Bat ecology and conservation in semi-arid and arid landscapes: A global systematic review

Abstract

1. Semi-arid and arid landscapes cover 41% of the Earth's surface over five continents. These areas are home to 55% of mammal species. Bats have the second highest species richness among mammals, and although many species are adapted to arid conditions, they are particularly sensitive in these habitats and require conservation priority.
2. However, information on bats in these landscapes is scattered, patchy and focused on small-scale studies, therefore we undertake a systematic review using the PRISMA protocol to identify the current knowledge status, detect knowledge gaps and propose future research priorities.
3. We analysed 346 papers published and found that the main topic types studied (e.g. taxa studied, methodologies used, morphology, etc.) were related to bat ecology and biology. Our network analysis of topics shows that most papers are focused on topics such as "distribution", "species richness" and "habitat use". When we analysed keywords, we found out that "phylogeny", "taxonomy" and "distribution" demonstrated relatively high presence. However, we found a gap in the topic type "conservation" (e.g. conservation status, roost conservation, etc.). Moreover, there are differences between the proportion of studies made and the surface area covered by semi-arid and arid landscapes across continents, with studies from Africa especially under-represented.
4. Our review reveals that the knowledge on the bats group in semi-arid and arid landscapes is biased towards new records of the distribution of species mainly. Many papers covered genetic and morphological aspects of bat biology.
5. We suggest that research on conservation measures and guidelines to protect the species in semi-arid and arid landscapes needs to be prioritised, together with the sharing of knowledge with local practitioners and the development of citizen science programmes.

Keywords: Chiroptera; dryland; Network analysis; PRISMA protocol; topics

Running head: Bats in semi-arid and arid landscapes

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1. Introduction

The Köppen climate classification defined dry (semi-arid and arid) climates as those where precipitation is less than potential evapotranspiration. If the annual precipitation is less than 50% of this threshold, the classification is BW (arid: desert climate); if it is in the range of 50-100% of the threshold, the classification is BS (semi-arid: steppe climate). A third letter can be included to indicate temperature (Peel et al. 2007). Dry environments are extremely diverse in terms of their land forms, soils, fauna, flora, water balance and human activities , they cover 41% of the land's surface (Verheye 2006) and are home to an estimated 64% of all bird, 55% of mammal and 25% of amphibian species (Peel et al. 2007, Davies et al. 2012, Durant et al. 2015; Figure 1). Therefore, it is important to summarize the knowledge about the different aspects of the biodiversity in these landscapes, especially to detect knowledge gaps and to identify trends and propose new research areas (Greenville et al. 2017).

Arid and semi-arid landscapes have unique faunas and floras and high biological diversity at multiple levels, and are areas of great conservation interest (Smith et al. 2001, Anadón et al. 2014). Also, desert and arid regions contain patchily distributed species whose range limits are under strong climatic control, have a relatively high rate of endemism due to adaptive processes exhibited by organisms in extreme environments, and are often locally endangered micro-hotspots of biodiversity (Davies et al. 2012, Murphy et al. 2012, Wilson & Pitts 2012, Brito et al. 2014) with climatic extremes generating sharp ecological gradients (Brito et al. 2014). Moreover, semi-arid and arid landscapes were barriers or refuges during the last glaciation and may contain phenotypes or high levels of genetic diversity that do not appear in other landscapes (Valera et al. 2011). Indeed, these areas are not isolated and represent transitional zones (Valera et al. 2011, Duncan et al. 2012, Brito et al. 2014) allowing many species with extensive distributions to have their distributional limits in these areas (Figure 1). Transition areas between biomes are particularly sensitive to environmental changes and our understanding of the impacts of climate change on terrestrial ecosystems has increased in recent years (Anadón et al. 2014).

Bats have the second highest species richness among mammal orders (> 1300 species, Voigt & Kingston 2016), representing a quarter of all mammal species. Bats are present in all habitats from high mountains to deserts, and many species are threatened (Voigt & Kingston 2016). Also, given their wide distribution and diversity in semi-arid and arid landscapes, bats could be good model taxa to study how mammals cope with aridity (Jones & Rebelo 2013, Razgour et al. 2017).They play an important role in the ecosystems and are effective bioindicators (Jones et al. 2009), providing important ecosystem services to humans such as pest suppression, pollination and seed dispersal (e.g. Jones et al. 2009, Boyles et al. 2011, Maas et al. 2016), especially in those areas where there are many mutualistic interactions between plants and bats (Williams-Guillén et al. 2016). In dry-lands, we found 299 (~ 23% of global richness) bats species documented as occurring in arid and 457 (~ 35.1% of global richness) in semi-arid landscapes (according to the GBIF dataset available in www.gbif.com), of which 246 species appear in both biomes. Also, we found that many bat species which appear in these biomes have extensive distributions (Rebelo et al. 2010, Sherwin et al. 2013, Ancillotto et al. 2016). However, information about the bat communities that live in semi-arid and arid landscapes is scattered, patchy and focused on small-scale studies, and a systematic review is needed to detect knowledge gaps in published literature and to prioritise geographical and conceptual research needs. Identifying topics and research directions can provide insights into how a discipline is changing over time (Greenville et al. 2017), in order to identify challenges and biases in this field and to improve guidelines for the development of management and conservation plans for this threatened mammals group.

Therefore, our main aim was to make a systematic review of the scientific literature about bat ecology and conservation in semi-arid and arid landscapes. Specifically, our aims were: 1) to characterize the studies in relation to the focus, languages and geographical areas; 2) to show the prevailing trends in these studies using five topic categories ("Taxa studied", "Methodologies used", "Biology", "Ecology", and "Conservation") involving 40 topics, the keywords used by authors and the geographical coverage; and 3) to suggest future directions and studies to increase knowledge about bat ecology in semi-arid and arid areas. To address our aims, we followed an international standard protocol for systematic reviews (the PRISMA protocol) and performed a network analysis of topics and keywords to understand interactions and emergent properties in the bat studies. This allows us to identify which are the most used topics and to detect gaps in the knowledge status as well as geographical areas with scarce data.

2. Methods

2.1. Data collection, PRISMA protocol and topics classification

We used the Web of Science®, Google Scholar®, and PubMed® search engines to locate publications with the following search words “bat*” OR “Chiropter*” AND “*arid” OR “desert*”. Our time period was from 1956 to 2018 (October). The majority of sources stemmed from peer-reviewed publications, we did not include Master’s and Ph.D. theses or published reports. We also inspected the bibliographies of relevant publications. Our searches were not limited to publications in English, because the majority of countries with these landscapes use other languages. Amano et al. 2016 demonstrated that the language used in scientific papers could be a barrier for conservation actions. We added a systematic search using the same words in French ("chauve-souris" OR "Chiropter*" AND "*aride" OR "desert"); Spanish ("murciélago" OR "Chiropter*" AND "*árido" OR "desiert*") and Portuguese ("morcego" OR "Chiropter*" AND "*arido" OR "desert*") language text or summaries to include local knowledge and to have a global vision avoiding bias. We selected these languages because more than 90% of the countries with semi-arid and arid landscapes used these as first or second languages. We only used those papers in which the abstract was in English because in this way the international community has access to, or the possibility of reading the paper.

We inspected the first 20 pages (10 results by page) of the listed search results, as this is a threshold used in other reviews (Razgour et al. 2016). Studies were excluded if they: 1) were not published in peer-reviewed journals; 2) did not provide an unambiguous definition of the analysed species in the main text or in the Supplementary Materials. This way, we collected a total of 405 papers. We added 106 papers with the same themes that did not appear in our search but which were present in our personal libraries. We consider, from our experience, that these papers are relevant to understanding bat biology in semi-arid and arid areas. Our final dataset contained a total of 511 papers. Then, after reading the papers, the following information was extracted from each one: "year of publication", "geographic area", five types of topics categories which are treated in the document ("Taxa studied", "Methodologies used", "Biology", "Ecology", and "Conservation problems"; See Figure 2 and Appendix S1), and the list of "keywords". We defined a topic as thematic elements that can be interpreted as a meaningful combination of ideas within a study (Westgate et al. 2015) so we categorized each article to one or more topics from these types of topics: "Taxa studied", "Methodologies used", "Biology", "Ecology" and "Conservation study". We defined keywords as those words provided by articles as "keywords".

We adopted the standard requirements of systematic reviews as specified by PRISMA (Moher et al. 2009, Shamseer et al. 2015; information is available at http://www.prisma-statement.org). PRISMA defines a systematic review as "*a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review*". Our methods are fully described below. The PRISMA checklist is attached (Appendix S2), and the flowchart is provided as Figure 3. Regarding sources, the PRISMA protocols provide a series of successive screening steps but treat all selected publications as of equal weight.

2.2. Network analysis of topics and keywords

Network analysis is used both in the field of social sciences (Borgatti et al. 2009) and experimental science (Bascompte & Jordano 2007) to understand interactions and emergent properties of complex systems. In this study, we use a novel network analysis of topics and keywords collected in the papers as a method for examining content in academic literature, by visualizing the patterns and structure of the network, describing the current research themes and obtaining measures of the most common studies and potential gaps (Popescu et al. 2014, Yun et al. 2016). Network analysis allow us to quantify the extent of which pairs of topics/keywords tend to occur in similar vs. different texts (Westgate et al. 2015). First, we standardized keywords (see Appendix S3), which are nodes or vertices in the network and are paired if they appear in the same paper. Second, each pair of topics (or keywords) involve an undirected link and has a value weight of 1. Therefore, if a pair of topics (or keywords) appears in another article, the weight of the link is incremented. We mainly focused on the network metrics "node degree" and "betweenness centrality" to describe the main characteristics and gaps on the literature of the 346 characterised articles (Popescu et al. 2014) (see Appendix S4 for more details). Node degree measures the number of relations between each node. Therefore, a topic or keyword with a high degree has many connections in the network and may suggest that it connects papers that share the same ideas. Betweenness centrality measures the number of shortest paths (node-to-node distance) that run through topics (or keywords) and identifies topics or keywords that connect each other ("connectors"). This metric is useful to identify the keywords that act as links and connect otherwise disparate keywords. We identified the main keywords and topics of this review as those with the highest network metrics. Other network metrics were calculated to describe the basic structure of both networks: the “network density” indicates if nodes were independent or connected (values from 0 to 1, respectively); “network clustering” the ratio of number of connections between all the neighbours of the node to all possible connections between neighbours and “distance (shortest path length)”, how close the nodes are in the network (see Appendix S4). The topic and keyword networks were built with the programme *Gephi* for analysis and visualization (Bastian et al. 2009). Both graphs were constructed using the Fruchterman-Reingold distribution. Some overall metrics from the networks were obtained by using the *NodeXL* programme (Smith et al. 2009).

3. Results

Our Internet search located 405 papers, and we added 106 papers more from our own library (approximately 20% of total) with the same topics (Figure 3). Following the PRISMA flow chart, we did not include 95 papers because they lacked "keywords" and 70 papers because they did not relate directly to bat ecology and conservation in semi-arid and arid landscapes. Some of these papers were related to palaeontological research in caves in arid areas, and others involved bats in the diet of owls. Finally, after applying filters, our final dataset contained 346 papers.

3.1. Focus, languages and geographical coverage

A total of 216 papers (62.4%) of the 346 were published in the last decade, while only the 10.1% of the papers were published in the last century.

The most used language in the papers was English (91.0%). The second most used was Spanish, representing about 6.6% of the papers analysed.

The papers were carried out mainly in the American continent (39.0%), Africa (16.8%) and Australia (4.5%). A high percentage of studies involved specific regions such as the Middle East (20.8%) and south Europe (5.2%). However, the number of studies at global scale was low (1.4%). We found that North America had the highest ratio (22.6) of the number of studies per million km^2, while this ratio was the lowest in Africa (3.4 studies per million km^2; Table 1).

3.2. Taxonomic groups

The taxonomic groups studied were focused at species level (109 of 224, 48.7%) or concerned bat communities in general (42.0%). Only a few studies were focused at family/genera level, mainly when taxonomic relationships were unclear (Figure 2a). The network analysis of keywords highlights that there are several taxonomic groups studied, including *Myotis* and Vespertilionidae, and *Leptonycteris curasoae* and Glossophaginae (Figure 5).

3.3. Surveying methods to study bat communities

The methodologies used (Figure 2b) in the bat studies in semi-arid and arid areas were based on inspection of museum specimens (Other methodologies: 49.7% of 346), where the researchers did not undertake field sampling. A third of studies used traditional methodologies as roost inspections and trapping with mist nets or harp traps (approx. 31.8% and 33.5% of the studies, respectively). Other techniques broadly used included acoustic surveys with bat detectors (23.1%) and genetic techniques (20.5%). However, the studies usually used a combination of different methodologies. There were few studies using mark/recapture, population studies or ethology/behavioural methods in our review.

3.4. Biological and ecological topics

In the biology topics category (Figure 2c), the studies focused on systematic aspects (25.4%), such as taxonomic classification and/or morphological differences between species. Also, there were a high number of studies describing diets (19.4%), especially for pollinators or seed dispersers related with columnar cacti. We found only a few studies where the authors studied reproductive aspects.

The main ecology topic concerned species distributions (70.5%; Figure 2d), but these studies contained just new presence data which increased the known species range. Also, "habitat use" and "species richness" were present in many of the studies analysed (46.2% and 34.7%, respectively). Other ecology topics such as "activity", "seasonality" and "environmental variables" were studied in depth.

The "water bodies’ role" and "food web" topics showed very low representation (< 20% of studies). Issues such as "pest control", "climate change" and "heavy metals/contaminants" occurred in < 5% of the studies (Figure 2d).

3.5. Conservation topics

The “Conservation topics” category (Figure 2e) was present in only a small fraction (< 15% of the total) of the studies analysed in our systematic review, although is a topic well connected to others (see Figure 4 and 5). These studies addressed issues such as "habitat conservation" or "species conservation". However, conservation issues were indirectly addressed in general. The role of protected areas for bat conservation in semi-arid and arid landscapes was neglected.

3.6. Network analysis of topics and keywords

The 346 articles were classified into 5 topic categories (Taxa studied, Methodologies studied, Biology, Ecology and Conservation), involving 40 topics (Appendix S1). Moreover, an article could be classified in more than one topic type. All topics were shown in a network of topics (Figure 4), which included 40 nodes (vertices of the keywords) and a total of 592 edges (pairs of vertices) connecting them, with 8851 duplicated edges and 98 unique edges (see Appendix S4 for description of network terms). The topics with highest node degree and betweenness connectivity, which are therefore both important and critical in connecting other topics were: “roosts”, “other biology”, “other methodology”, “habitat use”, “community” and “traps” (with a decreasing degree from 38 up to 36; Appendix S5). The values of node degree of topics were uniform, with a similar number of highly connected topics (i.e. with the half of the topics with a maximum degree of 38 up to 33) and a few topics with low node degree, being therefore the main gaps in literature (from 17 up to 3, with a decreasing degree: “heavy metals/pollutants”, “populations”, “zoonotic” and “mark and recapture”).

Regarding the network analysis of keywords, the 346 articles contained a total of 2044 keywords (average number of keywords per article is 6). Network analysis comprised 718 nodes and a total of 4373 edges, with 1686 duplicated edges and 3798 unique edges. The keywords with highest node degree and betweenness connectivity were: “bats”, “chiroptera”, “deserts”, “distribution”, “phylogeny”, “echolocation” and “morphology” (with a decreasing degree from 286 up to 94; Appendix S6). The values of node degree of keywords followed a clear gradient, with a reduced number of highly connected keywords (i.e. maximum degree for “bats” and “chiroptera”) and most keywords with limited pairwise connections (median node degree = 7). The interconnection between all the papers had an average of 2.70 keywords (shortest path length; Table 2). The most relevant keywords (those with a node degree higher than 10 after removing the nodes “bats” and “chiroptera”) (Figure 5) included 183 nodes and 1647 edges connecting them. Although network clustering was similar for both networks, other network metrics showed different values for both networks (Table 2). The network metric “network density” showed that nodes of the topic network were highly interconnected (0.76), whereas the nodes of the keyword network were less interconnected (0.02; Table 2); this is due to the high number of independent keywords without edges that appears in the 346 articles analysed. The metric “distance (shortest path length)“ was 1.21 and 2.66 for the topic network and keyword network respectively (Table 2), showing that the ideas tend to be more interrelated in the networks with the lower average keyword-to-keyword distance, i.e. in the topic network.

4. Discussion

4.1. Focus, languages and geographical coverage

Our review showed that there is a growing interest about bats in semi-arid and arid landscapes, with an increasing in the number of publications in the last decade. However, the growth in the number of papers published is a general trend in many scientific fields (Razgour et al. 2016, Voigt & Kingston 2016, Greenville et al. 2017), hence we expected increases in publication number over time in our study. The studies analysed in our review focused on ecology and biology topic types, while the conservation topic type was only studied indirectly, and few studies addressed conservation measures in semi-arid and arid landscapes.

Most of the studies were published in English and rarely in other languages. This is to be expected since papers in English have more impact within the scientific community. However, semi-arid and arid landscapes are mainly located in countries where English is not the official language. Consequently, stakeholders such as governmental organisations, land managers, and land owners in these non-English speaking countries may not have easy access to the scientific knowledge generated, and this may be detrimental for conservation actions (Amano et al. 2016). It is important to guarantee an efficient dialogue between researchers, practitioners and managers to develop effective management and conservation plans for bats, especially in regions with high levels of biodiversity (Kingston et al. 2016). Although most of the countries with arid or semi-arid landscapes had as first or second language those we selected to make our review (Spanish, French or Portuguese), we recognize that the inclusion of other languages such as Arabic, Chinese or Mongol could help to increase knowledge about the bat faunas in a more extensive part of the world with semi-arid and arid conditions, although such research activity is probably very limited.

Regarding study areas, most of the research was conducted in North America (USA and Mexico; Table 1). These studies were focused mainly in the relationship between bats and columnar cacti (Trejo-Salazar et al. 2016, Medellin et al. 2017). However, in South America studies were conducted in the arid regions of the Andean and the Brazilian Caatinga (See Data S2_Raw). Our analysis showed that there is a bias between the proportion of bat studies in these landscapes and its proportional surface on the continent. For example, the proportion of studies in the American continent (both North and South) achieved more than 22 studies per million km^2, while in Africa, where these habitats represent 38.4% of the dry-lands of the world, the equivalent ratio of studies was only 3.4 per million km^2 (Table 1). In countries with semi-arid or arid landscapes, the bat species richness is relatively high in these habitats (Appendix S7). However, there are discrepancies between the number of species recorded by the GBIF dataset and the maximum number of species present in the papers recorded. Therefore, it is necessary to increase our knowledge about bat faunas in these landscapes.

It is important to highlight the papers written by Benda and collaborators (e.g. Benda et al. 2006, 2008, 2010, 2014, Benda & Gaisler 2015) which increase knowledge on the distribution of many species and add to data about ecology and biology in North Africa. These papers also included information on habitat preferences, echolocation calls and taxonomic affinities. Several authors have also made important contributions for bat species in Middle East and Anatolian regions (e.g. Bilgin et al. 2006, 2008, 2009, 2012b, Furman et al. 2010b, a, 2013).

4.2. Taxonomic groups

Our results show that research is often based on single species and rarely on the bat community. When the studies were focused on a single species, they usually offered only new records. However, if the studies covered the bat community, they were focused on bat ecology in these landscapes (e.g. Hagen & Sabo 2012, Lisón & Calvo 2013, Hackett et al. 2013). The high number of papers with new records may suggest that there is new knowledge about the bat populations in semi-arid and arid zones, waiting to be published. This situation could be due to incomplete biodiversity inventories in these areas, probably because of the lack of bat researchers. For example, Carmel et al. 2013 showed that, from a survey of 750 articles, 70% of them studied single species, while ecosystem and communities studies only comprised 25% of articles. According to network analysis of keywords, the most studied taxonomic groups were *Myotis* and Vespertilionidae, and *Leptonycteris curasoae* was the most studied species.

4.3. Surveying methods to study bat communities

Our review shows that researchers usually take data from museums, especially to carry out morphological (skull and wing measures) and genetic analyses. These analyses were used to better understand phylogenetic relationships among species or subspecies, and to increase knowledge of their distributions (e.g. Juste et al. 2003, 2004, Benda et al. 2004a, Bilgin et al. 2006, Guevara-Chumacero et al. 2010, Benda & Gvoždík 2010, Furman et al. 2010a, 2013). However, the topic “distribution” is more frequent than the topics “morphology” and “systematics” (Figure 4). Also, authors used mainly classical techniques such as roost surveys and trapping (Kunz et al. 2009). However, most of the authors used a combination of techniques to avoid biases in their surveys (Flaquer et al. 2007), especially when the bat community was studied. This appears in our topic networks through the appearance of topics such as “traps” and “other methodologies”.

The number of studies using "radio-tracking" (e.g. Adams & Thibault 2006, Adams & Hayes 2008, Corbett et al. 2008, Monadjem et al. 2009), "stable isotopes" (e.g. Bullen & Dunlop 2012, Frick et al. 2014, Ramírez-Hernández & Herrera 2016) or "ecological niche modelling" are very scarce (e.g. Rebelo et al. 2010, Lisón & Calvo 2013, Lisón et al. 2013). These techniques involve highly skilled and qualified researchers, and therefore it is vital to support local biologists in acquiring these techniques or facilitate the access to specialised equipment through collaboration agreements between institutions, cooperation agencies and governments. Also, arid and semi-arid areas usually are remote and roadless, hence access for researchers can be difficult. This is important in a context where resources and funding are scarce. Indeed, many of the countries with extensive arid landscapes are under serious political conflicts (e.g. war, terrorism) which restrict fieldwork opportunities and, therefore it is key to support the local researchers and increase safety measures (Brito et al. 2018).

4.4. Biological and ecological topics

Studies on biological and ecological topics are mainly focused on morphological aspects, in which researchers try to understand the systematic position of bats in order to increase knowledge about distribution patterns and species richness in these landscapes. In recent decades, the taxonomy and systematics of bats has received considerable attention resulting in the discovery of 200 new bat species. The identification of new bat species is key to improving bat conservation (Tsang et al. 2016).

This situation could explain the differences between the number of bat species recorded in the GBIF dataset and the number of species which appeared in the papers reviewed (Appendix S6). The absence of bat information in many countries shows that more effort is required to gather bat inventories in such areas and justifies our reviewing effort.

Currently, semi-arid and arid landscapes are transitional areas between different biomes and represent the distributional limits of many species (Duncan et al. 2012, Brito et al. 2014, Durant et al. 2015, Maestre et al. 2016, Greenville et al. 2017). In transitional zones it is possible to find bat species undergoing speciation and even to discover new species (e.g. Benda et al. 2004b, Juste et al. 2004, Evin et al. 2011a, Bilgin et al. 2012a, Medina et al. 2014). Current genetic analyses are helping to resolve phylogenetic uncertainties based previously on morphological characters. These transition processes, distributional limits and species differentiations have been checked in the south of Spain, where the serotine species in the genus *Eptesicus* has been separated in two sibling species (Santos et al. 2014, Lisón 2015). Similarly, the bat faunas in north of Africa and Middle East represent transition zones between the European and Asiatic bat faunas (e.g. Benda et al. 2004b, Juste et al. 2004, Flanders et al. 2009, Evin et al. 2011b, Bilgin et al. 2012a). Phylogenetic affinities have been checked for many species, especially when they have a wide distribution, such as in *R. ferrumequinum* (Flanders et al. 2009) and *M. schreibersii* (Bilgin et al. 2006, Furman et al. 2010b, a, Bilgin et al. 2012a, 2016). Also, they have been researched in South Africa and Madagascar (Goodman et al. 2006, Goodman & Ranivo 2008, Odendaal & Jacobs 2011), although information on this subject in Latin America is limited (Giménez & Giannini 2011, Moratelli et al. 2011, Giménez et al. 2015).

On the other hand, semi-arid and arid zones in the Mediterranean Basin acted as a refuge during the last glaciation and currently are zones where novel haplotypes exist (distinct sequences of mtDNA inherited maternally) occur that are not present in other areas. This is especially important for some genera of bats, such as *Plecotus* spp. (Benda et al. 2004c, Juste et al. 2004, Razgour et al. 2013), *Pipistrellus* spp. (Benda et al. 2004b, Evin et al. 2011a, Benda et al. 2015), *Eptesicus* spp. (Santos et al. 2014) and *Barbastella* spp. (Juste et al. 2003).

Several genetic studies have tried to understand the phylogeography and evolution of these species and their current populations. However, there are few studies focused on the implications of climate change on bat populations and communities in semi-arid and arid landscapes (only a degree of 31 in the keyword network; Rebelo et al. 2010) and the adaptations of these species with regards to the aridity conditions have been little studied (Razgour 2015). Understanding how semi-arid and arid lands respond to current environmental changes is important for sustainability at global scale, since bat species are fundamental to sustain ecosystem services such as pest suppression, pollination and seed dispersal. This knowledge is essential to develop conservation and restoration measures in dry-lands, as biotic attributes can be actively managed at the local scale to improve ecosystem resilience to global change (Maestre et al. 2016). Therefore, studies in arid ecology (both past and present) may add greatly to our knowledge of changes under extreme weather events, and the responses of biota and ecological systems under future changes in the climate. (Greenville et al. 2017).

There are a few ecological studies on topics such as "bat activity during the night" (Kuenzi & Morrison 2003, Dalhoumi et al. 2014, Fisher-Phelps et al. 2017), “seasonality” (da Rocha et al. 2015) and, “water bodies’ role” (Adams & Hayes 2008, Razgour et al. 2010, Lisón & Calvo 2011, 2014, Hagen & Sabo 2012, Sirami et al. 2013, Korine et al. 2015). Indeed, studies on pest suppression, ecosystem services and zoonotic threats are very scarce (Silva-Iturriza et al. 2013, Memish et al. 2013, Maganga et al. 2014).

4.5. Conservation topics

Our results show that bat conservation is considered a minor topic in research in semi-arid and arid landscapes (Figure 4), however it is an important keyword (Figure 5). Most of the studies centred on “habitat conservation”, especially in those sites where habitat use was evaluated (e.g. Sandoval & Barquez 2013, Hackett et al. 2013, Smith et al. 2016). A relatively large number of papers concern the roles of bats as pollinators of columnar cacti (Fleming et al. 2001, Nassar et al. 2003). Some of these are of high economic interest because of the implications for the tequila industries (Trejo-Salazar et al. 2016).

Only 3.5% of studies concerned roost conservation, despite roosts being essential for bat conservation (Lisón et al. 2013, Furey & Racey 2016, Medellin et al. 2017). There are only studies about the role of protected areas from Spain (Lisón et al. 2013, 2015, 2017, Lisón & Sánchez-Fernández 2017).

4.6. Future directions

Our systematic review about bat ecology and conservation in semi-arid and arid landscapes has shown that there are topics that were poorly studied, and it is necessary to address them in future research.

We suggest the following future directions.

1. To develop new taxonomic and systematic studies, especially in little-studied areas of South America.
2. To increase the number of ecological studies, especially using methodologies such as radio-tracking, echolocation calls and dietary analysis. Also, studies should cover entire bat communities.
3. To implement new studies to elaborate conservation measures and guidelines to protect roosts and habitats of bat species in semi-arid and arid landscapes. Also, to increase and assess the role of the protected areas for bat conservation and to research the design of new protected areas. It is important to involve the people who live in these areas in the decision making.
4. To increase the number of papers made available in the native languages of regions with extensive semi-arid and arid landscapes, and to improve their availability to practitioners, policy makers and citizens. It will be valuable to develop citizen science programs to help local researchers in data collection.

5. Conclusion

In conclusion, even though there are a large number of papers published about bat ecology and conservation in semi-arid and arid landscapes, most of them focus on describing new records regarding the distribution of bat species. Many papers also describe new species or subspecies using genetic and morphological data. Overall there are large knowledge gaps about the bat fauna in semi-arid and arid landscapes, and the current taxonomic position of many species could be uncertain. Therefore, collaborations between ecologists and geneticist, and researches of ecological processes across spatial scales should contribute to the progress of arid landscape ecology greatly (Greenville et al. 2017).

In this systematic review we used the presence of topics based on our experience in bat studies, and this can have some limitations. For example, since we analysed only the available literature, new or emergent topics are hard to identify. Therefore, our study can only disclose gaps between existing topics. In spite of this, topic analysis is a valuable method to orient researchers as to where they can look for novel or emerging issues as well as research gaps where they can conduct their research efforts (Greenville et al. 2017). We identified some clear knowledge gaps and research priorities for the future.

Finally, this knowledge is essential to guide conservation and restoration efforts in dry-lands. Also, it is necessary to develop management plans and protected areas for the bats in these areas and to increase research on the resilience of these mammals to arid conditions.

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Tables

Table 1: Surface percentage of semi-arid and arid areas (BW+BS Köpper climate; VerHeye, 2009) and number of studies made in them, except those studies made in various continents (e.g. global or Mediterranean area).

Geographic area	All dry lands (BW + BS)[1]	% total surface	Number of studies	Number of studies per millions of km^2 of dry land area
Australia	6.1	79.3	25	4.1
Eurasia[2]	15.5	28.3	119	7.7
Africa	17.2	56.6	58	3.4
North America	3.4	13.7	77	22.6
South America	2.6	14.6	58	22.3

[1]Surface in millions of km^2

[2]We consider here Europe + Middle East + Asia

Table 2. Network-level metrics from the network analyses of topics and keywords for the 346 studies on bats in semi-arid and arid zones. See definitions of network metrics in Appendix S3.

Type of network	Nº of papers	Nº of nodes (topics)	Average nº of nodes per paper	Network density	Distance (shortest path length)	Network clustering
Topic network	346	40	0.12	0.76	1.21	0.89
Keyword network	346	718	2.07	0,02	2.66	0.83

Figure 1: Distribution map of arid and semiarid areas of the world according to the Köppen's classification. Available at Wikipedia under Creative Commons Licence (CC). https://commons.wikimedia.org/wiki/File:Koppen_World_Map_B.png

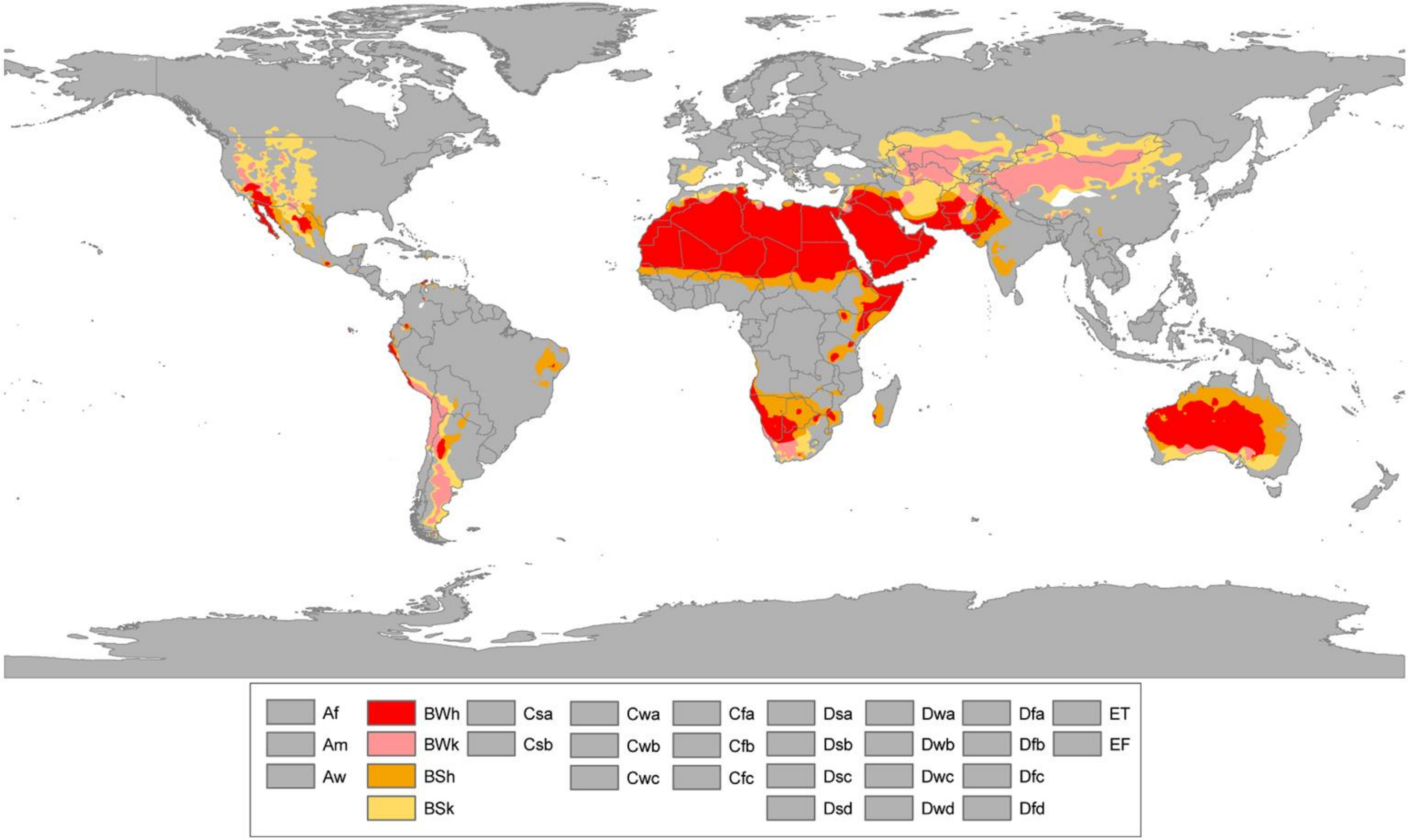

Figure 2: PRISMA flow Diagram followed in this study.

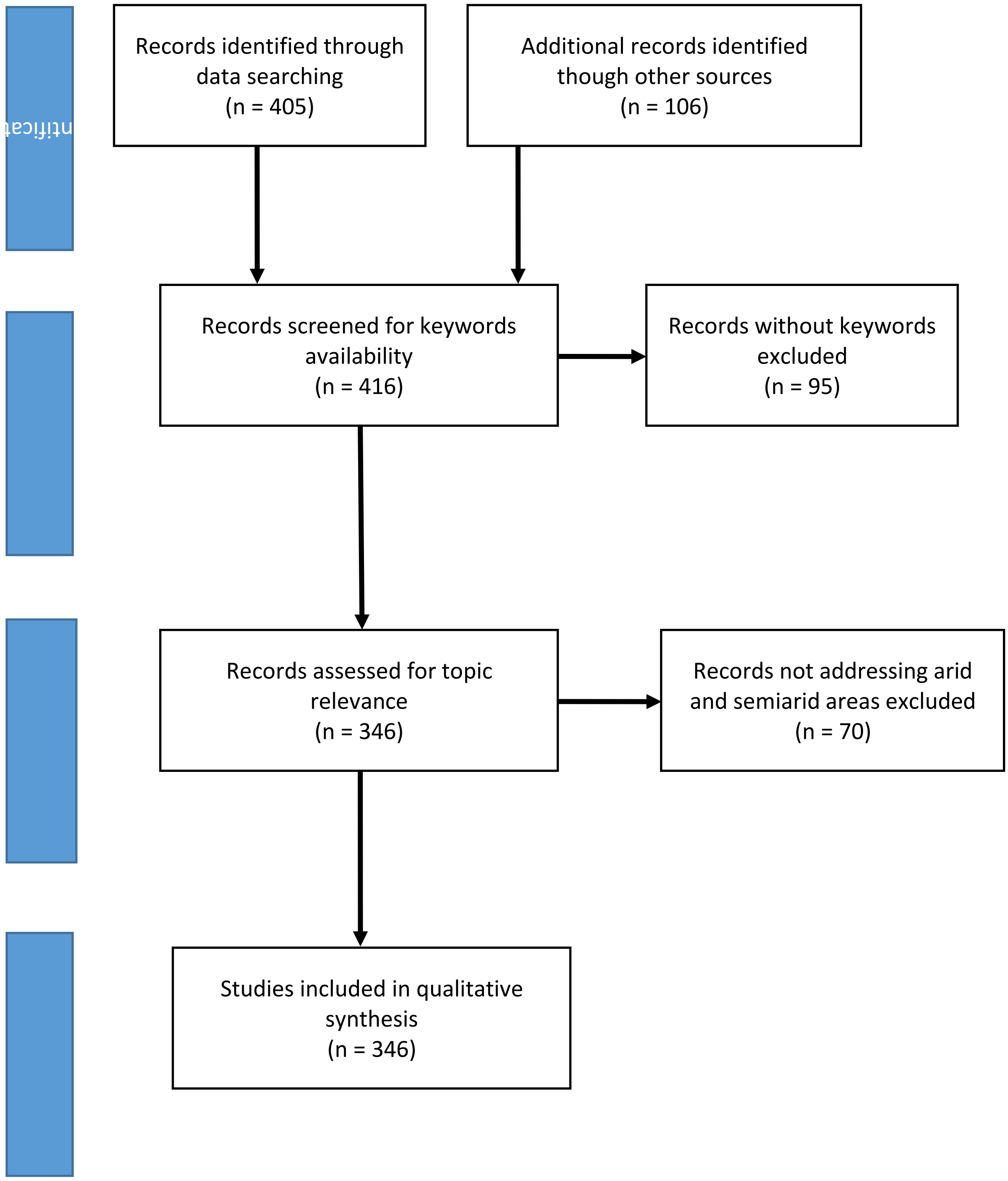

Figure 3. Topic network for the 346 studies on bats in semi-arid and arid landscapes. All nodes (i.e. vertices or 40 topics) are showed. A larger symbol size and colours from yellow to red indicate a higher node degree - the node degree is equal to the number of edges (pairs of topics) connected with the respective node. Edge sizes and intensity of colour represent edge weights.

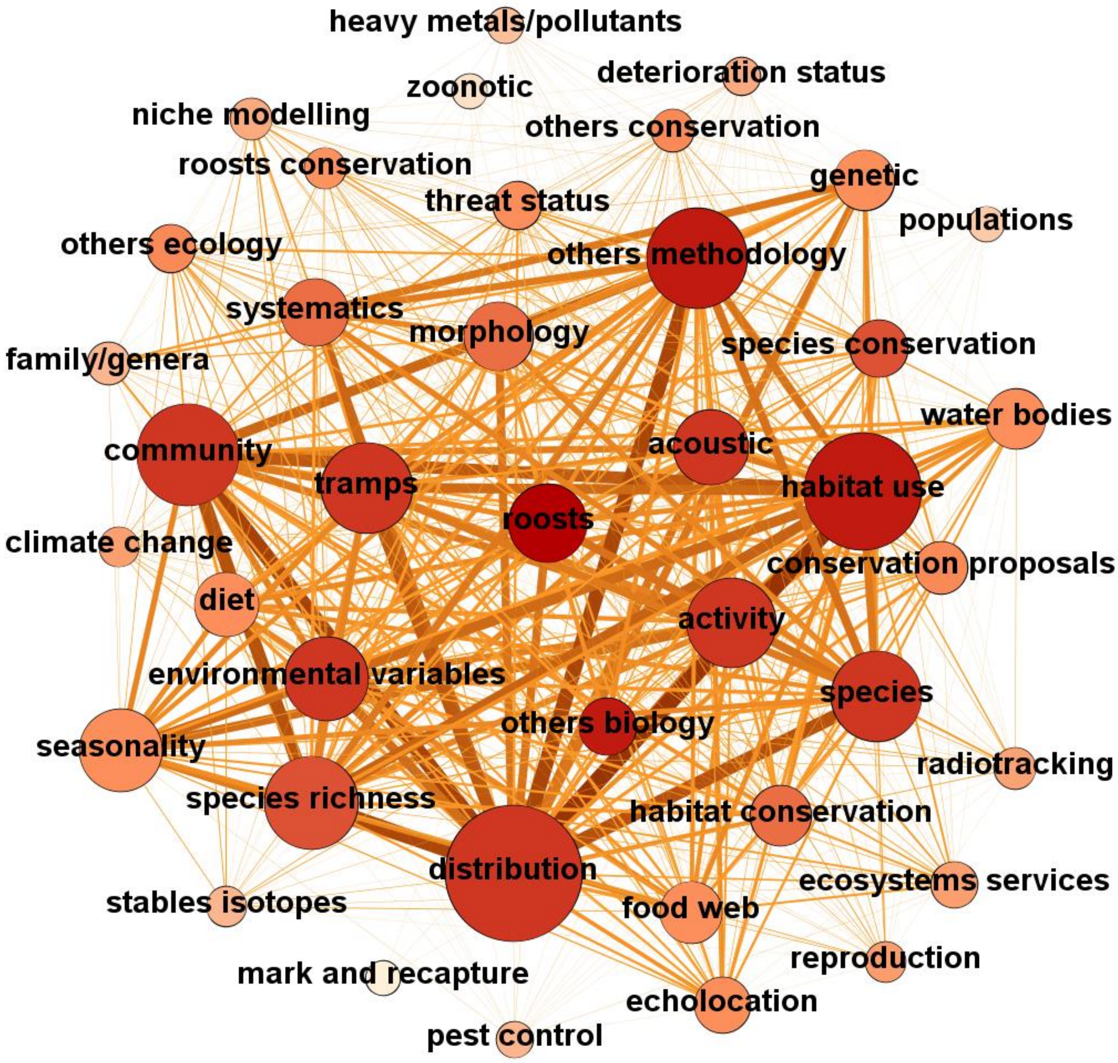

Figure 4. Keyword network for the 346 studies on bats in semi-arid and arid landscapes. Nodes or vertices with a node degree from 10 to 124 are showed (183 nodes and 1647 edges). The node degree is equal to the number of edges (pairs of keywords) connected with the respective node A higher symbol size and colours from yellow to red indicate a higher node degree. Edge sizes and intensity of colour represent edge weights.