Acta Herpetologica 15(2): 95-104, 2020
DOI: 10.13128/a_h-8478

A bibliometric-mapping approach to identifying patterns and trends in amphibian decline research

Claudio Angelini[1,*], Jon Bielby[2], Corrado Costa[3]

[1] *Via G. Marconi 30, 04018 Sezze, Italy*
[2] *Liverpool John Moores University, School of Natural Sciences and Psychology, Byrom Street, Liverpool, United Kingdom*
[3] *Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA) - Centro di ricerca Ingegneria e Trasformazioni agroalimentari (CREA-IT), Via della Pascolare 16, 00015 Monterotondo, Rome, Italy*
**Corresponding author.* E-mail: oppela@gmail.com

Submitted on: 2020, 20th April; Revised on: 2020, 21th October; Accepted on: 2020, 26th October
Editor: Marco Sannolo

Abstract. Amphibian decline is one of the most severe and well-documented examples of immediacy of the ongoing biodiversity crisis. In this study we analyze the scientific literature on amphibian declines with a view to identifying and analyzing emerging patterns within this large, and growing, body of knowledge. Focussing on peer-reviewed papers published between 1977 and 2018, we identified a total of 2,619 scientific publications, from the Scopus database. Using a visual-clustering approach, which allows us to investigate patterns and trends of research topics, we developed term-maps to identify how key terms cluster into research areas, and whether geographic patterns exist in the scientific literature on this subject. Overall, the average annual growth rate of the number of studies published on amphibian declines was 109.3%, with a decisive increase since 2001. The term map analysis revealed four main research areas: i) ecology; ii) causes and consequences of pollution; iii) global threats and extinction risk; and iv) pathogens (which includes many current publications, especially those focused on chytridiomycosis). We confirm the existence of a geographical research bias in the study of amphibian decline, with studies mainly located in western countries, which harbour a smaller number of threatened species. In contrast, studies on threatened species are consistently underrepresented. The literature on amphibian declines has increased at a greater rate than general amphibian literature, highlighting the possibility that the observed amphibian decline has been a driver for amphibian research.

Keywords. Global amphibian decline, chytridiomycosis, scientific literature, term map, threatened species.

INTRODUCTION

In the framework of Holocene extinction (see, e.g. Ceballos et al., 2017), the global amphibian decline is likely one of the most severe examples of a clade specific biodiversity crisis (reviewed in Ficetola, 2015). Its severity is due both to the number of species that have already gone, or are likely to become, extinct (e.g. Alroy, 2015) and to widespread ongoing population declines (Houlahan et al., 2000). Amphibian declines are multifactorial, including global changes (climate change, emerging infectious diseases, …), local causes (habitat destruction, invasive species, …), and meso-scale agents (environmental toxins, habitat fragmentation). Furthermore, due to their typical life history, ecology and physiology, amphibians are sensitive to changes of both aquatic and land environments, making them bio-indicators at global level.

In view of their ecological importance and susceptibility to anthropogenic driven change, it is striking that the relative importance of amphibian decline as a topic in scientific literature has largely increased since 1973 (Fig. 1), when the first paper dealing with the subject was pub-

ISSN 1827-9635 (print)
ISSN 1827-9643 (online)

lished (Beebee, 1973). The purpose of our paper is to provide an analytical overview of the production of scientific research that has dealt with amphibian declines in this time period. To our knowledge, there are only few bibliometric/scientometric studies on amphibians (Gardner et al., 2007; Ohmer and Bishop, 2011; Campos et al., 2014; Ficetola, 2015; Mormul et al., 2017), and those that do exist are all focused on quantitative elements of amphibian declines' studies. Such kind of studies can be useful for making a point and addressing future researches.

Rather than being a purely quantitative analysis of the literature, our analysis takes a different approach, using science mapping (or bibliometric mapping), which is a methodology that produces a spatial representation of the relations among the units of interest extracted from literature (key-words, authors, countries of origin, …) (Costa et al., 2019). Basically, such analytical approach produces a bibliometric network which allows us to spatially structure patterns and trends of research, which is the aim of our study. Research trends are detected by bibliometrics and by quantitative methods that analyze scientific publications as an information process. Once patterns and dynamics in scientific publications are identified, they can be used as a proxy for the development of the investigated disciplines (van Raan, 2004). Thus, bibliographic analysis is a powerful tool to measure scientific production of research and trends, facilitating better direction of science-based strategy to fill knowledge gaps and better complete the scientific information upon which policies are developed. By using such approach we aim to describe how the interest on amphibian declines has changed over time, accounting for topics' trends and geographic pattern which accompanied such changes. In doing so, it is inevitable referring to IUCN Red List Threat categorisation, which is a point of reference in the field of conservation. Our aim is not to discuss the IUCN strategies and monitoring, rather we used IUCN categories for a better comprehension of our findings, in particular for evaluating wheter research efforts are consistent with species' conservation status. While, of course, we can only depict what has been done, we expect that understanding patterns and trends underlying published research will help the planning of future studies and bring new questions.

MATERIALS AND METHODS

Database search

The Scopus database was consulted on July 20th 2018 and used to retrieve bibliographic records related to Amphibian Decline research for the period 1977-2018. To identify relevant amphibian decline publications, the following keywords were used in the combined fields of title, abstract and keywords (*per* publication): "Amphibian" AND "Decline". As the Scopus search was conducted in July 2018, publications from that year were not present in the Scopus database and as a consequence, the frequency of word occurrence in our search may be underestimated. The search was restricted to publications (Articles, Reviews, Book Chapter and Books) written in English. Before starting with the analysis in VOSviewer, a thesaurus file (supplementary text file S4) was created to ensure consistency for different term spelling and synonyms (an example: we used "agriculture" for more terms, such as "agricultural activity", "agricultural landscape", "cattle"). Only terms occurring at least nine times were extracted from the retrieved publications.

Bibliometric mapping and clustering

Bibliometric maps were created on retrieved publications, using the VOSviewer software version 1.6.5.0 (freely available at www.vosviewer.com). The software was specifically developed for creating, visualizing and exploring sciences' bibliometric maps basing on VOS (Visualization Of Similarities) mapping technique, that is closely related to the multidimensional scaling method (van Eck and Waltman, 2010; for further explanation on the method see van Eck and Waltman, 2011; van Raan, 2014; Nardi et al., 2016; Costa et al., 2019). Using VOSviewer we produced term maps. A term map, also called co-word map, is a two-dimensional representation of a research field, in which strongly related terms are located close to each other and the weaker the relationship between terms, the larger the distance is between them. The diameter of the circle representing a given term indicates the number of publications where it appears (in order to avoid overlapping labels, only a subset of all labels is displayed in the maps).

Once terms are in the map, the next step was to identify clusters of related terms. The software uses a weighted and parameterized variant of modularity-based clustering called VOS clustering technique (Waltman et al., 2010; Waltman and van Eck, 2013). The assignment of terms to the same cluster depends on their co-occurrences in the title or abstract of publications. A cluster that is made up of terms of the same colors represents a research theme in which one or more research topics can be identified. The same approach was applied on the bibliographic information on the same publication dataset to observe the countries of the co-authorship map with the aim of observing the collaborative clustering of the countries based on amphibian decline publications.

A term citation map was produced; this map analyzes the scientific impact of specific topic, whereas a term year map performs a timeline analysis of the research topics. More specifically, in the *term citation map,* the color of a term is determined by the normalized average citation impact of the publications where the term occurs, thus reflecting the average citation impact for the term. Therefore, a blue (cold) or red (hot) term indicates that publications in which the term occurs have low and high average citation impacts, respectively (van Eck et al., 2013).

A *term year maps* was also produced; in this map the color of a term indicates the average publication year of all the pub-

lications in which the term occurred. As for the *term citation map*, we used colors that range from blue (mean year term presence 2008 or earlier), to green (2010) to red (2012 or later). Therefore, blue terms were those occurring mainly in older publications, while red terms occur mainly in publications that were more recent.

Maps of amphibian decline publications both globally, and restricted to only EU countries and the UK (which for the duration of this study was part of the EU) were constructed using color intensities to illustrate the number of publications. The number of publications was counted considering the host institution of all the co-authors of a paper, hence a single paper may include multiple countries as its country of origin for this purpose. Further, a collaborative clustering map of the countries based on amphibian decline publications was also produced reporting the spatial relationship among countries.

In order to evaluate if and how the conservation status of species biased the scientific production about species or geographic areas, we used the I.U.C.N. Red List Threat category of the species and the I.U.C.N. spatial data for species' ranges; in the following we will refer to this information as IUCN (2019). Specifically, we evaluated the percentages of papers dedicated to species belonging to the different IUCN categories, and evaluated the relation between the numbers of threatened species a given continent harbours and the number of papers actually dedicated to species harboured in that continent.

RESULTS

Amphibian decline publication trends

A total of 2619 scientific publications fitted our search method based on relevance for the terms "amphibian" and "decline": 91.2% of the publications were regular articles, 7.4% review papers, 1.3% book chapters and the remaining 0.1% were books. The studies were published in 157 journals. Most commonly reported journals were Biological Conservation (n = 120; 5.8%), PLoS One (n = 106; 5.1%), Diseases of Aquatic Organisms (n = 103; 5.0%), Conservation Biology (n = 101; 4.9%) and Journal of Herpetology (n = 90; 4.3%). Figure 1 depicts the numbers of publications about amphibian declines from 1977 to 2018 July and their relative contribution to the total amount of literature about amphibians (i.e., number of publications in the Scopus database from a search with only "amphibian" as a keyword). It is possible to observe a decisive increase since 2001, with a light reduction in the frequency of keyword terms in 2014 followed by a recovery. The average annual growth rate (geometric mean) for the whole period has been 109.3%, being 107.8% until 2000 and 111.3% thereafter. Although the literature about amphibians increased by a factor of five in 40 years, the percentage of publications on amphibian declines increased more than four times in the same time period.

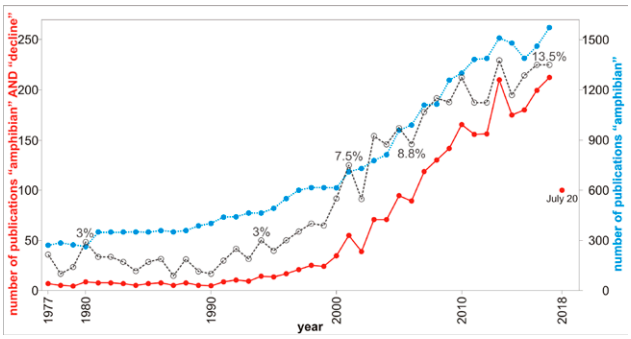

Fig. 1. Trend in amphibian publications from 1977 to 2018. Continuous (red) line is for the number of publications including both "amphibian" and "decline" (left y-axis), dotted (blue) line is for the number of publications including "amphibian" only (right y-axis), dotted (grey, with empty circles) line is for the annual percentage of "amphibian" and "decline" studies out of the total "amphibian" studies (some reference percentages is reported in the graph) (2018 publications were underestimated being not yet all inserted in the Scopus database at the time we consulted it).

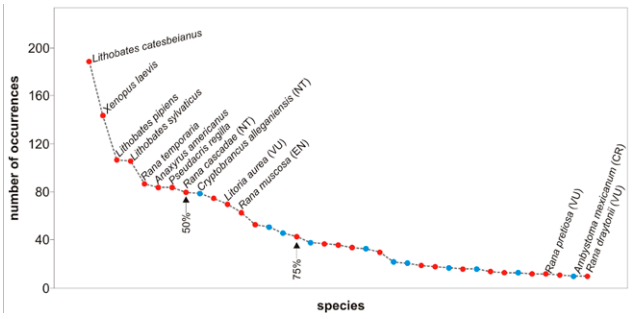

Fig. 2. Occurrences of amphibian species in the publication analyzed (analysis is based only on species with more than 10 occurrences; only the first eight species and non-Least-Concern species are shown; arrows mark the 50% and 75% of total occurrences); red dots are for anurans, blue dots for urodeles, no caecilian species occurs in more than 10 studies.

The species which occurred in at least 10 publications were 37, representing 12 families of amphibians. Eight species (belonging to four families) appear in half of the total number of studies in which single species were cited (Fig. 2), 75% is achieved with eight more species; 81% of the species have been assessed as Least Concern in the IUCN Red List. No caecilian species occurs more than 10, "caecilian" occurs 13.

Amphibian decline research topics and their citation impacts

In the *term map* (Fig. 3) the 579 terms displayed on the map are grouped in four clusters, which partial-

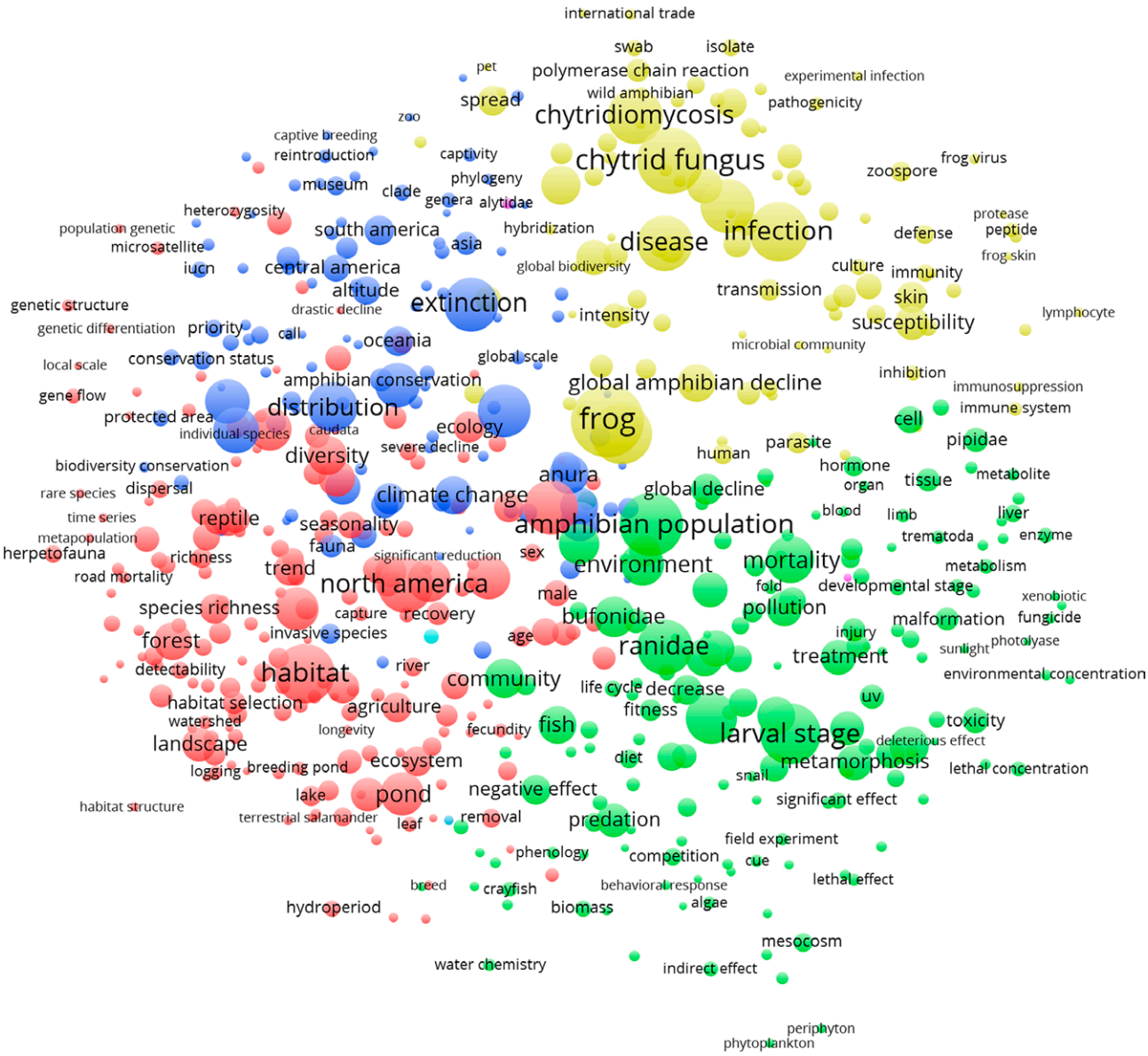

Fig. 3. Term map based on amphibian decline publications. Different colors represent the terms belonging to different clusters.

ly overlap and whose colors were arbitrarily chosen for visual purposes. The red cluster is characterized by terms related to ecology (e.g., "habitat", as well as various kind of habitats, habitat features and alterations, "population dynamics", "climate", "relationship"), but also "diversity" and "cause". Amphibian groups most typical of this cluster are Salamandridae, Ambystomatidae and "salamander" in general, whereas the geographic regions present are Europe and North America.

Green cluster is characterized by terms expressing altered environment ("agrochemical", "pollution", "stressor", …), and its "negative effect" on "amphibian population" ("mortality", "survival", "toxicity") as well as "physiology" and body organs ("muscle", "kidney", "liver", "malformation"), based on studies mostly on "larval stage" and "embryonic stage" and which take into account amphibian populations. Ranidae, Bufonidae and Hylidae characterize this cluster, which is not clearly geographically distinct.

The blue cluster is related to "extinction" and "risk" and "threat" to "amphibian species" and their "distribution", as well for "biodiversity", and what can be done to counteract them ("conservation", "conservation planning"). Important terms in this cluster are also "climate change" and "temperature". Apart from "Anura", no sys-

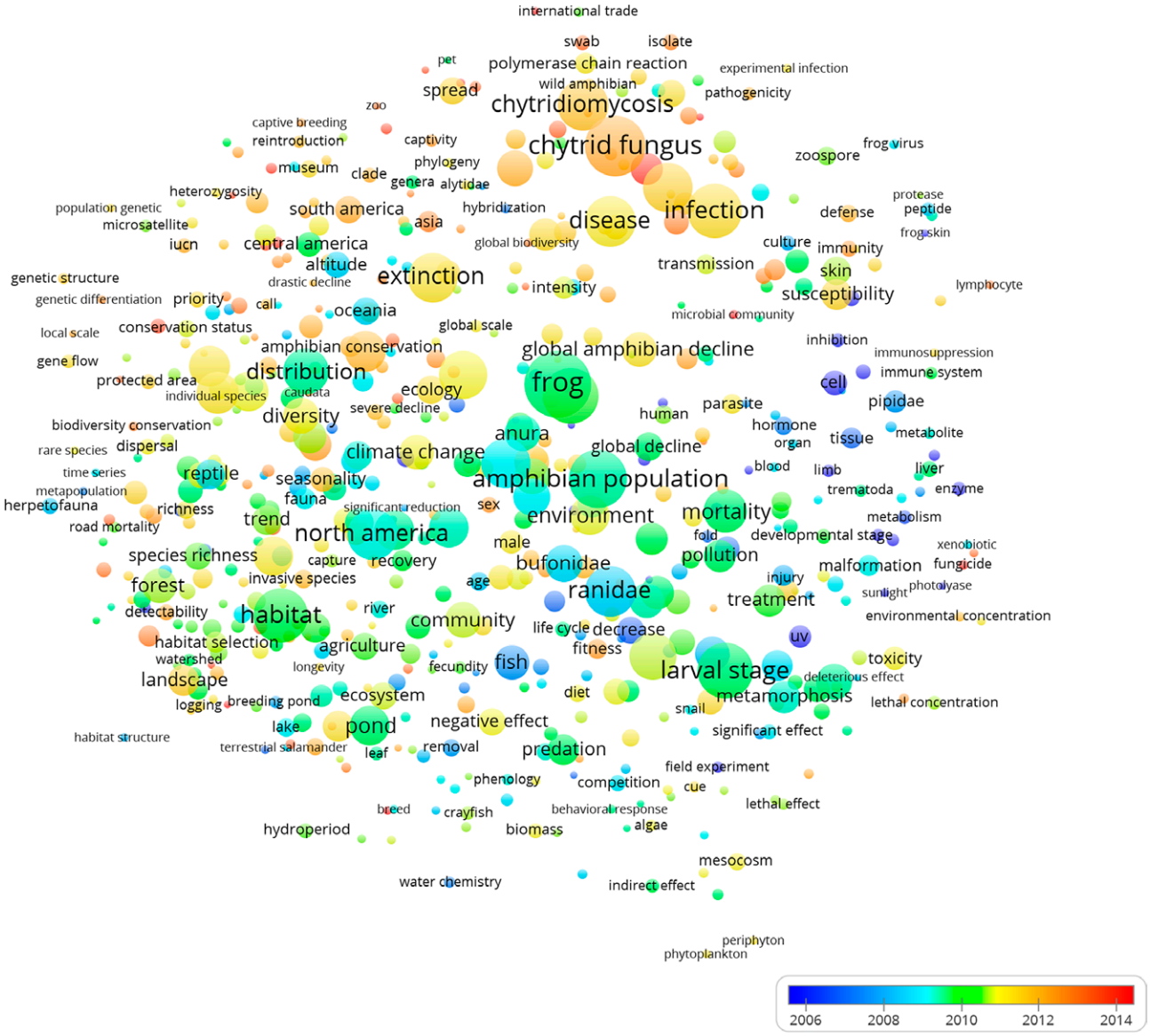

Fig. 4. Term year map based on amphibian decline publications. The scale represents the earlier (blue) or more recent (red) years when the term appeared.

tematic group is typical of this cluster. All continents (but Europe and North America, which are in the red cluster) are represented in this cluster.

The yellow cluster can be considered as the "disease" and "pathogen" cluster. Chytridiomycosis, and related terms (such as "Bd dynamics", "chytrid fungus", "zoospore") especially characterize this cluster. "Iridoviridae" and "virus" are present too. Techniques used for studying diseases are represented ("PCR", "culture", "swab", …), as well as body organs and structures targeted by diseases. "Population decline" and "global amphibian decline" are two important terms in this cluster. No families are represented in this cluster, but "frog" is the term with most weight in the analysis. No geographic area is represented in this cluster.

Figure 4 shows the *term year map* (the terms maintain the same position of the *term map*, Fig. 3). The colors show that terms used in early publications about amphibian declines (blue) are terms related to the proximate anatomical and physiological evidences of threats to amphibian ("cell", "tissue", "metabolism",…), Bufonidae and Ranidae were the most represented amphibians taxa, Oceania has been mostly studied in these early publication, as well as the occurring of "decrease", fishes

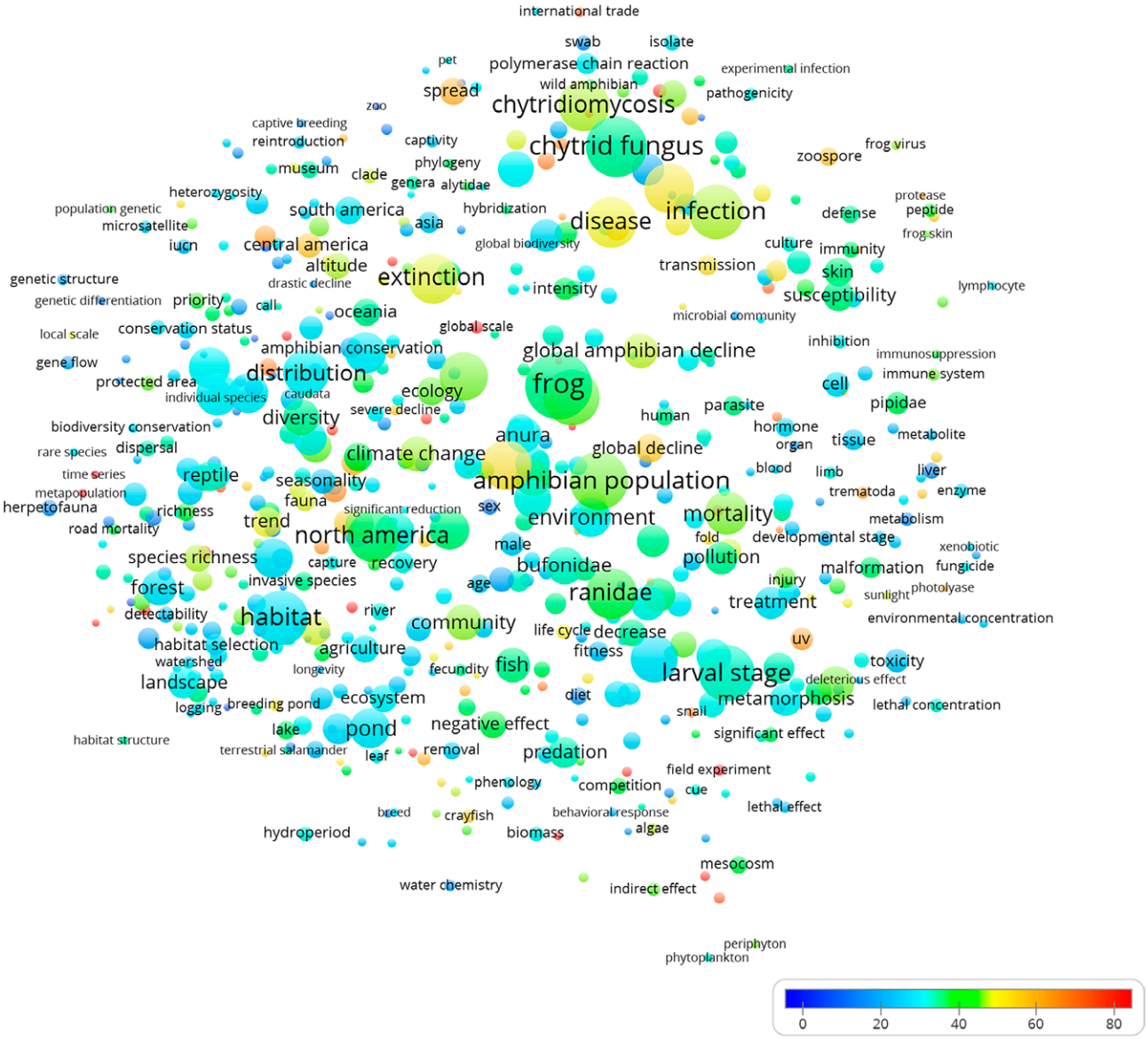

Fig. 5. Term average normalized citation map based on amphibian decline publications. The scale represents the average normalized citation rate, lower (blue) or higher (red).

and UV radiations decreased later. The terms covered in more recent publications (red) were mostly related to chytridiomycosis and diseases in general, but important terms are also "extinction", "amphibian conservation"; Asia and South America have been studied only recently. Terms covered in the middle (green) of the referred period (2010) are related to distribution, habitat, amphibian population, larval stage and frog.

The *term citation map* (Fig. 5) revealed as highly average age normalized cited terms (reddish colors) "international trade", "mass mortality" (in the yellow cluster in Fig. 3), "spatial pattern", "global scale", "alien species" (blue cluster), "rapid decline", "local population", "time series", "metapopulation" (red cluster), "ecological community", "field experiment" (green cluster). Although the "hot" term are rather scattered among the clusters, the red cluster in Fig. 3 appears to be the one with more terms having medium-low average normalized citation rate.

Geography of literature

Studies were carried out mainly in North America (40%), then in Europe (17%) and Oceania (12.6%) (Fig.

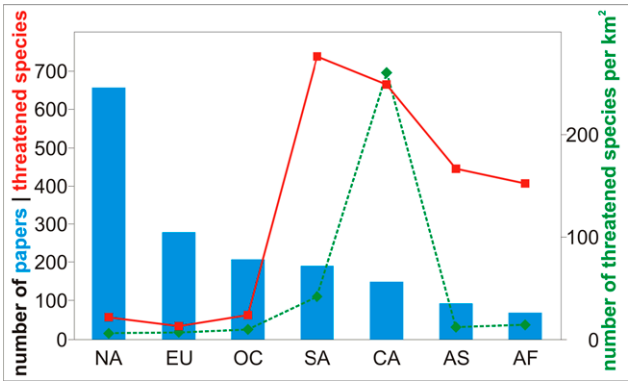

Fig. 6. Number of publication about amphibian decline (histogram) according to the continent were the studies have been carried out (NA: North America, EU: Europe, OC: Oceania, SA: South America, CA: Central America, AS: Asia, AF: Africa; analysis is based only on species with more than 10 occurrences), and the respective number (continuous red line) and richness (species per km^2, dotted green line) of threatened species (according to IUCN, 2019).

6). Figure 6 also shows that the number of studies is not commensurate with the number of IUCN threatened species (i.e., assessed as Critically Endangered, Endangered or Vulnerable) per continent (Spearman R = -0.61, P = 0.15), and even less with their continental richness (Spearman R = -0.71, P = 0.07). A consistent bias is evident when considering the species' ranges of species with more than 10 occurrences in amphibian declines literature (supplementary figure S1).

Amphibian declines research was published by authors working in 106 different countries, many of which based in EU (supplementary figure S2), with three main collaborative clusters (supplementary figure S3).

DISCUSSION

Our analyses outline how scientific papers on the subject of amphibian research have increased greatly in the past four decades. Further, our analyses highlight the important topics underpinning this increase, and the geographic and taxonomic trends within it. The first paper we found in the Scopus database which knowingly dealt with amphibian declines dates back to 1973 (Beebee, 1973; it was not included in the analyses), but papers per year were still few until the first half of '90. Then, the explicit interest in this topic increased: the studies increased to more than 50 per year in 2001 - it is worth highlighting that *B. dendrobatidis* was first discovered in 1998 (Berger et al., 1998) - and then doubled in 2007 and almost quadrupled in 2013, being produced at a consistent rate of approximately 200 per year since then. Notably, although the interest about amphibians steadily increased in the last 40 years, the contribution of amphibian decline studies to amphibian literature show a positive "allometric mean" (Fig. 1). The observed increase in papers on amphibians highlights the raised profile and interest in this global phenomenon, which is probably one of the most serious current biodiversity crises. It is also possible to consider that the observed amphibian declines of the past decades have been a driver for the general interest in amphibian research.

The vast majority of papers deal with Least Concern species (IUCN, 2019). This is even more surprisingly considering that LC species are about 50% of the amount of assessed species. On the other hand, this is not necessarily a negative sign, because the status of any species requires studies to be conducted, and the stages of species can change over time. Furthermore, information from most commonly abundant and widespread species are applicable also for the conservation of other species more difficult to be studied. It is also worth considering that many species that are listed as Least Concern on the Red List may have suffered serious localized declines, and even extinctions (such as the European midwife toad, *Alytes obstetricans*; Bosch et al., 2001; Rosa et al., 2013).

Geography seems to be a very important reason for Threatened species to be less studied then LC ones, as the areas which harbour a greater number of Threatened species were underrepresented in the literature: most publications were about North America, Europe and Australia, even if they harbour only 6.5% of the total amount of Threatened amphibian species (IUCN, 2019). Such bias, which has already been highlighted (see Ficetola, 2015, for a review), is rather consistent with the country of origin of researchers (Fig. S2), suggesting the relevance of economic influence on research. Wealthier countries will generally have most funds available for research, and the cost of conducting research outside of the funding country is more expensive and operationally difficult. The collaborative cluster mostly reflects geographic distance and historic relationships with those funding countries (Fig. S3). Interestingly, Asia and South America are getting more attention in recent years (Fig. 4), and Central America has high citation impact (Fig. 5), likely as a result of close relationships with the USA.

We identified four main research clusters in amphibian decline studies. One is mostly about ecology (red cluster, Fig. 3), with studies mostly based in North America and Europe and especially focused on the decline of newts and salamanders. It is an "evergreen" area of studies, but with some current topics of interest related to advance in ecology and methodology, such as landscape ecology, species distribution, CMR and occupancy stud-

ies (Fig. 4). A second area groups studies mostly about causes and consequences of pollution on amphibians, especially frogs and toads (green cluster). It is a rather "cold" area of interest, meaning that its topics have been less studied in recent years. A third area clusters studies on global threats to amphibians and extinction risk, and conservation of biodiversity. The topics this group clusters together are relatively new (e.g., the first systematic categorization of amphibian extinction risk was only conducted as recently as 2004), and are much more commonly investigated in current times than they were historically. However, the most current topics are grouped in the yellow cluster, representing the area of studies about pathogens, especially chytridiomycosis, and their role in amphibian declines.

In his review paper on the subject of amphibian declines, Storfer (2003) suggested four major areas of research in order to understand and facing decline, namely: well-grounded statistically monitoring techniques, metapopulation- and landscape-level researches, using molecular genetics, and using multi-factorial approaches in research. Actually, "detectability", a basic fact to be taken into account when monitoring decline, has few occurrences (47), as do "occupancy" (78) "capture-mark-recapture" (10), and "long-term monitoring" (52). Nevertheless, detection probability is increasingly taken into account, as we have seen just above. This is consistent with the finding of Ficetola (2015), who pinpoints that methods for taking into account detection probability have been developed relatively recently, and not immediately implemented in accessible softwares. However, those detection probability terms strongly characterize the red cluster, being far in the left corner of the graph (due to low occurrence, their labels are not visible in the figures). This means that almost exclusively ecological studies use robust methods for quantifying the scale of amphibian declines at a population level. "Landscape" as a term gets more attention (161), and even if it characterizes ecological studies, as well as less commonly occurring "land use" (69), "connectivity" (40) and "metapopulation" (15), it has connection with other research areas. Terms relative to molecular ecology have in general low occurrences; however, this term is present in ecological studies (red cluster, seven terms for an amount of 219 occurrences) and in studies about pathogens (yellow cluster, seven terms for an amount of 320 occurrences). Assessing whether multi-factorial approaches have been used is not feasible basing on our analyses.

The causes of amphibian declines are still under research, and complex interactions and local-scale factors make it difficult to identify precisely the drivers underpinning a given decline. However, there is a general agreement that climate change, land-use change and chytridiomycosis (as well as other parasites and pathogens) play a role (Hof et al., 2011). It has been debated whether chytridiomycosis (and climate change) has received more attention than other threats to amphibians, in particular habitat change (Gardner et al., 2007; Ohmer and Bishop, 2011), thus producing a research-bias. The term-map analysis shows that actually chytridiomycosis is a very important and ongoing topic of research, earning - *de facto* - its own cluster. Climate change received less research attention, but remains an important term, as well as "temperature", in the global-threat blue cluster; furthermore climatic variables may also be taken into account in ecological studies (red cluster). Terms linked to land use change, such as "habitat alteration" and "habitat loss", appear in ecological studies, although the lower occurring "deforestation" is considered a global threat for amphibians (blue cluster).

Amphibian decline has an ongoing increasingly scientific interest for researchers, so it is likely to be a driver for more general, fundamental amphibian research. Our analyses partly confirm previous findings based on different statistics and on literature surveys focused on specific topics, and partly identify additional information and research trends, identifying gaps in our knowledge too. We characterized four main areas of research: ecology, cause and consequence of pollution, global threat and conservation of biodiversity, and pathogens. The last one, mostly identifiable with studies on chytridiomycosis, appears as the most active area of research, in spite of direct threats to amphibians, such as altered environment and pollution, mostly acting at local scale, which got more attention in the past. Likely, the interest in localised threats has downsized because there is an increasing body of evidence that global changes are happening at unprecedented rates, and that they represent concrete threats for natural systems, including amphibians (IPBES, 2018). Nonetheless, detecting local threats is still important, because amphibian declines have not only multiple causes, but they also interact differently at different geographic scales (Campbel Grant et al., 2016). A second finding of our analyses is that species and population monitoring increasingly takes into account detectability, but that using such robust approaches is mostly limited to ecological studies. Instead, incorporating detectability into studies on, for example, infectious disease will furnish information on the actual occurrence of infection among populations, on real prevalence within populations, and a more reliable representation of both infected population and host-pathogen dynamics.

Our analyses confirm a geographical research bias which appears the main reason for Threatened species

being less studied than LC ones. Filling this gap requires specific attention, both because of the vulnerability of the species to be studied and the ecosystems they inhabit, and because they occur mainly in less well-developed countries, with less access to research funds. Increasingly, the disparity in funds available for western countries' researchers could cause a kind of colonialism in science (Hodgetts et al., 2019). Co-production of research (Nature, 2018), that is - in this case - the carrying out of researches jointly with local researchers and communities, from planning the study to publication and follow-up, could be a way to avoid this form of colonialism.

Lastly, despite the role the amphibian decline is playing in herpetological and biodiversity and conservation studies more in general, and despite the relative importance of "mainstream" topics as climate change and land-use change we found in these studies, it is noteworthy the very low frequency and importance in our survey of word as "government", "mitigation", "urbanization", "human health", "risk assessment", "culture", "(international) trade", "pet", and even the absence in our network of word such as "education" and "policy" (or related terms). This shows that the social and political impact of (studies devoted to) amphibian declines is still insufficient.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found at <http://www.unipv.it/webshi/appendix> manuscript number 8478.

REFERENCES

Alroy, J. (2015): Current extinction rates of reptiles and amphibians. PNAS **112:** 13003-13008. www.pnas.org/cgi/doi/10.1073/pnas.1508681112

Beebee, T.J.C. (1973): Observations concerning the decline of the British amphibia. Biol. Conserv. **5:** 20-24.

Berger, L., Speare, R., Daszak, P., Green, D.E., Cunningham, A.A., Goggin, C.L., Slocombe, R., Ragan, M.A., Hyatt, A.D., McDonald, K.R., Hines, H.B., Lips, K.R., Marantelli, G., Parkes, H. (1998): Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. PNAS **95:** 9031-9036

Bosch, J., Martínez-Solano, I., García-París, M. (2001): Evidence of a chytrid fungus infection involved in the decline of the common midwife toad (*Alytes obstetricans*) in protected areas of central Spain. Biol. Conserv. **97:** 331-337.

Campbell Grant, E.H., Miller, D.A.W., Schmidt, B.R., Adams, M.J., Amburgey, S.M., Chambert, T., Cruickshank, S.S., Fisher, R.N., Green, D.M., Hossack, B.R., Johnson, P.T.J., Joseph, M.B., Rittenhouse, T.A.G., Ryan, M.E., Waddle, J.H., Walls, S.C., Bailey, L.L., Fellers, G.M., Gorman, T.A., Ray, A.M., Pilliod, D.S., Price, S.J., Saenz, D., Sadinski, W., Muths, E. (2016): Quantitative evidence for the effects of multiple drivers on continental-scale amphibian declines. Sci. Rep. **6:** 25625.

Campos, F.S., Brito, D., Solé, M. (2014): Diversity patterns, research trends and mismatches of the investigative efforts to amphibian conservation in Brazil. An. Acad. Bras. Cienc. **86:** 1873-1886.

Ceballos, G., Ehlich, P.R., Dirzo, R. (2017): Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. PNAS **114:** 6089-6096.

Costa, C., Schurr, U., Loreto, F., Menesatti, P., Carpentier, S. (2019): Plant phenotyping research trends, a science mapping approach. Front. Plant Sci. **9:** 1933.

Ficetola, G.F. (2015): Habitat conservation research for amphibians: methodological improvements and thematic shifts. Biodivers. Conserv. **24:** 1293-1310.

Gardner, T., Barlow, J., Peres, C. (2007): Paradox, presumption and pitfalls in conservation biology: The importance of habitat change for amphibians and reptiles. Biol. Conserv. **138:** 166-179.

Hodgetts, T., Burnham, D., Dickman, A., Macdonald, E.A., Macdonald, D.W. (2019): Conservation geopolitics. Conserv. Biol. **33:** 250-259.

Houlahan, J.E., Findlay, C.S., Schmidt, B.R., Meyer, A.H., Kuzmin, S.L. (2000): Quantitative evidence for global amphibian population declines. Nature **404:** 752-758.

IPBES (2018): IPBES Assessment Guide Summary. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 12 pages.

IUCN (2019): The IUCN Red List of Threatened Species. Version 2018-2. http://www.iucnredlist.org . Accessed 20 April 2020.

Mormul, R.P., Mormul, T.D.S., Santos, G.M.B., Santana, A.R.A. (2017): Looking for attitudes related to amphibian species decline: how are peer-reviewed publications of education activities compared to ecological research? An. Acad. Bras. Cienc. **89:** 491-496.

Nardi, P., Di Matteo, G., Palahi, M., Scarascia Mugnozza, G. (2016): Structure and evolution of Mediterranean forest research: A science mapping approach. PLoS ONE **11:** e0155016.

Nature (Editorial) (2018): The best research is produced when re-searchers and communities work together. Nature **562**: 7.

Ohmer, M. E, Bishop, P. J. (2011): Citation rate and perceived subject bias in the Amphibian-Decline literature. Conserv. Biol. **25:** 195-199.

Rosa, G.M., Anza, I., Moreira, P.L., Conde, J., Martins, F., Fisher, M.C., Bosch, J. (2013): Evidence of chytrid-mediated population declines in common midwife toad in Serra da Estrela, Portugal. Anim. Conserv. **16:** 306-315.

van Eck N.J., Waltman, L. (2010): Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics **84:** 523-538.

van Eck N.J., Waltman, L. (2011): Text mining and visualization using VOSviewer. arXiv preprint arXiv:1109.2058. https://arxiv.org/abs/1109.2058 . Accessed 20 April 2020.

van Eck, N.J., Waltman, L., van Raan, A.F.J., Klautz, R.J. M., Peul, W.C. (2013): Citation analysis may severely underestimate the impact of clinical research as compared to basic research. PLoS ONE **8:** e62395.

van Raan, A.F.J. (2004): Measuring science. Capita selecta of current main issues. In: Handbook of Quantitative Science and Technology Research, pp. 19-50. Moed, H.F., Glänzel, W., Schmoch, U., Eds, Kluwer Academic Publishers, Dordrecht.

van Raan, A.F.J. (2014): Advances in bibliometric analysis: research performance assessment and science mapping. In: Bibliometrics. Use and Abuse in the Review of Research Performance, pp. 17-28. Blockmans, W.,Engwall, L., Weaire, D., Eds, (Wenner-Gren International Series) Portland Press, London.

Waltman, L., van Eck, N.J. (2013): A smart local moving algorithm for large-scale modularity-based community detection. Eur. Phys. J. B **86***:* 471.

Waltman, L., van Eck, N.J., Noyons, E.C.M. (2010): A unified approach to mapping and clustering of bibliometric networks. J. Informetr. **4:** 629-635.