UNIVERSIDADE FEDERAL DO PARANÁ

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PATTERNS AND GAPS ON PLANT-POLLINATION INTERACTIONS: A GLOBAL SYSTMATIC REVIEW

CURITIBA

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Trabalho de graduação apresentado à disciplina Projeto Final II do Curso de Engenharia Ambiental do Setor de Tecnologia da Universidade Federal do Paraná.

Orientador: Prof. Dr. Jean Ricardo Simões Vitule

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Aos meus pais, Wilson Yoshikatsu Kato e Rizelda Freire de Carvalho Kato, e a minha irmã, Ana Luiz Freire de Carvalho Kato, as pessoas mais importantes na minha vida. Obrigado por todo incentivo e sacrifício para que esse momento se tornasse real. Esse é somente o primeiro fruto da pequena semente que vocês plantaram e cultivaram nos últimos 23 anos.

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PRÓLOGO

A motivação para o tema do trabalho surgiu do estágio que realizei no departamento de segurança de produtos e sustentabilidade, no segmento agrícola da empresa BASF SE, sediada em Limburgerhof, Alemanha. Durante o estágio desenvolvi uma lista pioneira de indicadores relativos a biodiversidade na agricultura intensiva que foi baseado em pesquisa científica, *workshops* com especialistas e uma validação com outras localidades no mundo (Alemanha, Reino Unido, Itália, Estados Unidos e Brasil). O meu orientador Prof. Dr. Jean Ricardo Simões Vitule sugeriu-me escolher um desses indicadores para fazer uma análise mais detalhada e aprofundada com rigor científico e acurácia, por isso escolhemos fazer uma revisão sistemátizada no formato de artigo científico. Para elaboração do trabalho usei os moldes e exigências da revista Applied Ecology, considerada um influente periódico diretamente relacionado ao tópico em foco, por 3 motivos principais: i) a facilidade para uma potencial publicação futura; ii) a precisão e forma direta de se passar a informação de um artigo científico e iii) pelo desafio de elaborar a tese em inglês.

SUMÁRIO

Patterns and gaps on plant-pollination interactions: a global systematic review

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Summary

1. It is clear the importance of pollination interactions to maintain fundamental ecosystem services to the well-being of humans because of the global food supply and huge economic value that represents for agriculture. Although, there is a lot evidences on pollinator's losses associated to the increase of intensive farmland. A review of scientific knowledge of the topic is crucial to provide solutions to manage this ecosystem service loss issue.

2. We conducted a systematic review on plant-pollination interactions using ISI Web of Science and recorded the main information of each publication (year of publication, journal, location of study, species of flower, and the method for recording species). After that we analyzed the data recorded to identify patterns and gaps on the topic.

3. United Kingdom seems to be the driving country for plant-pollination interactions publications.

4. Hydrophyllaceae and Rhamnceae were the most relevant plant families, might because such plants have ensemble of functional traits that attracts pollinators.

5. *Synthesis and applications:* There is a necessity to conduct more studies on different climates zones, especially equatorial and tropical. Also to better understand the benefits by pollination relations to crops. In special, vegetables and fruits that are considered vulnerable crops due to pollination. Additionally, this review found that Hydrophyllaceae and Rhamnceae, considering the negative impacts by introducing new specie in an ecosystem, should be preferable plant families to enhance pollinator abundance and richness.

Key-words: flowering strips, ecological interactions, bees, scientometrics, agriculture

Introduction

It is unquestionable the importance of ecosystems services provides by biodiversity to the maintaince of humans well being, in particular those provided by plants (Albrecht et al. 2007), among which we are directed benefited (e.g. food supply). In agriculture, ecosystem services are organized in four categories: supporting (e.g. nutrient cycling), provisioning (e.g. food and fiber production), cultural (e.g. recreation) and regulating (e.g. pollination) (Zhang et al. 2007). The pollination services are extremely important, since 87 of the 115 main global cultivars are significantly benefit from pollinator's interactions (Klein et al. 2007). Accordingly to Ricou et al. 2014, the global economic value of pollination in 2005 was 153 billion, equivalent to 9,5% of total agricultural production. Furthermore, it is extremely important to maintain pollination to maintain genetic variability of the plants (Richards 1986), which is essential for evolution by natural selection (Fisher 1930).

There is a clear evidence of substantial losses of pollinators around several regions (e.g. Potts et al. 2010, Williams 1986). This fact draws a further attention of a potential insufficiency on pollination of agricultural crops that might affect the food supply and put on risk global food security. Three major factor have been reported as main driver of pollinators declines: decline of nesting sites, spatial and temporary configuration of resources and decline of food resources, which is considered the major threat of those three (Holzschuh, Steffan-Dewenter & Tcharntke 2008, Potts et al. 2010). The intensification of agriculture coupled with the habit fragmentation are attributed as the main causes of this loss of biological diversity. Even thought Winfree et *al*. (2009), in a metanalysis, indicated that agricultural environments have the capacity to maintain relatively diverse bee communities as long as sufficient natural habitat remains.

Due to the decrease of biological diversity caused by the agriculture environment schemes, direct payments to farmers for biodiversity management (e.g. flowering strips areas) have been implemented in most European countries since the early 1990s (Albrecht et al. 2007). Since than, the beneficial effects of agriculture environmental schemes on biodiversity have been monitored (Carvell et al. 2007, Carvell et al. 2015, Dicks et al. 2015). Managing flowering strips might consist on introducing a new flower or pollinator specie, which should be carefully conducted to avoid imbalance the local ecosystem. Some studies even suggested that wild bees are more efficient in pollinating rather than an invasive species (Holzschuh, Dudenhöffer & Tscharntke 2012) or also, that native vegetation is more efficient in attracts pollinator insects (Cunningham et al. 2012).

Thereby, the aim of this study was to perform a systematic review on plant-pollinator interactions in agriculture, in order to recognize patterns and identify possible gaps. In this study, we specifically answered the following patterns questions: i) which journals are more relevant for the topic? ii) is the interest on the topic increasing or decreasing? iii) which country is more relevant in terms of publication, considering investments on research and development iv) which is the most common method for surveying pollinators, and we also answered the following gap questions: v) which regions have a lack of studies vi) which crops are more vulnerable due to plant-pollination interactions vii) which plant families have functional traits to attract pollinators

Methods

Our systematic review used the ISI Web of Science database. In order to conduct the literature research, the following key words were utilized on a search engine:
Topic = ((farm* AND nectar flower) OR (polli* AND farm*) OR (polli* crops AND biodiversity) OR (environmental schemes AND polli*)).
From the initial search were found 1.573 papers, however, we selected filters to refine the analysis. We selected only the following research areas: environmental sciences, ecology, agriculture, biodiversity, and conservation, plant sciences, science technology other topics, reproductive biology, zoology, behavioral sciences, biotechnology, applied microbiology, evolutionary biology, toxicology, engineering, and microbiology. Non-relevant subjects such as history, sociology, and physics were excluded. To avoid propagate error, we used the original publications and we excluded reviews and meetings. Than, we refined by language, using publications only written in English. Thereafter, we define more specific selection criterion to filter the articles: i) is the publication mentioning the value for pollinators and pollination of flower strips or flowering crops and ii) how to enhance or maintain pollination and pollinators. Using this criterion, we screened initially all publications by title and abstract. Of this screening, we finally evaluated using full text and same criterion to include or not on the systematic review.

We recorded from the papers included on the systematic review the main information: year of publication, journal, location of study, species of flower, and the method for recording species. To analyze this data we used the following methodology:

Journals

We used the method described on Braga et *al*. (2012) to identify which journals have a higher importance to plant-pollinator interactions topics by the calculation of a relative weight (w):

$$w = \left(\frac{n}{p * e * y}\right) * 1000$$

where p is the average number of papers published in the first edition of each year, e is the average number of editions per year, y is the number of years of our survey and n is the number of resulting papers from our survey for the journal (Braga, 2012).

We used a subset of 5 years of the 15 years of our surveys (2001, 2006, 2009, 2012 and 2015). The selection of this specific year's was a gap of two years in between. There is an exception between 2001 and 2006 because, 4 years gap, because we didn't have any studies published in 2002 and 2005. We used only the first edition, so there was no problem to use the current incomplete year of 2015 as part of the analyses.

We also recorded the 2014 average 2 years Impact Factors (IF).

Year of Publication

We used an analogy of the method described on Braga et al. (2012) to understand the relevance of our topic during the years. We used the following weight (*wy*):

$$wy = \left(\frac{Y}{m}\right) * 10000$$

$$m = \sum_{0}^{w}(p * e)$$

where *m* the sum of all published papers for a year of all journals included on the survey and Y is the number of resulting paper from our survey for the same year. To calculate *m,* we defined *p* as the number of papers published in the first edition of each year for a journal, *e* is the number of editions per year for the same journal and *w* is the number of journals from our survey. We used the same assumptions for choosing the years as the methodology described for the journal. So, we used a subset of 5 years of the 15 years of our surveys (2001, 2006, 2009, 2012 and 2015). For those years we used the function trendline with a two period moving average to represent the weight factor for the 15 years of our survey.

Worldwide distribution of articles

We recorded on an excel database the exactly location and also the country in which the study was conducted. In order to analyze tendency or concentration we used a world map to represent the distribution of publications found through our survey. After that we grouped some countries based on the proximity to be more didactic. The countries grouped were: Sweden, Denmark and Finland; Germany and Switzerland; France and Netherlands.

R&D investments vs. publications distribution

To identify which countries published more papers regarding to Research and Development (R&D) investments we used the Gross Expenditures on Research and Development (GERD) of each country from the World Bank (2014). We used the following weight scheme (*ws*):

$$ws = \left(\frac{n}{G}\right) * 1000$$

where *n* is the number of resulting papers from our survey for a country, and G is GERD (Bil, US$) of the respective country. Egypt, Hungary, Uganda, New Zealand and Costa Rica were excluded from this analysis because the GERD was not significant when compared to the other countries in our survey.

Crop studied

To understand which crops were more studied, we used a weight factor (*wf*) to correlate with the respective area of that crop on the world,

$$wf = \left(\frac{n}{A}\right) * 1000$$

where *n* is the number of resulting papers from our survey and *A* is the total area for that crop (1000km2).

We used the FAO crop commodities classifications and definitions (FAO, 2002), to organize the crops found in our survey in 10 groups: oil-bearing, fibers, roots and tubers, cereals, fruits, vegetables, spices, pulses, fodder crops and other crops. We had two crops not included on this classification scheme: alfalfa, which we included in the vegetable groups because it is a legume; and almond, which was added to the fruit group. It is important to highlight that some articles didn't mentioned the crops studied, corresponding to 17% (n=12). We had a few publications that have more than one crop studied, so there was a double count in these cases. In total, were assessed 83% (n=58) of the articles. To organize our analyses, we grouped vegetables, spices (cardamom) and pulses (beans) in one group, because we had available area data of these crop groups together. The area of each of those groups was extracted from Leff, Ramankutty & Foley, 2004.

Plant family

To identify which plant family has been more cited, we used a plant factor (*pf*) to correlate with the species richness of the respective plant family around the world,

$$pf = \left(\frac{n}{S}\right) * 1000$$

where *n* is the number of species on the resulting papers from our survey and S is the number of plant species for that family group. For our analysis, we included only the articles that mentioned the plant family or plant species. We had some publications that mentioned more than one plant species, so we considered double counting. We searched for the plant family for all plant species on our survey. We used Wikipedia to identify the family. After this identification, we searched for the species richness of each of those families using the following criteria: i) first search on Encyclopedia Britannica, ii) if not found, we used The Plant list 2010 and iii) last case we used Wikipedia. We assessed the richness using 81% (n=34) Encyclopedia Britannica, 12%, (n=5) The Plant List 2010 and 7% (n=3) Wikipedia. We had 25 plant families that had very few species (less or equal to two) that were grouped as other families.

Method to survey pollinators

We assessed 97% (n=68) of the methods used for surveying the pollinators of all publications on our survey.

Results

For the initial search we found 1,573 publications. Of those, only 70 matched with our criteria and were included on the systematic review (Fig. 1).

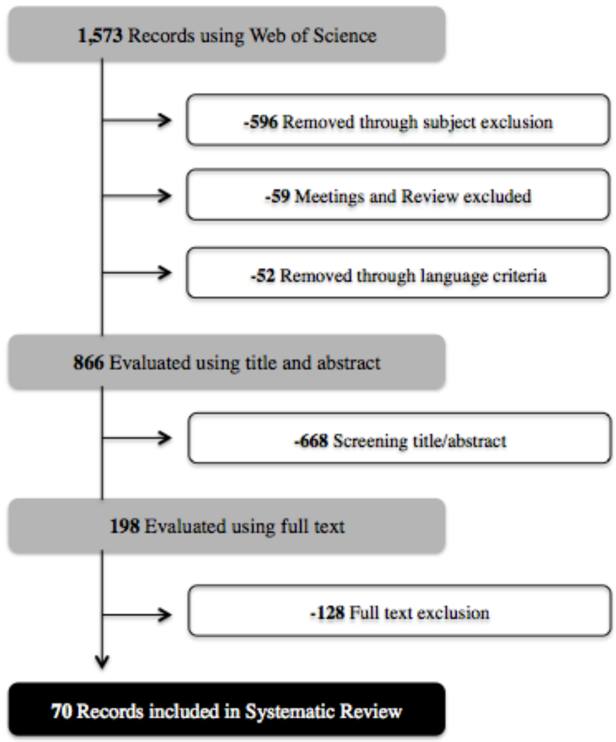

Fig. 1. Flow chart detailing the approach to refine search.

We found 24 scientific journals. The journals that had a highest amount of publications were: Journal of Applied Ecology (20%, n=14), followed by Journal of Biological Conservation (17%, n=12) and Journal of Agriculture, Ecosystem and Environment (14%, n=10). When considering the weight factor, Journal of Applied Ecology (9.71) and Journal of Biological Conservation (4.70) maintained their significant publication position, and the Journal of Basic and Applied Ecology (3.43) as the third most significant publication (Fig. 2).

The average 2-year Impact Factor (IF) of the resulting journals was 2.66 ± 0.24; the highest IF was 4.774 for Ecography (n = 1), followed by Applied Ecology (IF = 4.564, n = 14) and Conservation Biology (IF = 4.165, n = 1). A journal's 2-year impact factor showed a weak correlation with number of papers per journal (r = 0,4711 , p = 0,0311).

We had articles published between 2001 and 2015. In 2015, we had 17,1% (n=12) of all publications, followed by 2014 with 14.3% (n=10) and 2012 with 12.9% (n=9). According the weight factor, we had an increase of the publications related to plant-pollinator interactions higher than the increase of publications of other topics (Fig. 3).

We found publications from all the continents. The three major publishing countries were: United Kingdom (25.7%, n=19), followed by United States (13.5%, n=10) and Germany (9.5%, n=7), (Fig. 4).

Using the weighting factor based on R&D investments of each country, Indonesia (675.1), United Kingdom (597.1) and South Africa (450.5) were respectively the most relevant countries (Fig. 5).

Most of the studies were conducted on cereal fields (24.7%, n=21), followed by fruits (21.2%, n=18) and oil-bearing crops (15.3%, n=13). When the area weight factor was applied fruits (33), vegetables, spices and pulses (12.8) and other or coffee (7.3) were respectively the most relevant crop categories (Fig. 6).

We assessed the plant family of 41 publications (59%). The most common plant families were: Fabacea (21.6%, n=51), followed by Asteraceae (20.8%, n=49) and Poceae (8.5%, n=20). When the family species richness weighting factor was applied, Hydrophyllaceae (16.67), Rhamnaceae (6.67) and Amaranthaceae (3.75) as the most relevant plant families (Fig. 7). The other families group (0.66) was consisted by Scrophulariaceae, Violaceae, Campanulaceae, Adoxaceae, Papaveraceae, Chenopodiaceae, Myrtaceae, Dipsacaceae, Geraniaceae, Onagraceae, Malpighiaceae, Oxalidaceae, Zygophyllaceae, Anacardiaceae, Orobanchaceae, Asphodelaceae, Acanthaceae, Plantaginaceae, Urticaceae, Hypericaceae, Euphorbiaceae, Moraceae, Portulacaceae, Bignoniaceae and Sapindaceae.

We found three methods used to survey the pollinators. Standardized transect walk representing (59.2%, n=42), Observation Transect (21.1%, n=15) and Stick trap (15.5%, n=11). 4.2% (n=3) of the publications did not measure the pollinators (Fig. 8).

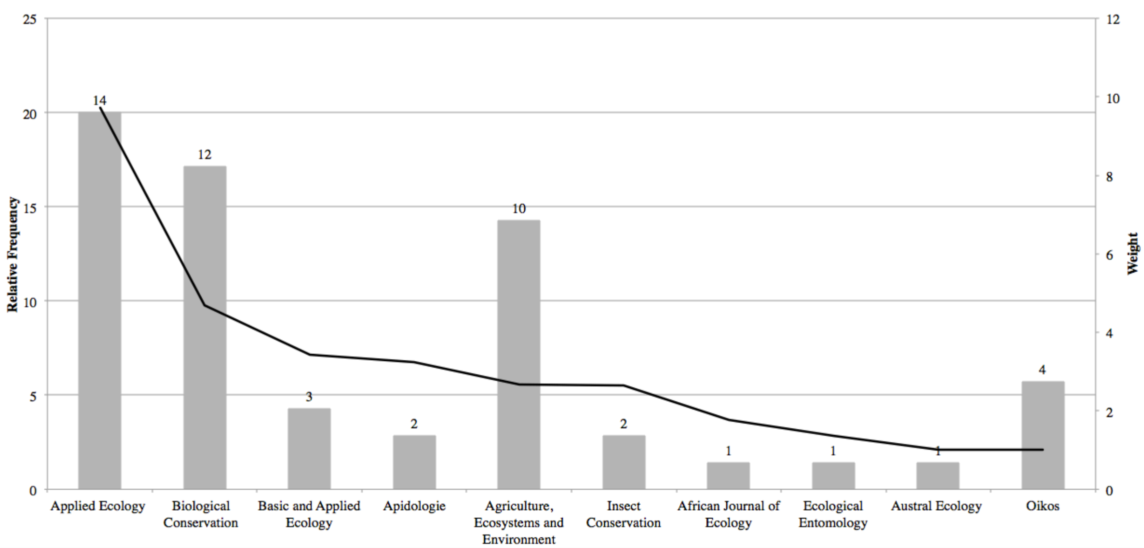

Fig. 2. Ten most relevant journals related to plant-pollinator interactions in agriculture. Grey bars represent the number of papers for each journal. The black line represents the relative weight (see the section 'Journal' on 'Methods') of each journal. Number above the bars represents *n* of resulting papers for each journal.

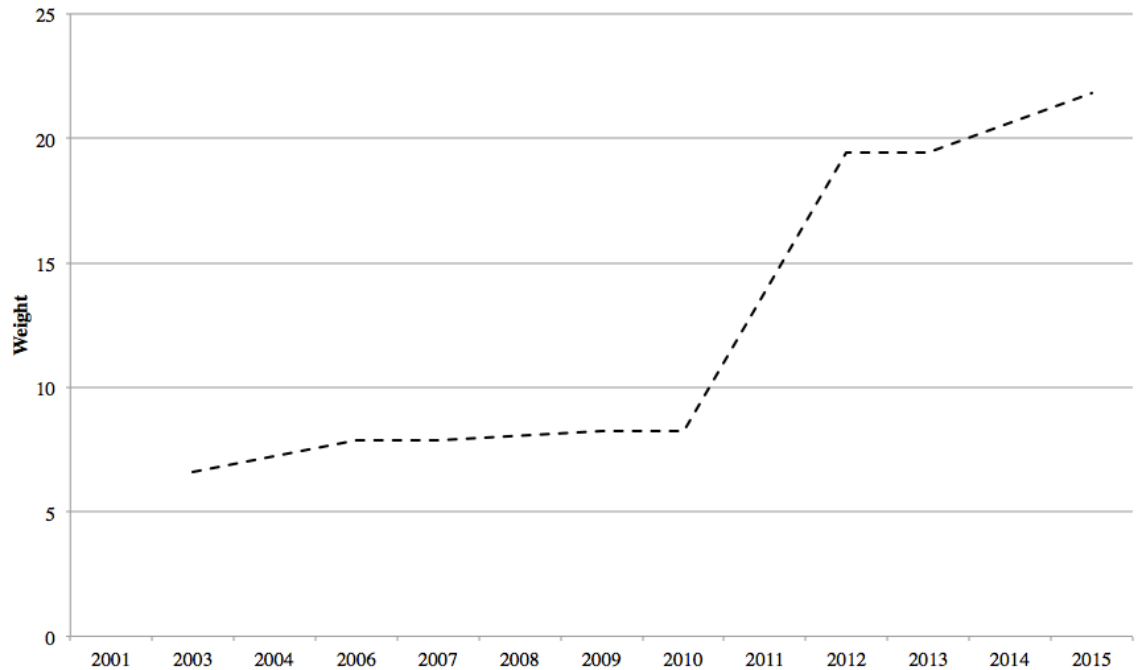

Fig. 3. Thirteen years had publications on topics related to plant-pollinator interactions in agriculture. The black line represents the weight (see the section 'Year of publication' on 'Methods') of each year. Number above the bars represents *n* of resulting papers for each year.

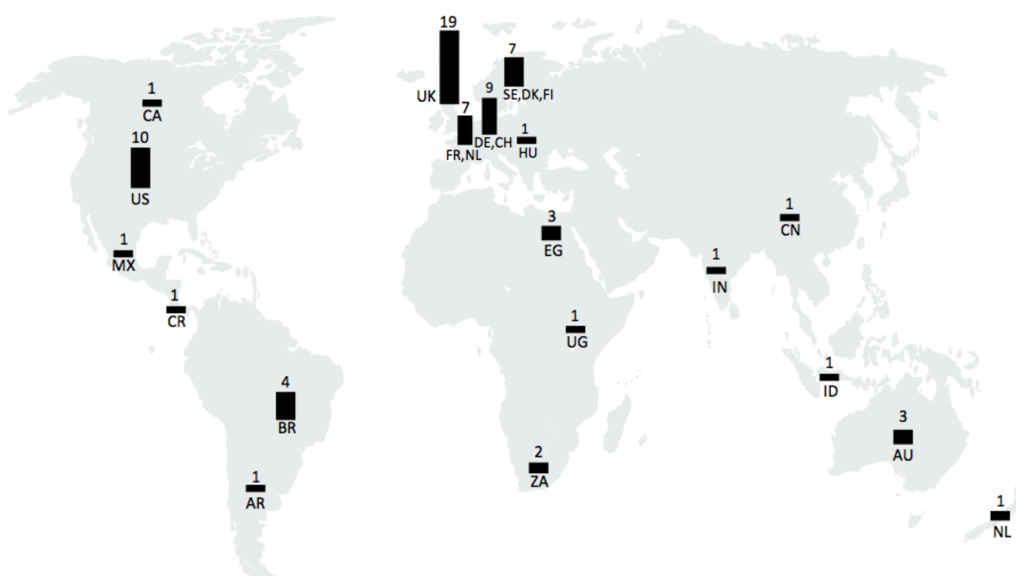

Fig. 4. Twenty-three countries published articles related to plant-pollinator interactions in agriculture. Grey bars represent the number of articles published. Number above the bars represents *n* of resulting papers for each country or group (see section 'Worldwide distribution of articles' on 'Methods').

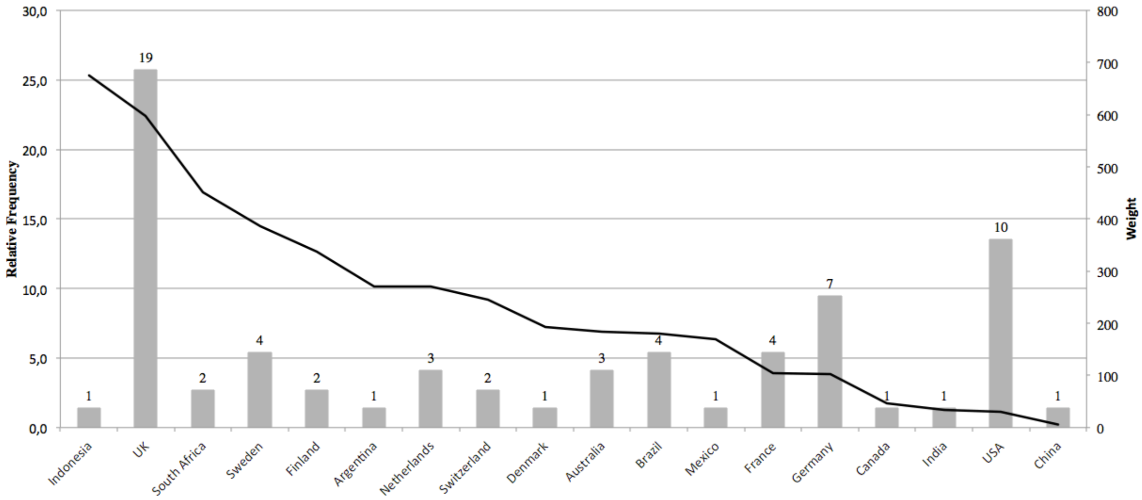

Fig. 5. Eighteen countries were analyzed. Grey bars represent the number of resulting papers for each country. The black line represents the R&D weight (see section 'R&D investments vs. publications distribution' on 'Methods') for each country. Number above the bars represents *n* of resulting papers for each country.

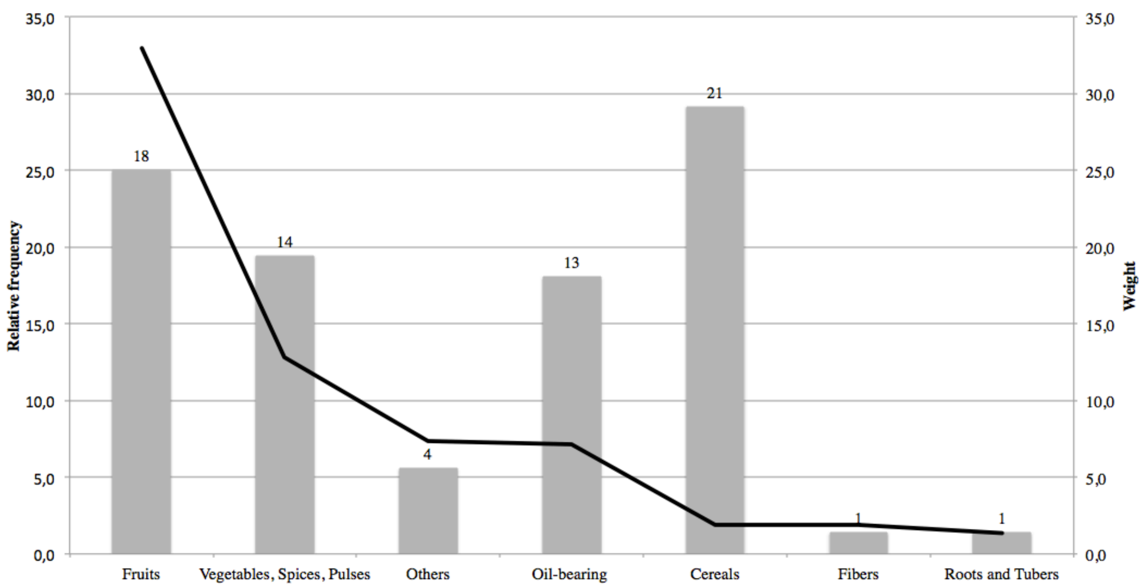

Fig. 6. Twenty-six crops were grouped in these 7 categories. Grey bars represent the number of crops in each category. The black line represents the area weight (see section 'Crop studied' on 'Methods') for each category. Number above the bars represents *n* of crops in each category.

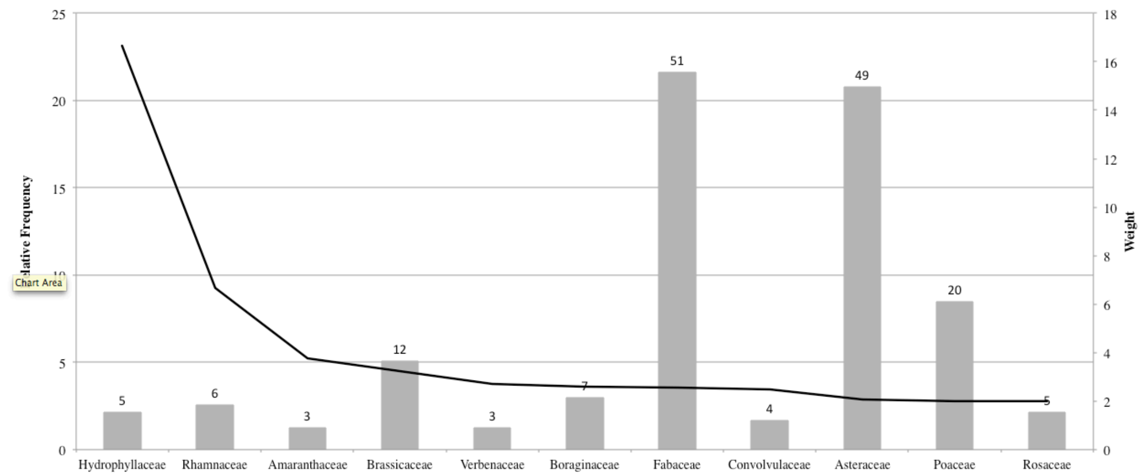

Fig. 7. Eleven most relevant plant families. Grey bars represent the number of species in each family. The black line represents the species richness weight (see section 'Plant family' on 'Methods') for each family group. Number above the bars represents *n* the number of species in each group.

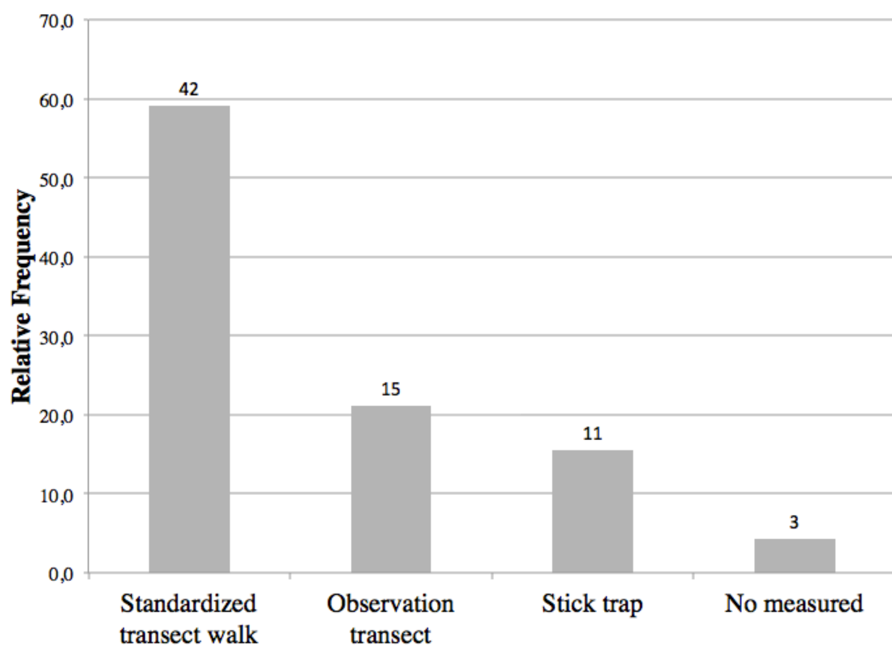

Fig. 8. The three methods used to survey pollinators. Grey bars represent the number of publications that used each of the survey methods. Number above the bars represents *n* of number of publications for each method.

Discussion

We observed that the most relevant journals, Journal of Applied Ecology and Journal of Biological Conservation, were also the journals that published more articles on plant-pollination interactions. Nevertheless, it is important to highlight that they are not journals restricted to plant-pollinators topics, respectively 0,68% and 0,33% of related publications compared to the overall publications for each journal. The journal of Basic and Applied Ecology, the third most relevant journal, had only three publications compared to ten publications of the Journal of Agriculture, Ecosystem and Environment, third journal with more publications. Due to the fact that Basic and Applied Ecology had 1248 articles published in contrast with 5366 publications of the Journal of Agriculture, Ecosystem and Environment during our survey.

The publication rates on plant-pollination interactions are increasing as well as any other topics. Although, it is important to conduct this publication rate analyze for the next years to guarantee that such important topic do not lose relevance.

Evaluating the distribution of publications worldwide, we see a concentration, 71.3% (n=51) basically in Western and Northern European countries (United Kingdom, France, Netherlands, Germany, Switzerland, Sweden, Denmark and Finland) and North America countries (United States and Canada), which are all located in Temperate Northern climates. This pattern shows the necessity of conducting more studies in different climate zones, especially in equatorial and tropical regions, once there are huge amount of flowering plants on tropical climates and they have no temperate representatives (Donoghue 2008).

When we analyze the investments on R&D and the number of articles published, we have Indonesia and South Africa as the first and third, respectively, most significant countries. Both countries had almost no publications. Indonesia had one article and South Africa only two, although the low Gross Expenditures on Research and Development (GERD) for those two countries, in comparison with other countries, enable even one publication to represent a height weight value. While United States have a GERD of US$ 447 billion, Indonesia and South Africa together have a GERD of US$ 8 billion. Therefore, ten publications in USA don't represent as much as one publication in Indonesia. This fact show that USA should study this field more intensely, once there are evidences that the rates of return to public investments on agriculture are consistently very high, above 20 percent (Sunding & Zilberman 1999).

United Kingdom is the second most significant country with a GERD of 43 Billion US$ and an impressive number of 19 publications, practically the double of publications of the second publishing country, USA. Due to the sensitivity of the weighting factor in Indonesia, we could assume that the UK is the driving country on plant-pollinator discussions at the moment. One of the reasons might be due to the UK has introduced the first agriculture-environmental scheme, which funds farmers for environmental land management (Dobbs and Pretty, 2000), in the European Union. So, there is a need of studies to understand the real effectiveness of such a scheme in terms of enhancing biodiversity, species diversity and abundance (e.g. Hanley 1998, Albrecht et al. 2007).

After using the weight factor for the crop categories we had a significant change on the position of the cereal groups, from the first to the fifth of seven positions, because the arable land area for cereals it is nearly triple of all others categories together. Therefore, 29.2% (n=21) of the cereals publications, when comparing with 25% (n=18) of the fruits category, but an area that represents approximately 5% of the cereals area, do not represent that much. This factor might be because plant-pollination interactions are more important and vulnerable for fruits and vegetables than for cereals, mainly wind-pollinated (Ghazoul, 2005). Even there, we had studies on the fruits category presenting a strong correlation with a higher crop productivity and also increase on the fruits weight due to pollinator's interactions (Carvalheiro, Seymour, Nicolson & Veldtman 2010 and 2013). However, another factor that might have a positive influence on our hypothesis. There is a concentration of studies on temperate northern climate, which are mainly arable lands of cereal fields, although there is more publications regarding the area on fruits or vegetables categories.

We had respectively Hydrophyllaceae (16.67), Rhamnceae (6.67) and Amaranthaceae (3.76) as the most significant plant families, families with less than 1,000 species each, in contrast with the most common plant families found, Fabeceae (21.6%, n=51), Astereaceae (20.8%, n=49) and Pocaeae (8.5%, n=20), families with more than 10,000 species. Hydrophyllaceae had five publications and only 300 species registered, meanwhile Fabeceae had fifty-one publications but 20,000 species. This pattern might affirm that Hydrophyllaceae and Rhamnceae have functional traits that attract pollinators (Eckart 1991). Another interesting fact is that a lot of the studies conducted on USA were in the arid environments near California, which Astereceae are farm more common than tropical forests (Donoghue 2008).

In terms of the methods to survey the pollinators we identified standardized transect walk representing 59.2% (n=42) as the most common. This result might be because the methodology is well established and widely tested. Even though was established on 1993, it is still in use nowadays (e.g. Carvalheiro et. al. 2010, Poots et. al. 2009). For more details about how to use such methodology see Pollard & Yates et al. 1993 and Pollard et al. 1997.

IMPLICATIONS FOR MANAGEMENT

Our systematic review helped to understand important patterns on the plant-pollinator interactions research by highlighting the journals with more publications and also with a higher significance to this topic. Showing that the publications rates are increasing accordingly to other topics. Presenting a higher concentration of publications on temperate northern climate, which rings a bell to the necessity of conducting more research on equatorial and tropical climates, which in general have higher species richness and abundance. This also, illustrates the distribution of these studies in terms of crops and pollination importance as well species of flowering families that might have a better functional trait to attract pollinators.

In summary, this paper achieved an actual, synthetic and comprehensive review of the available data, which should be considered to guide researches on the topic or political decisions.

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