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Essays and Perspectives

Conservation biology: four decades of problem- and solution-based research

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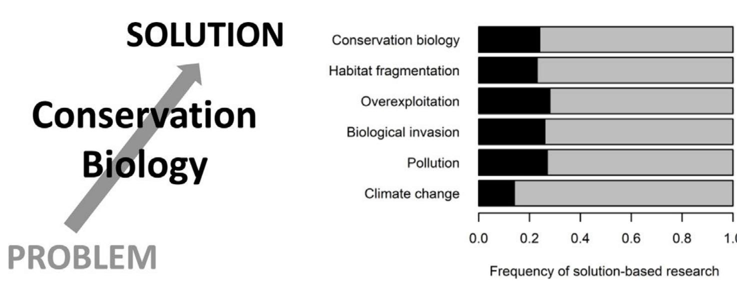
HIGHLIGHTS

- Conservation biology literature is dominated by problem-based research.
- Solution-based papers are becoming more common along the last four decades.
- Solution-to-problem word ratio suggests greater concern with conservation action.
- Higher emphasis on solution-based research can advance biodiversity conservation.

GRAPHICAL ABSTRACT



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ABSTRACT

Conservation biology is designed to identify pressing environmental problems and to solve them. This review evaluates the relative effort of conservation biology in problem-based and solution-based research, and tests whether or not this has changed in the past decades for five major drivers of biodiversity loss, i.e. habitat loss and fragmentation, overexploitation, biological invasion, pollution, and climate change. By randomly sampling papers from four decades of the conservation literature (1980–2019), we estimated the frequency of solution-based research related to the five biodiversity loss drivers. We also estimated how the ratio of the words 'problem' and 'solution' has changed over time, as a proxy for discourse bias. We found that a quarter of the scientific papers on conservation constitute solution-based research, while three-quarters were classified as problem-based. Temporal analyses showed that the proportion of solution-based papers increased along the four decades, from 0.18 to 0.30, mostly due to research on effects of habitat loss and fragmentation, and overexploitation. The solution-to-problem word ratio increased steadily, from almost zero in the 1980s to 0.60 in 2019. Significant increases occurred

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for all drivers of biodiversity loss, indicating an important temporal change in conservation discourse and concerns. We propose that, in order to be more effective against the biodiversity crisis, conservation science should expand the solution-based agenda by active changes in graduate education, research choice, research funding priority, editorial emphasis, and media coverage that can produce desired impacts on conservation practice, public perception, and environmental policies.

Introduction

Conservation biology has contributed to the understanding of the main problems causing the global biodiversity crisis and has provided tools to solve them. The basis and accomplishments of this broad research area has been repeatedly reviewed (Soule, 1985; Kareiva and Marvier, 2012; Soule, 2013; Doak et al., 2014; Mace, 2015). Recently, it has been argued that more drastic transformative changes will be necessary to halt the biodiversity crisis and to insure human well-being (Díaz et al., 2019). Although it is now clear that limited progress will be made without deep technological, economic and social changes, the expanding breadth and depth of the crises add extra pressure on conservation biology, making its future priorities to be questioned once more. In fact, there is a growing feeling that conservation biology needs a more positive agenda to improve its influence towards conservation practitioners, decision makers, and the general public (Beever, 2000; Redford and Sanjayan, 2003; Balmford, 2017; Balmford and Knowlton, 2017; Milner-Gulland, 2019, Williams et al., 2020). Here, we argue that conservation biology should enhance its solution-based research agenda.

The conservation biology literature can be clearly classified in one of two main lines of research: problem-based or solution-based studies (Table 1). Roughly speaking, problem-based studies aim to understand the main anthropogenic drivers associated with biodiversity loss and decline. In contrast, solution-based studies are directly designed to propose, evaluate, and implement solutions to environmental problems. This classification raises an important question: how much of the information provided by conservation science is dedicated to solution- or problem-based research? Also, since conservation biology has become a complex field, studying several biodiversity loss drivers, such as habitat loss and fragmentation, biological invasion, overexploitation, pollution, and climate change, it is necessary to understand how the relative effort in solution- vs problem-based research differs among drivers. Furthermore, since the field of conservation biology has matured in the past decades, it is also important to understand how the field is changing through time.

In this paper, we review four decades (1980–2019) of the scientific literature to investigate how much effort conservation biology devoted to solution- vs. problem-based research. This issue was approached for five major drivers of biodiversity loss: habitat loss and fragmentation, biological invasion, overexploitation, pollution, and climate change. First, we performed an in-depth investigation of a random sample of the most cited articles – possibly the most influential ones – to define the frequency and temporal trend of problem- and solution-based research in conservation biology. Then, a simple discourse analysis was carried out by estimating the relative use of the words 'problem' and 'solution' in the articles associated with these five major drivers. We expected to find that the conservation biology literature is dominated by problem-based studies, but that an increasing trend towards solution-based research should be detected for all drivers of biodiversity loss as society demands increase. Also, we expected the word solution to be more prominent over time, reflecting the conservation biology concerns. We conclude that conservation biology should create mechanisms to stimulate a shift in the balance of its scientific contribution, from problem-based narratives to evidence-based tests of the biological, social, and economic processes leading to solutions for environmental problems.

The problem-based conservation agenda

Problem-based research is widespread in the conservation biology literature. Problem-based research on habitat loss and fragmentation focuses on characterizing how different features of altered landscapes, such as habitat amount, fragment size and isolation, edge effects, matrix permeability, and landscape-scale processes affect biodiversity (Wang et al., 2014; Fahrig et al., 2019). Typically, it considers the effects of habitat loss and fragmentation on species occurrence, abundance, biomass, diversity or ecological processes, such as carbon storage, pollination, species dispersal, and other biotic interactions (Aizen and Feinsinger, 1994; Haddad et al., 2015; Fahrig, 2017). Problem-based research on overexploitation covers the direct exploitation of natural renewable resources and persecution of animals (e.g. Cinner and McClanahan, 2006; Robertson and Chilvers, 2011). Overhunting, overfishing, by-catch, and overexploitation of plant resources are important research areas (Pauly et al., 1998; Tasker et al., 2000). Many studies focus on resource depletion, extinction of exploited species, cascading effects, and deterioration of human health and economy. Problem-based biological invasion research focuses on the characterization of the negative effects of alien species on native populations, communities, and ecosystems (Sax et al., 2005). This research covers local lists of invasive species, competitive performance, and impact on mutualistic networks. Furthermore, beyond descriptions of present spatial distribution patterns, ecological niche modelling is used to predict the geographic spread of alien species (Peterson, 2003; Petitpierre et al., 2012). Problem-based pollution research typically analyses the release of organic or inorganic substances into the environment and their detrimental effect on biological organisms, including humans. It also investigates the effect of pollutants on biological communities and ecosystems through their direct toxic effects on organisms, species interactions, and processes (Diaz and Rosenberg, 2008). A major line of problem-based research on pollution is the analysis of direct toxicity of a pollutant for a target organism, often in a laboratory experiment, to determine for instance the LD50. Problem-based climate change research uses predicted temporal changes on global and regional temperature, rainfall, CO_2, and methane concentrations to model changes on individual performance, population spatial distribution and phenology, community structure, or ecosystem functioning, and services (Walther et al., 2002). Experimental studies on the subject have been developed in small-scale field experiments, greenhouses, and microcosms (Jentsch et al., 2007).

The solution-based conservation agenda

Solution-based conservation research also addresses all major biodiversity loss drivers. Solution-based papers on habitat loss and fragmentation are concerned with the consequences of different management actions and policies for mitigating or reversing the

Table 1
Illustrative examples of problem- or solution-based conservation research addressing five biodiversity loss drivers.

Biodiversity loss driver	Problem-based	Solution-based
Habitat loss	Estimate rates of habitat loss Evaluate alternative landscape metrics Describe population declines Record species extinction	Plan sustainable landscapes Establish corridors for connectivity Test agroforestry models Restore ecosystems
Biological invasion	Estimate invasive potential Evaluate susceptibility to invasion Predict areas to be invaded Evaluate impact on communities and ecosystems	Establish prevention agreements Control invasive populations Increment community resilience Mitigate effects
Overexploitation	Describe population decline Evaluate by-catch Estimate cascading effects Predict extinction risk	Implement population management Establish social agreements Test market economic tools De-extinction
Pollution	Describe pollutant concentration Evaluate effect on physiology Evaluate community alteration Describe bio-magnification	Test phytoremediation measures Promote pollutant stabilization Promote pollutant extraction Stimulate degradation or volatilization
Climate change	Predict climate alterations Predict changes in species distribution Describe population decline Predict alterations in ecosystem services	Evaluate effects of agreements Establish migration corridors Promote carbon capture Establish adaptation measures

fragmentation problem (e.g. Andersson and Bodin, 2009; Blom et al., 2010; McEvoy, 2012). These studies encompass a wide range of themes, including agricultural de-intensification, agroecology, forest transition analyses, rural afforestation of forest ecosystems, changes in forestry resource management, REDD + performance, and managing for connectivity, e.g. testing the effectiveness of corridors or stepping stones. Some solution-based papers are theoretical or propose new methods, but many evaluates the success or effectiveness of potential solutions quantitatively, demonstrating clearly which actions work, providing guidance on when and how the actions can be applied to stop or to reverse the negative effects of habitat loss and fragmentation. Also, systematic conservation planning has been effectively used to prevent biodiversity loss (Fonseca and Venticinque, 2018; Margules and Pressey, 2000; Sarkar and Illoldi-Rangel, 2010). Finally, the entire field of restoration ecology is solution-based (Jordan et al., 1987; Young, 2000). The starting point of any restoration project are degraded ecosystems and altered landscapes, and its aim is invariably to reach a more desirable state in terms of structure, diversity, composition, ecosystem functioning, or services (Jordan et al., 1987; Young, 2000).

Overexploitation has a long history on solution-based research as hunting and fishing pre-dated the origin of modern humans as resource-based activities, being practiced for subsistence, commerce, leisure, ritual or religion, protection of herds and people, and damage control. Overexploitation lead to a strong research tradition to guide management worldwide (Lawler et al., 2006). Multiple techniques and market-based conservation tools were developed to counteract overexploitation (Botsford et al., 1997; Sinclair et al., 2006; Manfredo, 2008). The main solution themes include the analysis of habitat management, predator control, restocking, establishment of no-take areas, quotas, protection of vulnerable development stages, and the development of models to estimate stocks in order to regulate harvests, effort and trade (e.g. Kennelly and Broadhurst, 2002; Linnell et al., 2010). Solution-based research also includes management scenarios (e.g. Tomillo et al., 2008), community-based management (Campos-Silva and Peres, 2016), market tools to promote conservation, such as the Payment for Environmental Services (PES) and ecolabelling (Begossi et al., 2011). Besides, some studies focused on education and politics to change targets and on the development of alternatives to the production of desired benefits. Other studies tackle the question of how to improve communication and collaboration between scientists and stakeholders in order to put solutions into practice (Cvitanovic et al., 2015).

Solution-based research on biological invasion uses the invasion sequence from introduction to landscape spread as a backbone for suggesting and testing management strategies (Hulme, 2006). This includes, for instance, systematic strategies to reduce the dispersal of potentially invasive species by transport, trade, and travel, measures to avoid naturalization once the species are introduced, eradication tools on islands or other well-defined areas, and mitigation of their impact on native populations, communities, and ecosystems. Applied research includes screening of transported materials, quarantine, biological, mechanical or chemical control, and modifications in land use. Solution-based research on biological invasion also investigates the engagement of relevant stakeholders and long-term political commitment. In addition, since biological invasions are often a transboundary problem, solution-based research considers international coordination and integration of measures for preventing, controlling and mitigating the effects of exotic species (Fonseca et al., 2009).

Pollution studies classified as solution-based research includes phytoremediation which uses plants and their associated microbes for environmental clean-up through pollutant stabilization, extraction, degradation, or volatilization (Pilon-Smits, 2005). Some studies show how different methods of pollution removal affect the rate of community recovery from the disturbed to the undisturbed state. Studies on the restoration or conservation of the riparian vegetation also have demonstrated its impact on water quality (Brancalion et al., 2016). It should be noticed, however, that solutions to environmental pollution problems involve technological development (e.g. air filters that reduce emissions into the air or water) and legislative procedures (e.g. limit the use of nitrogen fertilizer in agriculture).

Finally, solution-based papers on climate change are directed towards mechanisms minimizing the effect of climate change and how to adapt to it. Due to the spatial scale of the problem, many solution-based papers are conceptual, theoretical, and political in nature. Also, research is dedicated to evaluating the effect of halting carbon emission via deforestation or capturing carbon via restoration on climate change and biodiversity loss (Domke et al., 2020). Adaptive strategies include the dynamic nature of the natural world in landscape planning and conservation actions (Heller and Zavaleta, 2009). Solution-based research not only focuses on the establishment of networks of corridors for species dispersal in order to maximize their long-term survival (Heller and Zavaleta, 2009), but also highlights the key role of the anthropocentric matrix for biodiversity conservation (Fonseca et al., 2009; Ferreira et al., 2012; Kareiva and Marvier, 2012).

Methods

Classification of papers as solution-based and problem-based research

We performed a literature search within the Scopus database (http://www.scopus.com), covering four decades (1980–2019), to determine the relative number of papers in the biodiversity literature dealing with (1) solution- or (2) problem-based research. For all searches, the general biodiversity research area was defined by set of keywords *(species OR biodiv* OR diversity)*. From this large dataset, five biodiversity loss drivers were selected for investigation, using the following specific keywords: habitat loss and fragmentation ("habitat loss" OR "habitat fragmentation" OR deforestation OR "forest frag*"), biological invasions ("biological invasion" OR "invasive species"), overexploitation (overexploitation OR over-exploitation OR over-harvesting OR "over harvesting" OR overfishing OR overhunting OR hunting OR "by catch" OR persecution OR poaching), pollution (pollution), and climate change ("climate change"). The search for keywords was conducted in the title, the abstract, as well as in the keywords listed, for both articles and reviews. It should be noticed that we did not include studies of the grey literature, for instance, of conservation practitioners and environmental NGOs. This review, therefore, analyses the information provided by conservation scientists to peer-reviewed journals.

For each of the five drivers and each year of publication from 1980 to 2019, the 100 most cited papers were identified, from which three papers were randomly selected to be analyzed, potentially totalling 600 selected articles (40 years × 5 drivers × 3 papers). When fewer than 100 papers were returned by a query for a given year, the randomization was performed among the reduced number. Early in the time period queries returned only three or fewer papers in which case all of them were analyzed. When no paper was retrieved, the respective year was excluded from the analysis. Reviews, opinion papers and those published in meeting proceedings, as well as papers that upon closer examination did not explicitly deal with conservation issues or the specific studied driver were excluded from the sample and a new paper was randomly selected.

Each selected paper was classified by a group of two or three experienced researchers into solution- or problem-based research based on the abstract or the full text, when necessary. The criteria for identifying these categories were standardized within and among reviewing teams. Solution-based papers were those with solutions to biodiversity loss actively investigated, despite mentioning problems in the introduction and/or discussion. Problem-based articles described patterns, processes and/or mechanisms of biodiversity loss, but did not advance on solutions beyond general principles (Heller and Zavaleta, 2009). Articles with similar emphasis on problems and solutions were conservatively classified as solution-based.

We used chi-square, applied to a cross table, to test the independence between research type (i.e. solution- or problem-based research) and biodiversity loss driver (i.e. habitat loss and fragmentation, biological invasion, overexploitation, pollution, and climate change). Furthermore, logistic regressions (binomial errors) were used to test if the probability of solution-based papers ('solution probability') changed over the 40 years, with solution-based papers coded as '1' and problem-based papers as '0'. This analysis was performed for the pooled data-set and for each driver separately.

The use of the words 'solution' and 'problem'

We performed a simple quantitative discourse analysis technique to examine the relative use of the words 'solution' (SL) and 'problem' (PB) in the conservation literature and its temporal trend along the last four decades (1980–2019). We counted the number of papers using these words in the title, abstract or keywords for all papers retrieved every year by the searches described above. As caveats of this simple approach, notice that many papers used neither the word problem nor solution in their text while some used both. Additionally, due to the fact that in the chemistry literature the word solution is widely used with another meaning (e.g. saline solution), we avoided performing this analysis for the driver pollution. Despite these limitations, the meaning of solution and problem are expected to have remained unchanged over time, and any detected temporal trend is expected to reflect discourse changes. To test if the relative use of solution or problem was independent of the biodiversity loss driver, chi-square tests were used.

In order to test if the relative use of solution or problem increased or not over time in the conservation biology literature, we performed regressions with the ratio between the number of papers containing the word "solution" in relation to the number containing the word "problem" in a given year (henceforth, solution-to-problem ratio or SL:PB ratio) as the dependent variable and year (z-transformed) as the independent variable. In order to test for non-linear temporal patterns, in addition to linear regression models ($Y = bx + a$), we used exponential regression models ($Y = ae^{bx}$). Since the number of papers retrieved every year varied widely (from 1 to 602), in addition to ordinary least square regressions, we used weighted regressions where the contribution of each point for minimizing the residual sum of squares is proportional to a given weight, which was assumed to be 1/sqrt(SL + PB). Also, since time series can suffer from temporal autocorrelation, we add models aiming to correct for such possible bias. At the end, eight alternative models were compared by the Akaike criteria (Supplementary Material, Tables S1–S5, Figs. S1–S10). Model selection identified the weighted exponential regression model (wexp) as the best model (ΔAICc = 0) for the conservation biology literature (all drivers) as well as for each biodiversity loss driver. The weighted exponential regression model with temporal autocorrelation correction (wexp.tac) was also selected as an accepted model for biological invasion (ΔAICc = 1.61) and climate change (ΔAICc = 0.85). Temporal autocorrelation function plots of the best models indicated the virtual absence of temporal autocorrelation of the residuals. Also, homoscedasticity and normality of the residuals were visually inspected. All models are presented in the supplementary material, but for simplicity, only the best models are provided in the main text. Analyses were performed using the packages nmle and MuMin in R (R Core Team, 2014).

Results

Solution- or problem-based research: a quantitative assessment

Only a quarter of the 561 randomly selected conservation papers were classified as solution-based (24%, $S = 134$, $P = 427$, Fig. 1). The frequency of solution-based papers was similar for overexploitation (28%, $S = 34$, $P = 86$), pollution (27%, $S = 32$, $P = 88$), biological invasion (26%, $S = 26$, $P = 76$), and habitat loss and fragmentation (23%, $S = 28$, $P = 92$), but slightly lower for climate change (14%,

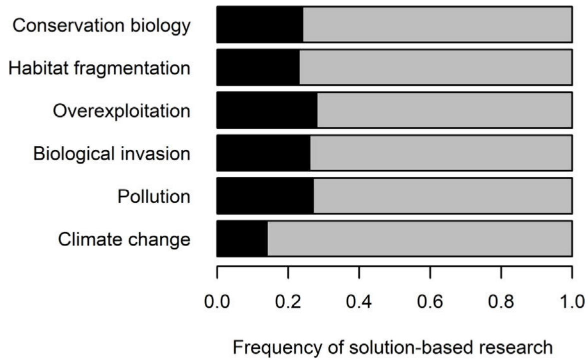

Fig. 1. Frequency of solution-based research (black bars) in the conservation biology literature produced over four decades (1980–2019). For each year and biodiversity loss driver, three articles among the 100 most cited articles of this year were classified as either problem-based or solution-based research (see text for more details). Frequencies were estimated for five major biodiversity loss drivers separately and for all drivers together (conservation biology). The frequency of problem-based research is shown in the grey bars ($N = 561$ papers).

Table 2
Temporal trend on the probability of solution-based papers along four decades of the conservation biology literature and its biodiversity loss drivers. The slopes (β) and their standard error (SE), effect size (z), and associated probability (P) were produced by logistic regression assuming solution-based papers as 1 and problem-based papers as 0.

Research field	β	SE	z	p
Conservation biology	0.0179	0.0091	1.98	0.048
Drivers				
Overexploitation	0.0374	0.0183	2.04	0.041
Habitat loss and fragmentation	0.0356	0.0195	1.83	0.068
Biological invasion	0.0318	0.0233	1.36	0.173
Pollution	−0.0112	0.0180	0.63	0.532
Climate change	0.0069	0.0301	0.23	0.820

$S = 14$, $P = 85$), although the differences among biodiversity loss drivers were not significant (Chi-square = 7.15, $df = 4$, $P = 0.128$).

Logistic regression indicated that the probability of solution-based papers in the conservation literature increased significantly over the four decades ($\beta = 0.0179 \pm 0.0091$ [SE], $z = 1.98$, $P = 0.048$, Fig. 2a). The estimated probability for a paper to be solution-oriented increased from 0.18 in 1980 to 0.30 in 2019. For individual drivers, the increase was significant for overexploitation, (Fig. 2c), marginally significant for habitat loss and fragmentation (Fig. 2b), but non-significant for biological invasion (Fig. 2d), pollution (Fig. 2e), and climate change (Fig. 2f, Table 2).

The relative use of solution and problem

Between 1980 and 2019, 1978 articles employed the word solution and 5267 problem (total 7245 articles), generating an overall solution-to-problem ratio of 0.38, or, equivalently, a 2.7 times bias in favour of problem. The solution-to-problem ratio was higher for the literature associated to climate change (SL:PB ratio = 0.45, $S = 887$, $P = 1969$) in relation to fragmentation (SL:PB ratio = 0.33, $S = 364$, $P = 1095$), biological invasion (SL:PB ratio = 0.32, $S = 564$, $P = 1777$), and overexploitation (SL:PB ratio = 0.34, $S = 332$, $P = 982$); these ratios varied significantly among drivers (Contingent table; Chi-square = 39.0, $df = 3$, $p < 0.001$).

Along the four decades, the solution-to-problem word ratio increased exponentially in the conservation biology literature, from around 0.07 at the beginning of the 1980s to almost 0.6 in 2019 ($a = 0.198 \pm 0.014$, $t = 14.1$, $p < 0.0001$, $b = 0.639 \pm 0.056$, $t = 11.4$, $p < 0.0001$, Fig. 3a). The exponential increase in the solution-to-problem ratio also occurred in the literature associated to habitat loss and fragmentation ($a = 0.221 \pm 0.027$, $t = 8.270$, $p < 0.0001$, $b = 0.545 \pm 0.103$, $t = 5.289$, $p < 0.0001$, Fig. 3b), overexploitation ($a = 0.203 \pm 0.029$, $t = 7.092$, $p < 0.0001$, $b = 0.655 \pm 0.113$, $t = 5.779$, $p < 0.0001$, Fig. 3c), biological invasion ($a = 0.216 \pm 0.025$, $t = 8.608$, $p < 0.0001$, $b = 0.410 \pm 0.101$, $t = 4.081$, $p < 0.0003$, Fig. 3d), and climate change ($a = 0.227 \pm 0.021$, $t = 10.626$, $p < 0.0001$, $b = 0.674 \pm 0.074$, $t = 9.164$, $p < 0.0001$, Fig. 3e). For further details about alternative models, see Supplementary Material (Tables S1–S5, Figs. S1–S10).

Discussion

In the past four decades, conservation biology has spent only a quarter of its scientific effort in solution-based research. However, evidence suggests that the frequency of solution studies has increased from 1980 to 2019, particularly in the field of overexploitation but also habitat loss and fragmentation. Furthermore, the exponential increase over time in the relative use of the word 'solution' in relation to 'problem' in the conservation literature suggests that desirable changes in the concerns and discourse of conservation biologists are already in place. This exponential temporal change in the conservation discourse occurred in the literature on all tested drivers. For biological invasion and climate change, however, the recorded increase in the solution-to-problem word ratio was not reflected by an increase in the proportion of studies doing solution-based research, which is a noticeable detachment between the discourse and the research focus. We posit that in order to push further the effectiveness of biodiversity conservation, an explicit effort should be made to shift the balance of conservation biology towards solution-based research.

The maturation of conservation biology

During most of human history, individuals would make use of local resources but be unaware of the regional or global consequences of the sum of their individual acts over many generations. This helps to explain, for instance, the extinction of the megafauna during the quaternary period in many different continents and the current threat of many ecosystems (Sandom et al., 2014). Since the 1960s, however, the spatial scale of our actions became clearer. The best-seller *Silent Spring*, by Rachel Carson (1962), showed that the use of pesticides had drastic and far-reaching consequences for ecosystem functioning and human health. In the same year, the nuclear arms race that led to the Cuban missile crisis let evident that humankind had the power to overturn the whole planet. Incipient environmental movements started to get organized against nuclear power and the impact of man on other species populations, such as whales. In 1969, with the first photo of Earth from the moon, the general public got aware that our planet and its resources are finite. It was in this social context that conservation biology established itself as a new research field.

From the 1970s, conservation biology started to characterize the biodiversity crisis and described the main biodiversity threats (Wilson, 1988). The importance of habitat loss and fragmentation, overexploitation, pollution, and biological invasion was recognized and made public to the society and decision-makers. As a late arrival, climate change was quickly incorporated into the citizens' vocabulary (Lee et al., 2015). From the 1990s, the society started to demand proposals designed to halt the biodiversity decline. For instance, the Rio-92 Convention on Biological Diversity (CDB) and the Kyoto Protocol successfully brought together important international players to establish goals and commitments to face the biodiversity crisis. This shift in perspective occurred in parallel with changes on the role and centrality of people and nature in conservation biology (Mace, 2015).

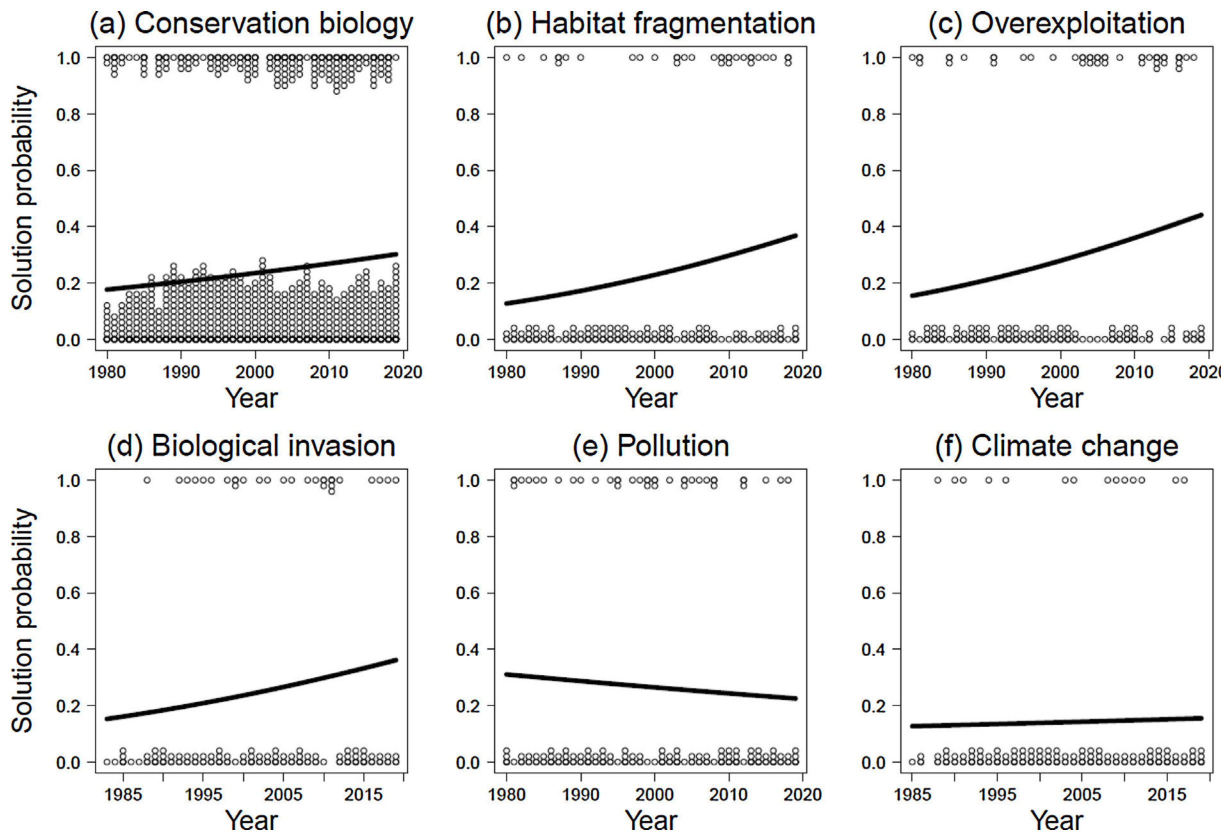

Fig. 2. Logistic regression analyses showing the probability of solution-based papers in the conservation biology literature over the past four decades (1980–2019). The solution probability is shown for (a) conservation biology – all drivers pooled together, (b) habitat fragmentation, (c) overexploitation, (d) biological invasions, (e) pollution, and (f) climate change. Logistic regressions were significant for a–d (see text). Selection of papers as for Fig. 1. Dots represent the presence of solution-based (1) and problem-based (0) papers in a given year. The lines represent the fit of the logistic models. In total, 561 papers were scored.

The high frequency of solution-based papers on overexploitation can be explained by the growing demand on population and resource management in industries associated to fisheries and forest products (Botsford et al., 1997). The increased frequency of solution-based research in the habitat loss and fragmentation literature is related to recent social and political demands for land-use planning. In many countries, the location of new protected areas is now decided based on systematic conservation planning (Margules and Pressey, 2000). In Brazil, for instance, systematic conservation planning guided the creation of dozens of large protected areas to safeguard the Amazon Forest (Jenkins and Joppa, 2009), which successfully lead to a decrease in deforestation rates (Nepstad et al., 2014). Besides, ecological-economic zoning (EEZ) now takes into consideration many aspects of landscape configuration and provision of ecosystem services, accommodating for some human use.

The unaltered high proportion of problem-based research on pollution during the past four decades can be attributed to the continuous emergence of new pollutants, their growing harshness, the advent of new analytical techniques, and changes in the world region where the problems are investigated. For instance, in addition to research focused on inorganic pollutants, heavy metals, and toxic compounds, such as insecticides or petrochemicals, recent research pays increasing intention to new threats such as nano-particles (Colman et al., 2013), including nanoplastic, or cyclic volatile methyl siloxanes (cVMS) that are present in personal care products (Wang et al., 2013). Furthermore, the emergence of new techniques fuelled traditional problem-based research in pollution. For instance, a typical study from the 1980s would compare the species composition (e.g. zooplankton) between polluted and unpolluted ecosystems. Recently, massively parallel pyrosequencing is used to answer the same type of question (Hong et al., 2010). Finally, while most problem-based research was initially carried out in the western world, this predominance is currently changing geographically. For example, in the 1980s, few papers on pollution originated in China, while China is now contributing a substantial number of publications on the subject.

Prevention is by far the most cost-effective way to avoid the environmental problems associated to climate change, as stated by the United Nations Framework Convention on Climate Change – UNFCCC (United Nations, 2015). Only socio-political measures ceasing the emission of CO_2 and other harmful greenhouse gases have the power to avoid drastic ecosystem changes and mass extinction. Thus, it is not surprising that studies on climate change effects on biodiversity show a strong dominance of problem-based papers. Indeed, those papers have contributed substantially to increase the awareness over the consequences of climate change (Bellard et al., 2012). Despite many studies on the role of biodiversity for mitigation and adaptation are part of the solution-based approach, there is no evidence that such studies are becoming more frequent over time. The increased relative use of the word solution in the associated literature contrast strongly with the observed research approach pattern. In fact, a review of biodiversity management recommendations regarding climate change found that there is a strong tendency for description of general principles in detriment of practical, specific strategies (Heller and Zavaleta, 2009). In order to ensure the resilience of socio-ecological systems in face of climate change, ecosystem-based adaptation research and actions should be further stimulated (Scarano, 2017).

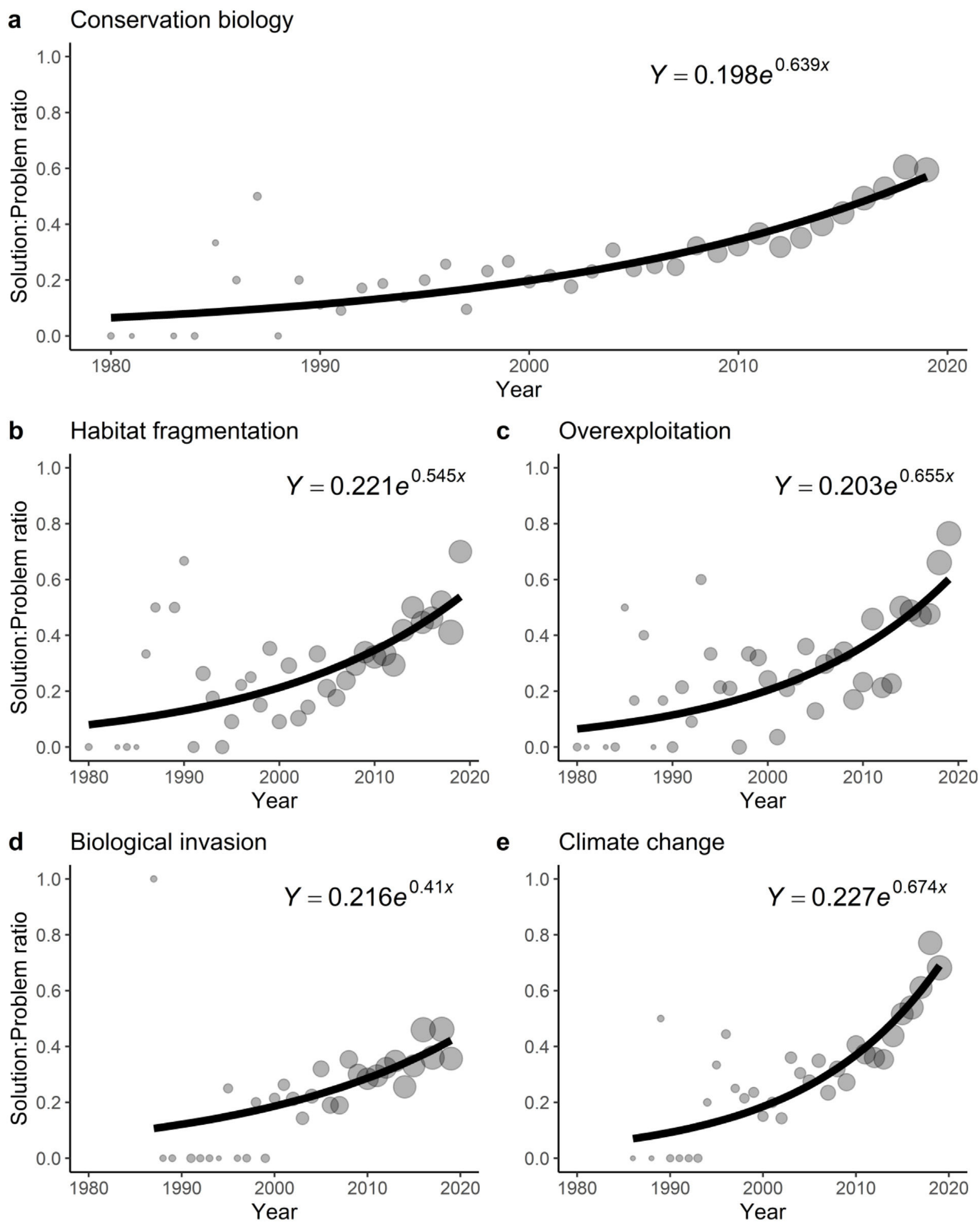

Fig. 3. Relative use of the word *solution* and *problem* in the conservation biology literature and its drivers along the past decades (1980–2019, $N = 7245$ articles). (a) conservation biology – all drivers pooled together, (b) habitat fragmentation, (c) overexploitation, (d) biological invasions, (e) climate change. Notice that pollution was not included in this analysis due to the different meaning of the word in chemistry. The curves represent weighted exponential regressions ($Y = ae^{bx}$). Dot size is proportional to the number of articles retrieved in that year.

Promoting solution-based research

We posit that in order to be more effective, conservation biology should enhance its solution-based research agenda. The promotion of solution-based conservation research should permeate the entire chain associated to the production, diffusion, and application of knowledge on biodiversity conservation. In order to produce a relevant shift from problem- to solution-based research, undergraduate and graduate programmes could increase their emphasis on how ecological theory, methods, and tools can be applied to the solutions of environmental problems (Lewinsohn et al., 2015). In many cases, new undergrad and graduate courses could be explicitly designed for this purpose. Conservation scientists should be aware of the solution-to-problem research bias and carefully consider the benefits of including solution-based research in their agenda when selecting their future research questions (Sutherland et al., 2009). Also, solution-based researches should be more connected to specific demands provided by environmental NGOs, conservation practitioners, and local communities (Cvitanovic et al., 2015). Research on biodiversity and ecosystem functioning (e.g. Weisser et al., 2017), as well as approaches working with ecosystem services (or nature's contributions to people, Pascual et al., 2017), may provide a powerful basis for this, as they emphasize the important role of biodiversity for human societies. The translation of ecosystem services into monetary values can be an additional argument to achieve support outside the field of biodiversity conservation (e.g. Costanza et al., 2014; Metzger et al., 2019).

An example in this sense are the nature-based solutions (NBS), defined as "solutions inspired and supported by nature, designed to address societal challenges which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience" (Eggermont et al., 2015; Raymond et al., 2017). This concept, which emerged around 2016, has been gaining force from publications of the *International Union for Conservation of Nature* (IUCN), and more recently has received substantial research funding from the European Union under the Horizon 2020 programme. Because they are solutions that seek to promote ecosystem services (provisioning, regulating or cultural, MEA, 2005), they depend less on built infrastructure, thus being less costly and more efficient, generating multiple benefits, both for human well-being and biodiversity (Cohen-Shacham et al., 2019). Among the NBS, ecosystem-based adaptation to climate change stands out (Scarano, 2017).

In order to speed up this shift to solution-based research agenda, national research funding agencies could actively open calls for solution-based research (as is the case with Horizon, 2020). Also, conservation journals could explicitly open special sections and issues, and alter their editorial directions to embrace solution-based research (e.g. Solutions Journal at http://www.thesolutionsjournal.com/, Milner-Gulland, 2019). Furthermore, governments could make sure that when highly-impact enterprises are financially supported, resources are also diverted to solution-stimulating activities.

The solution-based conservation agenda should be also concerned on how to promote commitment to environmental causes (Knowlton, 2017). It is interesting to highlight the emerging field of conservation psychology to promote environmental experiences and actions (Saunders and Myers, 2003) and to direct science communication to reach a wider audience, regardless of personal ideological positions (Myers et al., 2015). The recent growth of citizen-science programmes can also contribute to the public involvement in conservation action (Haywood et al., 2016). The solution-based conservation agenda could feed the fields of environmental sociology, ecological economics, and environmental politics in order to change the society's organization and values (Hannigan, 1995; Johns, 2007; Mace, 2015).

Solution-based conservation provides the scientific basis for the 'conservation optimism' and the 'Earth optimism' movements (Beever, 2000; Redford and Sanjayan, 2003; Balmford, 2017; Bennet et al., 2017; Balmford and Knowlton, 2017; Knowlton, 2017; Milner-Gulland, 2019). Along the last decades, citizens have been overloaded with reports on environmental problems. Both traditional and digital media announced that the human population would explode, primary forests would soon disappear, species would go extinct, and the seas would rise and flood coastal cities. Conservation biologists had much less success in spreading the solutions they developed. Science communicators should make a greater effort to spread the good news achieved by conservation biology (such as www.conservationevidence.com). By doing so, conservation biologists would find more effective allies and resources to their final cause.

Pushing forward solution-based research in no way denies the great significance of problem-based research. Clearly, one needs to understand a problem in order to solve it. But the opposite is also true. By testing different solutions one can reach a better understanding of the problem. Therefore, the question is how much effort should be invested in each approach. Solution-based research seems to deserve more than a quarter of the overall research effort, but how much more? – While a 50/50 partition seems natural, and a higher proportion can be desired, proposed advances should respect differences among research areas. For some well-known drivers, like habitat loss and fragmentation, and overexploitation, a greater effort into solution-based research seems already possible. In contrast, climate change is a relatively new subject and problem-based research is still highly valuable (even more when part of the society still denies the very existence of the problem). Similarly, for some species, ecosystems, or regions the problems have already been properly described, thus there is a greater potential for solution-based research. We envisage that when conservation biology reaches its full maturity solution-based research will become more widespread.

Finally, it should be noticed that the root of the biodiversity crisis lays on the globalized human consumption economy, deep asymmetries in the distribution of opportunities, wealth and income, as well as a questionable anthropocentric ethos. Thus, conservation biology as a scientific discipline has a key but limited role to play on the unfolding of the biodiversity crisis. This raises the question whether natural resource professionals should most constructively contribute to policy development by conducting rigorous research that is policy relevant and by effectively conveying the results and policy implications of that research to all, or whether scientists should firmly embrace politics and advocacy (Hannigan, 1995; Redford and Sanjayan, 2003; Johns, 2007; Scott et al., 2008).

Concluding remarks

In the year 2020, the COVID-19 crisis unequivocally demonstrated that humans depend on the fabric of life. A single virus was able to disrupt the world economy, deepen social inequalities, and alter the behaviour of the global population (Corbera et al., 2020). Despite the relevance of this event, however, the crisis ahead is much deeper. The capacity of nature to contribute to the good quality of our life is declining quickly for 14 of the 18 categories evaluated by the recent *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services Global Assessment* (Díaz et al., 2019). The seriousness of such threats requires ambitious goals and immediate evidence-based conservation actions (Díaz et al., 2020).

Conservation biology is a relatively young research area that has already played a key role to promote environmental awareness and advance evidence-based solutions to environmental problems. A few decades ago, we were unaware of deleterious effects of pollution, global wildlife population declines, habitat conversion rates, insidious effects of alien species, and the ability we have to impose changes to the Earth's climate. This awareness has already produced many changes in the society, altering individual behaviours (e.g. feeding habits, recycling), society organization (environmental NGOs), land use (conservation areas), management regimes (sustainable practices), national and international politics (green parties, environmental treaties), and economy (alternative energy sources). The solution-based conservation agenda sustains that, in the next decades, biodiversity conservation can gain strength if solution-based research receives a higher priority. We envisage that solution-based research can provide new ideas and tools able to change society further in order to halt de biodiversity crisis while promoting human well-being.

Conflicts of interest

None declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.pecon.2021.03.003.

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