Electronic Supplementary Material

Title: Towards a Unified Study of Multiple Stressors: Divisions and Common Goals Across Research Disciplines

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SM1: Web of Science Search

A search was conducted on the 30th of June 2019 on the *ISI Web of Knowledge* database (https://apps.webofknowledge.com) to collect publications from the multiple-stressor literature using the following search terms:

Title = ("multiple stress*" OR "stressors" OR "global change factors" OR “environmental factors” OR “global change drivers” OR “multiple drivers” OR "synerg*" OR “amplify*” OR "antagon*" OR “dampen*” OR "additive" OR “interactive effects” OR “multifactor” OR "nitrogen and phosphorus limitation" OR "multiple limiting resources" OR "nutrient co-limitation" OR "global change experiments")

AND

Topic = ("multiple stress*" OR "stressors" OR "global change factors" OR “global change drivers” OR “multifactor” OR "cumulative effect*" OR “net effect*” OR “combined effect*” OR “interacting” OR " nitrogen and phosphorus limitation " OR "multiple limiting resources" OR "nutrient co-limitation" OR “global change experiments”)

AND

Web of Science Category = ("Ecology" OR "Toxicology" OR "Environmental Sciences" OR "Plant Sciences" OR "Zoology" OR "Marine Freshwater Biology" OR “Limnology” OR “Oceanography” OR “Multidisciplinary Sciences”)

AND

Year Published = (1999-2019)

The search returned 2,268 results, which were extracted as full record .txt files.

SM2: Bibliometric Analysis Methods

Bibliometric analysis was conducted using *VOSviewer* version 1.6.11 (1). *VOSviewer* is a piece of software used for visualization and analysis of networks, primarily constructed using bibliometric data.

(i) Citation Network

In order to allow for readability of the networks, out of the 2268 results, only the top 300 publications based on the number of citations were used to construct initial citation networks. Due to a bias towards marine and freshwater publications in this initial citation network, the 25 next most highly cited terrestrial and ecotoxicological publications were added to the network so that all disciplines were similar in number. The largest connected network (150 publications) from this pool of 350 publications was selected so that irrelevant papers (i.e. publications that were not from the multiple stressor literature) were ignored. Citation networks of the 150 connected publications were constructed with the following settings in *VOSviewer*:

- *Bibliometric analysis = Citation Analysis*
- *Unit of analysis = Documents*
- *Counting methods = Full counting*
- *Minimum cluster size = 15 (Total number of publications divided by 10)*

Although these 150 publications are the most "influential" or cited publications in the multiple stressor literature and there is a roughly equal representation of publications from each of the four disciplines, to ensure that our networks were not biased we create four more networks comprised of the top 500, 1000, 1500 and 2000 publications based on the number of publications. The same settings were used as above except the minimum cluster size was modified so that there was always the same number of clusters in each network to allow for comparisons to be made.

(ii) Term Network

Using the same 150 papers that comprised the citation networks in Figure 1, term networks were constructed, again using *VOSviewer.* Terms were extracted from the title and abstract fields. Structured abstract labels and copyright statements were ignored. Terms that occurred at least 10 times were included, resulting in a network comprised of 161 terms. The following settings were used in *VOSviewer*:

- *Counting methods = Full counting*
- *Normalization = Association Strength*
- *Maximum number of links = 2500 (to enhance visibility)*

(iii) 150 publications used for citation and term networks, ordered by total citations

Name in Network	Discipline	Links	Citations (WoS)	Cluster	Document Title
elser (2007)	general	11	1683	1	Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems
brook (2008)	general	4	817	1	Synergies among extinction drivers under global change
crain (2008)	marine	31	773	5	Interactive and cumulative effects of multiple human stressors in marine systems
bopp (2013)	marine	3	455	3	Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models
strayer (2010)	fresh	1	437	2	Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future
didham (2007)	general	4	436	1	Interactive effects of habitat modification and species invasion on native species decline
folt (1999)	general	28	392	5	Synergism and antagonism among multiple stressors
hughes (1999)	marine	7	377	4	Multiple stressors on coral reefs: A long-term perspective
darling (2008)	general	26	352	5	Quantifying the evidence for ecological synergies
vinebrooke (2004)	general	24	342	1	Impacts of multiple stressors on biodiversity and ecosystem functioning: the role of species co-tolerance
harpole (2011)	general	8	337	1	Nutrient co-limitation of primary producer communities
holmstrup (2010)	ecotox	18	329	4	Interactions between effects of environmental chemicals and natural stressors: A review
heugens (2001)	ecotox	6	310	4	A review of the effects of multiple stressors on aquatic organisms and analysis of uncertainty factors for use in risk assessment
klein (2004)	terr	1	246	3	Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau
ormerod (2010)	fresh	16	245	2	Multiple stressors in freshwater ecosystems
statzner (2010)	fresh	8	204	2	Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems?
sokolova (2008)	ecotox	6	187	3	Interactive effects of metal pollution and temperature on metabolism in aquatic ectotherms: implications of global climate change
leuzinger (2011)	terr	5	185	1	Do global change experiments overestimate impacts on terrestrial ecosystems?
strayer (2008)	fresh	2	183	2	Freshwater Mussel Ecology: A Multifactor Approach to Distribution and Abundance
dieleman (2012)	terr	6	180	1	Simple additive effects are rare: a quantitative review of plant biomass and soil process responses to combined manipulations of CO_2 and temperature
luo (2008)	terr	7	180	1	Modeled interactive effects of precipitation, temperature, and [CO_2] on ecosystem carbon and water dynamics in different climatic zones

zavaleta (2003)	terr	4	179	3	Additive effects of simulated climate changes, elevated CO_2, and nitrogen deposition on grassland diversity
paerl (2006)	marine	1	177	6	Assessing and managing nutrient-enhanced eutrophication in estuarine and coastal waters: Interactive effects of human and climatic perturbations
tockner (2010)	fresh	8	173	6	Multiple stressors in coupled river-floodplain ecosystems
ollinger (2002)	terr	1	167	1	Interactive effects of nitrogen deposition, tropospheric ozone, elevated CO_2 and land use history on the carbon dynamics of northern hardwood forests
russell (2009)	marine	3	163	5	Synergistic effects of climate change and local stressors: CO_2 and nutrient-driven change in subtidal rocky habitats
townsend (2008)	fresh	14	162	6	Individual and combined responses of stream ecosystems to multiple stressors
harvey (2013)	marine	8	158	5	Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming
allan (2013)	fresh	2	156	5	Joint analysis of stressors and ecosystem services to enhance restoration effectiveness
sokolova (2013)	ecotox	8	153	3	Energy-Limited Tolerance to Stress as a Conceptual Framework to Integrate the Effects of Multiple Stressors
coors (2008)	ecotox	10	147	4	Synergistic, antagonistic and additive effects of multiple stressors: predation threat, parasitism and pesticide exposure in *Daphnia magna*
jackson (2016)	fresh	15	147	2	Net effects of multiple stressors in freshwater ecosystems: a meta-analysis
matthaei (2010)	fresh	8	147	6	Multiple stressors in agricultural streams: interactions among sediment addition, nutrient enrichment and water abstraction
davidson (2004)	terr	1	141	1	Nitrogen and phosphorus limitation of biomass growth in a tropical secondary forest
christensen (2006)	fresh	16	138	3	Multiple anthropogenic stressors cause ecological surprises in boreal lakes
carilli (2009)	marine	4	134	2	Local Stressors Reduce Coral Resilience to Bleaching
hecky (2010)	fresh	2	134	2	Multiple stressors cause rapid ecosystem change in Lake Victoria
ban (2014)	marine	19	133	2	Evidence for multiple stressor interactions and effects on coral reefs
boone (2003)	general	3	128	5	Interactions of an insecticide, herbicide, and natural stressors in amphibian community mesocosms
thurber (2008)	marine	2	127	2	Metagenomic analysis indicates that stressors induce production of herpes-like viruses in the coral *Porites compressa*
sih (2004)	general	3	123	3	Two stressors are far deadlier than one
ferreira (2011)	fresh	2	121	5	Synergistic effects of water temperature and dissolved nutrients on litter decomposition and associated fungi
gunderson (2016)	marine	15	121	3	Multiple Stressors in a Changing World: The Need for an Improved Perspective on Physiological Responses to the Dynamic Marine Environment

piggott (2015)	general	15	121	2	Reconceptualizing synergism and antagonism among multiple stressors
moe (2013)	ecotox	3	118	4	Combined and interactive effects of global climate change and toxicants on populations and communities
adams (2005)	marine	5	117	6	Assessing cause and effect of multiple stressors on marine systems
przeslawski (2015)	marine	12	117	5	A review and meta-analysis of the effects of multiple abiotic stressors on marine embryos and larvae
tian (2011)	terr	2	116	1	China's terrestrial carbon balance: Contributions from multiple global change factors
boone (2007)	general	3	115	5	Multiple stressors in amphibian communities: Effects of chemical contamination, bullfrogs, and fish
hooper (2013)	ecotox	3	109	4	Interactions between chemical and climate stressors: A role for mechanistic toxicology in assessing climate change risks
mikkelsen (2008)	terr	4	104	1	Experimental design of multifactor climate change experiments with elevated CO_2, warming and drought: the CLIMAITE project
hering (2015)	fresh	3	103	2	Managing aquatic ecosystems and water resources under multiple stress - An introduction to the MARS project
cote (2016)	general	16	101	1	Interactions among ecosystem stressors and their importance in conservation
boyd (2015)	marine	5	100	3	Biological ramifications of climate-change-mediated oceanic multi-stressors
lenihan (1999)	marine	3	96	6	The influence of multiple environmental stressors on susceptibility to parasites: An experimental determination with oysters
wagenhoff (2011)	fresh	9	96	6	Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers
aufauvre (2012)	ecotox	1	94	4	Parasite-insecticide interactions: a case study of *Nosema ceranae* and fipronil synergy on honeybee
porter (1999)	marine	4	94	2	The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test
darling (2013)	marine	3	91	1	Life histories predict coral community disassembly under multiple stressors
kawai (2007)	marine	2	91	5	Testing the facilitation-competition paradigm under the stress-gradient hypothesis: decoupling multiple stress factors
abell (2010)	fresh	1	89	1	Nitrogen and Phosphorus Limitation of Phytoplankton Growth in New Zealand Lakes: Implications for Eutrophication Control
kuntz (2005)	marine	4	89	2	Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species
przeslawski (2005)	marine	10	89	5	Synergistic effects associated with climate change and the development of rocky shore molluscs
smol (2010)	fresh	1	88	2	The power of the past: using sediments to track the effects of multiple stressors on lake ecosystems
todgham (2013)	general	8	88	3	Physiological Responses to Shifts in Multiple Environmental Stressors: Relevance in a Changing World

zhou (2006a)	terr	1	87	1	Main and interactive effects of warming, clipping, and doubled precipitation on soil CO_2 efflux in a grassland ecosystem
brown (2013)	marine	9	86	2	Managing for Interactions between Local and Global Stressors of Ecosystems
rohr (2004)	general	2	86	5	Multiple stressors and salamanders: Effects of an herbicide, food limitation, and hydroperiod
stendera (2012)	fresh	3	86	2	Drivers and stressors of freshwater biodiversity patterns across different ecosystems and scales: a review
gobler (2014)	marine	3	85	3	Hypoxia and Acidification Have Additive and Synergistic Negative Effects on the Growth, Survival, and Metamorphosis of Early Life Stage Bivalves
navarro-ortega (2015)	fresh	4	80	2	Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project
stone (2001)	ecotox	1	80	4	Time to death response in carabid beetles exposed to multiple stressors along a gradient of heavy metal pollution
alvarez-clare (2013)	terr	3	79	1	A direct test of nitrogen and phosphorus limitation to net primary productivity in a lowland tropical wet forest
strain (2014)	marine	10	79	5	Identifying the interacting roles of stressors in driving the global loss of canopy-forming to mat-forming algae in marine ecosystems
davidson (2007)	general	1	77	6	Multiple stressors and amphibian declines: Dual impacts of pesticides and fish on yellow-legged frogs
cottingham (1999)	fresh	3	75	6	Nutrients and zooplankton as multiple stressors of phytoplankton communities: Evidence from size structure
piggott (2012)	fresh	9	75	5	Multiple Stressors in Agricultural Streams: A Mesocosm Study of Interactions among Raised Water Temperature, Sediment Addition and Nutrient Enrichment
yan (2008)	fresh	3	75	4	Long-term trends in zooplankton of Dorset, Ontario, lakes: the probable interactive effects of changes in pH, total phosphorus, dissolved organic carbon, and predators
laskowski (2010)	ecotox	7	74	4	Interactions between toxic chemicals and natural environmental factors - A meta-analysis and case studies
breitburg (2015)	marine	5	72	3	And on Top of All That... Coping with Ocean Acidification in the Midst of Many Stressors
burton (2010)	ecotox	7	71	2	Assessing contaminated sediments in the context of multiple stressors
heugens (2006)	ecotox	12	71	4	Population growth of *Daphnia magna* under multiple stress conditions: Joint effects of temperature, food, and cadmium
harpole (2016)	terr	2	70	1	Addition of multiple limiting resources reduces grassland diversity
heathwaite (2010)	fresh	3	68	2	Multiple stressors on water availability at global to catchment scales: understanding human impact on nutrient cycles to protect water quality and water availability in the long term
niu (2009)	terr	2	68	1	Non-Additive Effects of Water and Nitrogen Addition on Ecosystem Carbon Exchange in a Temperate Steppe

cardoso (2008)	marine	3	67	6	The impact of extreme flooding events and anthropogenic stressors on the macrobenthic communities' dynamics
seo (2006)	ecotox	1	67	3	Environmental stressors (salinity, heavy metals, H_2O_2) modulate expression of glutathione reductase (GR) gene from the intertidal copepod *Tigriopus japonicus*
lirman (2007)	marine	1	66	2	Is proximity to land-based sources of coral stressors an appropriate measure of risk to coral reefs? An example from the Florida Reef Tract
altshuler (2011)	ecotox	10	65	4	An Integrated Multi-Disciplinary Approach for Studying Multiple Stressors in Freshwater Ecosystems: *Daphnia* as a Model Organism
babu (2001)	ecotox	1	64	2	Synergistic effects of a photooxidized polycyclic aromatic hydrocarbon and copper on photosynthesis and plant growth: Evidence that in vivo formation of reactive oxygen species is a mechanism of copper toxicity
downes (2010)	fresh	4	64	2	Back to the future: little-used tools and principles of scientific inference can help disentangle effects of multiple stressors on freshwater ecosystems
chen (2004)	ecotox	4	63	6	Multiple stress effects of Vision (R) herbicide, pH, and food on zooplankton and larval amphibian species from forest wetlands
yan (2004)	fresh	3	63	4	Recovery of copepod, but not cladoceran, zooplankton from severe and chronic effects of multiple stressors
lu (2012)	terr	3	62	1	Effect of nitrogen deposition on China's terrestrial carbon uptake in the context of multifactor environmental changes
mcbryan (2013)	general	5	62	3	Responses to Temperature and Hypoxia as Interacting Stressors in Fish: Implications for Adaptation to Environmental Change
bancroft (2008)	general	3	60	3	A meta-analysis of the effects of ultraviolet B radiation and its synergistic interactions with pH, contaminants, and disease on amphibian survival
noges (2016)	general	11	60	2	Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters
segner (2014)	general	15	59	4	Assessing the Impact of Multiple Stressors on Aquatic Biota: The Receptor's Side Matters
carilli (2010)	marine	3	58	2	Century-scale records of coral growth rates indicate that local stressors reduce coral thermal tolerance threshold
ateweberhan (2013)	marine	4	57	2	Climate change impacts on coral reefs: Synergies with local effects, possibilities for acclimation, and management implications
venterink (2010)	terr	1	56	1	Competitive interactions between two meadow grasses under nitrogen and phosphorus limitation
grantham (2010)	fresh	1	55	2	Climatic influences and anthropogenic stressors: an integrated framework for streamflow management in Mediterranean-climate California, USA
gunn (2001)	fresh	1	55	4	Use of water clarity to monitor the effects of climate change and other stressors on oligotrophic lakes

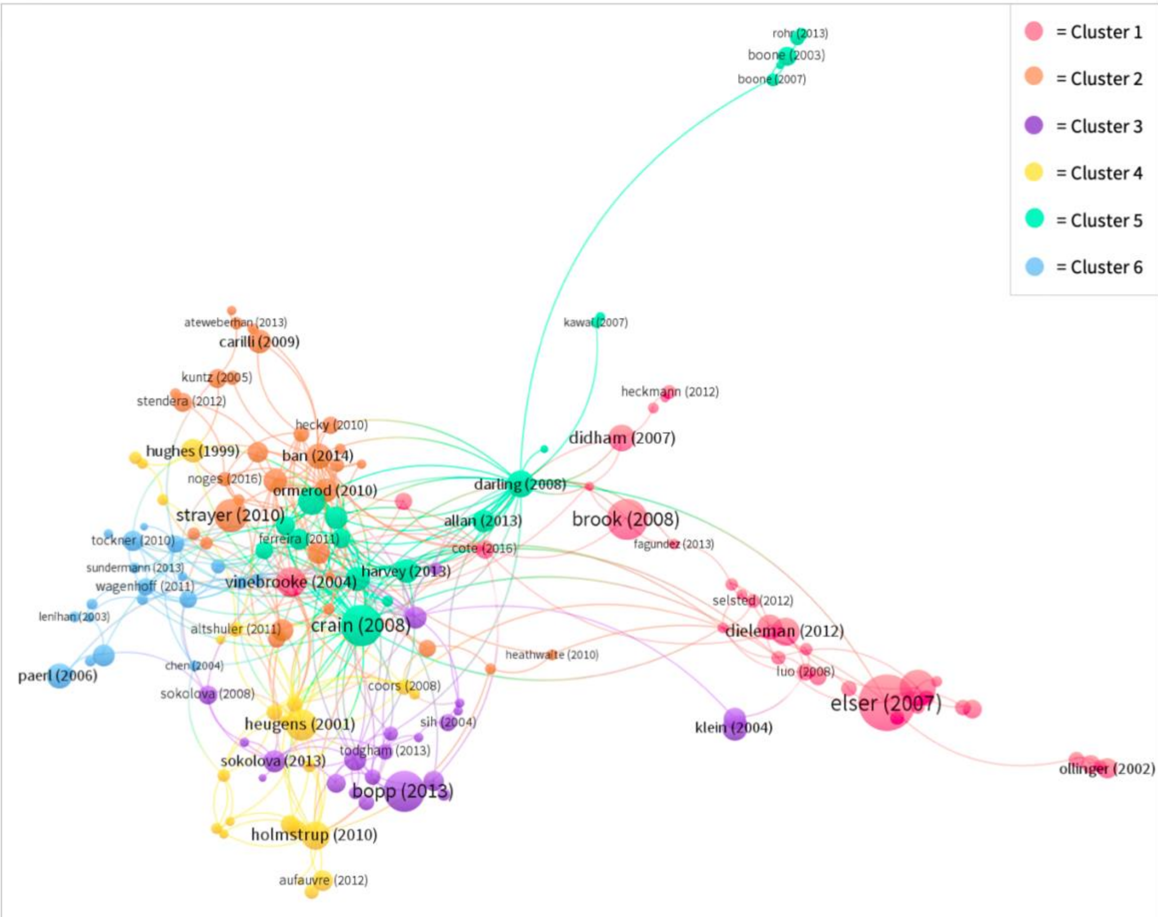
heckmann (2012)	general	1	55	1	Interactive effects of body-size structure and adaptive foraging on food-web stability
bernez (2004)	fresh	1	54	2	Combined effects of environmental factors and regulation on macrophyte vegetation along three rivers in western France
rohr (2013)	general	1	54	5	Climate Change, Multiple Stressors, and the Decline of Ectotherms
selsted (2012)	terr	4	53	1	Soil respiration is stimulated by elevated CO_2 and reduced by summer drought: three years of measurements in a multifactor ecosystem manipulation experiment in a temperate heathland (CLIMAITE)
adams (2003)	general	1	52	6	Establishing causality between environmental stressors and effects on aquatic ecosystems
lenihan (2003)	marine	1	52	6	Variation in marine benthic community composition allows discrimination of multiple stressors
piggott (2015a)	fresh	8	52	6	Climate warming and agricultural stressors interact to determine stream periphyton community composition
liess (2016)	ecotox	3	51	4	Predicting the synergy of multiple stress effects
thrush (2008)	ecotox	4	51	6	Multiple stressor effects identified from species abundance distributions: Interactions between urban contaminants and species habitat relationships
fredersdorf (2009)	marine	1	50	3	Interactive effects of radiation, temperature and salinity on different life history stages of the Arctic kelp *Alaria esculenta* (Phaeophyceae)
mueller (2016)	terr	2	49	1	Impacts of warming and elevated CO_2 on a semi-arid grassland are non-additive, shift with precipitation, and reverse over time
hessen (2000)	fresh	1	46	4	UV radiation and low calcium as mutual stressors for *Daphnia*
kolzau (2014)	fresh	2	46	1	Seasonal Patterns of Nitrogen and Phosphorus Limitation in Four German Lakes and the Predictability of Limitation Status from Ambient Nutrient Concentrations
rose (2009)	marine	1	46	3	Synergistic effects of iron and temperature on Antarctic phytoplankton and microzooplankton assemblages
davis (2010)	fresh	3	45	2	Multiple stressors and regime shifts in shallow aquatic ecosystems in antipodean landscapes
dunne (2010)	marine	3	45	2	Synergy or antagonism-interactions between stressors on coral reefs
o'gorman (2012)	marine	5	45	6	Multiple anthropogenic stressors and the structural properties of food webs
schulte (2007)	marine	1	45	3	Responses to environmental stressors in an estuarine fish: Interacting stressors and the impacts of local adaptation
firth (2009)	marine	4	44	3	The influence of multiple environmental stressors on the limpet *Cellana toreuma* during the summer monsoon season in Hong Kong
merriam (2011)	fresh	2	44	5	Additive effects of mining and residential development on stream conditions in a central Appalachian watershed
piggott (2015b)	fresh	12	44	6	Climate warming and agricultural stressors interact to determine stream macroinvertebrate community dynamics

ren (2012)	terr	3	44	1	China's crop productivity and soil carbon storage as influenced by multifactor global change
sundermann (2013)	fresh	4	44	6	Stressor prioritisation in riverine ecosystems: Which environmental factors shape benthic invertebrate assemblage metrics?
fagundez (2013)	terr	3	43	1	Heathlands confronting global change: drivers of biodiversity loss from past to future scenarios
fischer (2013)	ecotox	9	43	4	The toxicity of chemical pollutants in dynamic natural systems: The challenge of integrating environmental factors and biological complexity
albert (2011)	terr	3	42	1	Interactive effects of elevated CO_2, warming, and drought on photosynthesis of *Deschampsia flexuosa* in a temperate heath ecosystem
gergs (2013)	ecotox	1	39	4	Chemical and natural stressors combined: from cryptic effects to population extinction
zhou (2016)	terr	9	39	1	Interactive effects of global change factors on soil respiration and its components: a meta-analysis
bindesbol (2005)	ecotox	4	37	4	Stress synergy between environmentally realistic levels of copper and frost in the earthworm *Dendrobaena octaedra*
boone (2008)	ecotox	2	37	5	Examining the single and interactive effects of three insecticides on amphibian metamorphosis
chiogna (2016)	ecotox	3	37	2	A review of hydrological and chemical stressors in the Adige catchment and its ecological status
ivanina (2011)	ecotox	3	37	3	Interactive effects of cadmium and hypoxia on metabolic responses and bacterial loads of eastern oysters *Crassostrea virginica* Gmelin
Iokke (2013)	ecotox	5	37	4	Tools and perspectives for assessing chemical mixtures and multiple stressors
kelly (2010)	ecotox	1	36	6	Synergistic effects of glyphosate formulation and parasite infection on fish malformations and survival
hojer (2001)	ecotox	4	35	4	Stress synergy between drought and a common environmental contaminant: studies with the collembolan *Folsomia candida*
craine (2010)	terr	2	34	1	Plant nitrogen and phosphorus limitation in 98 North American grassland soils
janssens (2013)	ecotox	4	34	3	Synergistic effects between pesticide stress and predator cues: Conflicting results from life history and physiology in the damselfly *Enallagma cyathigerum*
binzer (2016)	terr	2	33	1	Interactive effects of warming, eutrophication and size structure: impacts on biodiversity and food-web structure
de sassi (2012)	terr	2	33	1	Plant-mediated and nonadditive effects of two global change drivers on an insect herbivore community
whitehead (2013)	ecotox	3	32	3	Interactions between Oil-Spill Pollutants and Natural Stressors Can Compound Ecotoxicological Effects
mcknight (2012)	ecotox	2	30	6	Integrated assessment of the impact of chemical stressors on surface water ecosystems

eder (2007)	ecotox	1	29	4	Pesticide and pathogen: Heat shock protein expression and acetylcholinesterase inhibition in juvenile Chinook salmon in response to multiple stressors
maestre (2009)	terr	1	28	5	On the relationship between abiotic stress and co-occurrence patterns: an assessment at the community level using soil lichen communities and multiple stress gradients
turner (2009)	terr	1	28	3	Interactive effects of warming and increased nitrogen deposition on 15N tracer retention in a temperate old field: seasonal trends
metz (2013)	terr	1	27	5	Unexpected redwood mortality from synergies between wildfire and an emerging infectious disease
yue (2017)	terr	7	27	1	Effects of three global change drivers on terrestrial C:N:P stoichiometry: a global synthesis
davalos (2014)	terr	5	26	1	Demographic responses of rare forest plants to multiple stressors: the role of deer, invasive species and nutrients

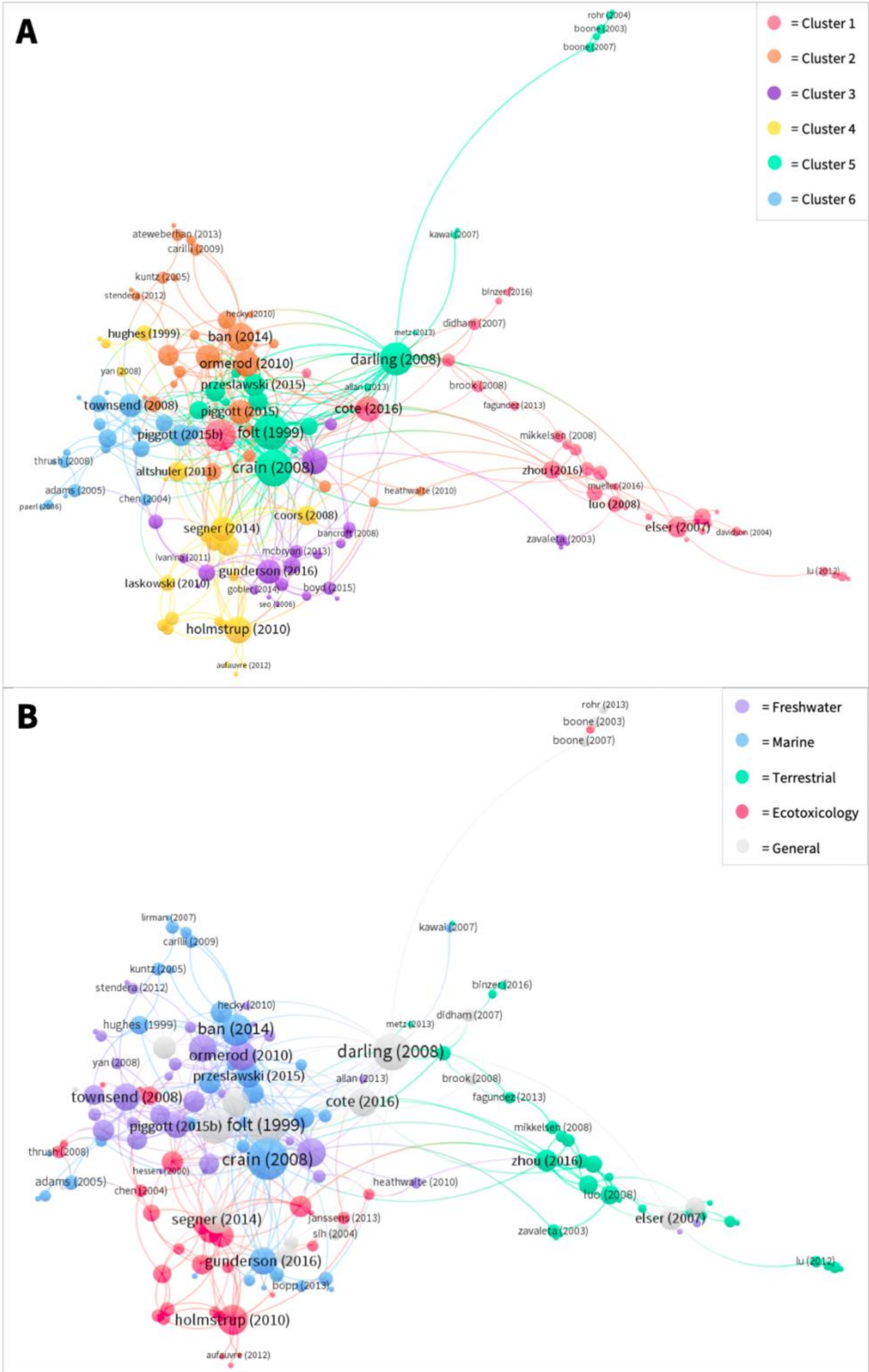
SM3: Citation Network with Colours based on Clusters

Citation network where the nodes represent publications and the links indicate the presence of a citation between connected publications. The size of the nodes represents the number of citations normalized by age. The distance between nodes is calculated using a citation analysis algorithm which determines the relatedness of items based on the number of times they cite each other. The colours of the nodes and their links represent the different clusters of publications.



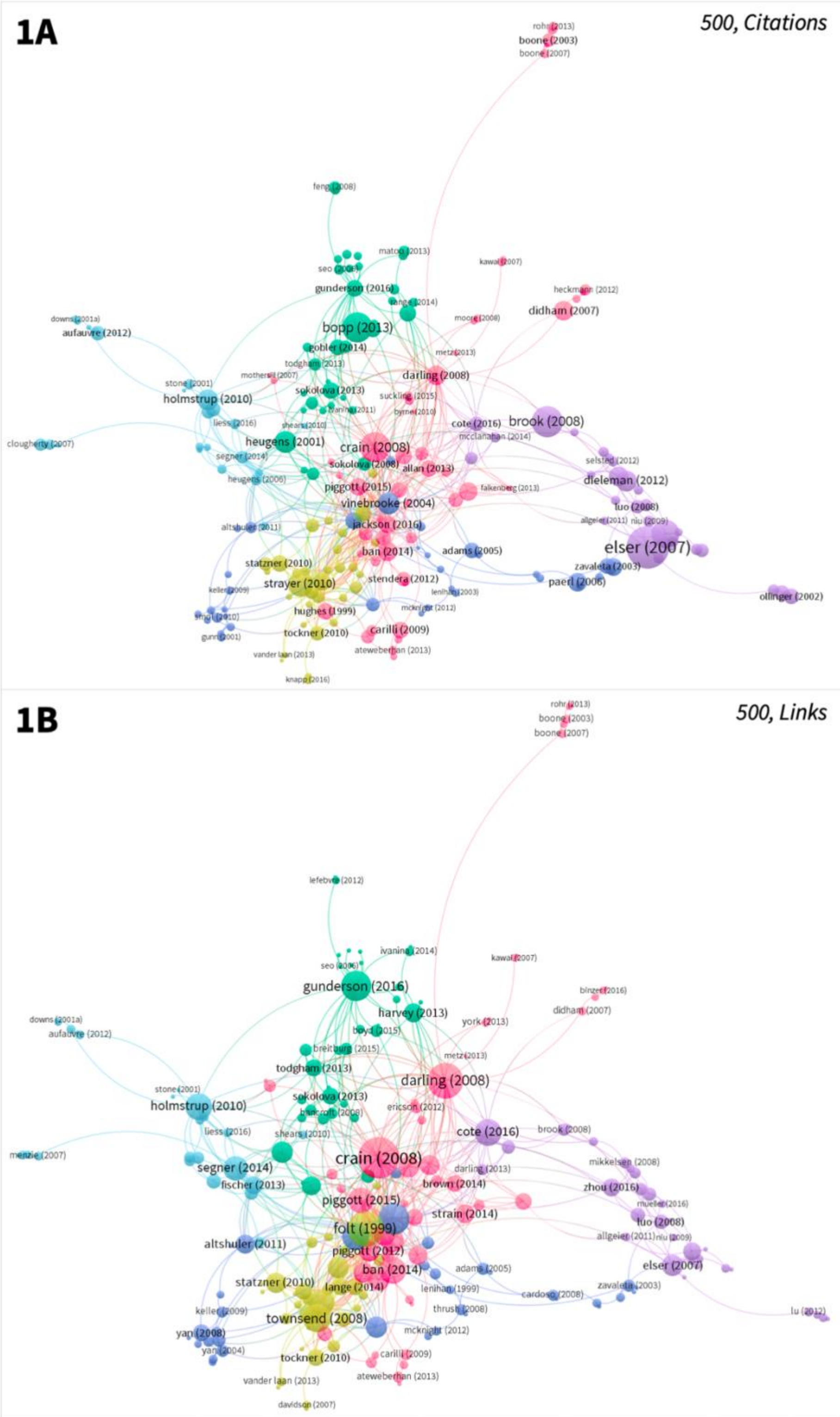
SM4: Citation Networks Where the Size of Nodes is Based on the Number of Citations

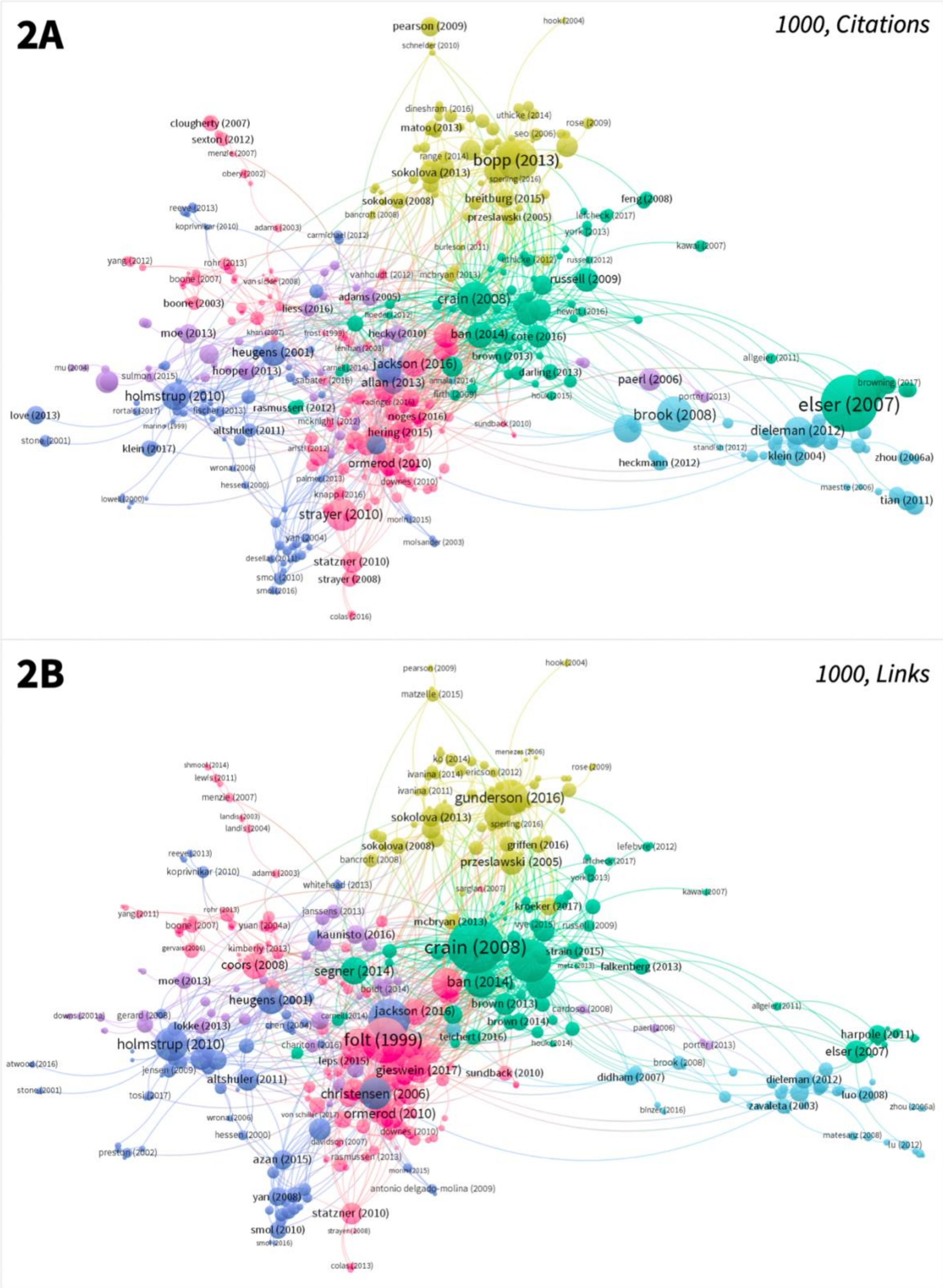
Citation network where the size of the nodes represents the number of links a publication has in the network. The colours of the nodes and their links represent (A) the different clusters of publications or (B) the disciplines they belong to.



SM5: Larger Citation Networks with Lower Citation Threshold

Citation networks constructed using the top 500 (1), 1000 (2), 1500 (3) and 2000 (4) publications based on citations using citations normalized by age of publication (A) and number of links (B) to calculate size of node. Minimum cluster size was modified so that there was always the same number of clusters in each network to allow for comparisons to be made.

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dieleman (2012)
altshuler (2011)
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christensen (2006)
zavaleta (2003)
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ormerod (2010)
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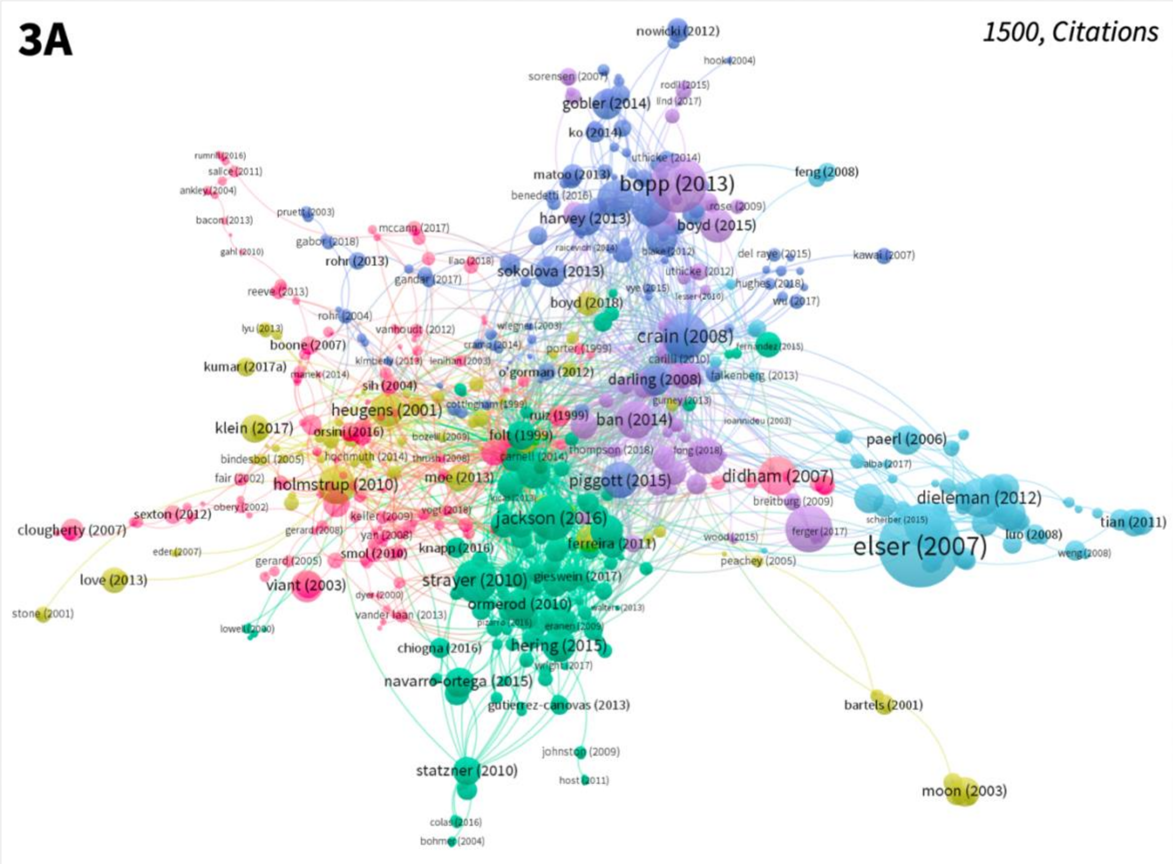
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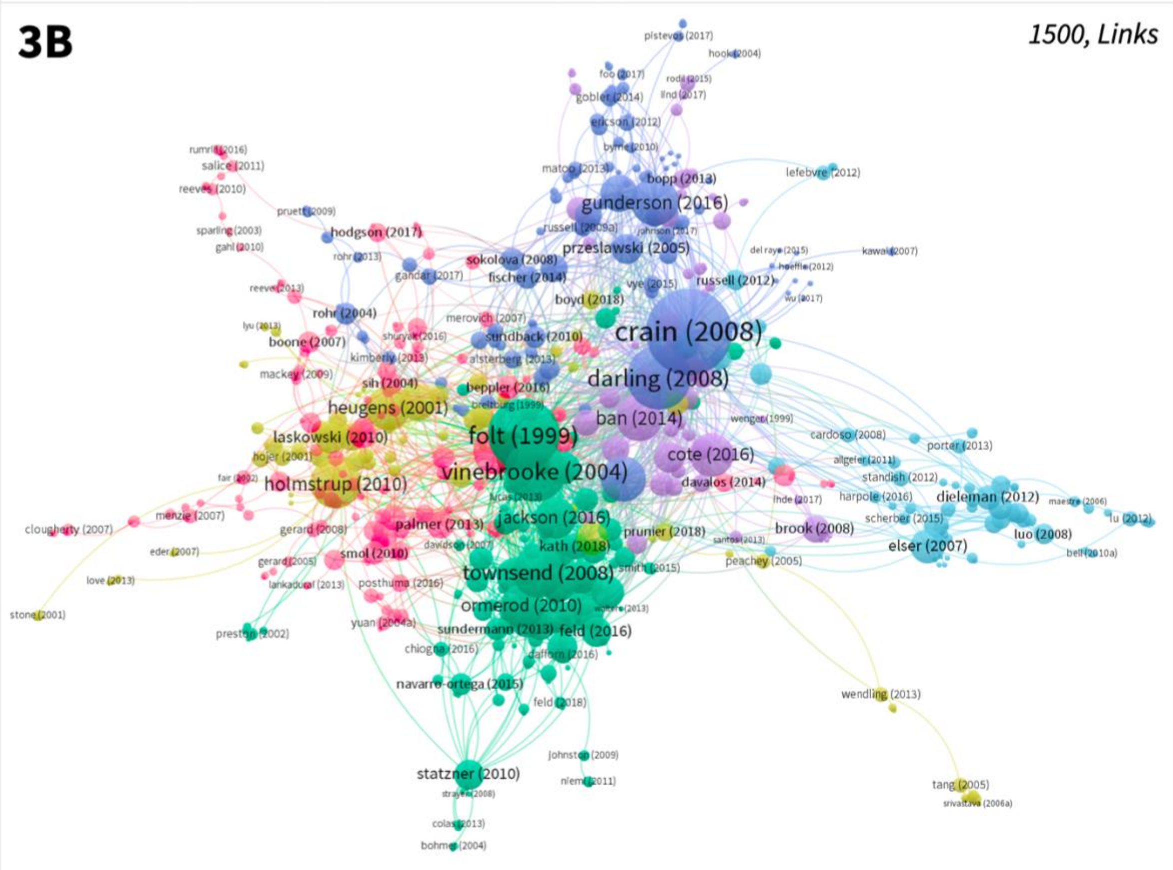
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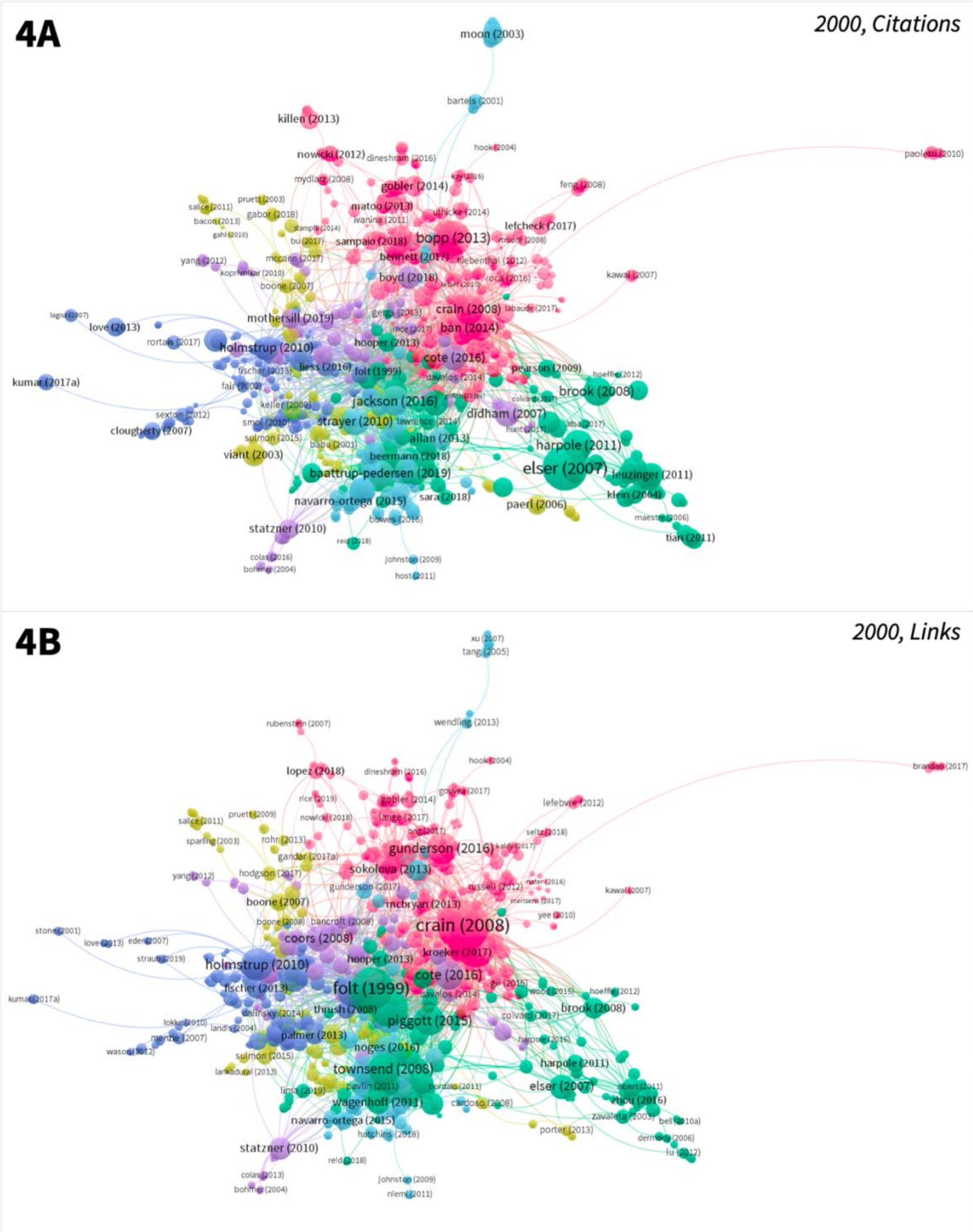
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SM6: Heat Map of Disciplines in Each Cluster

(i) Methods

1. For each cluster in the citation network the number of publications from each discipline was extracted.
2. These data were then converted to the percentage of each discipline in each cluster.
3. Finally, a heat map was constructed in R 3.6.0 (2) using the *gplots* package (3).

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Freshwater [34]	5.9% [2]	44.1% [15]	2.9% [1]	11.8% [4]	11.8% [4]	23.5% [8]
Marine [34]	2.9% [1]	29.4% [10]	26.5% [9]	2.9% [1]	20.6% [7]	17.6% [6]
Terrestrial [29]	82.8% [24]	0% [0]	10.3% [3]	0% [0]	6.9% [2]	0% [0]
Ecotoxicology [31]	0% [0]	9.7% [3]	19.4% [6]	54.8% [17]	3.2% [1]	12.9% [4]
General [22]	31.8% [7]	9.1% [2]	18.2% [4]	4.5% [1]	27.3% [6]	9.1% [2]

Percentage of Discipline

0 20 40 60 80

Heat map where cells contains the percentage (and number – in square brackets) of publications from each discipline found in the six clusters from SM3. The colour ramp, from light to dark red, corresponds to the percentage of publications from each discipline.

SM7: Terms in the Term Network

Terms from the term network ranked in order of number of occurrences. Disciplines have been manually assigned.

Term	Occurrences	Discipline
effect	387	General
stressor	298	General
response	160	General
interaction	155	General
study	150	General
change	143	General
multiple stressor	114	General
temperature	112	General
species	106	General
impact	104	General
level	97	General
factor	90	General
condition	88	General
ecosystem	85	General
experiment	85	General
stress	80	General
exposure	72	General
community	69	General
combination	68	General
growth	63	General
model	63	General
survival	57	General
approach	55	General
organism	55	General
site	54	General
water	54	General
scale	52	General
time	52	General
interactive effect	51	General
climate change	50	General
increase	50	General
process	50	General
population	49	General
treatment	49	General
salinity	48	Marine
addition	46	General
decline	46	General
lake	46	Freshwater

type	42	General
data	41	General
importance	40	General
plant	40	Terrestrial
evidence	39	General
nutrient	39	General
analysis	38	General
chemical	38	Ecotoxicology
climate	38	General
management	38	General
CO_2	37	General
mechanism	37	General
sediment	37	General
development	35	General
habitat	35	General
loss	35	General
soil	35	Terrestrial
abundance	32	General
acidification	32	Marine
diversity	32	General
hypothesis	32	General
mortality	32	General
tolerance	32	General
risk	31	Ecotoxicology
nitrogen	30	General
year	30	General
competition	29	General
pesticide	29	Ecotoxicology
risk assessment	29	Ecotoxicology
fish	28	General
relationship	28	General
driver	27	General
region	27	General
role	27	General
synergy	27	General
eutrophication	25	General
global change	25	General
number	25	General
precipitation	25	Terrestrial

river	25	Freshwater
drought	24	General
reduction	24	General
term	24	General
area	23	General
assessment	23	General
china	23	General
consequence	23	General
environmental factor	23	General
environmental stressor	23	General
hypoxia	23	General
mixture	23	General
stream	23	Freshwater
warming	23	General
negative effect	22	General
research	22	General
review	22	General
action	21	General
anthropogenic stressor	21	General
plot	21	General
toxicity	21	Ecotoxicology
biodiversity	20	General
contaminant	20	Ecotoxicology
light	20	General
need	20	General
coral	19	Marine
herbivory	19	Terrestrial
land use	19	General
additive effect	18	General
atrazine	18	Ecotoxicology
food	18	General
freshwater ecosystem	18	Freshwater
meta analysis	18	General
presence	18	General
coral reef	17	Marine
nutrient enrichment	17	General
synergism	17	General
variation	17	General
variety	17	General
amphibian	16	General
component	16	General
contrast	16	General
metamorphosis	16	General
phosphorus	16	General
synergistic effect	16	General
synergistic interaction	16	General
toxicant	16	Ecotoxicology
use	16	General
water quality	16	General
degrees c	15	General
disease	15	General
host	15	General
individual	15	General
local stressor	15	General
prediction	15	General
antagonistic interaction	14	General
elevated CO_2	14	General
example	14	General
future	14	General
knowledge	14	General
larvae	14	General
nitrogen deposition	14	General
oyster	14	Marine
paper	14	General
terrestrial ecosystem	14	Terrestrial
water temperature	14	General
aquatic ecosystem	13	General
difference	13	General
individual effect	13	General
order	13	General
reproduction	13	General
algae	12	Marine
case	12	General
combined effect	12	General
freshwater	12	Freshwater
heavy metal	12	Ecotoxicology
natural stressor	12	General
cumulative effect	11	General
global change driver	11	General
magnitude	11	General
antagonism	10	General
global climate change	10	General
halophyte	10	General
water resource	10	General

SM8: Cross-Discipline Comparison

A review of the literature was carried out to investigate how disciplines differ in their study of the ecological impacts of multiple stressors. Our aim was to compare the predictor and response variables, methods and key findings from meta-analyses of multiple-stressor research across disciplines. Below, we briefly summarize multiple-stressor research in each discipline.

1. Freshwater

Freshwater studies of multiple stressors have involved multi-factorial manipulative experiments focused on identifying the nature of net ecological impacts of paired stressors, and underlying causal mechanisms (4). Here, experimental approaches have ranged from *in vitro* microcosms (e.g., 5, 6, 7) to *in situ* mesocosm studies (e.g., 8, 9, 10). Warming combined with either nutrient enrichment or a chemical pollutant are most frequently studied (4).

Field survey-based approaches have also been employed to quantify the cumulative impacts of multiple stressors on freshwater ecosystems (e.g., 11). Here, geo-spatial analysis is increasingly being integrated into studies performed along environmental gradients (e.g., 12, 13, 14). In certain cases, a combined local-regional approach is taken by combining surveys and manipulative experiments (e.g., 11, 15, 16, 17). Other studies have involved multivariate analyses of long-term environmental and biological monitoring data (18), including paleolimnological investigations (19, 20).

In general, empirical evidence suggests that the cumulative ecological impacts of multiple freshwater stressors are most frequently non-additive. Jackson *et al.* (4) quantitatively synthesized 286 responses across different levels of biological organization and stressor identities to discover that the net impacts of paired stressors were most often less than the sum of their individual effects (*i.e.* antagonistic interactions). Here, net impacts ranged from being less than to near additive, suggesting that freshwater stressors typically dampen rather than amplify the ecological effect of each other. In a meta-analysis of findings from 29 factorial experiments involving freshwater fish, Lange *et al.* (21) found strong evidence of net effects of stressors being both less than additive and dependent on taxonomic identity and life stage. Synergistic responses to stressors were only evident at larger scales of investigation (21), a finding supported by evidence of nitrogen and phosphorus amplifying the direct effect of each other at the whole-ecosystem level (i.e. nutrient co-limitation; 17, 22). The importance of a dominant single stressor to the net ecological impact of several stressors has been demonstrated experimentally in microbial aquatic environments (5, 7). These findings suggest that the most damaging stressor often masks the effects of other less prevalent stressors, causing antagonistic impacts of multiple stressors in freshwaters, in contrast to the prevalence of synergisms reported in the marine literature (23).

2. Marine

The potential for multiple stressors to drive change in marine ecosystems has been widely recognized for over twenty years (24-26). Much of the early research in marine ecosystems focused on how changes in the trophic structure, often attributed to overharvest or disease, contributed to ecosystem-level phase shifts when coupled with physical disturbance (25). These phenomenological studies were followed by efforts to catalogue and map anthropogenic stressors and model the potential for cumulative effects of multiple stressors in the ocean (27, 28). These maps of cumulative effects were based on assumptions of additivity, but the realization that large swaths of the ocean were exposed to two or more anthropogenic stressors ignited research on potential “interactive effects”. Around the same time, a meta-analysis of all full-factorial multiple-stressor experiments in marine ecosystems (focused primarily on individual species) suggested that it was approximately equally likely that the combined effects of multiple stressors are “additive”, “antagonistic” or “synergistic” (29), although the probability of synergisms increased with the number of stressors.

Accelerated rates of global change have brought a renewed emphasis to multiple-stressor research in marine ecosystems. The increases in atmospheric carbon dioxide concentrations that cause global warming drive a series of abiotic changes in the ocean, including warming, stratification (which influences nutrient delivery), acidification, and deoxygenation (30, 31). The ubiquity of these co-occurring changes across the marine environment has led to the development of mechanistic, physiological models, such as the *Oxygen- and Capacity-Limited Thermal Tolerance* model (32) and the *Energy Limited Tolerance* model (33), which predict the combined effects of warming, acidification and deoxygenation. Despite the lack of a broadly accepted framework that describes the combined effects of temperature and carbonate chemistry on marine species or ecosystems, empirical data are accumulating that characterize the combined effects of warming and ocean acidification for a broad diversity of species and communities. Although the interactive effects vary among taxa, meta-analyses of full-factorial laboratory and mesocosm experiments suggest that there is a synergism between warming and ocean acidification (34, 35).

In recent years, marine scientists studying global change have established a standard terminology and a framework for designing multiple-stressor studies, to facilitate a broader understanding through synthesis and meta-analysis (36). Synthesis of other aspects of global change, such as ocean acidification, have benefitted from community-established standards for treatment levels and methods (37). However, the vast number of co-occurring stressors have precluded rigid standards for designing multi-stressor global change experiments. In addition, the recognition that interactions across different levels of organization can exacerbate or dampen the effects of multiple stressors highlights the challenges in predicting their combined effects (38).

3. Terrestrial

Unlike the aquatic realm, terrestrial meta-analyses across a range of multiple stressors are uncommon and tend to focus on pairs of multiple climate change and/or land-use change variables (39-43). In the last few decades, several terrestrial review papers and global meta-analyses of full-factorial designs in the field or in the laboratory have provided much needed benchmark data for understanding how plants and soil might respond to global change factors. Particularly, a slew of experiments have tested the combined effects of increased carbon dioxide concentrations, temperature, drought, nitrogen deposition, radiation and heavy metals (40, 44-46). There is also robust understanding of how eutrophication (excessive addition of nitrogen and phosphorus) may be offset or altered by human-induced herbivory. For example, Borer *et al.* (47) reported from their global-scale field experiment (*Nutrient Network*, http://www.nutnet.umn.edu/) that species loss from anthropogenic eutrophication can be ameliorated in grasslands where herbivory increases ground-level light (i.e. antagonistic or dampening effect).

Both models and experiments have been used in terrestrial ecosystem research to understand the impact of multiple drivers and their interactions on ecosystem parameters. One such interaction commonly described through experimental work is that both elevated carbon dioxide and warming typically increase total plant productivity (but not necessarily standing biomass), but in combination they may have additive, synergistic, or antagonistic outcomes (40, 48). Models, on the other hand, show mainly additive combined effects of these two drivers (49), which has led to major discrepancies between empirical and theoretical evidence (44). One way of testing the interacting effects between multiple stressors in terrestrial ecology is the use of congruent time series on animal populations (or substituting space for time), with climate change and land-use change replicated across landscapes (50). Such analyses have found a fairly consistent synergistic effect between baseline temperature conditions and habitat loss on a range of biological populations (43, 50, 51).

Taking a predictive approach to multiple stressors is another major advance in terrestrial ecology. Identifying areas or species at threat and predicting impacts under multiple interacting scenarios allows for more effective conservation planning and possible intervention. Climate change and land-use change are two stressors commonly projected under different scenarios (52), and the results have generally shown how changing land use could reduce or increase future climate change threats for some habitats and species (e.g., 53), or how climate change will mediate the effects of land-cover change (e.g., 54).

4. Ecotoxicology

Ecotoxicology is a discipline that integrates toxicology and ecology to study the effects of toxic chemicals at multiple biological scales. By describing the biological consequences of toxic chemicals, ecotoxicology underpins ecological risk assessment, which is a process that evaluates the probability of adverse ecological effects as a result of exposure to one or more chemical stressor (55, 56). The most frequently studied multiple stressors in ecotoxicology are mixtures of chemicals (57, 58). Chemical stressors, often referred to as toxicants, are described by their chemistry (*e.g.* polycyclic aromatic hydrocarbons, metals), modes of action (*e.g.* insecticides, antibiotics) or anthropogenic use (*e.g.* personal care products, flame retardants).

Most of the work addressing interactions between chemical and non-chemical stressors has been done in the context of climate change (59-61), although interactions with water scarcity (62), salinization (63, 64) and biotic stressors such as competition, food limitation, pathogens or predators (65, 66) have also been investigated. These studies either disentangle the effects of multiple stressors from field observations (e.g., 67, 68), or evaluate effects of (mostly two) stressors in factorial experiments usually on single species (e.g., 69) or occasionally on communities (e.g., 70).

Non-chemical stressors can impact the ecological effects of chemical stressors via 1) altering the exposure at the receptor or the susceptibility of the receptor (e.g., 71), 2) interacting effects at different receptors (e.g., 55), 3) effects on different species through ecological interactions (e.g., 72) or 4) changing the bioavailability of toxicants (e.g., 73). Systematic reviews on interactions between chemicals and non-chemical stressors when affecting terrestrial and aquatic environments have been performed, but the majority of these studies are limited to the individual level (65, 74). By studying the effects on individuals only, the ultimate ecological consequences of multiple stressors remain unknown (75, 76). Moreover, the individual species used in these studies are primarily model species, which further increases the uncertainty surrounding their ecological relevancy.

The question "How can interactions among different stress factors operating at different levels of biological organization be accounted for in environmental risk assessment?" was the most important question identified during the recent Society of Environmental Toxicology and Chemistry Europe's 'Global Horizon Scanning' workshop (77). The same topic was also identified as an important research direction in other reviews of the ecotoxicology literature (78, 79). Yet, the evidence produced by ecotoxicological research to date, due to its strong bias towards the individual level, with an overwhelming focus on just a few model species, does not help to answer these questions.

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