countries (with different colors depending on official language).

countries, their respective languages were considered (“Ameisen”, “Ants”, “Formiche”, “Formigas”, “Fourmis”, “Hormigas”, “Semut”, “Муравьи”, “アリ”). It was recognized that aspects that do not necessarily reflect people’s

interest in ants can show up when searching for the term “ants” on GT (e.g., sports teams, companies, and others) and show up when searching for “ant”. At the same time, the search term “ant” may produce other results that affect

Tab. 2: Shows the constancy of interest (mean of relative interest by country) (for country code, see Tab. 1) and standard deviation (SD), in the whole period (from 2007-2019). Results of correlations between relative interest by year and time. Columns present type of data distribution (family), the main factor that explains the relative interest ~ year. The value of significance (p), F test (F), R² adjusted (R²), and trend of positive (P), negative (N), non-significant (n.s.) correlations (for more details, see Tab. S2).

| Country code | \bar{x} Mean | SD | Family | p | F | R ² | Trend |
|--------------|----------------|-------|--------------|--------|---------|----------------|-------|
| AUS | 55.12 | 14.59 | Gaussian | <0.001 | 29.799 | 0.706 | P |
| CAN | 38.40 | 24.85 | Gaussian | <0.001 | 48.121 | 0.797 | P |
| IND | 50.33 | 15.82 | Quasipoisson | <0.001 | 19.808 | 0.605 | N |
| NGA | 18.46 | 18.51 | Quasipoisson | 0.142 | 2.505 | 0.101 | n.s. |
| GBR | 32.01 | 17.96 | Gaussian | <0.001 | 22.306 | 0.640 | P |
| USA | 45.11 | 19.51 | Gaussian | <0.001 | 75.866 | 0.862 | P |
| FRA | 35.04 | 19.15 | Gaussian | <0.001 | 406.400 | 0.971 | P |
| DEU | 24.37 | 20.85 | Gaussian | <0.001 | 254.560 | 0.955 | P |
| IDN | 50.33 | 15.82 | Gaussian | 0.036 | 5.690 | 0.281 | P |
| ITA | 29.91 | 18.53 | Gaussian | <0.001 | 103.070 | 0.895 | P |
| JAP | 37.62 | 10.86 | Gaussian | <0.001 | 21.200 | 0.627 | P |
| AGO | 6.57 | 2.20 | Gaussian | 0.017 | 7.936 | 0.366 | P |
| BRA | 70.76 | 12.63 | Gaussian | 0.338 | 1.003 | <0.001 | n.s. |
| MOZ | 4.63 | 2.82 | Quasipoisson | 0.637 | 0.223 | -0.079 | n.s. |
| PRT | 46.82 | 17.85 | Gaussian | <0.001 | 133.140 | 0.917 | P |
| RUS | 49.80 | 18.65 | Gaussian | <0.001 | 86.709 | 0.877 | P |
| ARG | 52.12 | 14.31 | Gaussian | <0.001 | 122.540 | 0.910 | P |
| COL | 56.35 | 16.38 | Gaussian | <0.001 | 48.740 | 0.799 | P |
| MEX | 56.30 | 15.59 | Gaussian | <0.001 | 117.250 | 0.906 | P |
| ESP | 46.01 | 20.09 | Gaussian | <0.001 | 36.271 | 0.746 | P |

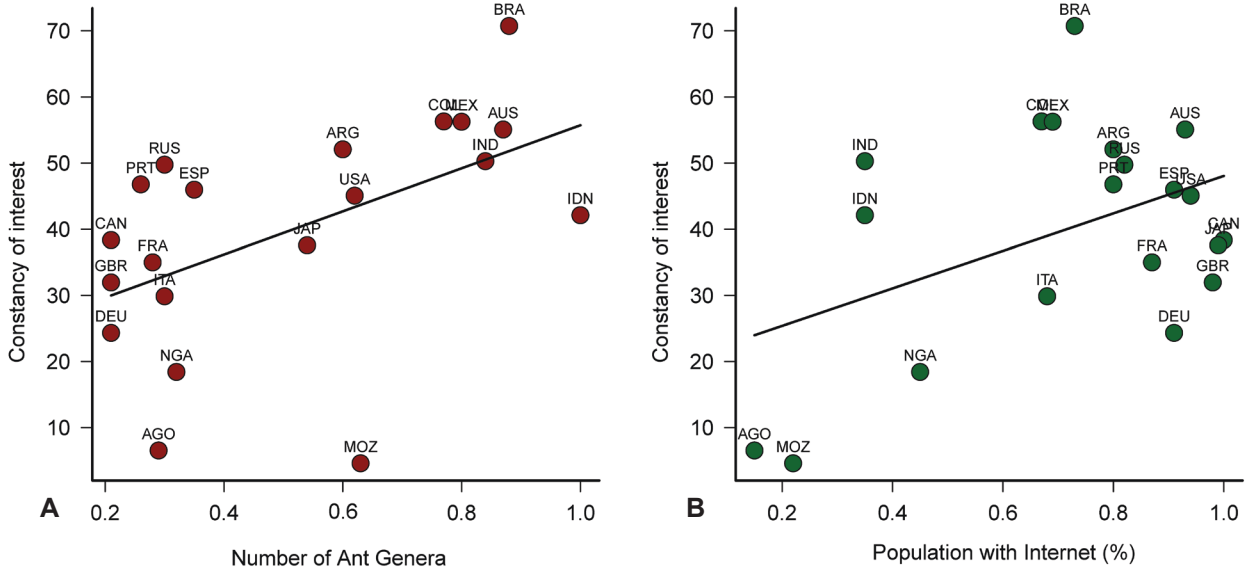


Fig. 2: Representation of the minimal adequate model (constancy of interest ~ number of ant genera + population with internet (%)) (n = 20). (A) Correlation between constancy of interest by country and number of ant genera (dark red circles, $y = 23.15 + 32.58 * x$). (B) Correlation between constancy of interest by country and population with internet (%) (dark green circles, $y = 19.72 + 28.34 * x$).

the evaluation of interest in ants due to data relativization (e.g., movies, artists' surnames, city name, and others). Furthermore, the influence of the Ant-Man franchise on temporal search patterns, due to the data relativization, affect the test of the hypotheses about temporal variation.

Because of that, "ants" and not "ant" was used as a search term. This strategy reduced the problem, although it did not eliminate it. Nonetheless, the results allowed to test hypotheses presented in this paper despite this possible shortcoming.

Tab. 3: Classes of the Top Related Queries per country (see Tab. 1 for country code). Top Related Queries were the most popular queries that users also searched for related to the term “ants”. Numbers represent query occurrences.

| Country Code | Ant keeping | Control | Curiosity | Daily | Dreams | Other animals | Positive | Ant species | Total |
|--------------|-------------|---------|-----------|-------|--------|---------------|----------|-------------|-------|
| AUS | - | 5 | 6 | 5 | - | 1 | - | 7 | 24 |
| CAN | - | 8 | 7 | 1 | - | - | - | 7 | 23 |
| IND | - | 5 | 6 | 5 | - | 1 | - | 7 | 21 |
| NGA | - | 1 | - | - | - | - | - | 1 | 2 |
| GBR | - | 7 | 8 | 4 | - | - | - | 4 | 23 |
| USA | - | 7 | 6 | 2 | - | 1 | - | 7 | 23 |
| FRA | - | 8 | 8 | 4 | - | - | - | 1 | 21 |
| DEU | - | 15 | 9 | - | - | - | - | - | 24 |
| IDN | 2 | 5 | 3 | 5 | 1 | 3 | 1 | 5 | 25 |
| ITA | - | 16 | 4 | 1 | 1 | - | - | 1 | 23 |
| JAP | - | 2 | - | 21 | - | 1 | - | - | 24 |
| BRA | - | 10 | 3 | 4 | 2 | 2 | - | 2 | 23 |
| PRT | - | 7 | 3 | 2 | 1 | 1 | - | - | 14 |
| RUS | 2 | 2 | 4 | 6 | 3 | 2 | - | 5 | 24 |
| ARG | - | 12 | 3 | 3 | 2 | - | - | 3 | 23 |
| COL | - | 4 | 2 | 7 | 2 | 3 | - | 2 | 20 |
| MEX | - | 8 | 2 | 3 | 6 | 1 | - | 2 | 22 |
| ESP | 1 | 12 | 6 | 2 | 1 | - | - | 1 | 23 |
| Total | 5 | 134 | 80 | 75 | 19 | 16 | 1 | 55 | 385 |

The countries were arbitrarily chosen due to the high variation of characteristics considering: official language, hemisphere and geographical location, population, percentage of the population with internet access, and economic data (Gross Domestic Product – GDP and GDP per capita). Social and economic data were retrieved from the WORLD BANK (2020), whereas information on the number of ant genera and species was retrieved from ANTWIKI (2020) (Tab. 1). First, 12 countries were selected that have English, Portuguese, and Spanish as their official languages (Australia, Canada, UK, and USA; Angola, Brazil, Mozambique, and Portugal; Argentina, Colombia, Mexico, and Spain). Nonetheless, due to the geographic location of these countries, large areas of the globe would not be included. Therefore, China, India, Japan, and Indonesia were selected. Those are Asian countries with large populations, ant diversity and / or economic development. Due to the low popularity of Google in China, the country was discarded. Nigeria, on the other hand, was included because it has the largest population on the African continent. Finally, European countries with different official languages were selected. Some of those present a similar language structure (e.g., France and Italy), high GDP, and internet access patterns (e.g., Germany and Russia). Additionally, these selected countries, located across all continents, share or do not share other traits, such as cultural similarity and colonization process.

The relative interest for the term “ants” for each country observed on GT over time is presented in Figure S1, as digital supplementary material to this article, at the journal’s web pages. Besides providing information about the variation in the interest for the term “ants” over the years, GT also permits one to download the 25 “Top Related Queries” (TRQ – “The most popular search queries. Scoring is on a relative scale where a value of 100 is the most commonly searched query, 50 is a query searched half as often as the most popular query, and so on.”) and the 25 “Top Related Topics” (TRT – “The most popular topics. Scoring is on a relative scale where a value of 100 is the most commonly searched topic and a value of 50 is a topic searched half as often as the most popular term, and so on.”). Then, TRQ and TRT related to the search term “ants” were collected.

Data analysis: I) To verify if the constancy of interest for the term “ants” varies in space, the mean and standard deviation were calculated of searches by country that represents the constancy of interest over the years. After that, to test if this variation was linked to ant biodiversity and / or internet access, the relation was tested of the constancy of interest in each country (as response variable), and population, population with internet access, number of ant genera, and number of ant species (as explanatory variables) ($y \sim x_1 + x_2 + x_3 + x_4$) with Generalized Linear Models (GLMs) and normal distribution ($p < 0.05$) (CRAWLEY 2013). All explanatory variables were rescaled between 0 and 1 values for also comparing the effects of

explanatory variables collected at different scales on the same response variable (GAIL & al. 2007).

II) A matrix of correlation through the Spearman method ($p < 0.05$) was built to discover if the tendencies of increasing and decreasing in relative interest in the term “ants” occurs synchronically in different countries of the same hemisphere and occurs regardless of their languages. It was necessary because not all data fitted in the normal distribution.

III) To evaluate the variation of the relative interest by year (annual mean) in the term “ants” over time, GLMs and normal distribution corrected when necessary were used (CRAWLEY 2013). It was verified through correlations (model a: relative interest per year ~ years) for each country if the relative interest per year in “ants” varies over the years ($p < 0.05$). Considering that the increase in relative interest per year may also be caused by the increase in internet access, for each case, the significance of the model b was checked (relative interest per year ~ percentage of internet access) ($p < 0.05$). In case a significant relationship was found, also model c was verified (residuals of model b ~ years) to confirm if part of the variation of the relative interest by year, which is not explained for the internet access in model b, is explained solely by the time in years. After that, it was tested if the relative interest in “ants” varies along the months using a statistical model for examining seasonal patterns through simple GLMs (BARNETT & al. 2012). For this test, the relative interest was used as the response variable and the months as explanatory variables. The reference month was set to January for all countries (bars represented 95% confidence intervals).

IV) To investigate which aspects are related to “Top Related Queries” (TRQ) when searching for “ants”, all the TRQ were listed by country for comparison in an occurrence table to assess which categories of queries were most related to the search for “ants”. Subsequently, the queries were classified into the following categories: “ant keeping” (related to ants as pets), “control” (related to ant control and eradication), “curiosity” (related to ant characteristics), “daily” (related to day-by-day things as places, food, and other cultural aspects), “dreams” (related to curiosity about the significance of dreams with ants), “other animals” (related to other animals), “positive” (related to positive aspects about ants or advantages provided by them), “species” (related to specific searches for ants, like fire ants, leaf-cutter ants), and “synonyms” (when people searched for “ants” synonyms, i.e., “ant” or “the ants”).

V) A cluster analysis was performed to verify similarities among countries concerning the “Top Related Topics” (TRT). The presence and absence of data related to the search for the term “ants” were verified through a matrix created with the Euclidean distance and Ward’s method (MURTAGH & LEGENDRE 2014). Subsequently, the information found was adjusted into four clusters.

To produce all analyses and graphs, the software R v.3.6.3 (R CORE TEAM 2020) and the following packages were used: corrplot 0.84 (WEI & al. 2017), cluster 2.1.0 (MAECHLER & al. 2019), ggplot2 (WICKHAM 2016), gplots

3.0.1.1 (WARNES & al. 2019), Hmisc 4.3-0 (HARRELL & HARRELL 2019), and season (BARNETT & BAKER 2020). A map was made with QGIS v.3.4.2-Madeira (QGIS DEVELOPMENT TEAM 2018).

Results

I) The constancy of interest per country over the years varied widely (Tab. 2). Higher constancy of interest was found in countries with higher number of genera ($p < 0.001$, $F = 23.692$, degree of freedom (d.f.) = 17, Fig. 2A) and higher percentage of population with internet ($p = 0.005$, $F = 10.156$, d.f. = 18, Fig. 2B). However, neither total population ($p = 0.154$, $F = 2.237$, d.f. = 18), nor number of species correlates with constancy of interest per country ($p = 0.143$, $F = 2.390$, d.f. = 15).

II) The tendencies of increasing and decreasing in relative interest in the term “ants” occurs synchronically in different countries, mainly in countries in the northern hemisphere, in temperate regions, regardless of the official language, as seen through the correlations (Fig. 3). Synchronicity is less evident in some countries of the southern hemisphere, also regardless of the official language (e.g., Argentina, Australia, and Brazil). Angola, Mozambique, and Nigeria do not present clear patterns when compared with other countries. Australia and Argentina, in the southern hemisphere, and India and Canada, in the northern hemisphere, presented negative correlations between themselves.

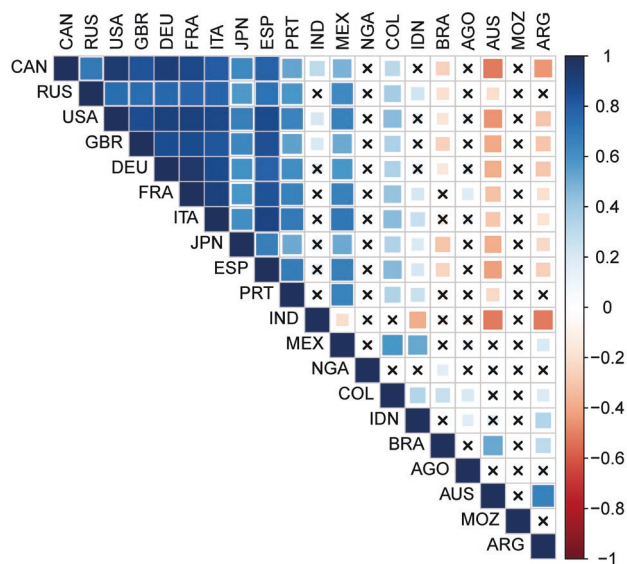


Fig. 3: Spearman correlation matrix representing the correlations among relative interest in countries organized by location on the globe (see Tab. 1 for countries and codes) over 13 years ($n = 156$). The squares represent coefficients of significance in correlations ($p < 0.05$). X represents non-significant correlations ($p \geq 0.05$). Blue squares represent positive correlations. Red squares represent negative correlations. Darker colors and bigger squares represent stronger correlations, lighter and smaller ones weaker (p and correlation values are available in Tab.S1).

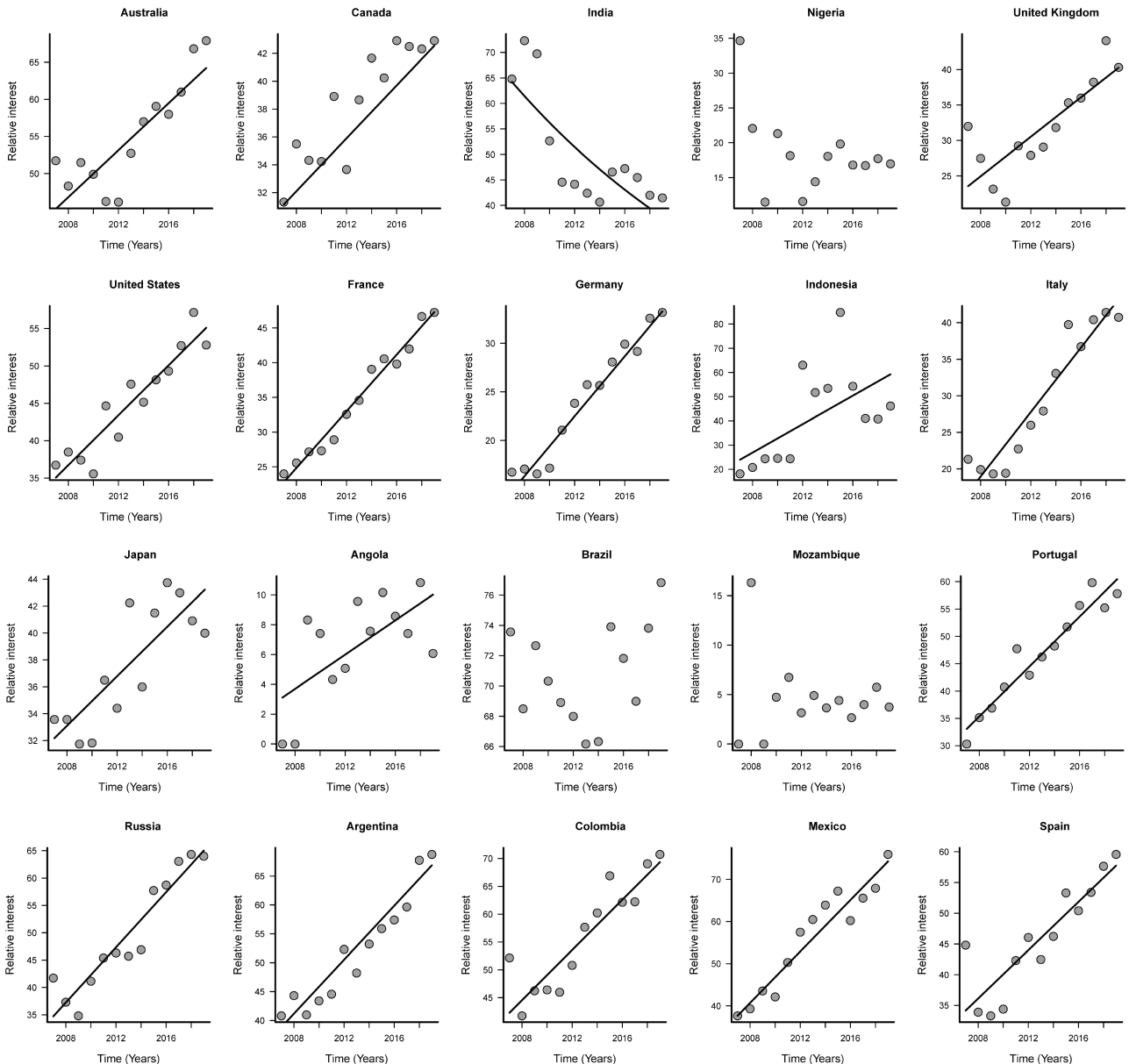


Fig. 4: Correlations between relative interest by year in the search term “ants” and time (years) (n = 13). See Table 2 for correlation values.

III) The relative interest per year in “ants” has increased in most countries over the years. This rise is due to the increase in internet access in almost all countries, except the UK, USA, and Angola. Only in India, the relative interest per year decreased over the years, also influenced by the increase in internet access. In Nigeria, Brazil, and Mozambique no trend was found concerning the relative interest per year over the time (Fig. 4, Tab.S2). Besides, there is greater relative interest in the term “ants” in warmer months and warmer seasons in most countries, with the exception of Nigeria, Indonesia, Angola, Mozambique, and Colombia. Countries in temperate regions of the northern hemisphere, such as Canada, the United Kingdom, USA, and Germany present clearer patterns of seasonality in the searches (Fig. 5).

IV) The Top Related Queries were more related to the “control” category, except for Australia, India, United Kingdom, Japan, Russia, and Colombia (Tab. 3). We observed more queries related to “species” in Australia and India, whereas in Colombia, Russia and Japan we observed more queries related to “daily”. We observed queries related to “curiosity” and “other animals” categories in many countries. Other countries showed interest in “ant keeping” and “dreams”. Only one query was related to the “positive” aspects of ants.

V) Considering the different Top Related Topics (different interests) regarding the search for “ants”, four groups of countries were obtained (Fig. 6): 1) Anglophone countries clustered by topics such as fire ants, home, *Lasius niger*, and *Camponotus*; 2) Latin countries in Europe and Latin America, where Portuguese or Spanish is spoken, clustered

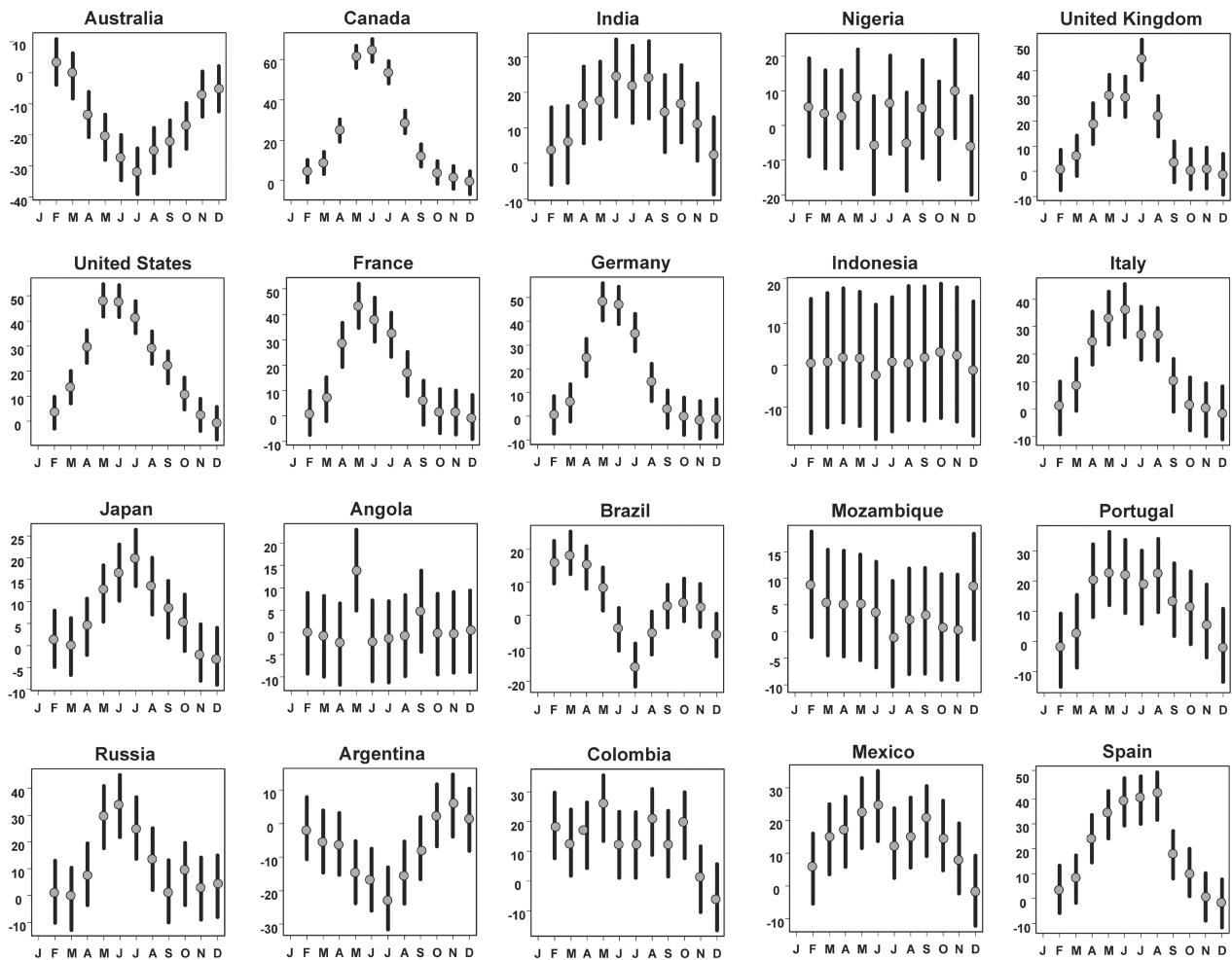


Fig. 5: Intra-annual variation in relative interest in the search term “ants”. The plots show the mean rate ratios and 95% confidence intervals of relative interest of the audience in the term “ants”. The reference month was set to January for all countries (n = 156).

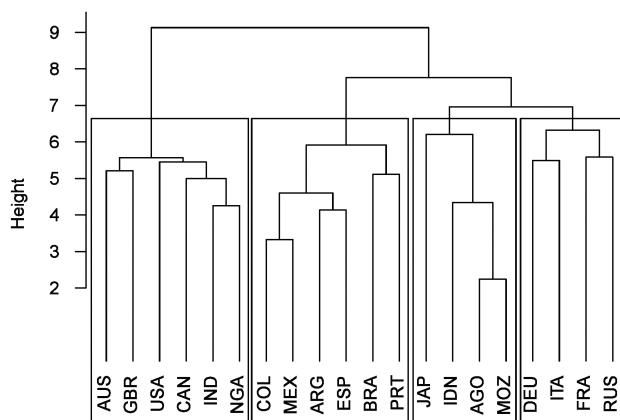


Fig. 6: Cluster analysis graph with the four groupings of countries (see Tab. 1 for country code) by Related Topics (the most popular topics that users also searched for related to our term “ants”) calculated by Euclidian distance and the Ward method (y-axis, height, represents distances between clusters).

by topics such as dream, food, poison, and medicine; 3) Lusophone countries in Africa and two Asian countries clustered by topics involving homemade medicine, companies, and games; and 4) other European countries clustered by topics involving *Formica rufa*, garden, and movies (Fig. S2).

Discussion

The constancy of interest in the term “ants” over the years has varied in space being correlated with internet access and the diversity of ant genera across countries. The tendencies of increasing and decreasing in relative interest were also synchronic regardless of the official language and hemisphere. The relative interest in “ants” has varied in time increasing over the years and in warmer months. In most countries, people looked at ways to control ants on the internet, and topics related to the term “ants” are grouped by cultural and language similarity.

Spatial and temporal patterns: We observed that both the percentage of the population with internet access and the number of ant genera were linked to variation in the constancy of interest in “ants” per country. Thus, the

term “ants” probably became more constantly searchable over the years when internet accessibility is widespread because searching for a subject on the web requires spending time and energy (RIPBERGER 2011). In countries with more diverse ant fauna, the higher constancy of interest in this term possibly occurs because higher diversity of ant shapes could evoke the curiosity of people (SHIPLEY & BIXLER 2017), which would stimulate web users in searches in a consistent way.

There are positive trends in the relative interest in “ants” over the years in most countries analyzed. These surprising trends seem to be linked to higher internet access over the years (ROSER & al. 2015) or the rise of Google as the major search engine. These positive trends may also be linked to the greater exposure of these animals in the media, as occurred with the term “ecosystem services” (NGHIEM & al. 2016). Other countries, like the USA and the UK, appear to have seen an increase in relative interest over time. These results may be due to the rise in temperature averages and the consequent increase in ant activity, or even the impact of cultural phenomena introduced by movies and news broadcasting.

The synchronicity of increase and decrease of relative interest observed in different countries, regardless of language or continent, may be linked to similarities in people’s curiosity about a search term at certain times of the year. Many terms sought at specific times of the year are related to health and well-being (OLSON & al. 2013, TOOSI & KALIA 2016, KUMAR & al. 2018), other terms turn evident when they are well shown in the media (e.g., major disasters, Olympic Games, World Cup). Then, this synchronicity is probably strongly linked to the seasonality of the relative interest in ants.

The higher relative interest in the term “ants” during warmer months and seasons is possibly due to the greater interaction between people and these animals. The greater interaction is related to the greater presence of ants and other insects in these months and seasons due to warmer or moister conditions, the greater amount of resources, and the absence of frozen ground (FRITH & FRITH 1985, ANDERSEN 1986, KASPARI & VARGO 1995, GRIMBACHER & al. 2018). In many cases, ant activity increases in spring, or the beginning of the rainy season, and decreases only with the fall or end of the rainy season (COOK & al. 2011). However, unseasonal patterns can be more common for insects in tropical countries (KISHIMOTO-YAMADA & ITIOKA 2015). Agreeing with this, temperate countries, which have stronger seasonality and harsh winters, show a synchronic increase of interest during the warmer months while no synchrony was observed for the tropical countries.

We must carefully look at the similarity (II) and intra-annual temporal (III) patterns found in India, Indonesia, and African countries. In these countries, access to the internet is more limited (Tab. 1). In India, for example, consumption of internet content is rising, mainly in the local languages (KEELERY 2020), and it is possibly affecting relative interest patterns. In this case, we have

to be cautious to say that Indian people are showing less interest in ants, but we can say that relative interest in ants detected by GT can be decreasing due to internet access in the country, which may be linked to data characteristics. Furthermore, some data obtained may have been affected by the low access to the internet (ZHANG & al. 2018) within these countries, which causes people to have a different relationship with the network. Thus, these results display limitations to the use of GT to make predictions based on trends observed in countries where internet access is low.

Moreover, other limitations that must be taken into account when using GT are the biased results due to relativized data. For example, *Ant-Man* (2015) and *Ant-Man and the Wasp* (2018), two successful movies, had a high impact in peaks of popularity of the term “ant” in July 2015 and July 2018, when they were released. The movies had little influence on search patterns for “ants”, and it is not possible to evaluate their impact on people’s interest in ants based on our data. Furthermore, the word “ant” refers to many artists’ surnames in the UK, which are searched along all months with low variation. In this sense, searches for “ant” in the UK are not exclusively related to the animals. Considering all these peculiarities, the bias presented by the term “ants” is less significant than the bias related to the term “ant” when assessing the relative interest of people in these animals across time and space. Thus, evaluating which benchmark to use as a search term when conducting analyses from GT data is a critical step involved in experimental design (NGHIEM & al. 2016).

Top queries related to “ants”: We observed that the vast majority of Top Queries related to “ants” is linked to ant “control”, while searches for “positive” aspects are almost absent. Some ant species cause damages to human health (in houses and hospitals), economic damage in crops, and are not welcome in the domestic environment because of the great discomfort caused by their presence or negative interactions (FERNÁNDEZ-MELÉNDEZ & al. 2007, MORE & al. 2008, PANTOJA & al. 2009, MONTOYA-LERMA & al. 2012, CASTRO & al. 2016, SHIPLEY & BIXLER 2017). Moreover, these damages (e.g., caused by imported fire ants) occur predominantly in the warmer seasons because of higher ant activities (VOGT & al. 2003). Another fascinating aspect is the search for curiosities about ants. Nonetheless, this search is normally intended to learn how to remove the animals due to the discomfort they provoke (BEISEL & al. 2013). Therefore, it is not surprising that ant control is the main motivation behind the search for the term “ants”, whereas just one query is related to the positive aspects of ants. However, some countries did not follow these overall patterns.

In some countries, searches seemed to be related to knowledge about ants, curiosities about the myrmecofauna or motivated by daily experiences. Australia and India, for example, presented more queries related to “species”, probably, because popular names of ants are more common in countries with a huge and well-known myrmecofauna (ANDERSEN 2007, BHARTI 2011). Meanwhile, in Colombia, Russia, and Japan searches associated with “daily”

aspects predominate. In Colombia, ants have been used in cooking since the pre-Columbian era (RUDDLE 1973) (e.g., “Hormigas culonas”). However, in Russia and Japan what most stimulates this connection with the term “ants” are artistic works (movies and books) and companies, respectively. In contrast, some countries display the interest in breeding ants as pets also known as “ant keeping”. Keeping animals as pets is part of human history, as well as a primitive practice (ALVES 2012), and ant keeping is common. This practice is an important tool for science and environmental education (CLARK & HOLBROOK 2009), which was popularized and commercially exploited in the USA for decades. However, the commercialization of ants is not regulated in many countries, such as Brazil. In theory, the commercialization of native ants without a license creates an illegal market with criminal practices (as in Brazil: Art. 29 of the Environmental Crimes Law) that can stimulate biopiracy (CARNEIRO GOMES 2007) and increase the risk of biological invasion (KRUSHELNYCKY & al. 2009). “Dreams” represent another class of queries related to the term “ants”, mainly in countries of Latin heritage. Dreams are linked to lived experiences whose manifestations represent activities of the unconscious recombination of memories processed day-by-day (STICKGOLD & al. 2001, LOPES 2012). Some people believe that through dreams it is possible to find some prediction of the future, which affects behavior and decision-making (MOREWEDGE & NORTON 2009). Therefore, the search is used to investigate the meanings of dreams about ants and to inform people’s decision-making.

Topics related to the term “ants”: Our four distinct clusters (1 Anglophone countries, 2 Portuguese- and Spanish-speaking countries in Europe and Latin America, 3 Lusophone countries in Africa and two Asian countries, 4 other European countries) were grouped by historic, cultural, geographical and language-based traits. The fact that Nigeria and India do not group with other countries from Sub-Saharan Africa or Southern Asia may reflect the influence of historic British colonialism in these regions but can also be a direct effect of the amount of English content available on the web. In contrast, the group formed by Spanish and Portuguese speaking countries from Europe and Latin America present common historical and cultural traits, the same is true for the Anglophone countries group.

Cluster analyses considering cultural aspects based on societal values and practices show that the countries in this study form eight groups: Anglophone cultures, Latin Europe, Germanic Europe, Eastern Europe, Latin America, Sub-Saharan Africa, Southern Asia, and Confucian Asia (see GUPTA & al. 2002). GUPTA & al. (2002) also present likely alternative groups for these clusters. The similarity between Japan and Indonesia and the two Sub-Saharan Lusophone African countries can be explained by their alternative cultural clusters and strong eastern orientation. Finally, the fact that other European countries (Germany, Italy, France, and Russia) are grouped demonstrates that their similarity is possibly related to their geographic location, regardless of the languages spoken

(HAN & al. 2015). Therefore, knowing how people from different backgrounds explore the same search term is an interesting way to plan global strategies. For this purpose, we suggest more investigation into this subject.

Findings, observations, and suggestions: The interest in ants increased over the years, especially due to greater access to the internet. Moreover, such interest followed climatic seasonality. Countries with higher seasonality in the same hemisphere presented synchronic tendencies in interest, with higher interest during warmer months (signaling seasonality of ants’ popularity), while for most tropical countries (less seasonal), the interest was almost homogenous over the year. Although the most important reason for searching for information about ants was their control, it was observed that historic, cultural, and linguistic similarities also influence the relative interest patterns.

This is the first study presenting patterns on public attention to ants (Hymenoptera: Formicidae) based on data from GT. Nonetheless, it is possible to find similar patterns for the majority of other groups of insects. Additionally, we point out that countries (especially those with large territories) may present internal variations, with different regions displaying different patterns. Then, engaging the public in activities that promote knowledge, empathy and curiosity about insects, in traditional and social media, is essential to protect the biodiversity and change the negative perception against these animals (BASSET & LAMARRE 2019).

These results can help researchers to gain insight into the psychology of the ordinary Google searcher and reveal the typical perception of ants. They also direct grant writing, framing research, choosing research directions, guide eventual public outreach activities, plan citizen science projects, and develop public health campaigns concerning the risks posed by ants in several countries. While many of us (myrmecologists) need no convincing why ants are interesting and ecologically important, this work gives perspective from outside of our group. Indeed, most people only think about ants when they are around us, and most, then, want to know how to get rid of them. In this way, the early months of the warmer seasons would be the best time frame for promotional activities on the benefits of ants, considering the peaks of interest to transmit information to a broader audience at the right time.

In this sense, we suggest: 1) high disclosure of information related to ants as environmental partners during warmer months, highlighting their positive aspects; 2) promoting environmental education in myrmecological holiday camps to children and teenagers; 3) developing game apps that display the positive aspects of ants; 4) stimulating partnerships between schools and universities where myrmecologists interact and work with students; 5) promoting existing initiatives (e.g., Sex & Bugs & Rock ‘n Roll, <http://www.festivalbugs.org/>); 6) developing interactive apps that allow people to obtain information from myrmecologists after sharing their location and pictures of their house / farm ants (e.g., an initiative similar

to iNaturalist, <https://www.inaturalist.org/>); 7) promoting public health campaigns in warmer months, especially in countries where ants present a health threat.

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