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Are we losing sight of insect biological control in cyberspace?

¿Estamos perdiendo de vista el control biológico de insectos en el ciberespacio?

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ABSTRACT

Insects are omnipresent across the globe, assume crucial roles within the world's natural and agricultural ecosystems, and generate billions of dollars of economic benefits to human society. Insect numbers are rapidly declining and their associated ecosystem services are degrading at unprecedented rates, yet little is known about how such trend is viewed by the public. Therefore, in this exploratory study, we venture into the emerging field of 'culturomics' and make use of text-mining tools and social-media analytics to assess temporal and geographic trends in the cultural visibility (or 'saliency') of various biological control concepts and organisms. Particular species, such as the predatory mite *Phytoseiulus persimilis*, Oecophylla weaver ants, and the encyrtid wasp *Anagyrus lopezi*, receive sustained and comparatively high public interest, and research is warranted to assess determinants of their popularity. Google Trends time lines equally reveal how a recent biological control effort against the invasive cassava mealybug, *Phenacoccus manihoti* (and its associated media campaign), triggered online social interest. Lastly, we contrast multi-year Google search volume between individual countries to emphasize how online public interest in a particular biological control organism can differ between contexts, cultures and geographies. Though exploratory in nature, our study underlines the urgent need for today's entomologists, agro-ecologists and biological control practitioners to effectively engage with the humanities and (digital) social scientists. Our work can help steer the development of adequate information to promote awareness-raising campaigns, and inform policy dialogue that safeguards the overall relevance of ecologically-based pest management in an increasingly globalized and digitalized world.

RESUMEN

Los insectos son omnipresentes en el planeta, asumen roles claves en ecosistemas naturales y agrícolas, generando billones de dólares en beneficios económicos para los seres humanos y sus comunidades. A pesar que la cantidad de insectos está disminuyendo rápidamente, muy poco se conoce sobre cómo esta tendencia es percibida por el público en general. Por lo tanto, en el presente estudio exploratorio nos aventuramos en el campo de la "culturómica" utilizando herramientas como *text-mining* y *social-media analytics* para determinar cambios temporales y geográficos en tendencias de visibilidad cultural (*saliency*) en distintos conceptos y organismos relacionados al control biológico. Especies como el ácaro predador *Phytoseiulus persimilis*, hormigas tejedoras del género Oecophylla, y la avispa encírtida *Anagyrus lopezi*, reciben comparativa y sostenidamente mayor interés del público, por lo que se justifica investigación que evalúe los factores que determinan su popularidad. Las series de tiempo de *Google Trends* revelan que un reciente esfuerzo de control biológico contra la conchuela de la Yuca *Phenacoccus manihoti* (y su campaña mediática asociada), provocaron interés social en internet. Finalmente, contrastamos la cantidad de búsquedas en *Google* para distintos años entre países, con el objetivo de enfatizar cómo el interés del público sobre un organismo de control biológico específico puede cambiar entre contextos, culturas y geografías. Aunque de naturaleza exploratoria, nuestro estudio realza la urgente necesidad que entomólogos, agroecólogos y practicantes de control biológico tienen por relacionarse efectivamente con las ciencias humanas y digitales. Nuestro trabajo puede ayudar a dirigir el desarrollo de información adecuada para promover campañas de concientización, e informar en el diálogo de políticas que protejan la relevancia del manejo ecológico de plagas en un creciente mundo globalizado y digitalizado.

Palabras clave: control biológico, culturómica, internet saliency, conservación de insectos, agricultura sustentable.

INTRODUCTION

Insects are some of the most abundant and diverse organisms on earth, and play a central role in the delivery of ecosystem services, such as pollination and biological control (Costanza *et al.*, 1997). Biological control is of vital importance to ecosystem functioning and helps keep the world 'green' (Hairston *et al.*, 1960; Polis, 1999), with its contribution to global agriculture valued at billions of dollars annually (Losey and Vaughan, 2006; Thancharoen *et al.*, 2018). Also, biological control provides a near tailor-made solution for globally-proliferating invasive pests and (often associated) surging rates of insecticide use, aids biodiversity conservation, and helps safeguard consumer and farmer health alike (e.g., Van Driesche *et al.*, 2010; Heimpel and Mills, 2017). As a central pillar of sustainable intensification and agro-ecology, biological control equally helps narrow crop yield gaps, boosts farm profitability and thus directly contributes to poverty alleviation (Tscharntke *et al.*, 2012; Bommarco *et al.*, 2013; Struik and Kuyper, 2017).

Despite these widely-recognized environmental and societal benefits, the popularity of biological control is rapidly declining in many parts of the world and across communities of digitally-enabled people, such as 'millenials' (Brodeur *et al.*, 2018). The discipline is equally losing critical traction in United States academia, including the suspension of entire curricula and the drastic reconfiguration of university priorities (Warner *et al.*, 2011). To make matters worse, the general public continues to have a deficient notion of biological control notwithstanding its outspoken interest in nutritious, pesticide-free food and a healthy environment (e.g., McNeil *et al.*, 2010; Reganold and Wachter, 2016). The above appears to be part of a larger worrisome trend, in which the general public and also farmers tend to view insects with ignorance, aversion or even fear (Hogue, 1987; Kellert, 1993; Lemelin *et al.*, 2016). Only large conspicuous insects (e.g., ground beetles, ants) and culturally-important ones (e.g., social wasps) tend to receive certain attention from growers, and their role in pest control is regularly thought to be minor (Bentley and Rodriguez, 2001; Wyckhuys *et al.*, 2018a). Although social science research could illuminate some of the underlying drivers of these phenomena (e.g., Wyckhuys and O'Neil, 2007), systematic and geographically-expansive surveys of public attitudes towards insects (and biological control organisms) are virtually non-existent.

In today's digitally connected world, internet-based technologies have come to permeate most levels of society and web-searches have now become an integral part of our daily lives. Web-crawling and online search engines offer unprecedented opportunities to tap these online queries and to quantify, track or map global trends in public sentiment regarding particular topics (Proulx *et al.*, 2014; Nghiem *et al.*, 2016; Ladle *et al.*, 2016). Word frequencies in digitized text can be analyzed with Google Trends or Google Ngram engines (Ladle *et al.*, 2016), while image digitization and machine learning can be used to 'mine' Instagram or Flick archives (Sherren *et al.*, 2017). These non-reactive methods for social science research through text mining and social-media analytics all resort under the newly-minted term 'culturomics' (Michel *et al.*, 2011), and have readily been embraced by political science, sociology, linguistics and also conservation biology disciplines (Jarić *et al*., 2019). Pioneering yet geographically-restricted work has been done in the entomology domain by Takada (2011, 2013) and Bragazzi (2014) in Japan and Italy, respectively. However, to our knowledge, culturomics have so far not been used to analyze global public sentiment and interest in aspects associated with agro-ecology or sustainable agriculture in general, nor insect biological control in specific (Wyckhuys et al., in press)(Wyckhuys *et al*., Science of the Total Enviroment in Press).

In this study, we employed culturomics for a first exploratory assessment of global public interest in different facets of insect biological control. More specifically, we conducted the following analyses: a) we use Google Ngram to assess the frequency of different biological control concepts or organisms in digitized books, their capturing temporal patterns in their cultural visibility or saliency (e.g., Correia *et al.*, 2017); b) we employ Google Trends to track the evolution in online public interest following a recent large-scale biological control campaign, i.e., the introduction of the parasitoid *Anagyrus lopezi* De Santis, 1964, for control of the invasive cassava mealybug (*Phenacoccus manihoti* Matile-Ferrero, 1977) in tropical Asia in 2009; and c) through Google Trends, we examine geographical differences in the global saliency of various biological control organisms. We close this article highlighting some opportunities for strategic use of digital media analytics in the global promotion of insect biological control aiming at enhancing sustainable agricultural systems.

MATERIALS AND METHODS

Our analysis focused on the three main types of biological control: a) classical biological control (CB), or the careful selection and subsequent release of a specialized natural enemy from the region of origin of an invasive pest; b) augmentation biological control (ABC), or the mass-rearing and periodic release of locally-present natural enemies, as widely used in greenhouse settings in Europe, Oceania and North America; and c) conservation biological control (CBC), or the deliberate protection and enhancement of naturally-occurring populations of natural enemies e.g., by manipulating habitats and physical features in the agricultural environment (Debach and Rosen, 1991; Van Lenteren, 2012; Heimpel and Mills, 2017). We primarily examined well-known cases of arthropod biological control, i.e., the use and manipulation of insect parasitoids, predators and predatory mites for control of pests. All queries were run through a laptop computer with a Google Chrome browser and regular internet connection during April 15-30, 2018, while based in Hanoi, Vietnam.

As Google is currently the internet's most popular search engine, we solely relied upon Google online products to compute quantitative metrics of public interest. First, we used Google Ngram Viewer to look for coverage of different terms (submitted as comma-delimited search strings) in sources printed between 1950 and 2008. In 2010, the Google Ngram Viewer covered a *corpus* of 15 million digitized books (Michel *et al.*, 2011), and this number likely had increased at the time our search was conducted. For each of the different types of biological control, different search strings were used reflecting globally-successful cases or widely-known concepts. For CB, we recorded relative frequencies of "vedalia beetle" (*Rodolia cardinalis* Mulsant, 1850) and "cassava mealybug" (*P. manihoti)* as widely-recognized successes from 1888 and the early 1980s, respectively. For the cassava mealybug biological control, we decided against querying the name of the biological control agent (i.e., *A. lopezi*) given its frequent taxonomic revision (Correia *et al.*, 2017; 2018). Also, we contrasted findings with one (rare) CB failure, reflective of poor practice or misguided efforts in the early to mid-1900s, by searching for the vertebrate predator "cane toad" (*Rhinella marina* L., Anura: Bufonidae) and one rather ambiguous case, which included the generalist ladybird *Harmonia axyridis* Pallas 1773 (Coleoptera: Coccinellidae) (Hoddle, 2004; Katsanis *et al.*, 2013; Hajek *et al.*, 2016). For ABC, we examined string frequencies for a total of 4 organisms with considerable global market value: *Trichogramma pretiosum* Riley, 1879 (Hymenoptera: Trichogrammatidae), *Phytoseiulus persimilis* Athias-Henriot, 1957 (Mesostigmata: Phytoseiidae), *Aphytis melinus* DeBach, 1959 (Hymenoptera: Aphelinidae) and *Aphidius colemani* Viereck, 1912 (Hymenoptera: Aphelinidae) (Van Lenteren, 2012). First (commercial) use of these organisms was estimated in 1974, 1968, 1961 and 1991, respectively. Lastly, for CBC, we examined the concept of "ecological engineering" (Gurr *et al.*, 2004) and its building blocks "flower strip" and "beetle bank" (e.g., MacLeod *et al.*, 2004; Westphal *et al.*, 2015). We equally assessed temporal changes in the relative frequency of "weaver ant" (*Oeophylla* spp. Smith, 1860; Hymenoptera: Formicidae); possibly the oldest example of CBC with written records in eastern Asia dating from 300 ad (Van Mele, 2008). For each of the above search strings, we examined temporal patterns in their relative frequency within the established Ngram corpora of digitized books.

Next, similar to Proulx *et al.* (2014) and Cha and Stow (2015), we examined Google Trends time series of search hits from 2008 to 2018, to track online public interest in a recent CB case. More specifically, we centred on the 2008 invasion of the cassava mealybug, *P. manihoti* (Homoptera: Pseudococcidae) in Southeast Asia, and the ensuing 2009 introduction of the effective, host-specific *A. lopezi* in Thailand and neighbouring countries for its control (i.e., Winotai *et al.*, 2010; Wyckhuys *et al.*, 2014; Wyckhuys *et al.*, 2018b). We used the weekly search volume for the terms "*Phenacoccus manihoti*" and "*Anagyrus lopezi*" in Google Trends as indicative of changes in global online public interest. Over a 2008-2018 time line, search volume was expressed as relative frequencies at a weekly basis, normalized to a 0-100 range (e.g., Nghiem *et al.*, 2016). The evolution in search hits was examined following particular events, including enhanced media attention during initial *A. lopezi* introduction and follow-up releases.

Finally, we employed Google Trends to geographically differentiate online public interest in particular biological control organisms (using their vernacular name; Correia *et al.*, 2017) at a global scale. More specifically, we queried "weaver ant", "predatory mite" and "parasitoid wasp" over a 14-year time period (2004-present) and plotted search interest on a world map. Furthermore, we quantified country-level relative search interest in each of the above organisms, and ranked countries accordingly. Country-based measures of search interest are computed on a scale from 0-100, with 100 attributed to the location with the highest proportion of all worldwide queries, which is not indicative of the absolute query count.

RESULTS AND DISCUSSION

For classical biological control (CB), Google Ngrams revealed highly variable temporal trends in the saliency of different biological control organisms (Figure 1). Though the use of *R. cardinalis* against the cottony cushion scale (*Icerya purchase* Maskell, 1878) in California dates back to 1888, the world's oldest case of CB is still regularly featured in the literature (with peak interest in the early 1970s). The second CB success story, the 1981 release of *A. lopezi* against *P. manihoti* in Africa's cassava belt (thus suppressing mealybug pests and averting famine for an estimated 20 million people), prominently features in the literature from the mid-1980s to the second half of the 1990s, and since then has received dwindling rates of attention. We are particularly encouraged by the continued public attention to the *R. cardinalis* case, given that both the biological control agent and its target pest largely disappeared from California's citrus orchards, in similar ways as with the extinction of North American birds (Ladle *et al.*, 2016). As for the CB failures, considerable attention has been given to the cane toad from the early 1990s onward and to the case of *H. axyridis* since the turn of the century. These patterns can be ascribed to the increased attention to non-target ecological effects of biological control since the 1990s (Louda *et al.*, 2003), and the ensuing gradual development of a more balanced perspective (Hajek *et al.*, 2016; Heimpel and Cock, 2018).

For augmentation biological control (ABC), our Google Ngram analysis showed a steady decline in public attention for all cases except for *A. colemani* (Figure 2). Considerable variability was recorded in the overall level (and temporal shifts) of saliency for the different organisms, which could be explained by multiple factors. Though both *P. persimilis* and *A. colemani* have large commercial value and are used at a global scale (Van Lenteren, 2012), the relative string frequency for *P. persimilis* was up to 30 times higher than the latter. For birds, abundance, phenotypic traits and distribution patterns largely shape cultural visibility (Żmihorski *et al.*, 2013; Correia *et al.,* 2016), with large-bodied species receiving substantially more attention. Yet, with *P. persimilis* being the smallest organism in our list of four ABC agents, this trend clearly does not hold for arthropod natural enemies. This possibly could be due to effective marketing of predatory mites for use in the European greenhouse sector (e.g., Van Lenteren *et al.*, 1997), though further scientific attention is warranted.

Lastly, for conservation biological control (CBC), Ngrams illuminated a high saliency of 'ecological engineering' over the past three decades, and a far lower though increasing visibility of the two habitat manipulation tactics (Figure 3). The term 'ecological engineering' was minted in the 1960s (Odum, 1962), gaining broader recognition in the 1980s (Mitsch and Jørgensen, 1989) and was then embraced by the biological control community in the early 2000s (e.g., Gurr *et al.*, 2004). Although 'ecological engineering' refers to the broader restoration of degraded ecosystem functions and the design of sustainable systems, its high scientific visibility might make it a suitable concept through which to further advance CBC, especially when includes the concept of habitat manipulation as a part of "engineering" agroecosystems (Gurr *et al.*, 2017). On

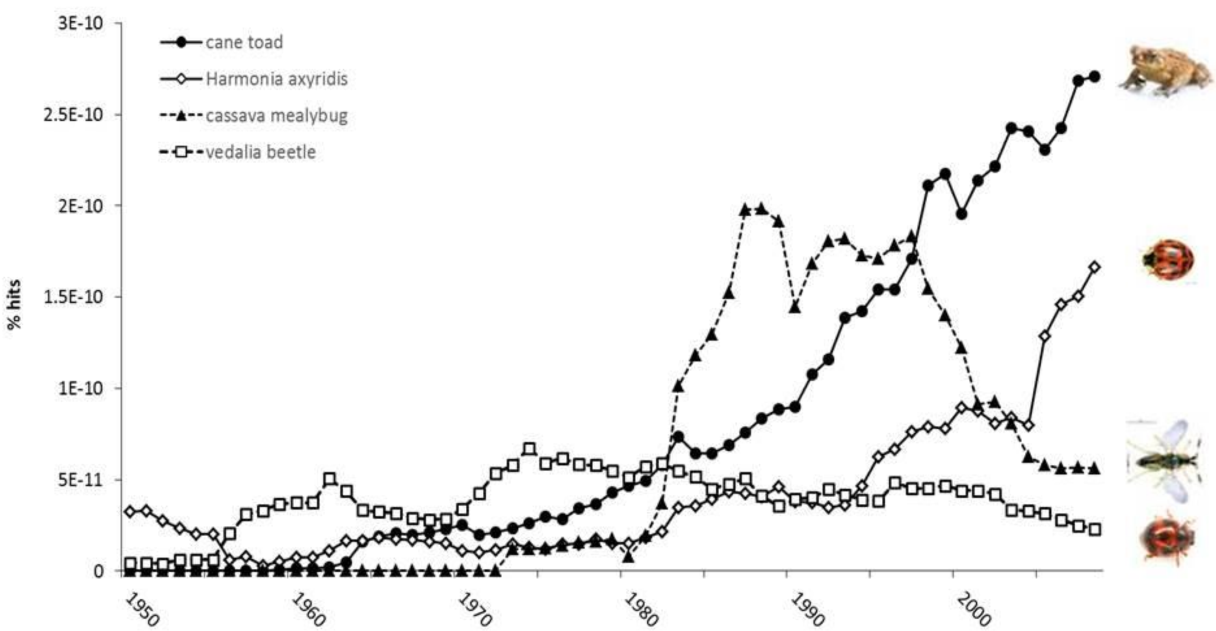

Figure 1. Ngrams for selected classical biological control cases, as organized by two successes (i.e., cassava mealybug x *Anagyrus lopezi*, cottony cushion scale x Vedalia beetle) one failure (i.e., cane toad) and a rather ambiguous case (i.e., *Harmonia axyridis*). Graphs are composed of data generated by Google's Ngram Viewer over a 1950-2008 time window, and depict frequencies of the various search terms in large bodies (or so-called *corpora*) of text. The search for cassava mealybug biological control was run with the string 'cassava mealybug' instead of *A. lopezi*.

Figura 1. Ngrams para casos de control biológico clásicos seleccionados, organizados por dos éxitos (es decir, escama de la Yuca x *Anagyrus lopezi*, conchuela de cojín algodonoso x escarabajo Vedalia), un fracaso (es decir, el sapo de la caña) y un caso bastante ambiguo (es decir, *Harmonia axyridis*). Los gráficos son compuestos de datos generados por 'Google's Ngram Viewer' en una ventana de tiempo de 1950-2008, y representan las frecuencias de varios términos de búsqueda en grandes cuerpos de texto (o también llamado *corpora* de texto). La búsqueda del controlador biológico para la escama de la Yuca se realizó con la clave 'cassava mealybug' en lugar de *A. lopezi*.

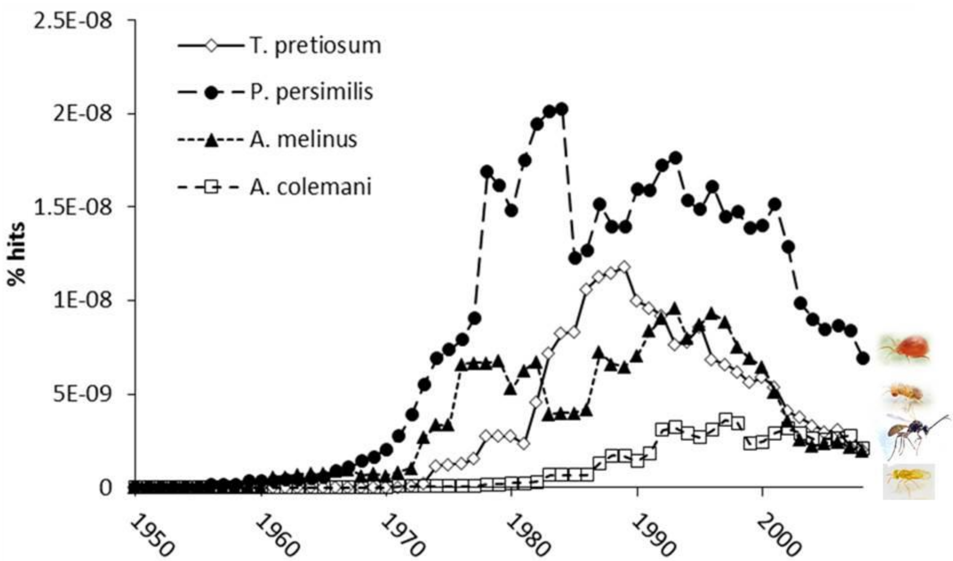

Figure 2. Ngrams for four selected natural enemies widely used in augmentation biological control. Graphs are composed of data generated by Google's Ngram Viewer over a 1950-2008 time window, and depict frequencies of the different search terms - entered as binomial scientific names of insect natural enemies - in large bodies (or so-called *corpora*) of text.

Figura 2. Ngrams para cuatro enemigos naturales seleccionados ampliamente usados en control biológico aumentativo. Los gráficos están compuestos de datos generados por 'Google's Ngram Viewer' en la ventana de tiempo de 1950-2008, y representan las frecuencias de los diferentes términos de búsqueda – ingresados como nombres científicos de enemigos naturales de insectos – en grandes cuerpos de texto (o también llamado *corpora* de texto).

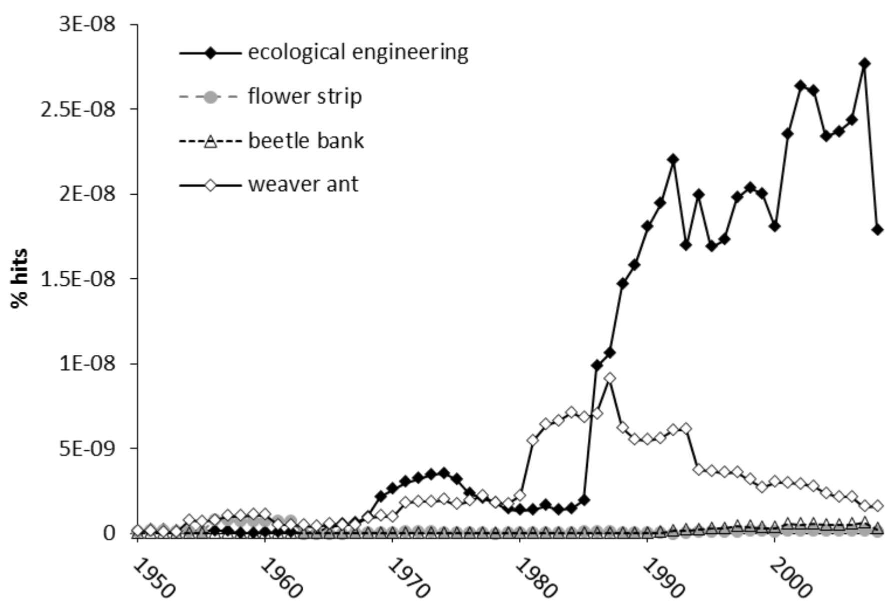

Figure 3. Ngrams for different concepts and organisms related to conservation biological control, and a broader 'ecological engineering' approach. Graphs are composed of data generated by Google's Ngram Viewer over a 1950-2008 time window, and depict frequencies of the different search terms in large bodies (or so-called *corpora*) of text.

Figura 3. Ngrams para diferentes conceptos y organismos relacionados a control biológico conservativo, y a un enfoque más amplio como 'ingeniería ecológica'. Los gráficos son compuestos por datos generados por 'Google's Ngram Viewer' en una ventana de tiempo de 1950-2008, y representan las frecuencias de los diferentes términos de búsqueda en grandes cuerpos de texto (o también llamado *corpora* de texto).

the other hand, the oldest CBC example -"weaver ants"- is losing public visibility, and received merely 17.5% of relative string frequency in digitized books in 2008 as compared to 1987. Similar declines were recorded when using "*Oecophylla*", "*O. smaragdina* F." and "*O. longinoda* Latreille, 1802" as search strings (data not shown). These patterns are not reflective of the increase in scientific research on *Oecophylla* spp. and its use in biological control from the 1990s onwards, as reported by Van Mele (2008), potentially have hampered the effective incorporation of weaver ant CBC in emerging organic farming or (export) fruits, nut or timber production in Africa, northern Australia or Asia.

Next, when examining Google search volume following the biological control intervention against cassava mealybug in SE Asia, we recorded increased interest in the parasitoid *A. lopezi* shortly after its introduction into Asia in late 2009 and especially after *P. manihoti* was declared to be under control in Thailand during late 2011 (Figure 4). Modest increases in search volume were also recorded following media releases by CGIAR institutions in mid-2010 and mid-2014, yet these did not elicit a sustained online public attention over the mid- to long-term (e.g., Cha and Stow, 2015). Also, over a 2008-2018 time frame, relative search interest in *A. lopezi* was consistently higher than in the invasive pest, *P. manihoti*. The above effectively shows that the general public is indeed responsive to biological control success stories, though its interest is far more moderated than in, for example, threatened mammals, birds or fish featured as FIFA World Cup mascots (Ladle *et al.*, 2016) or as key protagonists in Hollywood productions (Yong *et al.*, 2011; Silk *et al.*, 2018). Insect natural enemies, such as ladybeetles, praying mantids and ants, featured in productions such as the 1998 'A Bug's Life', the 1996 'Microcosm' and the 2008 'Kung Fu Panda', could help in creating a connection between those movie-appearing insects and the public, giving

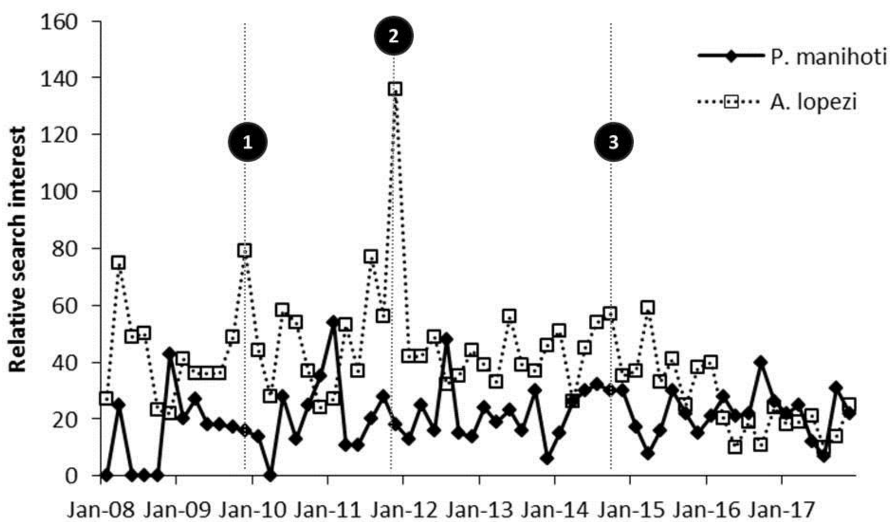

Figure 4. Global public interest in the cassava mealybug *Phenacoccus manihoti* and its host-specific parasitoid *Anagyrus lopezi* over 2008-2018, as visualized through Google Trends. This time window covered the *P. manihoti* invasion of Southeast Asia (late 2008 onward), the *A. lopezi* introduction into Thailand in late 2009 (Winotai *et al.*, 2010; event #1) and its September 2014 release in Indonesia (event #3)*. Event #2 likely relates to national media attention in Thailand following the country-wide suppression of *P. manihoti* as a result of sustained mass-releases of *A. lopezi* from June 2010 onward. Values indicate relative search interest, as summed over subsequent 2-month periods.
* Major global media campaigns were launched by CGIAR centers in 2010 and 2014: *Scientists mount a 'Sting Operation' in Thailand to tackle a devastating pest outbreak* (July 16, 2010); *Indonesia enlists wasps in war on crop killer* (Sept. 24, 2014).

Figura 4. Interés público global en la escama de la Yuca *Phenacoccus manihoti* y su parasitoide específico *Anagyrus lopezi* durante 2008-2018, visualizado a través de las tendencias de Google. Esta ventana de tiempo cubrió la invasión de *P. manihoti* en el sudeste de Asia (desde finales de 2008 en adelante), la introducción de *A. lopezi* en Tailandia a fnales del 2009 (Winotai *et al.*, 2010; evento #1) y su liberación en Indonesia en septiembre de 2014 (event #3)*. El evento #2 probablemente se relaciona con la atención mediática nacional en Tailandia tras la supresión en todo el país de *P. manihoti* como resultado de la masiva liberación de *A. lopezi* desde junio de 2010 en adelante. Los valores indican un interés de búsqueda relativo, sumados en periodos de 2 meses consecutivos.
* Los centros CGIAR lanzaron importantes campañas mediáticas globales en el 2010 y 2014: *los científicos montan una 'Operación aguijón' en Tailandia para hacer frente a un devastador brote de plagas (16 de Julio 2010); Indonesia recluta avispas para la guerra contra un asesino de cultivos* (24 de septiembre 2014).

interesting insights on how those releases altered (or reinforced) certain public perceptions at a global scale about insects. Also, enhancing the cultural connection between insects and humans by movies provides interesting insights on how to promote insect saliency through appropriate communication systems that are easily accessible by most of the public around the world. Unfortunately, the technical language often used to disseminate the scientific knowledge related to biological control can produce a communication gap between entomologists and the general public, similar to the one that occurs when sharing novel scientific knowledge from a nascent scientific area within an interdisciplinary scientific group (Hesketh *et al.*, 2018). Therefore, it is crucial to acknowledge the linguistic domains that internet (and non-internet) users may adopt when seeking entomology-related knowledge, to deliver biological control concepts and facts in an effective way that is easily understood by the target audience (Mann and Wratten, 1992; Adhiguru *et al.*, 2009). Understanding the features of insect natural enemies that elicit people's (online) attention can equally guide the development of future agricultural extension and awareness-raising campaigns, as the human interpretation of insect morphology and behavior has been driving cultural traditions and farming strategies during the last 2000 years (Hogue, 1987).

Our exploratory work also revealed marked geographical differences in online search interest for particular biological control agents (Figure 5). Relative search interest in "weaver ant" was highest in Malaysia (score of 100), followed by Indonesia (31) and Singapore (3), which is in line with the historical attention that *Oecophylla* spp. have received in Southeast Asia (Van Mele, 2008). Despite the importance of *O. longinoda* as a key predator of e.g., Tephritid fruit flies in mango and citrus in Africa, online search interest in weaver ants was too low to be recorded from this part of the globe and could possibly be related to low local rates of internet penetration, as it has been suggested for India (Adhiguru *et al.*, 2009). Interest in "predatory mite" was highest in Czechia (100), followed by Poland (54), Norway (49) and Spain (43), possibly reflective of its important use in the greenhouse sector and the associated online queries by growers. Lastly, global interest in "parasitoid wasp" was highest in Belarus (100), Russia (98), Kazakhstan (71) and Ukraine (53). As country-level search interest is a relative measure, this given search string received relatively constant public attention in small and large countries alike in Eastern Europe and Central Asia. This latter pattern is especially intriguing and may indicate a thriving interest in the use of parasitoids in biological control in this part of the world, and a potential opportunity for tailored messaging, enhanced marketing or research backstopping. In addition, this exploratory work can now constitute a basis for

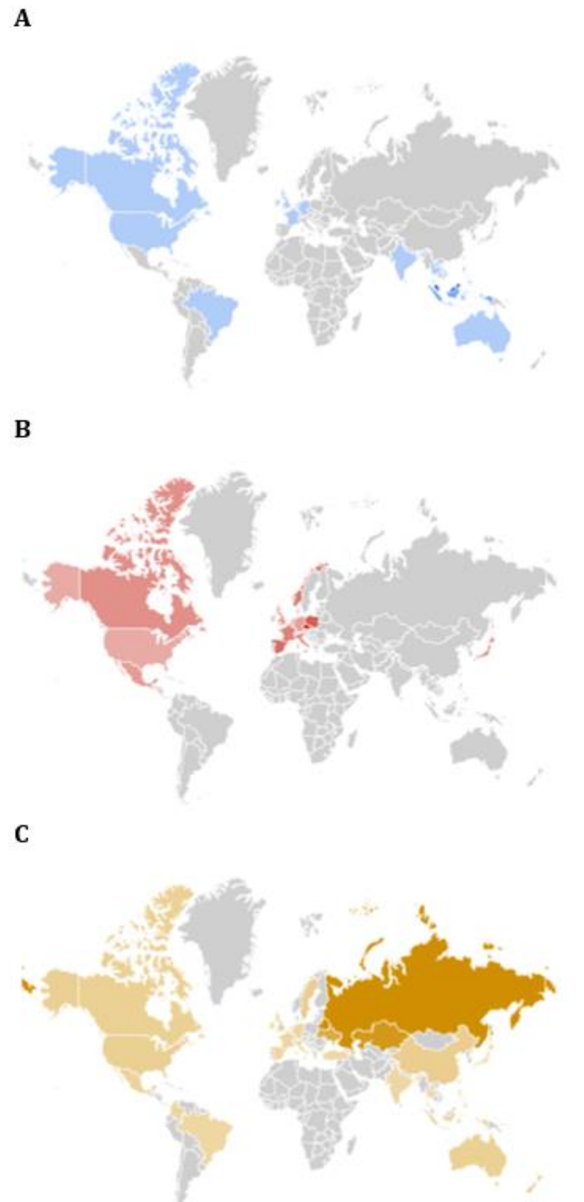

Figure 5. Geographical differences in online public interest in three different groups of natural enemies over a 14-year time window (i.e., 2004-present), as visualized through Google Trends. The natural enemies and associated search strings include: "weaver ant" (A), "predatory mite" (B) and "parasitoid wasp" (C). Darker colors represent increased search frequencies.

Figura 5. Diferencias geográficas en el interés público online sobre tres grupos diferentes de enemigos naturales en una ventana de tiempo de 14 años (es decir, 2004 a la fecha), visualizado a través de las tendencias de Google. Los enemigos naturales y las claves de búsqueda asociada incluyen: "homiga tejedora" (A), "ácaro depredador" (B) y "avispa parasitoide" (C). Los colores más oscuros representan un incremento de frecuencias de búsqueda.

further cross-cultural comparison of public interest in biological control, and the associated locality-specific factors that either elicit or constrain saliency of a particular biological control agent. Yet, challenges do arise in interpreting the above geographical patterns, as user profile is not necessarily reflective of the exact physical location of a device and user (Graham and Dutton, 2014). Therefore, we suggest that exploratory analyses in culturomics, like the one presented here, could be used as a guide to strategically position insect biological control at both global and country-specific levels, for example, by a) picking 'winners' for targeted communication campaigns and tailored information delivery, based upon the extent to which particular species appeal to the general public (see Simaika and Samways, 2018); b) assessing cultural impacts of invasive species and associated biological control interventions; and c) identifying geographies where biological control continues to have a soundboard with online communities and interest groups.

CONCLUSIONS

Internet search analysis as carried out in this study, provides a powerful and systematic means to gauge (online) public interest in insect biological control and ecologically-based pest management at a global level. Echoing findings of Brodeur *et al.* (2018), we reported a pronounced decline in public interest in the world's main types of biological control, as evident in temporal patterns of Ngram string frequency for various key concepts and iconic biological control cases. This decline parallels a far broader drop in public interest in environmental topics (Mccallum and Bury, 2013; Troumbis, 2017), with potentially detrimental consequences for sustainable farming, ecologically-based crop protection and on-farm biodiversity conservation, amongst others. Yet, Google Trends analysis revealed a) a notable online responsiveness of the public to recent biological control endeavors and their associated media campaigns, and b) substantial geographical and cultural differences in the saliency of particular types of arthropod natural enemies. Hence, if we want sustainable intensification, agro-ecology and biological control to resonate amongst internet users in a digitally-connected world, a far closer engagement with the humanities and (digital) social scientists will be necessary if not essential, further emphasizing the urgent need to engage in interdisciplinary science to effectively promote biological control at the global level.

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