Better integration of chemical pollution research will further our understanding of biodiversity loss

In the format provided by the authors and unedited

Supplementary Information file 1

Better integration of chemical pollution research will further our understanding of biodiversity loss

Francisco Sylvester[1,2,3], Fabian G. Weichert[1], Verónica L. Lozano[2,3], Ksenia J. Groh[4], Miklós Bálint[5,6,7], Lisa Baumann[8], Claus Bässler[1,9], Werner Brack[1,10], Barbara Brandl[11], Joachim Curtius[12], Paul Dierkes[1], Petra Döll[5,13], Ingo Ebersberger[1,5,6], Sotirios Fragkostefanakis[1], Eric J. N. Helfrich[1,6], Thomas Hickler[5,14], Sarah Johann[1], Jonas Jourdan[1], Sven Klimpel[1,5,6,29], Helge Kminek[15], Florencia Liquin[2], Darrel Möllendorf[16], Thomas Müller[1,5], Jörg Oehlmann[1], Richard Ottermanns[17], Steffen U. Pauls[6,18,7], Meike Piepenbring[1], Jakob Pfefferle[1], Gerrit Jasper Schenk[19], J.F. Scheepens[1], Martin Scheringer[20,21], Sabrina Schiwy[1], Antje Schlottmann[22], Flurina Schneider[1,23,5], Lisa M. Schulte[1], Maria Schulze-Sylvester[24,25,2], Ernst Stelzer[1,26], Frederic Strobl[1,26], Andrea Sundermann[1,18], Klement Tockner[1,18,], Tobias Tröger[27,28], Andreas Vilcinskas[7,29,6], Carolin Völker[1,23], Ricarda Winkelmann[30,31], Henner Hollert[1,6,32,*]

*Corresponding author (hollert@bio.uni-frankfurt.de)

[1]Faculty of Biological Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany.
[2]Facultad de Ciencias Naturales, Universidad Nacional de Salta, Salta, Argentina.
[3]Consejo Nacional de Investigaciones Científicas y Técnicas, CCT CONICET Salta-Jujuy, Salta, Argentina.
[4]Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland.
[5]Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt am Main, Germany.
[6]LOEWE Centre for Translational Biodiversity Genomics (LOEWE-TBG), Frankfurt am Main, Germany.
[7]Institute of Insect Biotechnology, Justus-Liebig-University Gießen, Gießen, Germany.
[8]Amsterdam Institute for Life and Environment (A-LIFE), Section Environmental Health & Toxicology, Vrije Universiteit Amsterdam, The Netherlands.
[9]Bavarian Forest National Park, Grafenau, Germany.
[10]Helmholtz Centre for Environmental Research, Leipzig, Germany.
[11]Faculty of Social Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany.
[12]Institute for Atmospheric and Environmental Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany.
[13]Institute of Physical Geography, Goethe University Frankfurt, Frankfurt am Main, Germany.
[14]Department of Physical Geography, Goethe University Frankfurt, Frankfurt am Main, Germany.
[15]Faculty of Educational Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany.
[16]Faculty of Social Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany.
[17]Institute for Environmental Research (IER), RWTH Aachen University, Aachen, Germany.
[18]Senckenberg Society for Nature Research, Frankfurt am Main, Germany.
[19]Institute of History, History of the Middle Ages, Technical University of Darmstadt, Darmstadt, Germany.
[20]Institute of Biogeochemistry and Pollutant Dynamics, ETH Zürich, Zürich, Switzerland.
[21]RECETOX, Masaryk University, Brno, Czech Republic.

[22]Department of Human Geography, Goethe University Frankfurt, Frankfurt am Main, Germany.

[23]Institute for Social-Ecological Research (ISOE), Frankfurt am Main, Germany.

[24]Geisenheim University, Department of Crop Protection, Geisenheim, Germany.

[25]Instituto de Bio y Geociencias del Noroeste Argentino (IBIGEO-CONICET), Salta, Argentina.

[26]Buchmann Institute for Molecular Life Sciences (BMLS), Goethe University Frankfurt, Frankfurt am Main, Germany.

[27]Department of Law, Goethe University Frankfurt, Frankfurt am Main, Germany.

[28]Leibniz Institute for Financial Research Sustainable Architecture for Finance in Europe, Frankfurt am Main, Germany.

[29]Branch Bioresources, Fraunhofer Institute for Molecular Biology and Applied Ecology, Gießen, Germany.

[30]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany.

[31]Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany.

[32]Department Environmental Media-related Ecotoxicology, Fraunhofer Institute for Molecular Biology and Applied Ecology, Schmallenberg & Frankfurt am Main, Germany.

Methods
Literature searches
On 20 July 2022, we searched the Scopus database to retrieve scientific articles on chemical pollution (abbreviated "chem" in Extended Data Tables and Source Data Fig. 1), climate change ("cc"), habitat degradation and loss caused by changes in land and water use ("land"), and invasion by non-indigenous species ("nis") published between 1990 and 2021. These stressors have been identified as major drivers of global ecosystem change leading to biodiversity loss ("bio") by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[1]. We also conducted similar searches for biodiversity loss. To identify articles on each topic, we used a selection of commonly used terms and Boolean modifiers to include variations of the terms. To minimize the number of irrelevant results, we avoided relatively uncommon synonyms and terms that did not substantially increase the number of papers retrieved. Specifically, we used: 1) For chemical pollution: "chemical contamin*", "chemical pollut*", "pharmaceutic* contamin*", "pharmaceutic* pollut*", "pesticid*", "herbicid*", "insecticid*", "fungicid*", "novel entit*", and "microplastic*"; 2) For climate change: "climate chang*" and "global warming"; 3) For habitat loss: "habitat* loss*", "habitat degradat*", "habitat* fragment*", "land use chang*", "land-use chang*", "deforest*", "landscape chang*", "landscape degradat*"; 4) For invasive species: "inva* species", "non-indigenous species", "non-native species", "alien species", "introduc* species", "colonizing species", "exotic species"; and 5) For biodiversity loss: "global biodiversity", "landscape biodiversity", "biodiversity loss", "biodiversity decline", "species loss", "species decline", "species extinct*", "animal* extinct*", "plant* extinct*". To avoid an avalanche of loosely connected or directly irrelevant results, we restricted our search of the above terms to the publications' titles and keywords. To exclude studies that were unrelated to ecology and ecosystems, we further required that the terms "ecolog*" or "ecosystem*" were included in the title, keywords, or abstract.

We restricted our search to the Scopus subject areas of Environmental Science, Agricultural and Biological Sciences, and Earth and Planetary Sciences. Since many important findings in biological sciences are published in Multidisciplinary journals, we also included this subject area. We limited the search to recent years because publication databases become increasingly spotty in old periods. We set 1990 as the bottom year for our study period because publications on most topics were scarce before this year, marked by the first IPCC report (1990)[2] and the 1992 Rio Earth Summit (https://www.un.org/en/conferences/environment/rio1992). We used 2021 as our upper search period limit as this is the last year with complete records available at the time when the searches were conducted. We searched only scientific articles since coverage of other types of publications is variable. The journals "Shengtai Xuebao" and "Acta Ecologica Sinica" were the same, so the results for the two were merged. For "Sustainability Switzerland" we used the name "Sustainability", following the current usage on the journal's website.

The exact search strings used were:

Chemical pollution
(TITLE ((chemical AND contamin*) OR (chemical AND pollut*) OR (pharmaceutic* AND contamin*) OR (pharmaceutic* AND pollut*) OR pesticid* OR herbicid* OR insecticid* OR fungicid* OR (novel AND entit*) OR microplastic*)

OR KEY ((chemical AND contamin*) OR (chemical AND pollut*) OR (pharmaceutic* AND contamin*) OR (pharmaceutic* AND pollut*) OR pesticid* OR herbicid* OR insecticid* OR fungicid* OR (novel AND entit*) OR microplastic*)) AND TITLE-ABS-KEY (ecolog* OR ecosystem*) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990))

Climate change
(TITLE ((climate AND chang*) OR (global AND warming)) OR KEY ((climate AND chang*) OR (global AND warming))) AND TITLE-ABS-KEY (ecolog* OR ecosystem*) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990))

Habitat loss
(TITLE ((habitat* AND loss*) OR (habitat AND degradat*) OR (habitat* AND fragment*) OR (land AND use AND chang*) OR (land-use AND chang*) OR (deforest*) OR (landscape AND chang*) OR (landscape AND degradat*)) OR KEY ((habitat* AND loss*) OR (habitat AND degradat*) OR (habitat* AND fragment*) OR (land AND use AND chang*) OR (land-use AND chang*) OR (deforest*) OR (landscape AND chang*) OR (landscape AND degradat*))) AND TITLE-ABS-KEY (ecolog* OR ecosystem*) AND (LIMIT-TO (DOCTYPE , "ar")) AND (

LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990))

Invasive species
(TITLE ((inva* AND species) OR (non-indigenous AND species) OR (non-native AND species) OR (alien AND species) OR (introduc* AND species) OR (colonizing AND species) OR (exotic AND species)) OR KEY ((inva* AND species) OR (non-indigenous AND species) OR (non-native AND species) OR (alien AND species) OR (introduc* AND species) OR (colonizing AND species) OR (exotic AND species))) AND TITLE-ABS-KEY (ecolog* OR ecosystem*) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990))

Biodiversity loss
(TITLE ((global AND biodiversity) OR (landscape AND biodiversity) OR (biodiversity AND loss) OR (biodiversity AND decline) OR (species AND loss) OR (species AND decline) OR (species AND extinct*) OR (animal* AND extinct*) OR (plant* AND extinct*)) OR KEY ((global AND biodiversity) OR (landscape AND biodiversity) OR (biodiversity AND loss) OR (biodiversity AND decline) OR (species AND loss) OR (species AND decline) OR (species AND extinct*) OR (animal* AND extinct*) OR (plant* AND extinct*))) AND TITLE-ABS-KEY (

ecolog* OR ecosystem*) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1993) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990))

To assess the accuracy of our searches, we randomly reviewed 100 results for each search to ensure that the retrieved articles were relevant to the targeted topic (Extended Data Table 1). We accomplished this by inspecting the titles and abstracts of the papers, and where necessary, by downloading and reviewing the entire paper.

For each search, we recorded the number of papers published per year and per journal (see results in Extended Data Tables 2, 3). Scopus provided information on the first 158 journals that published more papers on the topic. Some journals published papers on two or more topics, thus we ended with a list of 367 identified journals for all five topics. To identify the journals that were most relevant for each topic, we established a cut-off limit at 50% of the papers on each topic. We ranked the journals in order of the number of papers published and retained the most productive journals in each topic accounting for 50% of the papers during the analysed period (journals in yellow rows in Extended Data Table 3). In this way, we ended up with a total of 119 journals where research on the analysed topics has been predominantly published during the study period (Source Data Fig. 1). For each topic, we recorded the number of journals, the proportion of these journals that were ecology journals (i.e., journals belonging to the Scopus sub-subject areas of ecology, evolution, behaviour and systematics, or multidisciplinary), and the proportion of journals that published papers on biodiversity loss and on other drivers. This information was summarized in Fig. 1. Artworks in this figure were created with BioRender (www.biorender.com).

Potential caveats
The results of our automatised bulk search of papers unavoidably contained mishits and omissions, but an inspection of 100 random papers per topic showed a reasonably low proportion of mishits. On average, 90% of the papers were found to be pertinent to the targeted topic (see Extended Data Table 1). Although some duplications were detected, they represented extremely low percentages of the total papers. Due to the size of the datasets and the aims of the study, we did not attempt to remove the duplicated papers. Our study aimed to identify general research and publication trends, not to conduct a meta-analysis or review every single paper on a given topic.

Another potential limitation of our study is the use of Scopus categories to classify journals into disciplines. While these categories can have a degree of subjectivity, they are generally adequate for general purposes. Scopus assigns more than one category to each journal in most cases, which reduces the likelihood that a relevant category for a given journal was overlooked.

We could not find a satisfactory search string for "direct exploitation of organisms", a driver of global biodiversity loss identified by IPBES[1]. Therefore, this driver was excluded from our analyses.

1.   IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services: Summary for Policymakers*. *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* vol. 45 (IPBES secretariat, 2019).
2.   IPCC. *Climate change: The IPCC Scientific Assessment*. (Cambridge University Press, 1990).