# Harmonisation of international conceptual cause-effect tools, based on ecological evidence data for multiple stressor impacts on riverine ecosystems


**University of Natural Resources and Life Sciences, Vienna, Austria**

**Department of Water, Atmosphere and Environment**

**Institute of Hydrobiology and Aquatic Ecosystem Management**


Master thesis


Nona Humer

Supervisors:

Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Stefan Schmutz

Dipl.-Ing. Dr. nat.techn. Andreas H. Melcher

## Acknowledgements

I would first like to thank the supervisors of this Master thesis, Ao.Univ.Prof. DI Dr. Stefan Schmutz and DI Dr. Andreas Melcher. I am especially thankful to Andreas for being always there for me, but also for trusting me and giving me freedom to follow my own ideas.

Many great scientists in the MARS team deserve special thanks for their help and support. I want to thank Dr. Christian K. Feld for an introduction to the MARS project and his valuable feedback and advice throughout the project. Thanks also to Clara Chrzanowski for her comments and support, and to Dr. Florian Pletterbauer, who kindly provided me data on multiple stressor impacts on riverine ecosystems.

I am sincerely grateful to Dr. Susan Norton and Dr. Kate Schofield from the U.S. EPA's Causal Analysis Team and Dr. Angus Webb from the University of Melbourne for their collaboration, help and positive attitude concerning my work. It was an honour that the developers of the cause-effect tools were interested in my work.

Finally, I want to thank my amazing family and friends for their love and encouragement. This achievement would not have been possible without them. I want to dedicate this work to my dear husband Alois, and our beloved daughter Linda, who was born during this project. I am grateful for each moment that I can spend with you two. Thank you.

# Abstract

European rivers are impacted by multiple stressors, which alone and in combination cause changes in riverine ecosystems. The cause-effect chains leading to ecological impairments should be critically diagnosed in order to plan effective restoration measures to improve the biological condition. Methods for ecological causal assessment, as well as associated tools have been developed simultaneously in different parts of the world. These methods use scientific evidence in ecological literature to support causal assessments in environmental investigations. The objective of this thesis is to support the development of diagnostic and predictive tools in the EU-funded project MARS (Managing Aquatic ecosystems and water Resources under Multiple Stress), by studying existing methods and creating conceptual ecological models with their assistance.

The results of this work contain literature-based evidence on causes and ecological effects of excess fine sediment and nutrients in rivers. The results are visualised in conceptual diagrams, which organise and combine the evidence on cause-effect associations. The diagrams demonstrate how fine sediment and nutrients affect the ecological functioning of rivers by changing benthic invertebrate and fish community structures. The combined effects of the stressors are mainly additive multi-stressor relationships, but the reference literature also evidenced synergistic and antagonistic effects between the stressors. Additionally the study revealed a research gap concerning joint effects of the stressors on fish indicators. The main challenges for the future development of cause-effect tools are effective extraction of cause-effect associations from the primary studies and visualisation of complex multi-stress relationships in conceptual models.



Keywords: *conceptual models, riverine ecosystems, benthic invertebrates, fish, multiple stressors, causal assessment*

# Contents

1. Introduction ........ 5
1.1 What are conceptual cause-effect models and why do we need them ........ 7
1.2 International methods of evidence synthesis and conceptual models ........ 7
1.2.1 CADDIS ........ 7
1.2.2 Eco Evidence ........ 9
1.2.3 WISER ........ 10
1.3 DPSIR framework ........ 12
1.4 Multiple stressors and stressor interactions ........ 14
1.5 Case study ........ 14
1.6 Objectives of the study ........ 15
2 Material and methods ........ 16
2.1 Evidence search ........ 16
2.1.1 CADDIS Literature Resource ........ 17
2.1.2 Eco Evidence database ........ 21
2.2 Strength of the evidence ........ 22
2.3 Model construction ........ 24
2.3.1 CADDIS ICD application ........ 24
3 Results ........ 27
3.1 Evidence search ........ 27
3.1.1 CADDIS Literature Resource ........ 27
3.1.2 Eco Evidence ........ 28
3.2 Harmonisation of the biotic response variables ........ 30
3.3 Drivers and pressures causing increased fine sediment and nutrient concentrations ........ 30
3.4 Ecological effects of increased fine sediment concentration ........ 31
*Composition and abundance* ........ 31
*Diversity* ........ 31
*Sensitivity and tolerance* ........ 32
*Density and biomass* ........ 32
*Processes and functions* ........ 32
*Disease and deformities* ........ 33
3.5 Ecological effects of increased nutrient concentration ........ 33
*Composition and abundance* ........ 33

*Diversity* ..... 34
*Sensitivity and tolerance* ..... 34
*Density* ..... 35
*Processes and functions* ..... 35
*Disease and deformities* ..... 36
3.6 Ecological effects of multi-stressor impacts ..... 36
*Composition and abundance* ..... 36
*Diversity* ..... 36
*Sensitivity and tolerance* ..... 36
*Density* ..... 37
*Processes and functions* ..... 37
*Disease and deformities* ..... 37
3.7 Threshold concentrations ..... 37
3.8 Strength of the evidence ..... 39
3.9 Conceptual models ..... 41
4 Discussion ..... 50
4.1 Causal relationships ..... 50
4.1.1 Drivers and pressures causing increased fine sediment and nutrient concentrations ..... 50
4.1.2 Cause-effect linkages between the stressors and their ecological responses in rivers ..... 51
4.1.3 Stressor comparison ..... 53
4.1.4 Strength of the evidence ..... 53
4.2 Existing methods of evidence-based conceptual models ..... 54
4.2.1 CADDIS ..... 54
4.2.2 Eco Evidence ..... 56
4.3 MARS diagrams ..... 56
4.4 Challenges ..... 57
4.5 Conclusions and future recommendations ..... 57
References ..... 59
Appendices

# 1. Introduction

Rivers and streams are sensitive ecosystems, which are impacted by host of stressors caused by agriculture, hydropower production, flood protection, urban development, deforestation, industry and transport, to mention few. The impacts of the stressors individually or in combination typically lead to a decrease in biodiversity because of degraded habitat, reduced water quality, biologically unsuitable flow regimes, dispersal barriers, altered inputs of organic matter or sunlight, etc. (Palmer et al. 2010). Managers should critically diagnose the causes of the impairments and invest resources first in repairing those problems most likely to limit restoration (Palmer et al. 2010). For conservation to be effective, decision-makers should base their decisions on effectiveness, which is demonstrated by scientific evidence. But rather than evidence provided by scientific research, environmental conservation practise is largely based on traditional land management practises (Pullin et al. 2004) or expert opinions (Webb et al. 2012). Additionally very little evidence is collected on the consequences of current practice so that future decisions cannot be based upon the experience of what does or does not work (Sutherland et al. 2004). Evidence-based frameworks have become effective tools in medicine, incorporating the results of medical research into medical practice (Roberts et al. 2006). In environmental policy and practice, available science is still not widely used (Pullin & Knight 2003; Sutherland et al. 2004; Dicks et al. 2014). The limited use of scientific information in environmental decisions might be caused by difficulties to access relevant scientific literature (Pullin & Knight 2003; Pullin et al. 2004), lack of effort to incorporate the growing evidence base into decision frameworks (Dicks et al. 2014), lack of scientific studies addressing the right questions (Dicks et al. 2014), and limited collection of information from individual practitioners in a form that could be used by others (Sutherland et al. 2004). Additionally many management interventions remain unevaluated (Pullin et al. 2004; Sutherland et al. 2004). The result is that decisions are often made without access to the best quality evidence thus increasing the probability that inappropriate management options will be adopted (Pullin & Knight 2003). Review articles are often the only source of evidence used by decision makers in conservation and environmental management to assess effectiveness and impact of actions (Roberts et al. 2006). When ecological reviews (reviews from the disciplines of conservation, ecology and environmental management) were compared to medical systematic reviews, ecological reviews were more likely to be prone to bias, lacking details in the methods used to search for studies, and were less likely to assess the relevance of studies, quality of the original experiments and to quantitatively synthesise the evidence (Roberts et al. 2006). Review updates and amendment is standard practice in medicine, and the search infrastructure and information databases available to the medical community are better integrated than those in ecology (Stewart et al. 2005).

There is a growing interest in integrating evidence-based approaches to conservation practises as well (Pullin & Knight 2003; Pullin et al. 2004; Sutherland et al. 2004; Roberts et al. 2006; Pullin & Knight 2009). Sutherland et al. (2004) believe that a greater shift to evidence-based conservation would be highly effective, and additionally likely to result in enhanced funding by actively demonstrating this effectiveness to funders and policy formers.

Evidence syntheses that review and combine the findings from primary research articles to assess the effectiveness of an environmental intervention or the impact of an exposure are important for consolidating research, as the evidence provided by primary studies is expanding rapidly (Woodcock et al. 2014). Scientific evidence should be easily accessible, quantified, and in usable format to be used effectively by water managers. Ecological cause-effect evidence databases and conceptual models can offer useful tools to gather, store, organize, visualise and share the expanding evidence base. Conceptual models, which are based on ecological evidence data extracted from scientific peer reviewed literature offer highly repeatable, transparent, and structured method for causal assessment. They can be used as support in conservation and environmental management, helping in shifting to more evidence-based decision making in environmental issues.

This thesis is part of the MARS project (Managing Aquatic ecosystems and water Resources under multiple Stress), which is an EU-funded project supporting water managers and policy makers at the water body, river basin and European scales in the implementation of the Water Framework Directive (WFD, 2000/60/EC, Hering et al. 2015). The project investigates how multiple stressors affect rivers, lakes and estuaries. These complex mix of stressors result from urban and agricultural land use, water power generation and climate change (MARS website).

The information generated in the MARS project will finally be combined with existing knowledge in the form of information systems and diagnostic and predictive tools, which will be applicable at the three spatial scales (Hering et al. 2015). The diagnostic tool should be able to diagnose linkages between multiple stressors affecting water bodies, and their biological responses, as well as offer management options to cope with the problems. The ultimate goal is to improve the conditions of European water bodies to meet the objectives of the WFD. The first step is to create literature-based conceptual models visualising the linkages between stressors and their responses in the ecosystems. In this thesis conceptual models on causal chains leading to ecological impairments in riverine ecosystems will be created with help of existing international cause-effect modelling tools. These models will support the creation of the final diagnostic and predictive tools in the course of the MARS project.

## 1.1 What are conceptual cause-effect models and why do we need them

Conceptual ecological models are qualitative models which are based on causal linkages among sources, stressors and biological effects. In this thesis, the models will be based on quantitative evidence supporting the given cause-effect associations. The work will examine existing international cause-effect tools, which can be used for gathering, storing and visualising causal ecological relationships. Understanding such relationships is required in sound decision making in environmental research and management (e.g. Norris et al. 2012; Webb et al. 2012). The cause-effect tools can be used to gather together several studies supporting given ecological causal linkage. In this means many individually weak studies are accumulated to strengthen the evidence, which helps in identifying the causes of impairments and the necessary steps for management actions. Conceptual cause-effect models also help indicating knowledge gaps where more research would be needed in order to have sufficient evidence to reach a conclusion.

Causal relations are difficult to demonstrate in natural environments because of the difficulty of performing experiments, natural variability, lack of replication, and the presence of confounding influences. Partly because of this, most environmental management decisions are made using expert opinion (Webb et al. 2012). Such decisions can lack transparency. Literature-based cause-effect models yield scientifically defensible results by transparent and reproducible evaluation. The method can identify causal relationships that are not immediately apparent and prevent biases. All the evidence supporting given causal relationship increase confidence that restoration effects can improve biological condition.

## 1.2 International methods of evidence synthesis and conceptual models

### 1.2.1 CADDIS

CADDIS (The Causal Analysis/Diagnosis Decision Information System) is a website developed by U.S. EPA, to help scientists and engineers conduct causal assessments in aquatic systems. It provides a process for identifying stressor or combination of stressors that cause biological impairment. The approach is an example of causal pluralism, in that multiple concepts of causation are accepted as well as all relevant evidence and methods for turning data into evidence. Although a cause can never be proven and can seldom be disproven, the method can determine which causal hypothesis is best supported by the evidence (U.S. EPA 2010).

In the Stressor Identification Guidance Document provided by CADDIS is stated that biological assessments have become increasingly important tools for managing water quality. These methods, which use measurements of aquatic biological communities, are particularly important for evaluating the impacts of chemicals for which there are no water quality standards, and for non-chemical stressors such as flow alteration, siltation, and invasive species. However, although biological assessments are critical tools for detecting impairment, they do not identify the cause or causes of the impairment. The Stressor Identification Guidance Document is intended to lead water resource managers through a process that identifies stressors causing biological impairment in aquatic systems, and provides a structure for organizing the scientific evidence supporting the conclusions (U.S. EPA 2000). The essence of the CADDIS approach to causal inference is the comparison of alternate candidate causes by determining which is the best supported by the totality of evidence. Its standard process provides transparency and reduces inferential errors without restricting the types of evidence used (U.S EPA 2010).

CADDIS website is organized into five volumes:

1. Stressor identification – provides a step-by-step guide for identifying probable causes of impairment in a particular system, based on the U.S. EPA's Stressor Identification process.

2. Sources, Stressors & Responses – provides background information on many common sources, stressors, and biotic responses in stream ecosystems

3. Examples & Applications – provides examples illustrating different steps of causal assessments

4. Data analysis – provides guidance on the use of statistical analysis to support causal assessments

5. Causal Databases – provides access to literature databases and associated tools for use in causal assessments

The fifth volume, Causal Databases, provides two tools to help users access and apply literature-based evidence in causal assessments. The Interactive Conceptual Diagram (ICD) application uses conceptual diagrams as an organizing framework to provide supporting literature for linkages among different sources, stressors and responses. Users can view existing diagrams and the literature supporting the linkages of the causal pathways. The application can as well be used in creating own diagrams and saving the literature references supporting the linkages. The other tool provided by this section is the CADDIS Literature Resource (CADLit), which contains information on stressor-response associations reported in the peer-reviewed scientific literature. The CADLit database can be used to search for information by keywords, or by location, habitat, exposure parameter or taxa. The search results can be further downloaded to an Excel spreadsheet (U.S. EPA 2007).

### 1.2.2 Eco Evidence

Eco Evidence is another method that uses evidence in the extensive published ecological literature to assess support for cause-effect hypotheses in environmental investigations. Eco Evidence is provided by eWater Cooperative Research Centre, a publicly owned not-for-profit organisation, which is committed to ecologically sustainable water management in Australia and around the world. Eco Evidence provides an 8-step process (figure 1) in which the user conducts a systematic review of the evidence for one or more cause-effect hypotheses to assess the level of support for an overall question. Eco Evidence is based partly upon the epidemiological method of causal criteria analysis (Susser 1991). It uses a subset of 'causal criteria' most relevant to environmental investigations, and weights each piece of evidence according to its study design such that stronger studies contribute more to the assessment of causality, but weaker evidence is not discarded. The outputs of the analysis are a guide to the strength of evidence for or against the cause-effect hypotheses. It strengthens confidence in the conclusions drawn from the evidence, but cannot ever prove causality (eWater website).

The method is supported by the freely available Eco Evidence software package, which produces a standard report, maximizing the transparency and repeatability of the assessment. Using the Eco Evidence method, environmental scientists can better use the extensive published literature to guide evidence-based decisions and undertake transparent assessments of ecological cause and effect hypotheses (Norris et al. 2012). Eco Evidence helps answer cause-effect questions, make assessments, plan for restorations, and carry out critical reviews on a specific topic of interest.

The Eco Evidence software also provides an online database (Webb et al. 2015), which stores information about causal relationships extracted from environmental science studies. This information is specifically geared to support cause and effect assessments. The online database can be used in searching evidence supporting causal relationships between the parameters of specific interest. The other software tool provided by Eco Evidence is the Eco Evidence Analyser software, which guides users through the 8-step framework gathering and weighting the evidence and produces a concluding report. The method has been described e.g. by Norris et al. (2012) and Webb et al. (2012).

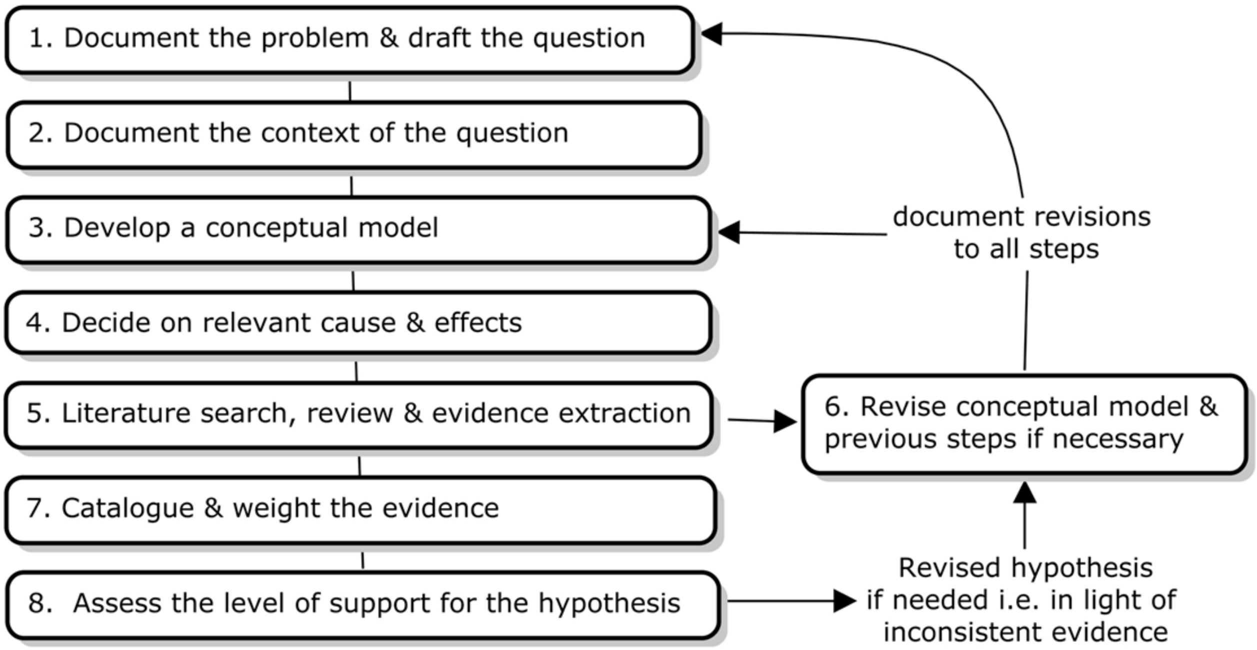
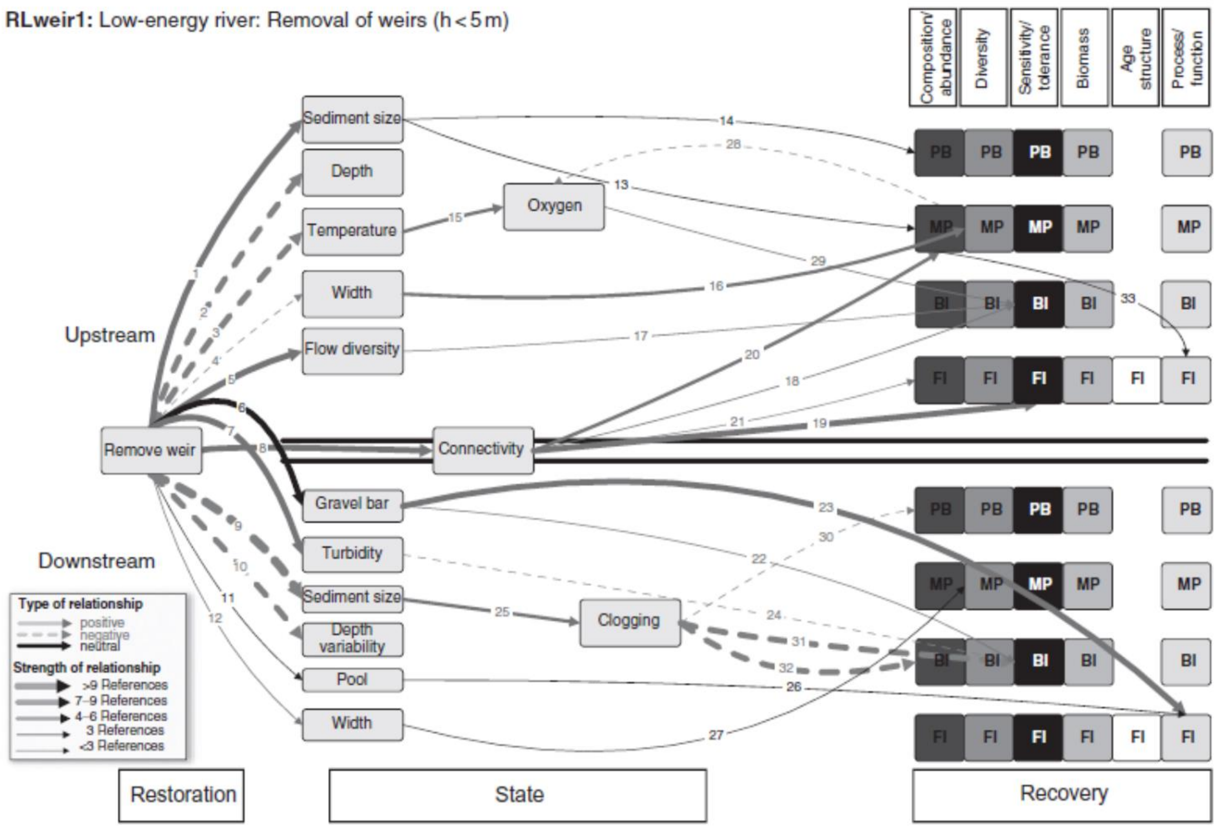



**Fig 1** The 8-step framework provided by the Eco Evidence analyser software (http://www.toolkit.net.au/tools/eco-evidence)

### 1.2.3 WISER

The WISER (Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery) was an EU project, which ended in 2012. The WISER aimed to support the implementation of the WFD by developing tools for the integrated assessment of the ecological status of European surface waters. In module five of the project (management and restoration – impacts of pressure reduction and climate change on the ecological status), methods for assessing and restoring aquatic ecosystems were developed. The results include conceptual models (figure 2) illustrating the relationships between restoration measures, their effects on instream environmental key variables, and eventually the impact of changing variables on benthic algae, macrophytes, benthic invertebrates and fish (WISER website).




| A | Model link No. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | First author | Year |
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | x | | | | | | | | Schlosser | 1982 |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | x | | | | | | | | Harvey | 1991 |
| 3 | | | | | | | | | | | | | | | | | | | x | | x | | | | | | | | | | | | | Iversen | 1993 |
| 4 | | | x | | x | | | | | | | | | | x | | | | | | | | | | | | | | | | | | x | Hill | 1993 |
| 5 | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Kanehl | 1997 |
| 6 | | | | | | | | x | | | | | | | | | | | | | | | | | | | | | | | | | | Poff | 1997 |
| 7 | | | | | | | | | | | | | x | x | | | | | | | | | | | | | | | | | | | | Baattrup-Pedersen | 1999 |
| 8 | | | | | | | | | | | | | | | | | | | | | | | x | | | | | | | | | | | Bednarek | 2001 |
| 9 | | x | x | | x | | | | | x | | | | | x | | | | | | | | | | | | | | x | | x | | | Bushaw-Newton | 2002 |
| 10 | | | x | | x | x | | x | | | | | | | | | | | x | x | x | | x | | | | | | | | | | | Gregory | 2002 |
| 11 | | x | | x | x | | | x | x | | | | | | | x | | | x | | | | | | | | | | | | | | | Hart | 2002 |
| 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Pizzuto | 2002 |
| 13 | | | | x | | | | | | | | | | | | x | | | | x | | | | | | | x | | | | | | | Shafroth | 2002 |
| 14 | | | x | | | | | | | | x | | | | x | | | | | | | x | | | | x | | | | | | | | Stanley | 2002 |
| 15 | | x | x | | | | x | | | | | | | | x | | | | | | | | | | | | | x | | | | | | Chaplin | 2003 |
| 16 | x | | | | | x | x | | x | | | | | | | | | | | | | | x | | x | | | | | | | | | Hart | 2003 |
| 17 | x | x | | | | x | x | | x | x | | | | | | | | | | | | | | | | | | | | | | | | Randle | 2003 |
| 18 | | | | | | x | x | | x | x | x | x | | | | | | | | x | | | | | x | | | | | | | | | Rathburn | 2003 |
| 19 | x | | | | | | | | x | | | | | | | | | | | | | | | | x | | | | | | x | x | | Pollard | 2004 |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Doyle | 2005 |
| 21 | | | | | | | | x | | | | | | | | | | | x | | | | | | | | | | | | | | | Schmitt | 2005 |
| 22 | | | | | | | | | x | | | | | | | | | | | | | | x | | | | | | | x | x | x | | Thomson | 2005 |
| 23 | | | | | | | | | | | | | | | | | | | | | | | | x | | | | | | x | x | x | | Orr | 2006 |
| 24 | | | | | | | x | | x | x | | | | | | | | | | | | | | | | | | | | | | | | Cheng | 2007 |
| 25 | | | | | | | | | | | | | x | x | | | | | | | | | | | | | | | | | | | | Kuhar | 2007 |
| 26 | | | | | | | | | | | | | | | | | | | x | | | | | | | | | | | | | | | Leaniz | 2008 |
| 27 | | | | | | | | | | | | | | | | | x | x | | | | | | | | | | | | | | | | Maloney | 2008 |
| 28 | | x | | x | | | | | | x | x | x | | | | | | | | | | | | | | | | | | | | | | Burroughs | 2009 |
| 29 | | | | | | | | | x | | x | | | | | | | | | | | | | | | | | | | | | | | Ahearn | 2005 |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Ashley | 2006 |
| 31 | | | | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Evans | 2007 |
| 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Velinsky | 2006 |
| 33 | | | | | | | | | | | | | | | | | | | x | | x | | | | | | | | | | | | | Stanley | 2008 |
| 34 | | | | | | | | | x | | | | | | | | | | | | | | | | x | | | | | x | x | x | | Orr | 2008 |
| 35 | x | | | x | x | | | | x | | | x | | | | | | | | | | | | | | | | | | | | | | Rumschlag | 2007 |
| 36 | | | | | | | | | | x | | | | | | | | | | | | x | | | | | | | | | x | x | | Tzsydel | 2009 |

**Fig 2** Example of conceptual models made in the WISER project, illustrating the relationships between restoration measures and their effects on riverine ecosystems (Feld et al. 2011)

## 1.3 DPSIR framework

The diagrams, which will be created in this study, will follow *Driver-Pressure-State-Impact-Response* categories, which are used slightly differently as introduced by European Environment Agency (EEA 1999). In the MARS project, the terminology defined by CIS Guidance IMPRESS (2002) is followed, except for the definition of the *Impact* category. The DPSIR indicator categories used in the MARS can be defined as follows:

**Driver** is an anthropogenic activity that may have an environmental effect (e.g. agriculture, industry).

**Pressure** is the direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry).

**State** is the condition of the system under study (e.g. water body) resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics).

**Impacts** are effects on human beings, ecosystems and man-made capital resulting from changes in environmental quality with relevance for ecosystem processes and/or components actively or passively required, demanded or used by man (e.g. ecosystem services), triggering social *Response.*

**Responses** are the measures taken to improve the state of the water body (e.g. restricting abstraction, limiting point source discharges, developing best practise guidance for agriculture.

The drivers lead to pressures, which in turn lead to changes in the abiotic and biotic states of the water body. The altered states cause impacts on human beings. Finally the responses can be addressed to any of the other DPSIR categories in order to improve the state of the water body (figure 3).

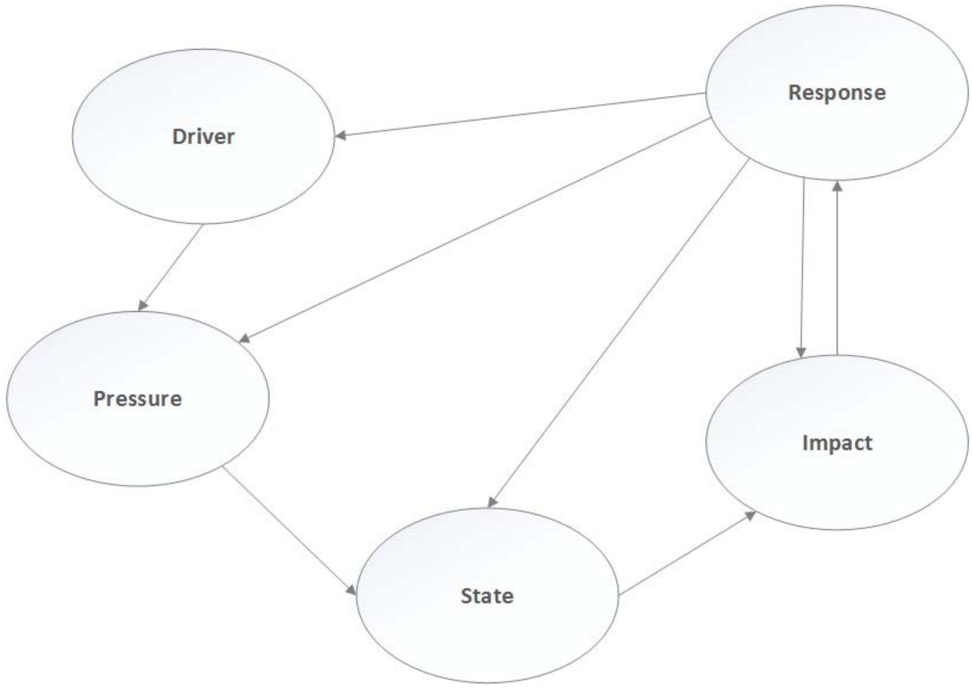



**Fig 3** DPSIR framework (modified after EEA 1999)

Additionally the term *Stressor* is defined in the MARS project as follows:

1. A Stressor is any environmental change in a factor that causes some response by the system of interest (Odum 1985, Underwood 1989, Kolasa & Pickett 1992). The system of interest can be at any organizational level, e.g. organism, population, ecosystem.

2. A Stressor can be of natural or anthropogenic origin. The response caused by the Stressor can be beneficial or deleterious to the system of interest (Ban et al. 2014).

3. The term Stressor is not used in the terminology of the DPSIR framework. According to (1) a Stressor can belong to either the Pressure or State category; the main thing is: it's the (putative) cause in a cause-and-effect chain.

4. A direct stressor represents the immediate cause of an effect (e.g. oxygen depletion causing suffocation of fish). If the stressor-effect on a species/biological community is studied, direct stressors affect the niche of the species/habitat template of the community.

Indirect stressors are preceding factors in a causal pathway conditioning an effect (e.g. flow variation [causing changes in near bottom flow] causing response in invertebrate communities; Statzner & Bêche 2010). Direct stressors are often difficult to measure, thus empirical (field) studies mostly make use of indirect stressors as explanatory variables.

## 1.4 Multiple stressors and stressor interactions

European rivers are affected by alterations of water quality, hydrology and morphology (Schinegger et al. 2012). Most European water bodies are affected by multiple stressors, yet little is known about their combined effects (Hering et al. 2015). Human pressure often alter more than one environmental factor, and also pressures from several sources often coincide (Ormerod et al. 2010). This means that most human activities create impacts on the environment via multiple, prospective pathways of cause and effect (Downes 2010). Stressors often interact with each other, and sometimes the effects of these interactions are synergistic or antagonistic in character, rather than simply additive. When combined effect of multiple stressors is greater than the sum of effects by individual stressors, the interaction is called synergistic. In antagonism, the effect is less than the sum of individual stressors. This is the most common scientific usage of these terms (Folt et al. 1999). The complexity of multiple stressor interactions makes it difficult to identify their combined effects to the ecosystems. Also identifying and prioritising the management issues is challenging (Ormerod et al. 2010). Freshwaters appear to be at particular risk of multiple-stressor effects, which might be caused by conflicts between multiple uses of water and the protection of freshwater environments (Ormerod et al. 2010). It is difficult to sort out which stressors are the direct causes of an unacceptable change and which are just correlates (Downes 2010). Nevertheless, the exact cause-effect relationships should be identified in order to understand the various pathways how stressors alone and in combination affect river ecosystems. This is crucial for the restoration measures to be effective.

## 1.5 Case study

In this thesis a prototype of a causal conceptual diagram visualising the cause-effect pathways leading to ecological impairments in river ecosystems will be created for the MARS project. Two international methods (CADDIS and Eco Evidence), and the tools that they offer, will be tested by searching and evaluating causal ecological data, and creating diagrams with their assistance. The diagrams will address stressors, their causes and ecological effects on running water ecosystems. The cause-effect linkages will be gathered from several sources. Nõges et al. (2016) reviewed publications concerning multiple stressor impacts in rivers, lakes, transitional and coastal waters, as well as groundwaters. The part of the review, which consists data of multiple stressor impacts on riverine ecosystems (reviewed by Florian Pletterbauer), acts as a starting point to this work. The most common stressor combination in numbers of evidence items (cause-effect relationships) in this part of the review, is excess in fine sediment and nutrients. The conceptual diagrams will be constructed based on these data, and more evidence will be gathered concerning the common and individual effects of these stressors on biological indicators in rivers. According to the DPSIR categories used in the MARS project, increased fine sediment and nutrient concentrations represent the altered abiotic states of the water bodies. Their causes (drivers and pressures) and ecological responses (biotic state variables) will be extracted from scientific literature and visualised in form of conceptual diagrams. The ecological indicators of the impairments selected to be used in this study are fish and benthic invertebrates.

## 1.6 Objectives of the study

The objectives of this Master's thesis are:

1. To collect quantified cause-effect data concerning the ecological impacts of fine sediment and nutrients (nitrogen and phosphorus) in rivers, and possible thresholds of these stressors to be further used in the MARS project
2. To give an overview of existing methods of standardized evidence based conceptual models and to find out the suitability of their components to the European purposes
3. To create a causal conceptual model concerning excess in fine sediment and nutrients, as well as the interactions of these stressors and their ecological effects in rivers, using fish and benthic invertebrates as indicators of the impairments

# 2 Material and methods

## 2.1 Evidence search

Nõges et al. (2016) quantified biotic and abiotic responses to multiple stress in freshwater, marine and groundwater ecosystems. The part of this literature review concerning rivers forms a basis to this study. The cause-effect relationships will be gathered from these scientific references, and used in the diagrams. Additional literature search on single stressor effects will be performed. This search will focus on fine sediment or nutrients as stressors affecting riverine ecosystems, and fish and benthic invertebrates as ecological indicators of the impairments. The causes for altered abiotic states (increase in nutrients and/or fine sediment content) of the waterbodies will be searched from the same references where the relationships between abiotic and biotic state variables will be gathered. These causes will be divided in drivers and pressures according to the DPSIR categories used in the MARS project. Only quantitative evidence will be regarded in this study. Furthermore evidence on causal ecological linkages will be searched from the CADDIS Literature Resource (CADLit, http://cfpub.epa.gov/cadlit/index.cfm) and Eco Evidence online database of the eWater toolkit (http://www.toolkit.net.au/tools/Online/EE/).

The biotic response variables will be harmonised by dividing them into broad variable categories which were introduced in WISER project by Feld et al. (2011):

1. composition and abundance
2. sensitive and tolerant taxa
3. diversity
4. age structure
5. biomass
6. processes and functions

The information about the cause-effect relationships will be collected to an Excel table. Also all the thresholds or breakpoint values in the responses between fine sediment or nutrient concentrations and biotic indices will be gathered from the reference literature. Such threshold values might be of great importance when the final predictive and diagnostic tools will be developed in the MARS project.

### 2.1.1 CADDIS Literature Resource

CADLit database can be searched using *Keyword Search* or *Advanced Search*. Keyword Search can be conducted in three ways: Search For, Boolean Search, or Field Search. The Search For option will search all fields within all records for the entered term. The Boolean Search option allows the user to specify multiple search terms that are separated by the logical operators, and, or, or not. The Field Search option in turn, allows the user to search for words that are contained within specific fields in the database. The fields that can be searched are *citation* (i.e., authors' names, year, journal name or title), *source* (i.e., a source of a stressor, defined as an origination point, area, or entity that releases or emits an agent that may be an indirect cause or a proximate cause), *exposure parameters* (i.e., a physical, chemical or biological entity that can induce a biological effect), *response parameters* (i.e., a biological effect), *stressor* (i.e., a physical, chemical or biological entity that can induce an adverse biological effect), or *taxa* (i.e., the common name, assemblage, species, genus, tribe, family, order, etc. that was studied, U.S EPA 2007).

Advanced search was used to query CADLit literature database. Rivers or streams were selected as habitats, and nutrients or suspended sediment as exposure parameters. The exposure parameters include all the more specific child parameters of these two parameter classes. Benthic macroinvertebrates and fish were selected as the effected taxa. Location fields were left empty (figure 4).

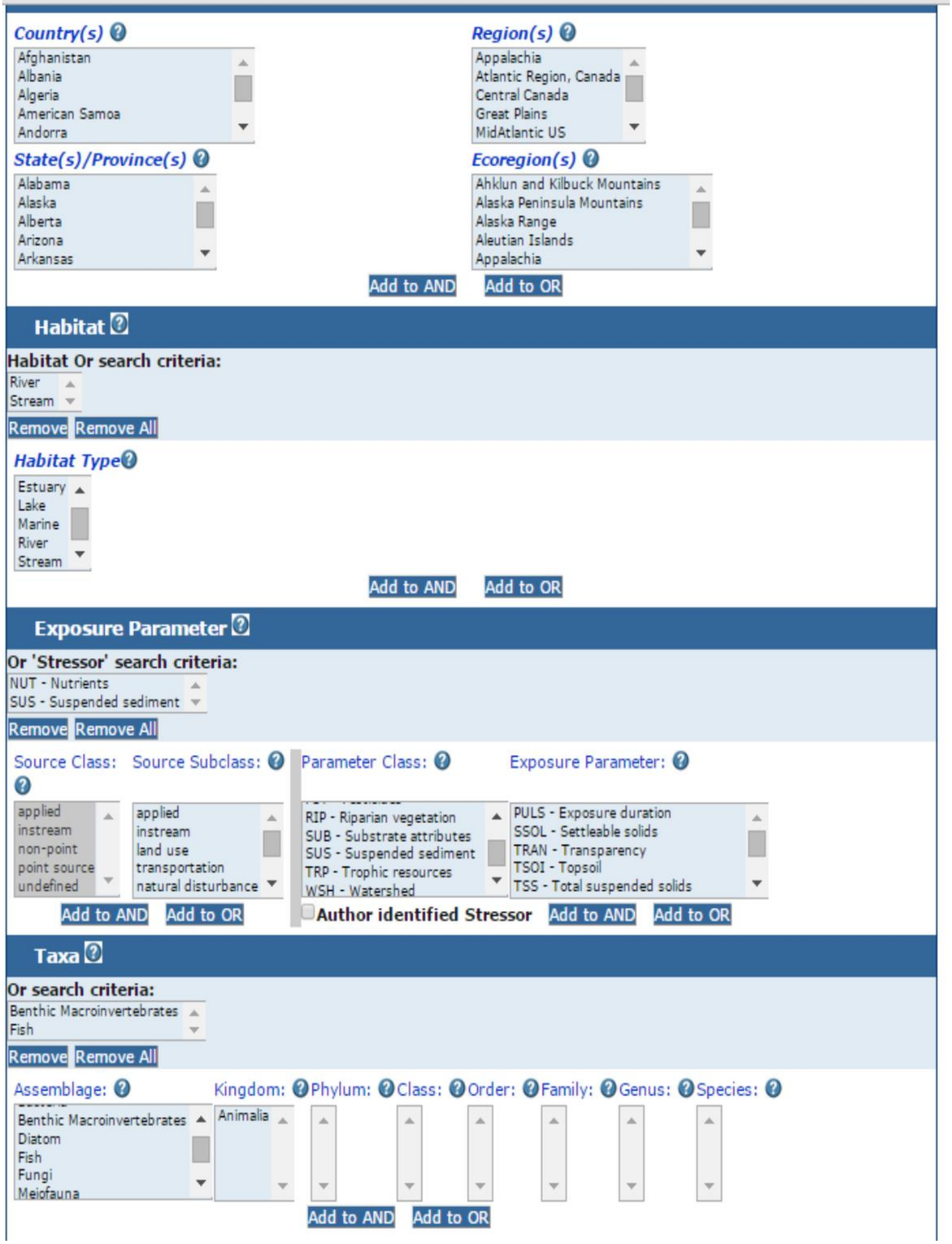



**fig 4** Advanced search view in the CADLit literature database, where habitat types, exposure parameters and effected taxa are used as search criteria

When each check box is selected, the produced Excel file will include the following categories:

Citation:

- Authors (CIT_AUTHOR),
- publication date (CIT_YEAR),
- title (CIT_TITLE),
- journal name (CIT_PUB_CODE),
- volume, issue and pages (CIT_VOLUME_ISSUE_PAGE) and
- dataset identification number (DATASET_ID)

Sources:

- Dataset identification number (DATASET_ID),
- source class (SOURCE_CLASS_CODE),
- source subclass (SOURCE_GROUP_CODE) and
- description of source subclass (SOURCE_OF_STRESS_ CODE)

Design:

- dataset design (DATASET_DESIGN_TYPE_CODE),
- study duration (DATASET_ DURATION),
- measurement units for study duration (DATASET_DURATION_UNIT_CODE),
- habitat (DATASET_HABITAT_CODE),
- dataset identification number (DATASET_ID),
- replications of measurements 12 (DATASET_NUM_REPS_SU),
- number of sampling units (DATASET_NUM_ SAMPLING_UNITS),
- description of sampling unit (DATASET_SAMPLING_UNIT_TYPE),
- season of study (DATASET_SEASON) and
- study type (DATASET_STUDY_TYPE_CODE).

Exposure:

- Dataset identification number (DATASET_ID),
- number of exposure classes (EXPOS_IS_ STRESSOR),
- frequency of exposure measurements (EXPOS_MEASUREMENT_FREQUENCY),
- units for frequency of exposure measurements (EXPOS_MEAS_FREQ_UNIT_CODE),
- location of exposure measurement (EXPOS_MEAS_LOC_CODE),
- method for measuring exposure (EXPOS_MEAS_ METHOD),
- exposure measurement time (EXPOS_MEAS_TIME_CODE),
- exposure measurement type (EXPOS_MEAS_TYPE_CODE),
- exposure media (EXPOS_MEDIA_CODE),
- exposure parameter class (EXPOS_PARAM_CLASS_CODE),
- exposure parameter group (EXPOS_PARAM_GROUP),
- exposure parameter measure (EXPOS_PARAM_MEAS_CODE),
- exposure parameter measure units (EXPOS_ PARAM_UNIT_CODE), and
- exposure sample size (EXPOS_SAMP_SIZE_STAT).

- Quantitative exposure and response data:
- Exposure class description (CLASS_DESCRIPTOR),

- dataset identification number (DATASET_ID),
- maximum exposure measurement in class (EXPOSURE_ CLASS_EXP_MAX),
- minimum exposure measurement in class (EXPOSURE_CLASS_EXP_MIN),
- standard deviation of exposure measurements in class (EXPOSURE_CLASS_EXP_STD_DEV),
- mean of exposure measurements in class (EXPOSURE_CLASS_EXP_MEAN),
- response description (RESPONSE_DS_CLASS_CODE),
- maximum response measurement in class (RESPONSE_MAX),
- mean response measurement in class (RESPONSE_MEAN),
- minimum response mean (RESPONSE_MIN),
- standard deviation of response measurements in class (RESPONSE_STANDARD_DEV).

Response:
- Dataset identification number (DATASET_ID),
- Life stage (RESPONSE_LIFESTAGE_ CODE),
- method for measuring response (RESPONSE_MEAS_METHOD),
- description of way response was measured (RESPONSE_METHOD),
- response parameter class (RESPONSE_PARAM_CLASS2_ CODE),
- response parameter (RESPONSE_PARAM_CODE),
- response parameter group (RESPONSE_PARAM_GRP2_CODE) and
- response site (RESP_SITE_CODE)

Taxonomic:
- dataset identification number (DATASET_ID),
- assemblage (TAX_ASSEMBLAGE_ CODE),
- class (TAX_CLASS_CODE),
- coldwater/warm water (TAX_COLD_WARMWATER),
- common name (TAX_COMMON),
- family (TAX_FAMILY_CODE),
- functional feeding group 1 (TAX_FFG1),
- functional feeding group 2 (TAX_FFG2),
- dominant functional feeding group (TAX_FFG_EDAS),
- functional feeding group reference (TAX_FFG_REF),
- lowest level taxonomic identification (TAX_FINAL_ID),
- level of taxonomic identification (TAX_FINAL_TIPE),
- genus (TAX_GENUS_ CODE),
- guild (TAX_GUILD),
- habitat 2 (TAX_HABIT_2),
- habitat 1 (TAX_HABIT_1),
- primary habitat (TAX_HABIT_EDAS),
- habitat reference (TAX_HABIT_REF),
- kingdom 13 (TAX_KINGDOM_CODE),
- lithophilic taxa (TAX_LITHOPHIL),
- minnows (TAX_MINNOWS),
- native taxa (TAX_NATIVE),
- order (TAX_ORDER_CODE),
- phylum (TAX_PHYLUM_CODE),
- resident trout (TAX_RESIDENT_AND_TROUT),

- species (TAX_SPECIES_CODE),
- stratum (TAX_STRATUM),
- top carnivore (TAX_TOP_CARNIVORE_AND_TROUT),
- tribe (TAX_TRIBE_CODE),
- trophic group (TAX_TROPHIC) and
- variety (TAX_VARIETY_CODE).

### 2.1.2 Eco Evidence database

The Eco Evidence online database can be used for storing and sharing evidence items. It provides a permanent repository for causal evidence items and allows users to access and re-use evidence items entered by other users (Webb et al. 2011). The information in the database is organized such that a citation can have one or more evidence items, which is a summary of the findings contained in a study assessing a cause-effect linkage (Webb et al. 2012). An evidence item consists of a set of standard attributes, which can be seen in table 1. Drop-down lists are used for many attributes, because the various options have specific interpretations and weightings applied within the Eco Evidence Analysis. Only a small subset (cause, description of cause, effect, description of effect, study design) of the fields in an evidence item are compulsory (Webb et al. 2012).

**Table 1** Fields and their organisation in an Eco Evidence evidence item (modified after Webb et al. 2012)

| Grouping | Drop-down, list, or restricted type fields | | | Free text fields |
|---|---|---|---|---|
| Cause | Trajectory | Term & attribute | | Description |
| Effect | Trajectory | Term & attribute | | Description |
| Design & replication | Type | Impact units | control units | Description |
| Association | Type | | | Description |
| | Dose-response | Form of D/R | | Description |
| Analysis | Appropriate? | | | Description |
| | Cause in biota? | Suitable for meta-analysis | | |
| Strength of association | Type | Effect size | Variability | Description |
| Time order | Type | | | Description |
| Coherence | Type | | | Description |
| Predictive performance | | | | Description |
| Information for other users | | | | Question asked |
| | | | | Design pp |
| | | | | Results pp |
| | | | | Discussion pp |

The cause-effect data in Eco Evidence online database describes study's location or environment, methods and study design, results and citation details. The evidence can be searched by citation details or by selecting cause or causes and effect or effects in evidence fields. The users can search for evidence items using the following criteria (from Webb et al. 2012):

• Bibliographic information from the original literature item

• Multiple causes and/or effects from the standard terms list

• The 'question' recorded by the original extractor of the evidence

• Study characteristics to restrict scope of search

• Search only with the 'my evidence' list for the user to restrict scope of search to evidence entered / modified by that user

The causes and effects are identified by typing key words into the cause or effect fields, or by selecting them from the standard terms list. The search in this study was conducted by selecting cause parameters in evidence fields. The selected causes were: bedload, substrate, nutrients, suspended sediment and turbidity. Fish and invertebrates were selected in effect fields. Selecting fish in general includes the following sub-categories: abundance, age structure, assemblage, behaviour, competition, condition, deformities, disease, dispersal, diversity, exotic invasion, fish kills, gasping, growth, mortality, recruitment, reproduction and tissue toxicant concentration. The sub-categories in invertebrates' field are: abundance, age structure, assemblage, behaviour, competition, condition, deformities, disease, dispersal, diversity, exotic invasion, growth, mortality, recruitment and reproduction.

A similar search was conducted to find possible drivers eventually leading to eutrophication and increase in fine sediment content. In this search the following parameters were selected to the cause fields: agriculture, floodplain, flow regulation, industry and land use. The causes of the previous search (bedload, substrate, nutrients, suspended sediment and turbidity) were selected in effect fields.

## 2.2 Strength of the evidence

The quality of the evidence can be evaluated with the Eco Evidence tool in terms of three study quality attributes, which are:

1. study design type
2. number of independent sampling units used as controls, and
3. numbers of (potentially) impacted independent sampling units

Studies in which the error terms are well controlled (e.g. BACI designs) attract greater weighing than less rigorously controlled designs. Also studies with more than one impact location have more weight, as well as increasing numbers of control locations (Greet et al. 2011). The overall study weight is given by summing the weights of each of these three attributes. The default weightings are listed in table 2. They can also be adjusted to suit the particular circumstances of a review, but any changes made by the user should be documented and justified (Greet et al. 2011).

**Table 2** The default weightings in Eco Evidence Analysis (modified after Nichols et al. 2011)

| **Study design type** | **Weight** |
|---|---|
| After impact only | 1 |
| Reference/Control vs. impact (no before) | 2 |
| Before vs. after (no reference/control) | 2 |
| Gradient response model | 3 |
| BACI or BARI MBACI or Beyond MBACI | 4 |
| **Number of control/reference locations** | |
| 0 | 0 |
| 1 | 2 |
| ≥2 | 3 |
| **Number of impact locations** | |
| 1 | 0 |
| 2 | 2 |
| >2 | 3 |
| **Number of impact locations in gradient-based designs** | |
| 3 | 0 |
| 4 | 2 |
| 5 | 4 |
| ≥6 | 6 |

## 2.3 Model construction

The conceptual diagrams will be constructed with CADDIS ICD application and Microsoft Visio diagramming platform, as the Eco Evidence tool is missing this function. The diagrams will visualise the causal linkages gathered from the literature, and the literature references supporting the given linkages will be stored in the CADDIS model. The same input data will be used to create diagrams with CADDIS ICD application and with MS Visio in order to compare the possibilities of a ready-customised diagramming application and a freely usable diagramming program.

### 2.3.1 CADDIS ICD application

The ICD application has two modes; view mode (figure 5) and edit mode (figure 6). View mode can be used to view existing diagrams and search for the references saved in the diagrams, and the edit mode can be used to create new and modify already existing diagrams. The edit mode is only visible to registered and logged in users. Without logging in only the diagrams made by U.S. EPA can be viewed. In the edit mode, the diagrams will be created to an empty background canvas (figure 7). The shapes, which are representing different entities in the cause-effect chains, have predefined definitions in the application (figure 8). They can also be used differently, and in this work the shapes will be defined according to the DPSIR framework used in the MARS project (figure 9). The causal linkages between the entities will be supported by scientific literature references, which are gathered in the evidence search. These references will be saved in the diagram (figures 10 & 11).


**Fig 5** Toolbar in the View mode of the CADDIS ICD application

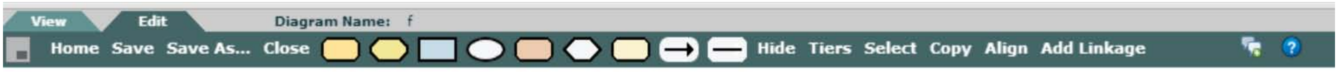



**Fig 6** Toolbar in the Edit mode of the CADDIS ICD application

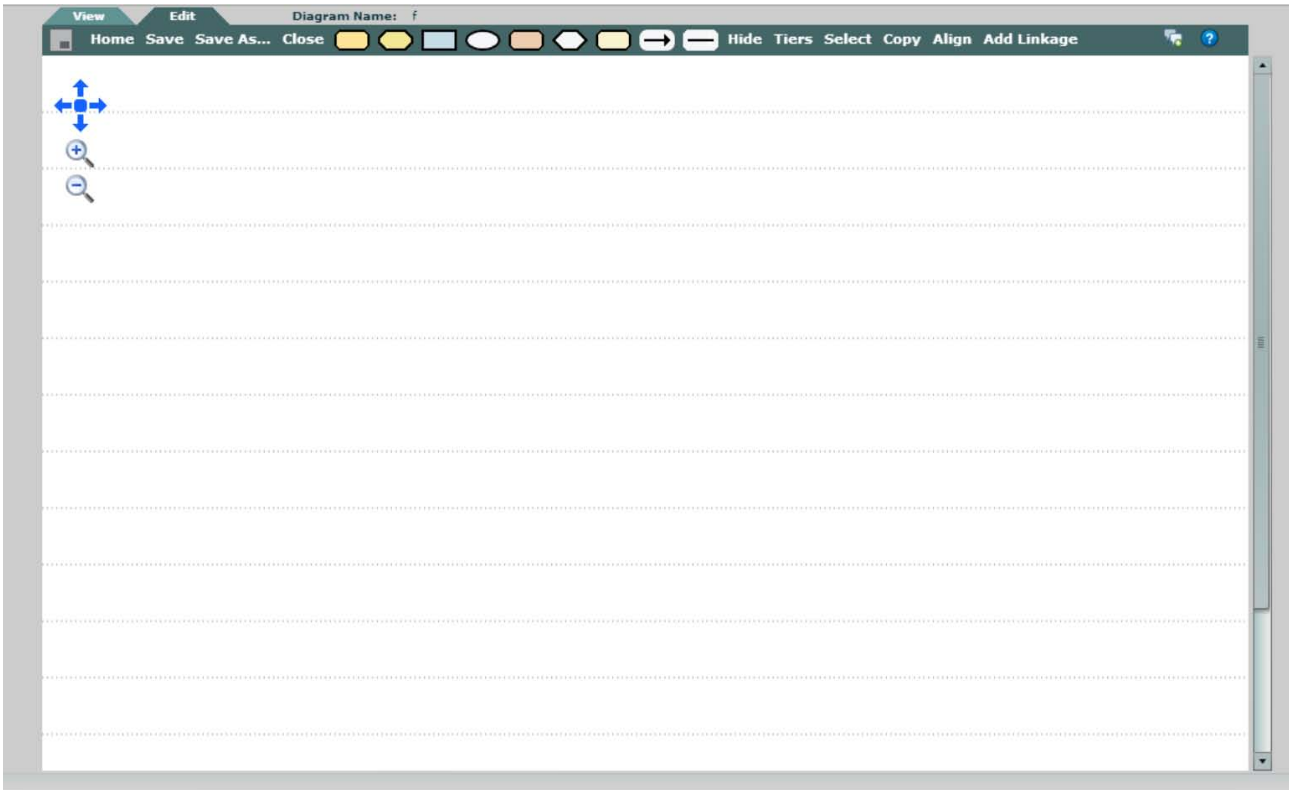



**Fig 7** An empty background canvas, where a new diagram can be created in the CADDIS ICD application

| Shape | Definition |
|---|---|
| Human Activity | Activity or land use that directly or indirectly leads to one or more sources |
| Source | Entity that directly or indirectly leads to one or more proximate stressors |
| Stressor | Physical, chemical, or biological entity that directly or indirectly induces one or more biotic responses of concern |
| Response | Biological result of exposure to one or more stressors |
| Modifying Factor | Process or state that modifies delivery or expression of a stressor |
| Mode of Action | Process or state that causally connects a stressor to a biotic response |
| Additional Steps | Process or state that causally connects a source to a stressor |

**Fig 8** The shapes and their predefined definitions as recommended in CADDIS


**Fig 9** The ICD shapes and the categories they are representing in this work

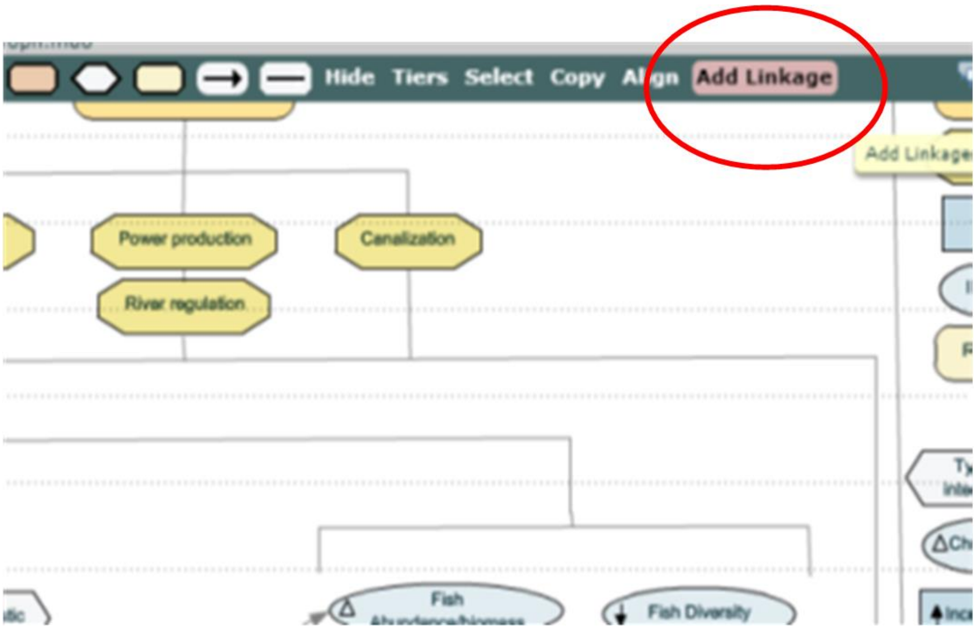



**Fig 10** Literature references can be saved in the ICD application by selecting 'Add Linkage' from the toolbar in edit mode of the application

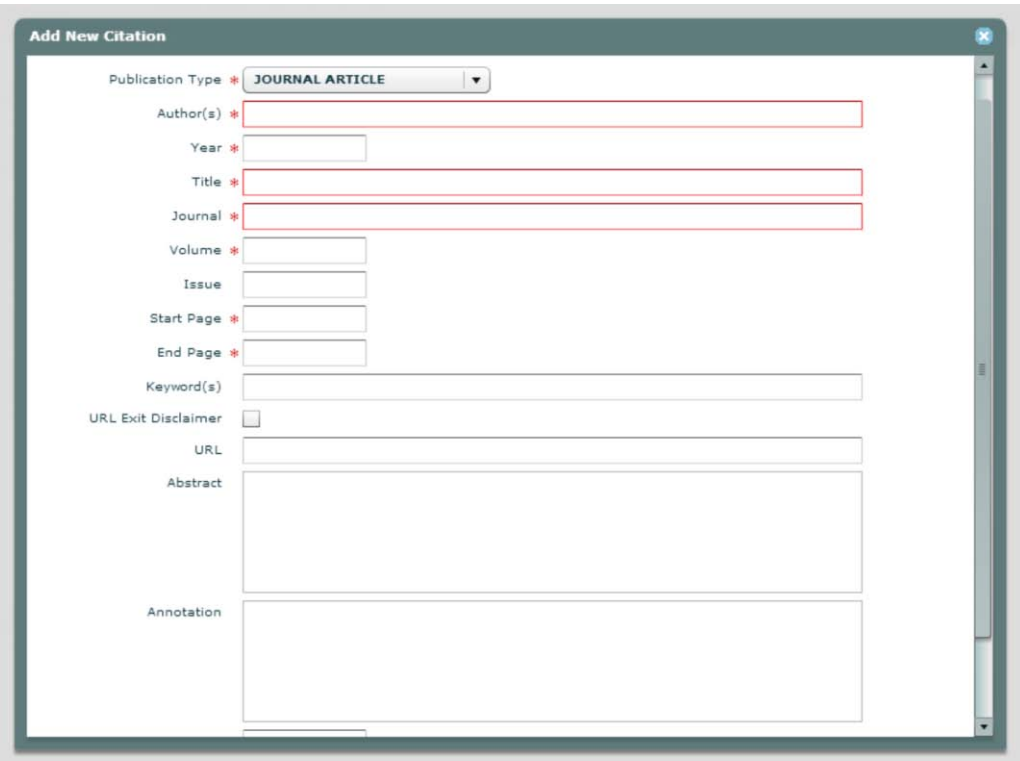



**Fig 11** A pop-up window where literature citations can be linked to shapes in the CADDIS ICD application

# 3 Results

## 3.1 Evidence search

The results of the literature search are listed in appendix A. In the table each row consists one evidence item, which besides the citation details includes information about at least the abiotic state (nutrients or fine sediment or both) and the biotic state which is impacted by it. Same citation might have multiple evidence items, which are listed on separate rows of the table. The original information, which was collected to the excel table includes the following details. Only the bold fields are listed in the appendix (A). Full citations can be found in the reference list of this study.

- **Number of evidence item**
- **First author**
- **Year of publication**
- Full reference
- Country
- Study type (survey or experiment)
- **Drivers and pressures causing increased fine sediment (fs), nitrogen (N) and/or phosphorus (P) levels**
- **Stressor(s) and type of interaction (synergistic [syn], additive [add] or antagonistic [ant])**
- Fine sediment compartment and unit
- Fine sediment minimum value
- Fine sediment maximum value
- Nitrogen compartment
- Nitrogen minimum value (µg/l)
- Nitrogen maximum value (µg/l)
- Phosphorus compartment
- Phosphorus minimum value (µg/l)
- Phosphorus maximum value (µg/l)
- **Indicator group, macroinvertebrates (MI) or fish (FI)**
- **Indicator metric**
- **Sign of the response of the indicator metric (+, - or +/- [subsidy-stress response])**
- Remarks
- Nitrogen threshold
- Phosphorus threshold
- Fine sediment threshold
- Other thresholds
- **Variable category**

### 3.1.1 CADDIS Literature Resource

The results of the CADLit search were downloaded to an excel spreadsheet. The database contained 95 citations concerning the selected parameters. The excel file consists of several thousand rows and

78 columns containing various amount of information, which is extracted from the scientific literature. Nevertheless, the specific cause-effect linkages are not identified, and therefore the information cannot be used in this study.

### 3.1.2 Eco Evidence

Eco Evidence online database contained 39 evidence items supporting the linkage between channel bedload and invertebrates, and one evidence item supporting the linkage between substrate as physical habitat and fish (figure 12). The structure of the downloaded list of evidence items can be seen in figure 13. The 40 evidence items were checked individually to find the suitable references for the diagrams. The list included several citations, which were already part of the reviewed literature. New citations were added to the diagrams to strengthen the evidence supporting the causal ecological linkages.

| Cause \ Effect | fish | invertebrates |
|---|---|---|
| channel (bedload) | - | 39 items |
| physical habitat (substrate) | 1 item | - |
| water quality (nutrients) | - | - |
| water quality (suspended sediment) | - | - |
| water quality (turbidity) | - | - |

**Fig 12** Eco Evidence search matrix. The database contains 39 evidence items linking channel bedload and invertebrates, and one evidence item linking physical habitat and fish

| Tools | Details [Sort: Last modified \| Cause \| Effect \| Author \| Title \| Year ] |
|---|---|
| SelectView citation | **Citation:** Bjornn, T.C., Brusven, M.A., Molnau, M., Milligan, J.H., Kalmt, R.A., Chacho, E., Schaye, C. (1977) *Transport of Granitic sediment in streams and its effects on insects and fish*<br>**Linkage:** ↑ channel (bedload) → Δ invertebrates (abundance)<br>**Cause detail:** 1/3 substarte emdededness<br>**Effect detail:** Decreased total abundance |
| SelectView citation | **Citation:** Larsen, S. and Ormerod, S.J. (2010) *Low-level effects of inert sediments on temperate stream invertebrates*<br>**Linkage:** ↑ channel (bedload) → Δ invertebrates (abundance)<br>**Cause detail:** field experiment where fine sediment was added to a stream (4-5kg/m2- 25-30%) substrate composition<br>**Effect detail:** decrease in overall density |
| SelectView citation | **Citation:** Harrison, E.T. (2010) *Fine sediment in rivers: scale of ecological outcomes*<br>**Linkage:** ↑ channel (bedload) → ↓ invertebrates (abundance)<br>**Cause detail:** fine sediment threshold- 10% substrate composition<br>**Effect detail:** decrease Coleoptera Elmidae density |

**Fig 13** The first three evidence items supporting the linkage between bedload and invertebrates from the list of references downloaded from the Eco Evidence database

The search for the possible drivers from the Eco Evidence database resulted in only one piece of evidence, supporting the linkage between floodplain and substrate (figure 14). Closer look revealed that the evidence item could not be used in this study, but the cause-effect relationship concerned the association between floodplain accretion and soil nitrogen content. Therefore no additional causes for the stressors were found in the Eco Evidence database.

| Cause \ Effect | channel (bedload) | physical habitat (substrate) | water quality (nutrients) | water quality (suspended sediment) | water quality (turbidity) |
|---|---|---|---|---|---|
| agriculture | - | - | - | - | - |
| floodplain | - | 1 item | - | - | - |
| flow regulation | - | - | - | - | - |
| industry | - | - | - | - | - |
| land use | - | - | - | - | - |

**Fig 14** The search for possible drivers found one evidence item in Eco Evidence database

## 3.2 Harmonisation of the biotic response variables

One of the original variable categories, which were introduced in WISER project by Feld et al. (2011) is absent in the results of this work (age structure). In the reference literature used in this study, no metrics concerning the age structure of fish or invertebrate communities were found. On the other hand one additional variable category, *disease and deformities*, is introduced here. The categories describing ecological impacts in this work are:

1. composition and abundance (e.g. relative abundance of specific taxa, total community abundance, indices of biotic integrity),
2. sensitive and tolerant taxa (e.g. metrics concerning salmonid fish species or benthic invertebrates belonging to Ephemeroptera-Plecoptera-Trichoptera [EPT] taxa),
3. diversity (e.g. diversity indices, taxon richness),
4. biomass and density (e.g. fish biomass, invertebrate dry mass, density of specific taxa, total density),
5. processes and functions (e.g. species traits such as feeding types or body size),
6. disease and deformities (e.g. percentage of fish with disease or deformities).

Each biological response variable has been placed to only one of these categories. Therefore e.g. EPT diversity indices are grouped in the *sensitive and tolerant taxa* even though they could also be placed in *diversity* or *composition and abundance.* Also *processes and functions* overrides the other categories despite the fact that changes in the species traits also affect the total community composition.

## 3.3 Drivers and pressures causing increased fine sediment and nutrient concentrations

Agriculture and farming intensity were identified as drivers causing excess fine sediments in many surveys (Lange et al. 2014a; Mondy & Usseglio-Polatera 2013; Scruton et al. 2008; Robertson et al. 2008; Sutherland et al. 2002; Townsend et al. 2008; Wagenhoff et al. 2011). Absence of forest was related to high fine sediment concentrations as well (Robertson et al. 2008). Osmundson et al. (2002) found reduced high flows caused by river regulation as cause for the elevated fine sediment levels. In some surveys the sediment transport was naturally high (e.g. Buendia et al. 2013), or natural situation was exacerbated by forest clearance (Richardson & Jowett 2002). In experimental study designs there were naturally no drivers but the high sediment rates were artificially created for research purposes (e.g. Matthaei et al. 2010; Piggott et al. 2012; Wagenhoff et al. 2012).

Farming and agriculture in general were causing increased nitrogen and phosphorus levels in the investigated waterbodies (Wang et al. 2007; Robertson et al. 2008; Mondy & Usseglio-Polatera 2013; Lange et al. 2014a; 2014b). Absence of forest was correlating with nitrogen and phosphorus levels in the study by Wang et al. (2007) and with nitrogen levels only by Robertson et al. (2008). Additionally water abstraction was related to increased phosphorus concentrations (Lange et al. 2014a). In some studies the drivers were not specified concerning nutrients (e.g. Miltner & Rankin 1998; Larsen et al. 2009), and in experimental studies they were absent (e.g. García Molinos & Donohue 2010; Matthaei et al. 2010; Piggott et al. 2012).

## 3.4 Ecological effects of increased fine sediment concentration

*Composition and abundance*

Increase in fine sediment caused a decrease (Bjornn et al. 1977; Bo et al. 2007; Larsen et al. 2011) or increase (Piggott et al. 2012) in total invertebrate abundance. In the study by Larsen et al. (2009), invertebrate abundance response to increased fine sediment depended on the location of the survey, being positive at upland locations and negative in improved grasslands. Bryce et al. (2010) found a decrease in Macroinvertebrate Index of Biotic Integrity (IBI) and Robertson et al. (2008) reported an increase in Hilsenhoff Biotic Index (HBI) following increased fine sediment levels. Several studies reported changes in taxa level (e.g. Larsen et al. 2009; Matthaei et al. 2010; Piggott et al. 2012; Lange et al. 2014a). Taxa level responses to increased fine sediment concentrations were e.g. increase in relative abundance of Oligochaeta (Larsen et al. 2009; Lange et al. 2014a), decrease in relative abundance of Coleoptera (Larsen et al. 2009) and increase in Nematoda abundance (Piggot et al. 2012).

Fish responses to increase in fine sediment were all negative. Richardson & Jowett (2002) found a decrease in fish abundance and Robertson et al. (2008) in number and relative abundance of riverine fish species, as well as a decrease in Fish IBI.

*Diversity*

Total invertebrate taxon richness decreased in several studies (Rabení et al. 2005; Bo et al. 2007; Robertson et al. 2008; Larsen et al. 2009; Harrison 2010; Matthaei et al. 2010; Larsen et al. 2011: Clapcott et al. 2012; Wagenhoff et al. 2012 Buendia et al. 2013). Piggot et al. (2012) found a hump shaped (increase followed by a decrease) response of taxon richness to increase in fine sediment concentration. Evenness increased with increasing fine sediment levels (Lange et al. 2014a), or the response was hump shaped (Wagenhoff et al. 2012).

Concerning fish, diversity decreased with increasing fine sediment concentration (Richardson & Jowett 2002).

*Sensitivity and tolerance*

Following increase in fine sediment, EPT richness decreased in several studies (Zweig & Rabeni 2001; Kaller & Hartman 2004; Townsend et al. 2008; Larsen et al. 2009; Harrison 2010; Wagenhoff et al. 2012; Buendia et al. 2013). Relative abundance of EPT taxa increased in some studies (e.g. Larsen et al. 2009; Buendia et al. 2013), and decreased in others (e.g. Bryce et al. 2010; Wagenhoff et al. 2012). EPT density mainly decreased (Angradi 1999; Zweig & Rabeni 2001; Wagenhoff et al. 2012; Buendia et al. 2013), but also increase was reported (Townsend et al. 2008). Pollution tolerant taxa increased (Robertson et al. 2008).

Sensitive fish metrics were negatively impacted by increase in fine sediment content. The following indicators decreased when fine sediment concentration increased: Incubating brook trout survival (Argent & Flebbe 1999), four sediment-sensitive fish species (Bryce et al. 2010), trout presence and trout density (Lange et al. 2014b) and number of species considered intolerant of degradation (Robertson et al. 2008).

*Density and biomass*

Invertebrate density was negatively impacted by increase in fine sediment (e.g. Angradi 1999; Osmundson et al. 2002; Larsen & Ormerod 2010; Matthaei et al. 2010; Buendia et al. 2013), or the response curve was hump shaped (Wagenhoff et al. 2012). Wagenhoff et al. (2012) reported also several other subsidy-stress responses to increasing fine sediment in taxa level (Oligochaeta density, Nematoda density, Copepoda density, Ostracoda density).

*Processes and functions*

Invertebrate trait responses to increase in fine sediment levels were investigated in several studies. Fine sediments impacted e.g. feeding groups (Rabení et al. 2005; Bo et al. 2007; Wagenhoff et al. 2012; Buendia et al. 2013; Mondy & Usseglio-Polatera 2013), body size or shape (Wagenhoff et al. 2012; Buendia et al. 2013), reproduction (Townsend et al. 2008; Wagenhoff et al. 2011; Wagenhoff et al. 2012; Buendia et al. 2013; Mondy & Usseglio-Polatera 2013; Lange et al. 2014a), locomotion (Rabení et al. 2005; Townsend et al. 2008; Wagenhoff et al. 2012; Buendia et al. 2013; Mondy & Usseglio-Polatera 2013; Lange et al. 2014a), respiration (Townsend et al. 2008; Wagenhoff et al. 2012; Buendia et al. 2013), and life cycle duration (Buendia et al. 2013, Lange et al. 2014a).

In most studies filter feeders were impacted negatively (Rabení et al. 2005; Bo et al. 2007; Wagenhoff et al. 2011; Wagenhoff et al. 2012; Buendia et al. 2013), but also an increase in relative abundance of filterers was found (Mondy & Usseglio-Polatera 2013). The effects to shredders were positive (Rabení et al. 2005) or negative (Buendia et al. 2013) depending on the study. Also scrapers were reported to have positive (Buendia et al. 2013) as well as negative (Rabení et al. 2005; Mondy & Usseglio-Polatera 2013) responses to increasing fine sediment content. The richness of scrapers, gatherers, filterers and predators decreased (Rabení et al. 2005). A decrease was found in relative abundance of grazers (Wagenhoff et al. 2012), and an increase in relative abundances of gatherers (Rabení et al. 2005), deposit feeders (Wagenhoff et al. 2012) and predators (Wagenhoff et al. 2012). Clear trends in responses in body shape and size were missing. Concerning reproduction a decrease in surface egg laying (Townsend et al. 2008; Wagenhoff et al. 2012) and cemented eggs (Mondy & Usseglio-Polatera 2013; Lange et al. 2014a) were observed, as well as an increase in single individual reproduction (Wagenhoff et al. 2011, Wagenhoff et al. 2012), to mention few responses. Burrowers responded positively to increase in fine sediment (Townsend et al. 2008; Wagenhoff et al. 2012; Mondy & Usseglio-Polatera 2013; Lange et al. 2014a), but also a negative response was found (Buendia et al. 2013). Crawlers decreased in two of the studies (Buendia et al. 2013; Mondy & Usseglio-Polatera 2013). The richness of spawlers, swimmers and clingers decreased (Rabení et al. 2005). The results concerning respiration were controversial as well. The share of respiration with gills decreased in the study by Townsend et al. (2008), and increased in the study by Wagenhoff et al. (2012).

Concerning fish, benthic crevice and gravel spawners were negatively impacted by fine sediment (Sutherland et al. 2002). Also Robertson et al. (2008) found a decrease in percentage of individuals that are lithophilic spawners. Feeding types were investigated by Robertson et al. (2008). They found a decrease in suckers and insectivores.

*Disease and deformities*

Diseases or deformities of invertebrate or fish following increase in fine sediment levels were not focused in the reference literature used in this study.

## 3.5 Ecological effects of increased nutrient concentration

*Composition and abundance*

Increasing nitrogen caused a decrease in Invertebrate Community Index (ICI, Miltner & Rankin 1998) and Macroinvertebrate Index of Biotic Integrity (MIBI, Wang et al. 2007), but an increase in HBI (Wang et al. 2007; Robertson et al. 2008). Relative abundances of e.g. Ostracoda (Lange et al. 2014a), Isopoda (Wang et al. 2007), and midge individuals (Wang et al. 2007) increased following a nitrogen increase.

Increase in phosphorus concentrations were followed by a decrease in ICI (Miltner & Rankin 1998), and an increase in HBI (Wang et al. 2007; Robertson et al. 2008). Relative abundances of Isopoda taxa and individuals increased (Wang et al. 2007).

Increase in nitrogen and phosphorus caused an increase in total invertebrate abundance (Piggott et al. 2012).

Concerning fish, nitrogen caused a decrease in fish IBI (Miltner & Rankin 1998; Wang et al. 2007; Robertson et al. 2008), as well as number of riverine species and percentage of their share of the total biomass (Robertson et al. 2008). Also relative number of native species as well as native fish individuals decreased (Wang et al. 2007). Increase in relative number of sunfish species and individuals were found by Wang et al. (2007).

Phosphorus had a negative effect in IBI (Miltner & Rankin 1998; Wang et al. 2007). Number of riverine species and their relative abundance decreased as well (Robertson et al. 2008).

*Diversity*

Phosphorus caused a decrease in invertebrate species richness (Robertson et al. 2008), and a similar response was followed by an increase in nitrogen concentrations (Wang et al. 2007; Robertson et al. 2008). Increase in nitrogen also caused a decrease in Shannon diversity (Wang et al. 2007). Wagenhoff et al. (2012) found a hump shaped response of total invertebrate taxon richness to increased nitrogen and phosphorus content, and an increase in evenness.

*Sensitivity and tolerance*

Nitrogen and phosphorus caused a decrease in relative abundance of EPT taxa (Wang et al. 2007; Robertson et al. 2008). Robertson et al. (2008) additionally reported a decrease in relative abundances of Ephemeroptera and Plecoptera individuals. Increase in nitrogen concentration was followed by an increase in relative abundance of Trichoptera individuals (Robertson et al. 2008). Mean pollution tolerance value increased with both nitrogen and phosphorus (Wang et al. 2007; Robertson et al. 2008).

Increase in nitrogen and phosphorus were followed by an increase in total EPT abundance (Piggott et al. 2012) and in relative abundance of EPT taxa (Wagenhoff et al. 2012). EPT density and EPT richness had hump shaped responses to nitrogen and phosphorus contents (Wagenhoff et al. 2012), Chironomidae abundance and Conoescidae abundance increased (Piggot et al. 2012). Chironomidae density and Deleatidium density had hump shaped responses to increased nitrogen and phosphorus concentrations (Wagenhoff et al. 2012).

Trout density decreased with increasing nitrogen (Lange et al. 2014b), and intolerant fish species (number of species considered intolerant of degradation) were negatively affected by both nitrogen and phosphorus increase (Robertson et al. 2008). Wang et al. (2007) reported decreases in intolerant fish catch, relative abundance of individuals of intolerant species as well as relative abundance of intolerant fish species following both nitrogen and phosphorus increases. Salmonids were negatively affected by nitrogen and phosphorus (catch of salmonid fishes decreased), and tolerant species increased (percentage of individuals of tolerant fishes, percentage of number of tolerant species and catch of tolerant fishes per 100m) when nitrogen concentration increased (Wang et al. 2007).

*Density*

Increase in nitrogen and phosphorus concentration caused an increase in total invertebrate density (Matthaei et al. 2010), and a decrease in densities of Oligochaeta, Cladocera and Ostracoda (Wagenhoff et al. 2012). Tanypodinae density, Psilochorema density and total invertebrate density had hump shaped responses to the common increase of nitrogen and phosphorus (Wagenhoff et al. 2012).

Fish densities were responding to increased nitrogen concentrations in a couple of studies. Bully density had unimodal response (Lange et al. 2014b) and fish biomass increased with increasing nitrogen (Wang et al. 2007).

*Processes and functions*

Invertebrate functional trait responses to increase in nitrogen were reported in few studies (Wang et al. 2007; Robertson et al. 2008; Lange et al. 2014a). Most of them were related to feeding types. Lange et al. (2014a) found a decrease in scrapers and an increase in deposit feeders and predators. Robertson et al. (2008) found a decrease in relative abundance of scrapers and an increase in shredders. Wang et al. (2007) reported an increase in relative abundances of gatherer taxa, filterer taxa, shredder taxa, shredder individuals and scraper individuals. A decrease was found in relative abundance of predator taxa and number of (predator) individuals (Wang et al. 2007). Additionally a decrease in crawlers and atmospheric oxygen respiration were related to an increase in nitrogen (Lange et al, 2014a).

Common impacts of nitrogen and phosphorus were investigated by Wagenhoff at al. (2012). The nutrients effected e.g. respiration and reproduction types, body size and body shape. The only effect on feeding types was a decrease in relative abundance of filterers.

Concerning fish, nitrogen caused decreases in relative abundances of lithophilic spawners, round-bodied suckers and insectivores (Robertson et al. 2008). The same functional groups were affected by phosphorus, with the similar responses (Robertson et al. 2008). Relative abundances of carnivore fish species and individuals, as well as catch of carnivores per 100m decreased with both nitrogen increase and phosphorus increase (Wang et al. 2007). An increase was found in percentage of omnivore individuals (in relation to nitrogen) and in percentage of omnivore species (in relation to both nitrogen and phosphorus, Wang et al. 2007).

*Disease and deformities*

Increases in total phosphorus and nitrate concentrations increased the percentage of fish with diseases or deformities (Robertson et al. 2008).

## 3.6 Ecological effects of multi-stressor impacts

*Composition and abundance*

Lange et al. (2014a) found additive effects of fine sediment and nitrogen to relative abundances of *Potamopyrgus* spp. and Copepoda as well as to Macroinvertebrate Community Index (MCI). The interaction between the stressors was antagonistic when affecting relative abundance of Nematoda and synergistic when affecting relative abundance of *Sphaerium* spp. (Lange et al. 2014a). Nitrogen, phosphorus and fine sediments affected synergistically to *Austrosimulium* spp. (Matthaei et al. 2010), Oligochaeta (Wagenhoff et al. 2011) and Elmidae (Wagenhoff et al. 2011). MCI decreased caused by an additive effect of the stressors (Wagenhoff et al. 2011). Also in the study of Lange et al. (2014a) the response of MCI was negative.

*Diversity*

Synergistic interactions of the stressors decreased invertebrate taxon richness (Townsend et al. 2008; Lange et al. 2014a), and Shannon diversity (García Molinos & Donohue 2010).

*Sensitivity and tolerance*

The combined effect of the stressors to EPT richness was additive in some studies (Wagenhoff et al. 2011; Lange et al. 2014a), but synergistic in others (Townsend et al. 2008; Wagenhoff et al. 2012). In all the before mentioned studies the response was negative (decrease in EPT richness). Relative abundance of EPT taxa decreased by an antagonistic effect of nitrogen and fine sediment (Lange et al. 2014a) and synergistic effect of nitrogen, phosphorus and fine sediment (Wagenhoff et al. 2011). Lange et al. (2014a) found also other additive (% *Deleatidium* spp.), synergistic (% Orthocladiinae) and antagonistic (*Corynoneura* spp.) effects. Wagenhoff et al. (2011) found a synergistic interaction between nutrients and fine sediment causing a decrease in relative abundance of *Deleatidium.*

Lange et al. (2014b) found an additive interaction of nitrogen and fine sediment, causing a decrease in trout density.

*Density*

Total invertebrate density had a hump shaped response to a synergistic interaction between nutrients and fine sediment on tile samples (Matthaei et al. 2010).

*Processes and functions*

Concerning feeding types, Lange et al. (2014a) found an additive response of shredders and filter feeders. Maximum body size was affected in synergistic, antagonistic or additive patterns depending on the size class (Lange et al. 2014a). Patterns affecting body form were antagonistic in the cases of flattened and cylindrical body form (Lange et al. 2014a), and additive in the case of spherical body form (Wagenhoff et al. 2012; Lange et al. 2014a). The reproduction variables were affected in additive multi-stressor patterns in the study of Lange et al. (2014a). Townsend et al. (2008) and Wagenhoff et al. (2011) found also synergistic responses (e.g. more than two reproductive cycles per individual). Lange et al. (2014a) studied also respiration techniques, life duration and locomotion types of invertebrates. The responses were mostly following additive multiple stressor patterns, although swimmers were affected synergistically.

*Disease and deformities*

There were no multiple stressor relationships concerned in the reference literature, which would have caused diseases or deformities to invertebrate or fish indicators.

## 3.7 Threshold concentrations

Bryce et al. (2010) defined minimum-effect sediment levels for areal percentage of fines to be 5% for fish, when the sediment size is equal or less than 0.06mm, and 13% when the grain size is equal or less than 2mm. The thresholds for macroinvertebrates were 3% and 10%, respectively. Clapcott et al. (2011) recommend, that sediment should not exceed either 20% cover or 450g/m² (SIS) to protect stream biodiversity and fish habitat. Sutherland et al. (2002) studied fish assemblage structure, and found in their study that during baseflow conditions the disturbed streams nearly always exceeded 10 Nephelometric Turbidity Units (NTU), while reference streams never exceeded this threshold. Additionally their findings suggest the existence of a threshold of non-forested land cover between

10 and 20%, beyond which Benthic crevice spawner and gravel spawner species cannot persist (Sutherland et al. 2002).

Miltner and Rankin (1998) diagnosed detectable deleterious effect of increasing nutrient concentration on fish communities in low order streams (in Ohio) when nutrient concentrations exceeded background conditions (total inorganic nitrogen and phosphorus > 0.61mg $L^{-1}$ and 0.06mg $L^{-1}$, respectively). Robertson et al. (2008) and Wang et al. (2007) defined the thresholds or breakpoint values as the concentrations at which the rate of response was greatest and therefore represented a critical concentration with ecological significance. The thresholds for nutrient concentrations by selected fish and invertebrate indicators, which were identified by Wang et al (2007), can be seen in tables 3 and 4 and thresholds or largest breaking points by Robertson et al. (2008) are shown in tables 5 and 6. Robertson et al. (2008) noted, that unlike the trends in the macroinvertebrate indices, at concentrations above even the highest threshold or breakpoint values, the biotic fish indices usually continued to degrade.

Nitrogen thresholds, after which the subsidy effect turned into stress reaction, were 107µg DIN $L^{-1}$ for *Pycnocentrodes* and 144µg DIN $L^{-1}$ for % EPT (Wagenhoff et al. 2011). In another study the inflection points of subsidy-stress responses to nutrient enrichment occurred at the concentrations of 728µg DIN $L^{-1}$ and 70µg DRP $L^{-1}$ for EPT density, relative abundance of EPT taxa, total taxon richness, EPT taxon richness and the mayfly *Deleatidium* and the caddis *Psilochorema* (Wagenhoff et al. 2012). Miltner & Rankin (1998) found significantly higher mean (fish) IBI scores in headwater streams when TIN and TP concentrations were below the 50$^{th}$ percentile of the investigated streams (N < 1.37mg $L^{-1}$ and P < 0.17mg $L^{-1}$). In wadable streams mean IBI scores were significantly lower at each successive category of increasing nutrient concentration, starting at a comparably low threshold (N > 0.61mg $L^{-1}$ and P > 0.06mg $L^{-1}$). Additionally mean IBI and ICI scores at sites having concentrations of $NH_3$-N ≥ 1.0mg $L^{-1}$ were usually significantly lower than all other categories across stream size (Miltner & Rankin 1998).

**Table 3** Nutrient threshold concentrations (mg $L^{-1}$) for wadeable streams in Wisconsin identified by selected fish indicators by Regression-Tree (left value) an by Kolmogorov-Smirnov (right value) techniques (Wang et al. 2007)

| Fish Index | Total phosphorus | Total nitrogen |
|---|---|---|
| Individuals of carnivores (%) | 0.06/0.09 | 0.54/1.22 |
| Fish index of biotic integrity | 0.06/0.07 | 0.54/1.36 |
| Catch of salmonoid fishes per 100m | 0.06/0.06 | 0.61/0.63 |
| Individuals of intolerant fishes (%) | 0.07/0.09 | 0.54/1.83 |

**Table 4** Nutrient threshold concentrations (mg $L^{-1}$) for wadeable streams in Wisconsin identified by selected macroinvertebrate indicators by Regression-Tree (left value) and by Kolmogorov-Smirnov (right value) techniques (Wang et al. 2007)

| Macroinvertebrate Index | Total phosphorus | Total nitrogen |
|---|---|---|
| Number of EPT taxa (%) | 0.09/0.08 | 0.98/1.68 |
| EPT individuals (%) | 0.09/0.09 | 1.11/1.30 |
| Hilsenhoff biotic index | 0.09/0.09 | 0.61/1.14 |
| Total number taxa | 0.04/0.04 | 0.85/0.87 |

**Table 5** Thresholds or breakpoints in the responses in fish indices to changes in nutrient concentrations for nonwadeable rivers in Wisconsin (mg $L^{-1}$) by Regression-Tree analysis (Robertson et al. 2008)

| Fish Index | Total phosphorus | Total nitrogen |
|---|---|---|
| Wisconsin large-river index of biotic integrity | 0.139 | 0.635 |
| Percentage of suckers by weight | 0.091 | 0.634 |
| Number of intolerant species | 0.139 | 1.125 |
| Percentage of individuals that are river species | 0.079 | 0.556 |
| Number of river species | 0.147 | 1.965 |
| Percentage of individuals that are lithophilic spawners | 0.055 | 0.634 |

**Table 6** Thresholds or breakpoints in the responses in macroinvertebrate indices to changes in nutrient concentrations for nonwadeable rivers in Wisconsin (mg $L^{-1}$, nss, not statistically significant at $p < 0.05$) by Regression-Tree analysis (Robertson et al. 2008)

| Invertebrate Index | Total phosphorus | Total nitrogen |
|---|---|---|
| Species richness | 0.150 | 1.925 |
| Mean pollution tolerance value | 0.064 | 0.634 |
| Percentage of individuals from order Ephemeroptera | 0.040 | 0.527 |
| Hilsenhoff Biotic Index | 0.150 | 1.990 |
| Percentage of individuals from order Plecoptera | 0.148 (nss) | 1.965 (nss) |
| Percentage of individuals that are scrapers | 0.034 | 0.527 |

## 3.8 Strength of the evidence

The strength of the evidence was calculated according to the Eco Evidence Analysis (Nichols et al. 2011). Instead of calculating the strength of different cause-effect relationships, each reference paper received a weight according to the study design and number of control and impact locations (tables 7 & 8). The study design details were imported from the Eco Evidence for those reference articles, which were found in the database. A review paper (Clapcott et al. 2012) was excluded from the weighing. The maximum weight is 10, which was not reached by any of the studies. Mean Eco Evidence weight of the reviewed papers was 7,2. In experimental designs the number of different treatments or treatment combinations in the study was used as the number of impact locations.

**Table 7** Study design, number of impact locations and number of control locations in the reference studies

| First author | Year | Study design | Number of impact locations | Number of control/reference locations | Number of impact locations in gradient-based designs |
|---|---|---|---|---|---|
| Angradi | 1999 | Reference/Control vs. impact (no before data) | 3 | 3 | |
| Argent | 1999 | Gradient Response | | | 3 |
| Bjornn | 1977 | After impact only | 2 | | |
| Bo | 2007 | Gradient Response | | | 1 |
| Bryce | 2010 | Gradient Response | | | 557 |
| Buendia | 2013 | Gradient Response | | | 8 |
| Cover | 2008 | After impact only | 6 | | |
| Harrison | 2010 | Reference/Control vs. impact (no before data) | 4 | 2 | |
| Kaller | 2001 | Reference/Control vs. impact (no before data) | 10 | 10 | |
| Kaller | 2004 | After impact only | 18 | | |
| Lange | 2014a | Gradient Response | | | 43 |
| Lange | 2014b | Gradient Response | | | 36 |
| Larsen | 2009 | Gradient Response | | | 56 |
| Larsen | 2010 | BACI or MBACI or Beyond MBACI | 2 | 2 | |
| Larsen | 2011 | Reference/Control vs. impact (no before data) | 3 | 3 | |
| Lintermans | 1998 | Gradient Response | | | 4 |
| Matthaei | 2010 | Gradient Response | | | 18 |
| Miltner | 1998 | Gradient Response | | | 1657 |
| Molinos | 2010 | Gradient Response | | | 9 |
| Mondy | 2013 | Gradient Response | | | 1724 |
| Osmundson | 2002 | Gradient Response | | | 1 |
| Piggot | 2012 | Gradient Response | | | >6 |
| Rabeni | 2005 | Gradient Response | | | 4 |
| Richardson | 2002 | Gradient Response | | | 38 |
| Robertson | 2008 | Gradient Response | | | 41 |
| Sutherland | 2002 | Reference/Control vs. impact (no before data) | 2 | 2 | |
| Townsend | 2008 | Gradient Response | | | 32 (field), 9 (experiment) |
| Wagenhoff | 2011 | Gradient Response | | | 43 |
| Wagenhoff | 2012 | Gradient Response | | | >6 |
| Wang | 2007 | Gradient Response | | | 240 |
| Wood | 2005 | After impact only | 6 | | |
| Zweig | 2001 | Gradient Response | | | 4 |

**Table 8** Weight of the evidence in the reference publications calculated according to the Eco Evidence Analysis

| First author | Year | Study design weight | Sampling unit weight | Total Evidence weight |
|---|---|---|---|---|
| Angradi | 1999 | 2 | 3+3 | 8 |
| Argent | 1999 | 3 | 0 | 3 |
| Bjornn | 1977 | 1 | 2 | 3 |
| Bo | 2007 | 3 | 0 | 3 |
| Bryce | 2010 | 3 | 6 | 9 |
| Buendia | 2013 | 3 | 6 | 9 |
| Cover | 2008 | 1 | 3 | 4 |
| Harrison | 2010 | 2 | 3+3 | 8 |
| Kaller | 2001 | 2 | 3+3 | 8 |
| Kaller | 2004 | 1 | 3 | 4 |
| Lange | 2014a | 3 | 6 | 9 |
| Lange | 2014b | 3 | 6 | 9 |
| Larsen | 2009 | 3 | 6 | 9 |
| Larsen | 2010 | 4 | 3+2 | 9 |
| Larsen | 2011 | 2 | 3+3 | 8 |
| Lintermans | 1998 | 3 | 2 | 5 |
| Matthaei | 2010 | 3 | 6 | 9 |
| Miltner | 1998 | 3 | 6 | 9 |
| Molinos | 2010 | 3 | 6 | 9 |
| Mondy | 2013 | 3 | 6 | 9 |
| Osmundson | 2002 | 3 | 0 | 3 |
| Piggot | 2012 | 3 | 6 | 9 |
| Rabeni | 2005 | 3 | 2 | 5 |
| Richardson | 2002 | 3 | 6 | 9 |
| Robertson | 2008 | 3 | 6 | 9 |
| Sutherland | 2002 | 2 | 3+2 | 7 |
| Townsend | 2008 | 3 | 6 | 9 |
| Wagenhoff | 2011 | 3 | 6 | 9 |
| Wagenhoff | 2012 | 3 | 6 | 9 |
| Wang | 2007 | 3 | 6 | 9 |
| Wood | 2005 | 1 | 3 | 4 |
| Zweig | 2001 | 3 | 2 | 5 |

## 3.9 Conceptual models

The first conceptual model (figure 15), was made with CADDIS ICD application. The drivers are visualised on top of the diagram, followed by pressures, abiotic state variables and their interactions. Biotic state variables, which are the indicators of the ecological impairments, are visualised in round shapes. The diagram is intended to be used interactively (online). By selecting two variables of the diagram, it is possible to view and download a list of citations supporting the selected linkage (figure 16).

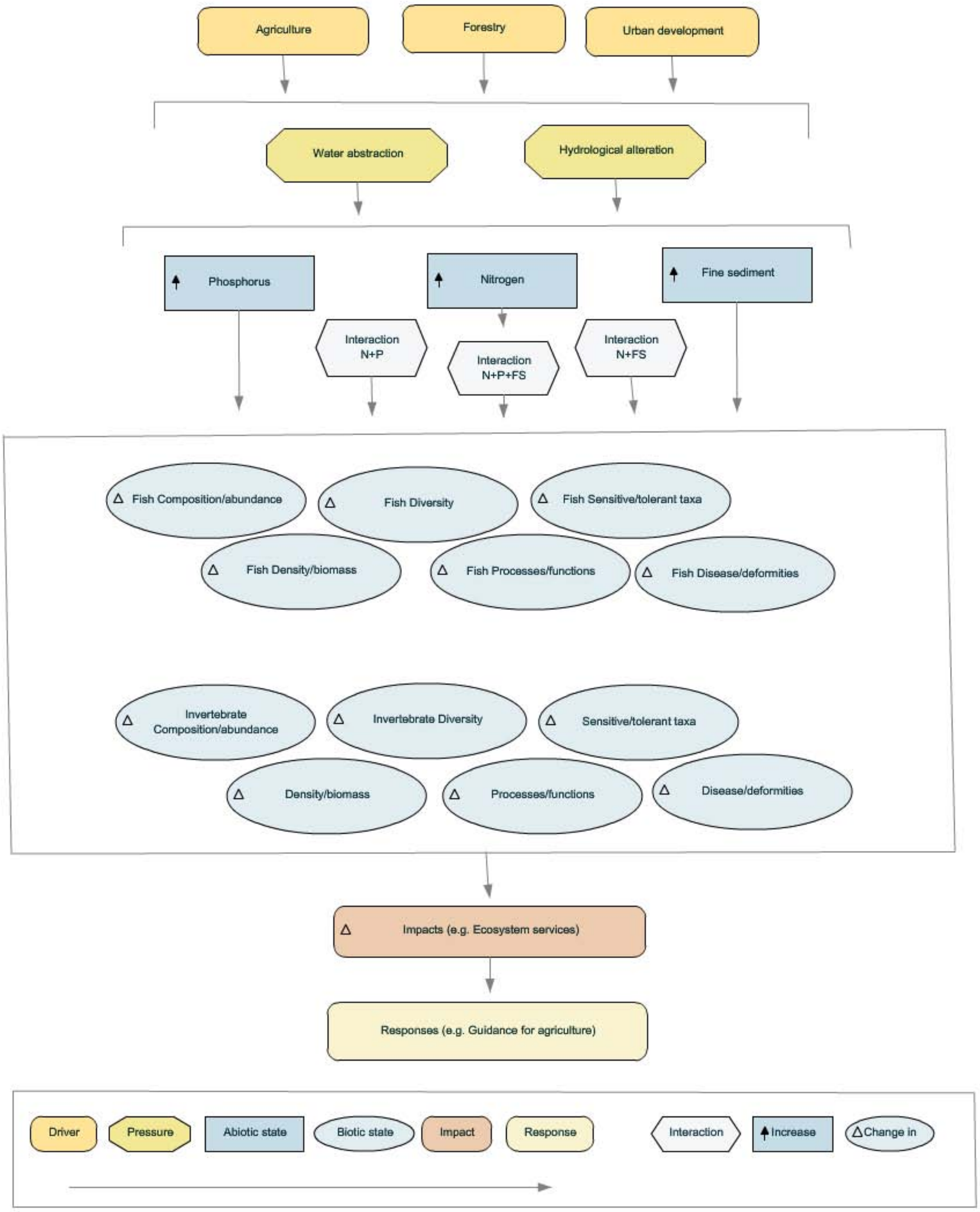



**Fig 15** Conceptual model visualising causes and ecological responses of excess nutrients and fine sediment in river ecosystems. The model is made with the CADDIS ICD application of U.S. EPA

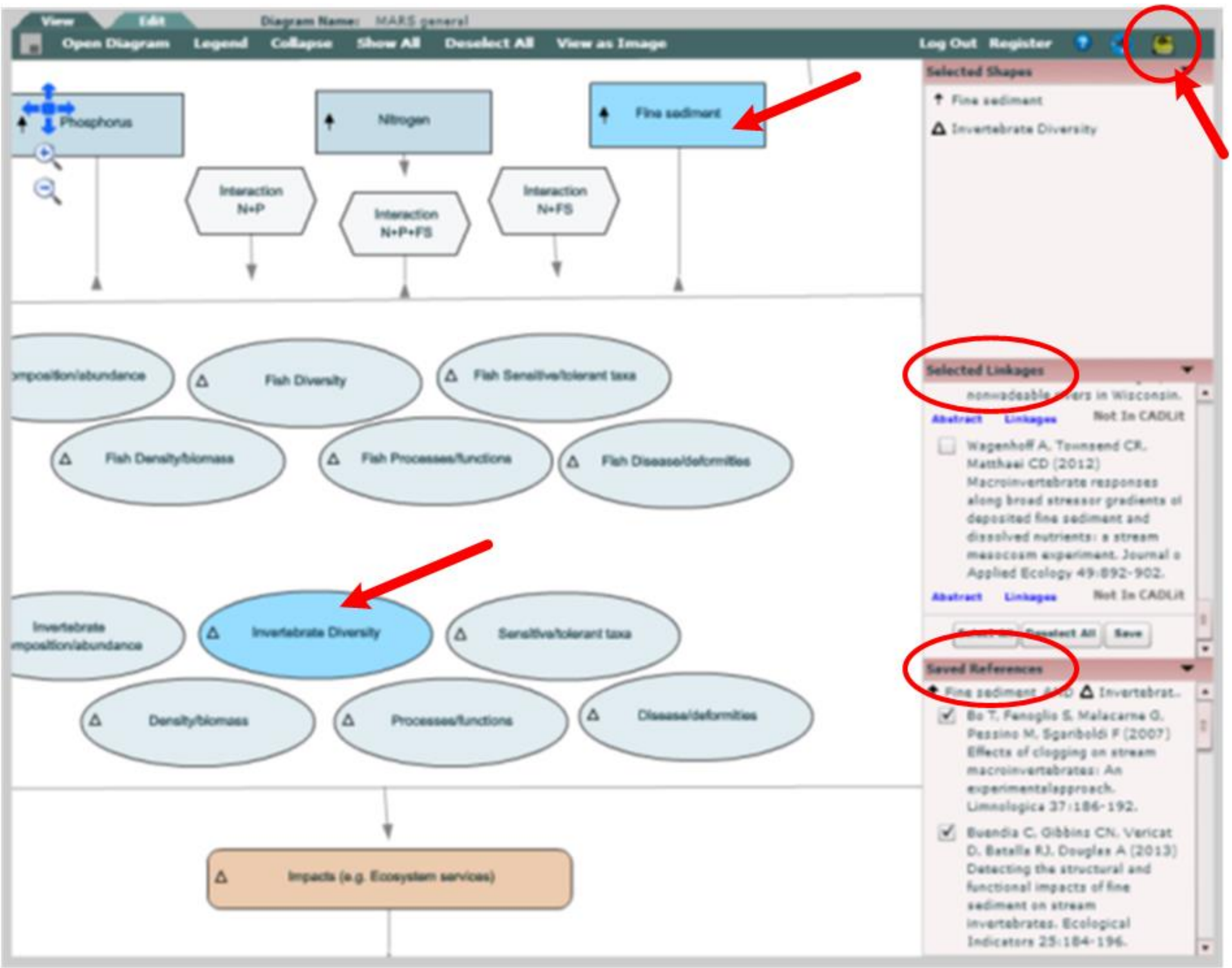



**Fig 16** By selecting two variables and clicking the book icon on the right corner of the View mode of the ICD application, the list of citations supporting the selected linkage appears. The user can select references from the list to be saved and downloaded

The following flowcharts were made without customised cause-effect diagramming tools, using Microsoft Visio for drawing. The pattern is following the approach, which was used in the EU project WISER (see Feld et al. 2011). Figure 17 shows a general conceptual framework presenting the outlines of the model construction. In the final models (figures 18 & 19) the linkages between abiotic and biotic state variables are divided into two diagrams. The first one visualises the single-stressor relationships (figure 18), and the second one shows the multi-stressor relationships (figure 19). This division was made to make the diagrams readable, otherwise the flowcharts are identical. On the left side of the diagrams the drivers, which were identified (and quantified) in the reference literature, are presented. The drivers are followed by pressures, abiotic state variables and biotic state variables, which are harmonised by dividing them into the six metric groups. The cause-effect linkages between the variables are presented by lines, showing the type of relationship (positive, negative, neutral) by colour, and number of supporting reference papers by thickness. The lines are numbered, and the numbers are linked to the reference literature in table 9. The relationship is marked as positive, when majority of the cause-effect linkages between the variables are positive. This does not mean that there would not be any evidence supporting the opposite direction. The relationship is marked as neutral when both positive and negative relationships are more or less equally dominant or the majority of the biotic effects are subsidy-stress responses. Individual biotic indicator metrics within one variable group can have strong positive or negative responses caused by the stressor, regardless of the mean response type. Special interaction shapes are placed between the abiotic state variables, indicating interactions between the stressors. The type of interaction is visualised by different dashed line types, uniting the interaction shapes with biotic response variables.

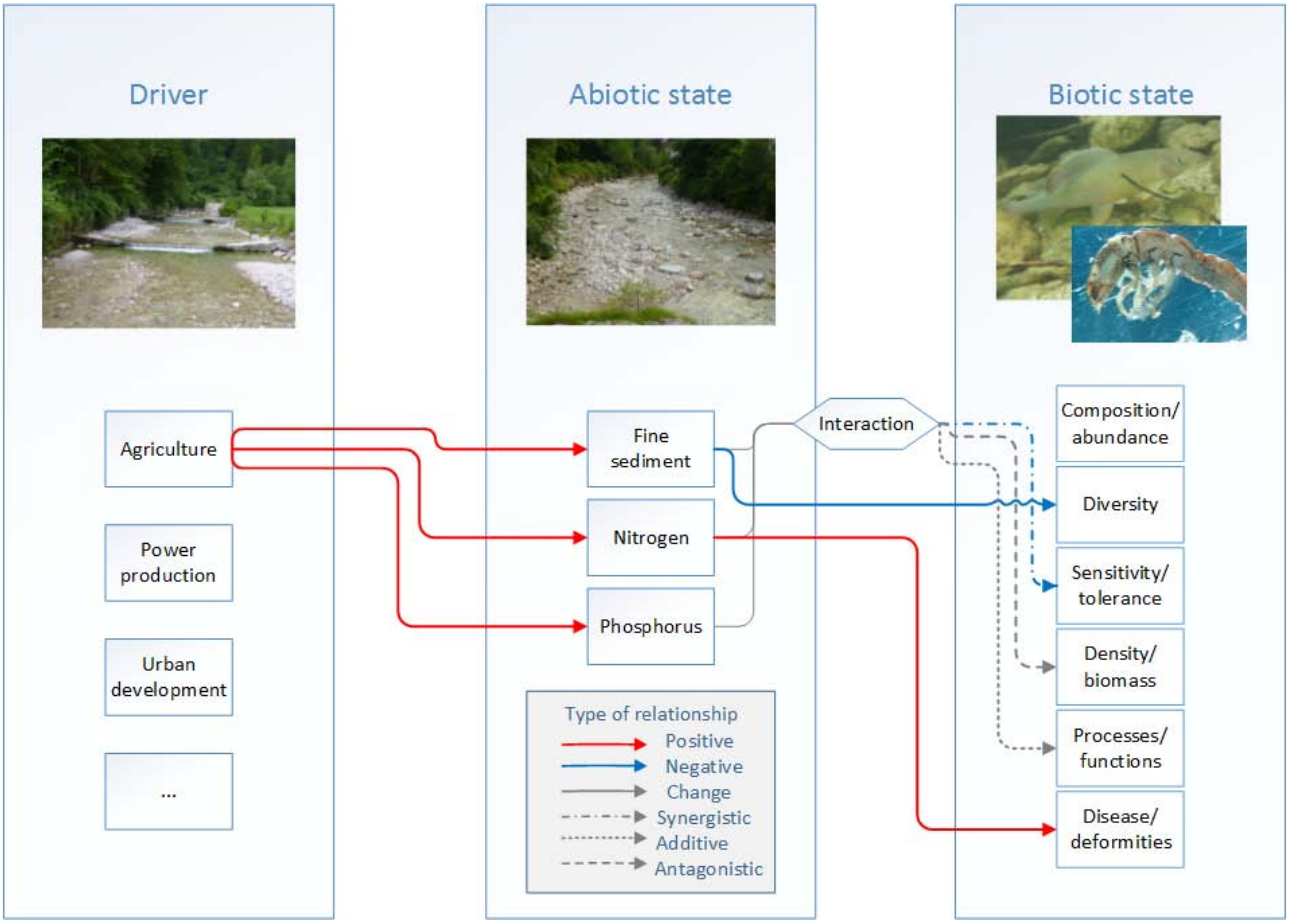



**Fig 17** General conceptual model presenting the structure of the diagrams and the types of interaction between the variables (pictures: Hans Rund [*Thymallus thymallus*] & Günther Jans-Danzer [*Polycentropus excisus*])

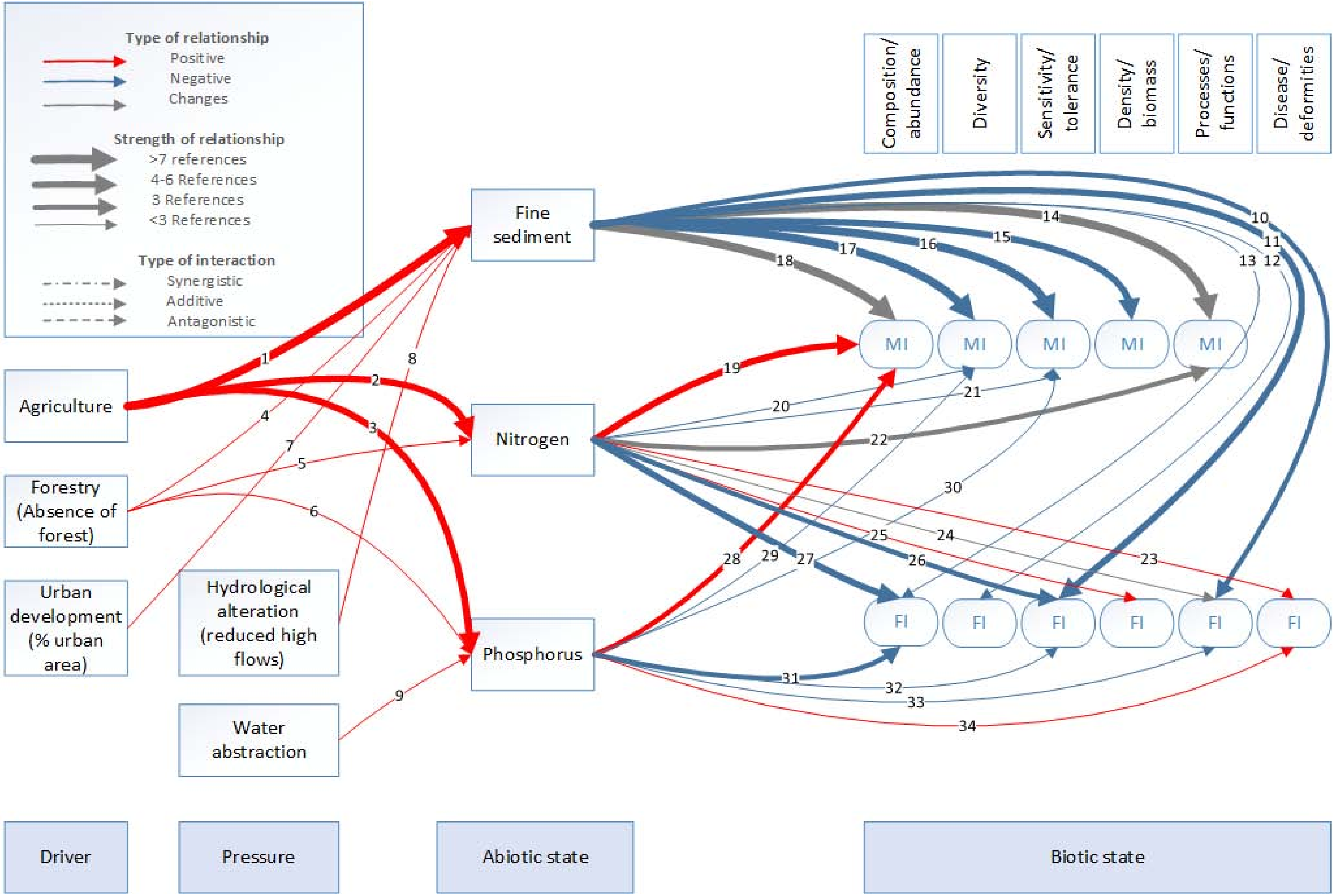



**Fig 18** Conceptual diagram visualising the causes and ecological effects of fine sediment and nutrients in rivers. The variable group Sensitivity/tolerance shows negative responses when sensitive taxa are affected negatively or tolerant taxa positively. MI – macroinvertebrates, FI - fish

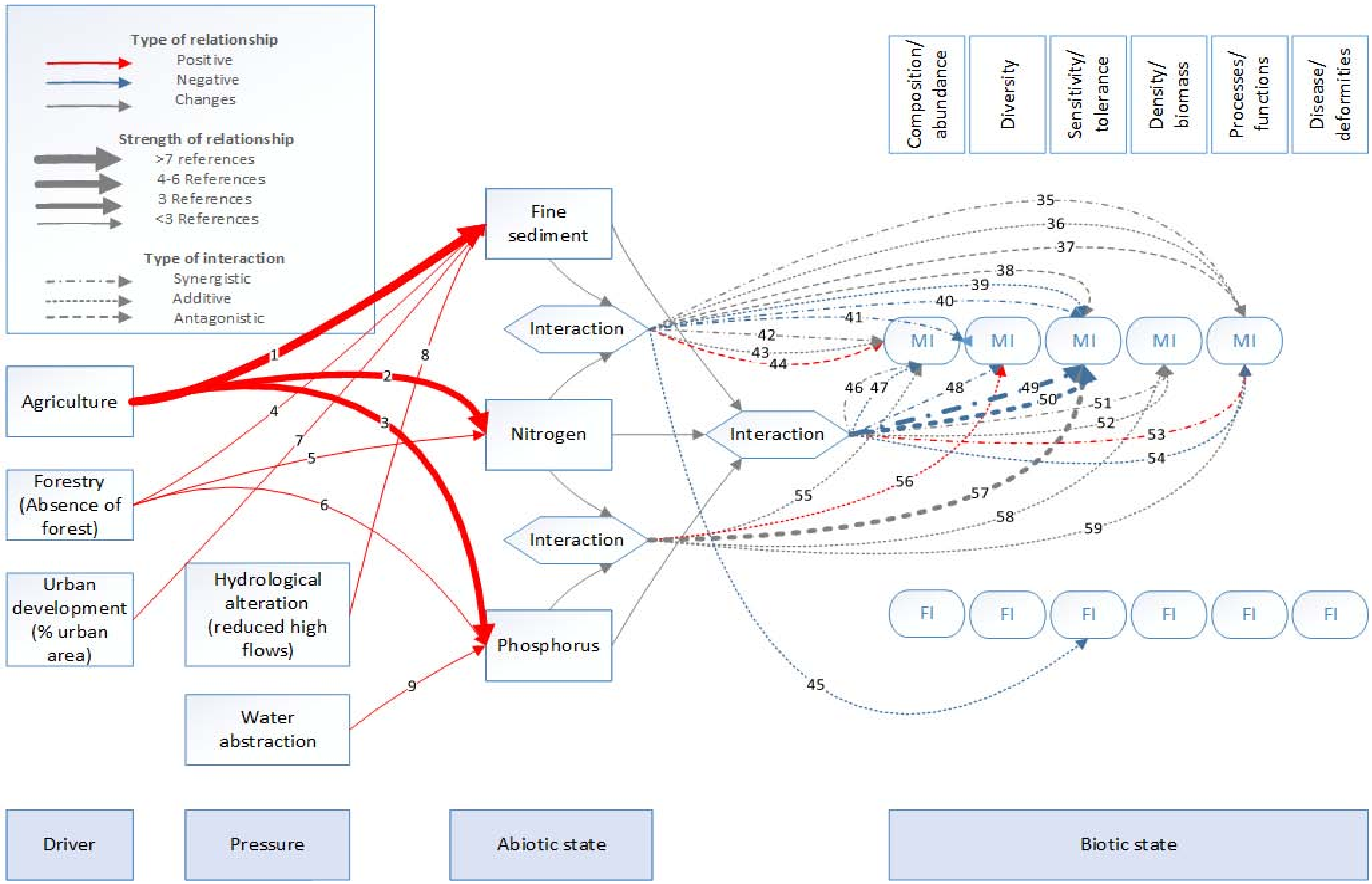



**Fig 19** Conceptual diagram visualising the multi-stress relationships and their effects on biotic state variables. The variable group Sensitivity/tolerance shows negative responses when sensitive taxa are affected negatively or tolerant taxa positively. MI – macroinvertebrates, FI - fish

**Table 9** The articles supporting the cause-effect linkages in the diagrams (fig. 18 & 19). Study weight is calculated according to the Eco Evidence analysis (Nichols et al. 2011). Full citation information in the reference list

| | Model link No. |||||||||| |||||||||| |||||||||| |||||||||| |||||||||| |||||||| | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | Serial No. | First author | Year | Study weight |
| 1 |||||||||| ||||x|x||x||| |||||||||| |||||||||| |||||||||| ||||||||| 1 | Angradi | 1999 | 8 |
| 2 |||||||||| x||||||||| |||||||||| |||||||||| |||||||||| ||||||||| 2 | Argent | 1999 | 3 |
| 3 |||||||||| |||||||x||| |||||||||| |||||||||| |||||||||| ||||||||| 3 | Bjornn | 1977 | 3 |
| 4 |||||||||| |||x|||x|x||| |||||||||| |||||||||| |||||||||| ||||||||| 4 | Bo | 2007 | 3 |
| 5 |||||||||| x|||||x||x||| |||||||||| |||||||||| |||||||||| ||||||||| 5 | Bryce | 2010 | 9 |
| 6 |||||||||| |||x|x|x|x||| |||||||||| |||||||||| |||||||||| ||||||||| 6 | Buendia | 2013 | 9 |
| 7 |||||||||| ||||||x|||| |||||||||| |||||||||| |||||||||| ||||||||| 7 | Clapcott | 2011 | review |
| 8 |||||||||| |||||x||x||| |||||||||| |||||||||| |||||||||| ||||||||| 8 | Cover | 2008 | 4 |
| 9 |||||||||| ||||x|x|x|||| |||||||||| |||||||||| |||||||||| ||||||||| 9 | Harrison | 2010 | 8 |
| 10 |||||||||| |||||||||| |||||||||| |||||||||| |||||||||| ||||||||| 10 | Kaller | 2001 | 8 |
| 11 |||||||||| |||||x||||| |||||||||| |||||||||| |||||||||| ||||||||| 11 | Kaller | 2004 | 4 |
| 12 |x|x|x||||||x|| |||x|||x|x|x|| |x||||||||| ||||x|x|x|x|x|x| x|x|x|x|||||| ||||||||| 12 | Lange | 2014a | 9 |
| 13 |x|x|x|||||||| x||||||||| ||||x|x|x|||| |||||||||| ||||x|||||| ||||||||| 13 | Lange | 2014b | 9 |
| 14 |||||||||| |||||x|x|x||| |||||||||| |||||||||| |||||||||| ||||||||| 14 | Larsen | 2009 | 9 |
| 15 |||||||||| ||||x|x||||| |||||||||| |||||||||| |||||||||| ||||||||| 15 | Larsen | 2010 | 9 |
| 16 |||||||||| |||||x|x|x||| |||||||||| |||||||||| |||||||||| ||||||||| 16 | Larsen | 2011 | 8 |
| 17 ||||||||||x| |||||||||| |||||||||| |||||||||| |||||||||| ||||||||| 17 | Lintermans | 1998 | 5 |
| 18 |||||||||| ||||x|x|x|x||| |||||||||| |||||||||| |||||x|||x|| x||||x||x|x|| 18 | Matthaei | 2010 | 9 |
| 19 |||||||||| ||||||||x|| ||||||x|x||| x||||||||| |||||||||| ||||||||| 19 | Miltner | 1998 | 9 |
| 20 |||||||||| |||||||||| |||||||||| |||||||||| |||||||x||| ||||||||| 20 | Molinos | 2010 | 9 |
| 21 |x|x|x||||||||| |||x||||||| |||||||||| |||||||||| |||||||||| ||||||||| 21 | Mondy | 2013 | 9 |
| 22 ||||||||x||| ||||x|||||| |||||||||| |||||||||| |||||||||| ||||||||| 22 | Osmundson | 2002 | 3 |
| 23 |||||||||| |||||x|x|x||| |||||||||| |||||||||| |||||||||x| ||||x||x||| 23 | Piggot | 2012 | 9 |
| 24 |||||||||| |||x|||x|||| |||||||||| |||||||||| |||||||||| ||||||||| 24 | Rabeni | 2005 | 5 |
| 25 |||||||||| |x|x|||||||| |||||||||| |||||||||| |||||||||| ||||||||| 25 | Richardson | 2002 | 9 |
| 26 |x|x|x|x|x||x|||x| x||x|||x|x|x|x|x| x|x|x|x||x|x|x|x|x| x|x|x|x||||||| |||||||||| ||||||||| 26 | Robertson | 2008 | 9 |
| 27 |x|||||||||x| |||||||||| |||||||||| |||||||||| |||||||||| ||||||||| 27 | Sutherland | 2002 | 7 |
| 28 |x||||||||| |||x|x|x||||| |||||||||| |||||||||| |||||||x|x|| ||x||||||| 28 | Townsend | 2008 | 9 |
| 29 |x|x|||||||||| |||x||||x||| |||||||||| |||||||||| |||||x|x||x|x| ||x|x|||||| 29 | Wagenhoff | 2011 | 9 |
| 30 |||||||||| |||x|x|x|x||| |||||||||| |||||||||| ||||||||x|x| |x||x||x|x|x|x| 30 | Wagenhoff | 2012 | 9 |
| 31 ||x|x||x|x||||| ||||||||x|x| x|x||x|x|x|x|x||x| x|x|x|||||||| |||||||||| ||||||||| 31 | Wang | 2007 | 9 |
| 32 |||||||||| |||||x||||| |||||||||| |||||||||| |||||||||| ||||||||| 32 | Wood | 2005 | 4 |
| 33 |||||||||| x||||||||| |||||||||| |||||||||| |||||||||| ||||||||| 33 | Zweig | 2001 | 5 |

The lines between abiotic and biotic state variables are based on 591 quantified relationships, which were extracted from the reference literature. Fish variables were indicators of the impairments in 192 relationships, and macroinvertebrates in 399 relationships. *Processes and functions* category contains the biggest share of the effects, 34% (211 cause-effect relationships) respectively. The number of cause-effect relationships per variable category, as well as the share of the total number of evidence items per variable category, are presented in table 10. The share of the effects caused by the different abiotic stressors (fine sediment, nutrients and multi-stress) on response variable categories is calculated as well.

**Table 10** The share of all effects and effects caused by different abiotic stressors on different response variable groups. The number of all effects per variable category in brackets

| Variable category | % all effects | % fine sediment effects | % nutrient effects | % multi-stress effects |
|---|---|---|---|---|
| Biomass/density (29) | 5 % | 9 % | 3 % | 1 % |
| Composition/abundance (128) | 23 % | 18 % | 28 % | 13 % |
| Disease and deformities (2) | 0 % | 0 % | 1 % | 0 % |
| Diversity (42) | 7 % | 11 % | 5 % | 4 % |
| Processes/functions (211) | 34 % | 34 % | 30 % | 56 % |
| Sensitivity/tolerance (179) | 31 % | 29 % | 33 % | 25 % |
| **Grand Total (591)** | **100 %** | **100 %** | **100 %** | **100 %** |

The majority of individual, as well as combined impacts of fine sediment and nutrients, caused negative responses in ecological indicators. Fine sediment effects were more negative than those caused by nutrients (tables 11 a-f). Diversity indices and sensitive invertebrate and fish species were affected especially negatively (tables 11 d & f).

**Tables 11 a-f** The shares of positive, negative and subsidy-stress responses of indicator metrics to increase in fine sediment, nutrients and combination of them per variable category. Total amount of associations in brackets

a)

| Biomass/density | % all effects (29) | % fine sediment effects (18) | % nutrient effects (10) | % multi-stress effects (1) |
|---|---|---|---|---|
| Positive | 14 | 6 | 30 | 0 |
| Negative | 52 | 67 | 30 | 0 |
| Unimodal | 34 | 28 | 40 | 100 |
| Total | 100 | 100 | 100 | 100 |

b)

| Composition/ abundance | % all effects (126) | % fine sediment effects (24) | % nutrient effects (93) | % multi-stress effects (9) |
|---|---|---|---|---|
| Positive | 48 | 38 | 52 | 33 |
| Negative | 49 | 63 | 48 | 22 |
| Unimodal | 3 | 0 | 0 | 44 |
| Total | 100 | 100 | 100 | 100 |

c)

| Disease and deformities | % all effects (2) | % fine sediment effects (0) | % nutrient effects (2) | % multi-stress effects (0) |
|---|---|---|---|---|
| Positive | 100 | 0 | 100 | 0 |
| Negative | 0 | 0 | 0 | 0 |
| Unimodal | 0 | 0 | 0 | 0 |
| Total | 100 | 0 | 100 | 0 |

d)

| Diversity | % all effects (42) | % fine sediment effects (22) | % nutrient effects (17) | % multi-stress effects (3) |
|---|---|---|---|---|
| Positive | 7 | 9 | 6 | 0 |
| Negative | 86 | 82 | 88 | 100 |
| Unimodal | 7 | 9 | 6 | 0 |
| Total | 100 | 100 | 100 | 100 |

e)

| Processes/ functions | % all effects (209) | % fine sediment effects (68) | % nutrient effects (103) | % multi-stress effects (33) |
|---|---|---|---|---|
| Positive | 31 | 34 | 33 | 24 |
| Negative | 59 | 63 | 67 | 33 |
| Unimodal | 10 | 3 | 0 | 42 |
| Total | 100 | 100 | 100 | 100 |

f)

| Sensitivity/ tolerance | % all effects (175) | % fine sediment effects (52) | % nutrient effects (109) | % multi-stress effects (16) |
|---|---|---|---|---|
| Positive | 19 | 13 | 25 | 0 |
| Negative | 75 | 87 | 71 | 63 |
| Unimodal | 5 | 0 | 5 | 38 |
| Total | 100 | 100 | 100 | 100 |

# 4 Discussion

## 4.1 Causal relationships

The first objective of this work was to collect quantified cause-effect data and possible thresholds of fine sediment and nutrients and their ecological effects in rivers to be used in the conceptual diagrams and further used in the MARS project. Finding literature, where the evidence is quantified, was challenging. The same was realised by Nõges et al. (2016), who state that many of the cause-effect linkages seem to be accepted as common knowledge. The reference list which is used in this study is not comprehensive, but rather a starting point on which the further evidence can be built on.

### 4.1.1 Drivers and pressures causing increased fine sediment and nutrient concentrations in rivers

Many references list common causes for elevated nutrient and fine sediment concentrations, but only part of the studies (e.g. Lange et al. 2014; Mondy & Usseglio-Polatera 2013; Scruton et al. 2008; Robertson et al. 2008; Sutherland et al. 2002; Townsend et al. 2008; Wagenhoff et al. 2011; Wang et al. 2007) link them statistically to the abiotic state variables. Many of the studies (e.g. Piggott et al. 2012; Wagenhoff et al. 2012; Matthaei et al. 2010) were experimental in character, where drivers usually do not exist. Research papers often do not contain the complete cause-effect chain, but in a conceptual diagram the data from different sources can be united to form complete causal pathways. The causes for changes in abiotic states can therefore be searched separately and brought into the diagrams. According to the reviewed literature, the most common driver causing elevated nutrient as well as fine sediment concentrations in the waterbodies was agriculture (e.g. Lange et al. 2014; Mondy & Usseglio-Polatera 2013; Robertson et al. 2008). The two stressors were also linked to absence of forest (e.g. Robertson et al. 2008), which nevertheless is often related to agriculture. As the same causes lead to an increase in both abiotic state variables, it is not surprising that these stressors often occur together. Better management results are gained if their ecological impacts are also quantified together.

Only two of the identified causes belong to the pressure category. These are reduced high flows (Osmundson et al. 2002) and water abstraction (Lange et al. 2014a). Diffuse pressure from agriculture was not quantified in the literature and therefore the link between agriculture and the abiotic states is missing in the diagrams as well. This might be caused by difficulties to measure the diffuse pressure quantitatively. The conceptual diagrams are also weaker in presenting the possible drivers and pressures, as the primary focus of the literature search was to find evidence supporting the cause-effect linkages between the abiotic and biotic state variables.

### 4.1.2 Cause-effect linkages between the stressors and their ecological responses in rivers

*Fine sediment*

Fine sediment is a natural and essential component in running waters, but excess input of fine sediment affects the biological functioning in rivers by altering habitat quality and quantity (Owens et al. 2005). In the reviewed literature an increase in fine sediment caused mostly negative effects on stream invertebrate metrics. Most uniform responses, which were also supported by several scientific references were e.g. decrease in total taxon richness (e.g. Rabení et al. 2005; Bo et al. 2007; Robertson et al. 2008; Larsen et al. 2009; Matthaei et al. 2010; Clapcott et al. 2012; Wagenhoff et al. 2012; Buendia et al. 2013), decrease in EPT richness (e.g. Zweig & Rabení 2001; Townsend et al. 2008; Larsen et al. 2009; Wagenhoff et al. 2012, Buendia et al. 2013) and decrease in total invertebrate density (Osmundson et al. 2002; Matthaei et al. 2010; Buendia et al. 2013). Investigated fish metrics were less, but they were without exceptions negative concerning fish abundance (Richardson & Jowett 2002; Robertson et al. 2008), diversity (Richardson & Jowett 2002), sensitive fish species (Argent & Flebbe 1999; Robertson et al. 2008; Bryce et al. 2010; Lange et al. 2014b), and several functional groups, e.g. spawning types (Sutherland et al. 2002; Robertson et al. 2008) and feeding types (Robertson et al. 2008).

*Nutrients*

There has been a significant reduction in the levels of nutrients in European freshwaters over the past two decades (EEA 2015). However, nutrient enrichment is still widespread and diffuse pollution from agriculture remains a significant pressure in more than 40% of Europe's rivers (EEA 2015). In the reference studies nutrient enrichment caused diverse responses in invertebrate metrics. Increase in nitrogen and/or phosphorus had both positive and negative effects to the indicator metrics in all but one (disease and deformities) response categories. Common type of response curve was hump-shaped, indicating a subsidy-stress response. Many indicator metrics first benefit from increasing nutrient concentration, but after reaching a threshold level the direction of the response curve changes to negative. At modest levels, nutrient enrichment can stimulate primary production, which in turn can increase production of invertebrates and fish. Further eutrophication, however, can lead to algal blooms that are stressful to most animals by causing low dissolved oxygen and poor habitat quality (Niyogi et al. 2007). Subsidy-stress relationships might lead to the situation, where the type of response in the studies differ depending on the background level of the nutrients (if the threshold is already reached), and the enriched nutrient concentration (if the threshold will be reached during the study). This makes it important to quantify these threshold values, and recognize the critical concentrations. In the study by Piggot et al. (2012) nutrient enrichment generally acted as a subsidy, increasing both pollution-tolerant (e.g. Chironomidae) and sensitive taxa (EPT), indicating that enriched levels were still within the range providing subsidy effects. Enriched nutrient concentrations corresponded to moderate levels in New Zealand dairy farming streams, but higher anthropogenic levels occur elsewhere in the world (Piggot et al. 2012).

Concerning fish the impacts of nutrients were mostly negative. Fish IBI decreased by the impact of nitrogen (Miltner & Rankin 1998; Wang et al. 2007; Robertson et al.2008) and by phosphorus (Miltner & Rankin 1998; Wang et al. 2007). Salmonids and other sensitive species were affected negatively as well (Wang et al. 2007; Robertson et al. 2008; Lange et al. 2014b). Some positive effects were also found (e.g. increasing fish biomass), following the increase in nitrogen concentration (Wang et al. 2007). Increase in nutrients also increased the percentage of fish having disease or deformities (Robertson et al. 2008).

*Multi-stressor relationships*

Fine sediment and nutrients had additive, synergistic, as well as antagonistic multi-stressor impacts on benthic invertebrates. Three references supported synergistic interactions affecting negatively on invertebrate diversity indices (Townsend et al. 2008; García Molinos & Donohue 2010; Lange et al. 2014a). Synergistic interaction is harmful for the ecosystem, but important to recognise for planning appropriate management actions. By eliminating one stressor, the state of the ecosystem can improve more than expected based on single stressor impacts. On the contrary, in case of antagonistic interaction both stressors may need to be removed or moderated to produce any substantial recovery (Jackson et al. 2016). Concerning sensitive EPT taxa, the effects were negative, but all possible interaction types were reported. Trait-based responses to multiple stressors were mainly additive (e.g. Wagenhoff et al. 2012; Lange et al. 2014a). The collected evidence items contain altogether 69 biological responses to multi-stressor impacts, where nutrients (N or P or both) and fine sediment are interacting. Approximately 60% of the effects were additive, 30% were synergistic and 10% antagonistic. In recent meta-analysis of the effects of multiple stressors in freshwater ecosystems, net effects of stressor pairs were frequently more antagonistic (41%) than synergistic (28%), additive (16%) or reversed (15%, Jackson et al. 2016). Nevertheless the effects for nutrification paired with habitat alteration (including sedimentation) were additive (Jackson et al. 2016), supporting the results of this study.

Only one multi-stressor relationship was found, which affects the fish communities. This relationship was additive in character, causing decrease in trout density (Lange et al. 2014b). Synergistic or antagonistic effects between the stressors were not observed (Lange et al. 2014b). It could be, that these stressors differ more fundamentally in their mode of action for fish as opposed to invertebrates and therefore act independently when affecting fish populations (Lange et al. 2014b).

A fact sheet of joint effects of the stressors was filled for the MARS project, and is presented in Appendix B.

### 4.1.3 Stressor comparison

The effects of fine sediment were generally more negative than the effects of nutrient enrichment. Also many references indicate that fine sediment is more pervasive stressor (Wagenhoff et al. 2011; Piggot et al. 2012; Wagenhoff et al. 2012), counteracting and overwhelming initial subsidy effects of increased nutrients. Macroinvertebrate responses to sediment seemed to be more common and more often negative. Effect sizes were considerably larger and effects were predicted with greater certainty than those of nutrients (Wagenhoff et al. 2012). The effects of high nutrient concentrations were weaker and modelled with less certainty, probably reflecting the indirect modes of action of nutrients (Wagenhoff et al. 2011). The indirect influences of anthropogenic nutrient enrichment on fish and macroinvertebrates might result from overgrowing primary producers that create low oxygen-associated conditions (Wang et al. 2007). In the study by Lange et al. (2014a) the nutrients showed more marked effects via food availability. Nevertheless nutrients also interacted synergistically (e.g. Townsend et al. 2008; Matthaei et al. 2010; Wagenhoff et al. 2011; Lange et al. 2014a) and antagonistically (Lange et al. 2014a) with fine sediment, and the best restoration outcomes would be achieved by addressing both stressors (Wagenhoff et al. 2011).

### 4.1.4 Strength of the evidence

A simple type of weighing the evidence is used in the diagrams, as the line thickness indicates the number of reference papers supporting the given relationship. Additionally the strength of the evidence was calculated according to the Eco Evidence Analysis (Nichols et al. 2011) for each reference paper (except a review) that was used in the diagrams. The average study design weight of the reviewed papers was relatively high, being 7,2. Many of the studies followed gradient-response model, which usually provides evidence on the dose-response relationships. This was not a coincidence, because the reference literature was chosen in a way that it provides quantified evidence on cause-effect relationships. This already excludes very weak pieces of evidence. Nevertheless, it should be taken into account that information about the strength of the correlation or the coefficient of determination is not provided in the diagrams. Every statistically significant relationship was considered even if the relationship was weak.

## 4.2 Existing methods of evidence-based conceptual models

Second objective was to give an overview of existing methods of standardized evidence based conceptual models and to find out the suitability of their components to the European purposes (MARS project). The methods, which were tested in this work, are CADDIS and Eco Evidence. These methods have been shortly described in the introduction chapter, and further presented in the methods. My subjective view and discussion about the suitability of their functions to the purposes of the MARS project will be given in the next sub-chapters.

### 4.2.1 CADDIS

*CADDIS Literature resource*

CADLit literature database contains vast amount of citations, especially concerning sediment and nutrients. The database contains detailed information on study design and context, exposure parameters and response parameters, but it does not provide specific cause-effect linkages between them. Therefore the database did not offer direct help in identifying causal relationships. At the moment an update of the CADDIS Literature Database is under development. The new release targets to explicitly capture information on specific cause-effect relationships, which can then be linked directly to ICD diagrams (Kate Schofield, personal communication, February 17, 2016). CADLit database was originally conceived as a centralized storage place for detailed stressor-response information, which could be used by the scientists working in the Office of Research and Development (ORD) of the U.S. EPA. One objective of the new release is broaden the community of users that would help to populate the database by simplifying data entry process. The new literature resource will also allow data exchange between the CADLit and similar databases developed by the collaborators of the U.S. EPA (e.g., Eco Evidence). The new CADDIS database is foreseen to be released in fall 2016 (Kate Schofield, personal communication, February 17, 2016).

*ICD application*

The ICD application was easy to use and it offers a great tool for storing and visualising ecological evidence on causal pathways. The application does not produce diagrams automatically, but the user has to place the shapes and other features on the canvas and feed the information about the linkages and citations. The strength is in organising the evidence supporting different cause-effect relationships. From the ready diagram it is easy to see where the evidence is strong or where it is insufficient for a robust conclusion. In such cases the need for future research can be identified. The advantage of such an approach is also that it collects together evidence from different sources to form complete causal pathways and strengthen the evidence. The chain of causal relationships can therefore be followed from the driving forces until the ecological effects thus providing a better understanding of the linkages between the biological indicators and their physical environment.

The possibility to connect literature citations with cause-effect linkages is the best feature of the application. Finding the relevant references from CADDIS diagrams is fast and easy, as the citations can be viewed linkage by linkage. The second big advantage is the practical and convenient interactive operation of the application, which unfortunately is difficult to demonstrate without the possibility to online usage. A nice feature is also, that the user can not only create diagrams, but also view and edit diagrams made by other users (with their allowance).

The diagrams (e.g. the ones which were made for this study) cannot be used interactively without registering and logging into the application. The interactive use is the key to use the diagrams in an effective way, especially when larger or more complex diagrams are in question. The diagrams can be exported from the application as pictures, but then arrows or other visual linkages are required in order to see the relationships between the entities. In large diagrams this is not easy to visualise with the functions of the application. It would be a good addition if there would be a way to view the diagrams online without the registration process (e.g. with a link provided by the creator of the diagram).

The linkages in the diagrams can be created between two shapes only. Visualising multi-stressor relationships is challenging. It is possible to select multiple shapes and create a linkage between all the possible combinations of two shapes between them. But even by this mean the result is always considering only two shapes, and the user can view and search references between two shapes only.

In the application it is not possible to ad attributes to the linkages. Positive and negative effects on indicator biota cannot be indicated by different colours or by adding this information in the reference list. Instead the information on the direction of the ecological impact has to be incorporated in the shapes, which increases the amount of shapes that are used in the diagrams. In case of multi-stressor impacts the type of the interaction cannot be visualised with the current functions of the application.

### 4.2.2 Eco Evidence

Eco Evidence literature database offered genuine help in searching for references supporting the ecological linkages in the diagrams. The structure of the database is clear and good, and the possibility to search for the evidence according to causes and effects, and to weigh the evidence makes it an excellent tool for causal assessments. Eco Evidence is easy to use, and the data is clearly structured. Registration is simple and searching for evidence is fast and convenient. The disadvantage is that concerning many topics the database is not comprehensive. A diagramming application would be a useful addition, as in the 8 step process user is asked to draw a conceptual model (in step 3).

## 4.3 MARS diagrams

The final objective of this thesis was to create a causal conceptual model visualising the causes and ecological effects of excess nutrients and fine sediment in riverine ecosystems using fish and benthic invertebrates as indicators of the impairments. The Eco Evidence and CADDIS tools offered help in searching and evaluating cause-effect data and perceiving the structure of causal conceptual diagrams, but the final models were made with MS Visio diagramming platform. The advantage compared to the CADDIS ICD application is that the possibilities to visualise the information are more versatile. The disadvantage is that there are no pre-designed patterns, but the model construction has to be done from the beginning on by selecting the appropriate shapes and linkage types for the model. Also the reference list has to be created separately and cannot be automatically linked to the cause-effect relationships as in the ICD application. Therefore updating the models is more complicated than with the CADDIS tool.

The structure of the flowcharts largely follow the approach of the past EU project WISER. The important change compared to the previous methods is the central role of multiple stressor impacts, and the need to visualise the stressor interactions. Diverse ways of interaction and effect types necessarily increase the complexity of the final diagrams. The functions of the CADDIS ICD application were not applicable to the MARS approach, but the ideas and structures are converted to the MS Visio diagrams.

## 4.4 Challenges

Finding research papers where the effect is quantitatively linked to the given cause (stressor) with statistically significant results was not easy and required lots of time. Also comparing the data from multiple studies is always challenging because of different study designs, diverse measurement units and unprecise expressions as well as natural variability in abiotic and biotic conditions. The first step is to harmonise and merge existing information in a way that it can be effectively used. These challenges highlight the importance of evidence databases and conceptual models. Ideally the harmonised information would already be found in an open access database, in such format that it would be ready to be used in analyses.  This would save time and resources, and make evidence synthesis easier to conduct. Eco Evidence and CADDIS are good examples of such methods. Both methods and associated tools are continuously under development, and they are also collaborating, aiming to link existing databases and allowing data exchange between the projects (Ziegler et al. 2015). The challenge is to make the cause-effect tools used by the scientific community in a way, that the databases are up to date and include all the relevant evidence information. The Eco Evidence also aims to become a peer-produced and user-moderated resource (Webb et al. 2012). In ideal case authors themselves would enter the evidence into the database, and thus increase the probability that their studies are cited (Webb et al. 2012).

The effectiveness of such tools depends not only on the commitment of the scientific community, but also on the willingness of environmental managers to adopt new methods and change their habits and beliefs. According to the study by Pullin et al. (2004) management plan compilers are not making full or systematic use of the available information to support their decision-making. Additionally when the beliefs of conservation managers were investigated in UK, only small minority (5%) considered evidence-based information more influential than experience-based information (Pullin et al. 2004). Evidence-based findings might not result in managers learning and updating their beliefs, even if presented and explained to managers (McConnachie & Cowling 2013).

## 4.5 Conclusions and future recommendations

The main objective of this study was to create conceptual ecological models to be used in the MARS project. Existing international methods and tools (CADDIS and Eco Evidence) offered great help, but could not alone fulfil the needs of the MARS approach. The main challenge was the central role of multiple stressor effects and the need to visualise these linkages in the models.

More evidence on the ecological effects of fine sediment as well as nutrients would be available, and could be extracted from the primary research papers. On the other hand, studies combining the effects of these stressors are rare, especially the ones that quantify their effects simultaneously along both stressor gradients. Existing studies are also conducted mainly by the same group of researches, and cover small geographic area. More multiple stressor studies would be needed in order to gain strong evidence on the joint effects of the stressors. Especially distinct research gap exists concerning the joint effects of fine sediment and nutrients on fish indicators. This knowledge gap is also visible in the created conceptual diagram (figure 19).

In future models it should be considered if spatial and temporal scales, river type, geographical and geological parameters or other characteristics should be taken into account in creating the models. Also in the studies reviewed for this work the scale and location impacted the ecological effects of fine sediment (e.g. Larsen et al. 2009) as well as nutrients (e.g. Miltner & Rankin 1998). The biological quality elements, which should be considered according to the WFD, include also composition and abundance of aquatic flora (EC, 2000). Therefore the models could be expanded to include macrophyte and diatom indicators as well.

The evidence search conducted in this work focused on finding quantified relationships between abiotic and biotic state variables. The models could be completed with more evidence linking other DPSIR categories to the causal pathways.

Most importantly, the causal databases should be completed with associations concerning larger scope of topics. The challenge remains how to extract causal relationships effectively from the primary studies to complete the online databases. Ziegler et al. (2015) suggest that some combination of mark-up, text-mining and crowdsourcing may offer the best hope for widespread cataloguing of associations.

Evidence-based frameworks could, if becoming a standard procedure help in shifting from expert-based decision making to evidence-based environmental management. The growing interest to the topic appears in the projects aiming to synthesise the evidence with cause-effect tools by working groups from several continents. By working together and sharing data and information effective tools for causal assessment can be further developed.

## References


Argent, D.G. & P.A. Flebbe, 1999. Fine sediment effects on brook trout eggs in laboratory streams. Fisheries Research, 39: 253–262.

Von Bertrab, M.G., Krein, A., Stendera, S., Thielen, F. & D. Hering, 2013. Is fine sediment deposition a main driver for the composition of benthic macroinvertebrate assemblages? Ecological Indicators, 24: 589–598. Available at: http://dx.doi.org/10.1016/j.ecolind.2012.08.001.

Bo, T., Fenoglio, S., Malacarne, G., Pessino, M. & F. Sgariboldi, 2007. Effects of clogging on stream macroinvertebrates: An experimental approach. Limnologica, 37: 186–192.

Bryce, S. A., Lomnicky, G. A. & P. R. Kaufmann, 2010. Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically based streambed sediment criteria. Journal of the North American Benthological Society, 29: 657–672.

Buendia, C., Gibbins, C. N., Vericat, D., Batalla, R. J. & A. Douglas, 2013. Detecting the structural and functional impacts of fine sediment on stream invertebrates. Ecological Indicators, 25: 184–196. Available at: http://dx.doi.org/10.1016/j.ecolind.2012.09.027.

Clapcott, J. E., Collier, K. J., Death, R. G., Goodwin, E. O., Harding, J. S., Kelly, D., Leathwick, J. R. & R. G. Young, 2012. Quantifying relationships between land-use gradients and structural and functional indicators of stream ecological integrity. Freshwater Biology, 57: 74–90.

Dicks, L. V., Walsh, J. C. & W. J. Sutherland, 2014. Organising evidence for environmental management decisions: a "4S" hierarchy. Trends in Ecology & Evolution, 29: 607–613. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169534714001992.

Downes, B. J., 2010. Back to the future: little-used tools and principles of scientific inference can help disentangle effects of multiple stressors on freshwater ecosystems. Freshwater Biology, 55: 60–79. Available at: http://doi.wiley.com/10.1111/j.1365-2427.2009.02377.x.

EC, 2000. Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of Water Policy. PE-CONS 3639/1/00.

EEA [European Environment Agency], 1999. Environmental indicators: Typology and overview. European Environment Agency, Copehagen.

EEA, 2015. The European environment — state and outlook 2015: synthesis report, European Environment Agency, Copenhagen.

eWater, website www.toolkit.net.au/tools/eco-evidence [last access 5.4.2016]

Feld, C. K., Birk, S., Bradley, D. C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D., Pedersen, M. L., Pletterbauer, F., Pont, D., Verdonshot, P. F. M. & N. Friberg, 2011. From Natural to Degraded Rivers and Back Again : A Test of Restoration Ecology Theory and Practice. Advances in Ecological Research 44: 119-209. Available at: http://dx.doi.org/10.1016/B978-0-12-374794-5.00003-1.

Folt, C. L., Chen, C.Y., Moore, M. V. & J. Burnaford, 1999. Synergism and antagonism among multiple stressors. Limnology and Oceanography, 44: 864–877.

García Molinos, J. & I. Donohue, 2010. Interactions among temporal patterns determine the effects of multiple stressors. Ecological Applications, 20: 1794–1800.

Greet, J., Webb, A. J. & R. D. Cousens, 2011. The importance of seasonal flow timing for riparian vegetation dynamics: A systematic review using causal criteria analysis. Freshwater Biology, 56: 1231–1247.

Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cardoso, A. C., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J., Hellsten, S., Jeppesen, E., Kodeš, V., Lyche Solheim, A., Nõges, T., Ormerod, S., Panagopoulos, Y., Schmutz, S., Venohr. M. & S. Birk, 2015. Managing aquatic ecosystems and water resources under multiple stress - An introduction to the MARS project. The Science of the total environment 503-504: 10-21.

IMPRESS (2002). Guidance for the analysis of pressures and impacts in accordance with the Water Framework Directive. Common Implementation Strategy Working Group 2.1, 156 pp. Office for Official Publications of the European Communities.

Jackson, M.C. et al., 2016. Net effects of multiple stressors in freshwater ecosystems: a meta-analysis. Global Change Biology, 22: 180-189. Available at: http://doi.wiley.com/10.1111/gcb.13028.

Lange, K., Townsend, C. R. & C. D. Matthaei, 2014a. Can biological traits of stream invertebrates help disentangle the effects of multiple stressors in an agricultural catchment? Freshwater Biology, 59: 2431-2446.

Lange, K. Townsend, C. R., Gabrielsson, R., Chanut, P. C. M. & C. D. Matthaei, 2014b. Responses of stream fish populations to farming intensity and water abstraction in an agricultural catchment. Freshwater Biology, 59: 286–299.

Larsen, S., Vaughan, I.P. & S. J. Ormerod, 2009. Scale-dependent effects of fine sediments on temperate headwater invertebrates. Freshwater Biology, 54: 203–219.

Matthaei, C.D., Piggott, J.J. & C. R. Townsend, 2010. Multiple stressors in agricultural streams: Interactions among sediment addition, nutrient enrichment and water abstraction. Journal of Applied Ecology, 47: 639–649.

MARS Project, website www.mars-project.eu [last access 5.4.2016]

McConnachie, M. M. & R. M. Cowling, 2013. On the accuracy of conservation managers' beliefs and if they learn fromevidence-based knowledge: A preliminary investigation. Journal of Environmental Management, 128: 7–14. Available at: http://dx.doi.org/10.1016/j.jenvman.2013.04.021.

Miltner, R.J. & E. T. Rankin, 1998. Primary nutrients and the biotic integrity of rivers and streams. Freshwater Biology, 40: 145–158.

Mondy, C.P. & P. Usseglio-Polatera, 2013. Using conditional tree forests and life history traits to assess specific risks of stream degradation under multiple pressure scenario. Science of the Total Environment, 461-462: 750–760.

Nichols, S., Webb, A., Norris, R. & M. Stewardson, 2011. Eco Evidence analysis methods manual: a systematic approach to evaluate causality in environmental science. eWater Cooperative Research Centre, Canberra.

Niyogi, D. K., Koren, M., Arbuckle, C. J. & C. R. Townsend, 2007. Stream Communities Along a Catchment Land-Use Gradient: Subsidy-Stress Responses to Pastoral Development. Environmental Management 39: 213-225.

Nõges, P., Argillier, C., Borja, Á., Garmendia, J. M., Hanganu, J., Kodeš, V., Pletterbauer, F., Sagouis, A. & S. Birk, 2016. Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. The Science of the total environment, 540: 43-52.

Norris, R. H., Webb, J. A., Nichols, S. J., Stewardson, M. J. & E. T. Harrison, 2012. Analyzing cause and effect in environmental assessments: using weighted evidence from the literature. Freshwater Science, 31: 5–21.

Ormerod, S.J., Dobson, M. Hildrew, A. G. & C. R. Townsend, 2010. Multiple stressors in freshwater ecosystems. Freshwater Biology, 55: 1–4.

Osmundson, D. B., Ryel, R. J., Lamarra, V. L. & J. Pitlick, 2002. Flow-Sediment-Biota Relations : Implications for River Regulation Effects on Native Fish Abundance. Ecological Applications, 12: 1719–1739.

Owens, P. N., Batalla, R. J., Collins, A. J., Gomez, B., Hicks, D. M., Horowitz, A. J., Kondolf, G. M., Marden, M., Page, M. J., Peacock, D. H., Petticrew, E. L., Salomons, W. & N. A. Trustrum, 2005. Fine-grained sediment in river systems: environmental significance and management issues. River Research and Applications, 21: 693–717. Available at: http://doi.wiley.com/10.1002/rra.878.

Palmer, M. A., Menninger, H. L. & E. Bernhardt, 2010. River restoration, habitat heterogeneity and biodiversity: A failure of theory or practice? Freshwater Biology, 55: 205–222.

Piggott, J. J., Lange, K., Townsend, C. R. & C. D. Matthaei, 2012. Multiple Stressors in Agricultural Streams: A Mesocosm Study of Interactions among Raised Water Temperature, Sediment Addition and Nutrient Enrichment. PLoS ONE, 7(11): e49873. doi:10.1371/journal.pone.0049873

Pullin, A. S., Knight, T. M., Stone, D. A. & K. Charman, 2004. Do conservation managers use scientific evidence to support their decision-making? Biological Conservation, 119: 245–252.

Pullin, A. S. & T. M. Knight, 2009. Doing more good than harm - Building an evidence-base for conservation and environmental management. Biological Conservation, 142: 931–934. Available at: http://dx.doi.org/10.1016/j.biocon.2009.01.010.

Pullin, A. S. & T. M. Knight, 2003. Support for decision making in conservation practice: an evidence-based approach. Journal for Nature Conservation, 11: 83–90. Available at: http://www.sciencedirect.com/science/article/pii/S1617138104700382.

Rabení, C. F., Doisy, K. E. & L. D. Zweig, 2005. Stream invertebrate community functional responses to deposited sediment. Aquatic Sciences, 67: 395–402.

Richardson, J. & I. G. Jowett, 2002. Effects of sediment on fish communities in East Cape streams, North Island, New Zealand. New Zealand Journal of Marine and Freshwater Research, 36: 431–442.

Roberts, P. D., Stewart, G. B. & A. S. Pullin, 2006. Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biological Conservation, 132: 409–423.

Robertson, D. & D. Graczyk, 2006. Nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin, Available at: http://cat.inist.fr/?aModele=afficheN&cpsidt=18018872.

Robertson, D. M., Weigel, B. M. & D. J. Graczyk, 2008. Nutrient concentrations and their relations to the biotic integrity of nonwadable rivers in Wisconsin: U.S. Geological Survey Professional Paper 1754, 81 p.

Schinegger, R., Trautwein, C., Melcher, A. & S. Schmutz, 2012. Multiple human pressures and their spatial patterns in European running waters. Water and Environment Journal, 26: 261–273.

Scruton, D. a. et al., 2008. A synopsis of "hydropeaking" studies on the response of juvenile Atlantic salmon to experimental flow alteration. Hydrobiologia, 609: 263–275.

Statzner, B. & Bêche, L. a., 2010. Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems? Freshwater Biology, 55: 80–119.

Stewart, G. B., Coles, C. F. & A. S. Pullin, 2005. Applying evidence-based practice in conservation management: Lessons from the first systematic review and dissemination projects. Biological Conservation, 126: 270–278.

Susser, M, 1991. What is a cause and how do we know one - a grammar for pragmatic epidemiology. American Journal of Epidemiology 133: 635-648.

Sutherland, A B., Meyer, J.L. & E. P. Gardiner, 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. Freshwater Biology, 47: 1791–1805.

Sutherland, W. J., Pullin, A. S., Dolman, P. M. & T. M. Knight, 2004. The need for evidence-based conservation. Trends in Ecology and Evolution, 19: 305–308.

Townsend, C. R., Uhlmann, S. S. & C. D. Matthaei, 2008. Individual and combined responses of stream ecosystems to multiple stressors. Journal of Applied Ecology, 45: 1810–1819. Available at: http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2664.2007.01428.x.

U.S. EPA, 2000. Stressor Identification Guidance Document. U.S. Environmental Protection Agency, Office of Water, Washington

U.S. EPA, 2007. CADDIS Literature Resource (CADLit) search and download functions. U.S. Environmental Protection Agency Office of Research and Development.14 p.

U.S. EPA, 2010. Causal Analysis/Diagnosis Decision Information System (CADDIS). Office of Research and Development, Washington, DC. Available online at https://www.epa.gov/caddis. Last updated September 23, 2010.

Wagenhoff, A., Townsend, C. R., Phillips, N. & C. D. Matthaei, 2011. Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. Freshwater Biolog*y*, 56: 1916–1936.

Wagenhoff, A., Townsend, C. R. & C. D. Matthaei, 2012. Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: A stream mesocosm experiment. Journal of Applied Ecolog*y*, 49: 892–902.

Wang, L., Robertson, D. M. & P. J. Garrison, 2007. Linkages between nutrients and assemblages of macroinvertebrates and fish in wadeable streams: Implication to nutrient criteria development. Environmental Management, 39: 194–212.

Webb, J. A., de Little, S. C., Miller, K. & M. J. Stewardson, 2012. Eco Evidence Database : a distributed modelling resource for systematic literature analysis in environmental science and management.In: R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.), International Environmental Modelling and Software Society (iEMSs) 2012 International Congress on Environmental Modelling and Software. Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Sixth Biennial Meeting, Leipzig, Germany. http://www.iemss.org/society/index.php/iemss-2012-proceedings. ISBN: 978-88-9035-742-8

Webb, J. A., Miller, K. A., de Little, S. C., Stewardson, M. J., Nichols, S. J. & S. R. Wealands, 2015. An online database and desktop assessment software to simplify systematic reviews in environmental science. Environmental Modelling and Software 64: 72-79.

Webb, J. A., Wealands, S. R., Lea, P., Nichols, S. J., de Little, S. C., Stewardson, M. J. & R. H. Norris, 2011. Eco Evidence: using the scientific literature to inform evidence-based decision making in environmental management. In: Chan, F., Marinova, D., Anderssen, R.S. (Eds.), Proceedings of MODSIM 2011-International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, Perth, Australia, pp. 2472-2478

WISER, website, www.wiser.eu [last access 5.4.2016]

Woodcock, P., Pullin, A.S. & M. J. Kaiser, 2014. Evaluating and improving the reliability of evidence syntheses in conservation and environmental science: A methodology. Biological Conservation, 176: 54–62. Available at: http://dx.doi.org/10.1016/j.biocon.2014.04.020.

Ziegler, C. R., Webb, J. A., Norton, S. B., Pullin, A. S. & A. H. Melcher, 2015. Digital repository of associations between environmental variables: A new resource to facilitate knowledge synthesis. Ecological Indicators, 53: 61-69.

Zweig, L. D., and Rabení, C. F. (2001). Biomonitoring for deposited sediment using benthic invertebrates: a test on four Missouri streams. Journal of the North American Benthological Society 20: 643–657.

# Appendix A

Table of relationships between the stressors and their biological effects, extracted from scientific reference literature *(No – Number of evidence item, Author – first author, Year – year of publication, Drivers/pressures – drivers and pressures causing increased fine sediment/nutrient levels, Stressor(s) – fs (fine sediment), N (nitrogen), P (phosphorus), add (additive relationship), ant (antagonistic relationship), syn (synergistic relationship), Ind – Indicator group [MI-macroinvertebrates, FI – fish], Metric – indicator metric, sign – direction of the ecological response to increased stressor[s])*

| No | Author | Year | Drivers/pressures | Stressor(s) | Ind | Metric | sign | variable category |
|---|---|---|---|---|---|---|---|---|
| 1 | Bo | 2007 | | fs | MI | invertebrate abundance | - | composition/ abundance |
| 2 | Bo | 2007 | | fs | MI | taxa richness | - | diversity |
| 3 | Bo | 2007 | | fs | MI | density of filterers | - | process/ functions |
| 4 | Bryce | 2010 | | fs | MI | IBI | - | composition/ abundance |
| 5 | Bryce | 2010 | | fs | MI | IBI | - | composition/ abundance |
| 6 | Bryce | 2010 | | fs | MI | 8 sensitive species | - | sensitivity/ tolerance |
| 7 | Bryce | 2010 | | fs | MI | 8 sensitive species | - | sensitivity/ tolerance |
| 8 | Buendia | 2013 | | fs | MI | density | - | biomass/ density |
| 9 | Buendia | 2013 | | fs | MI | taxon richness | - | diversity |
| 10 | Buendia | 2013 | | fs | MI | Shannon index | - | diversity |
| 11 | Buendia | 2013 | | fs | MI | max size 0.25-0.5mm | - | process/ functions |
| 12 | Buendia | 2013 | | fs | MI | max size 0.5-1mm | + | process/ functions |
| 13 | Buendia | 2013 | | fs | MI | max size 1-2mm | + | process/ functions |
| 14 | Buendia | 2013 | | fs | MI | max size 2-4mm | - | process/ functions |
| 15 | Buendia | 2013 | | fs | MI | max size 4-8mm | - | process/ functions |
| 16 | Buendia | 2013 | | fs | MI | life-cycle duration <1 year | + | process/ functions |
| 17 | Buendia | 2013 | | fs | MI | life-cycle duration >1 year | - | process/ functions |
| 18 | Buendia | 2013 | | fs | MI | potential generations per year <1 | - | process/ functions |
| 19 | Buendia | 2013 | | fs | MI | potential generations per year = 1 | - | process/ functions |
| 20 | Buendia | 2013 | | fs | MI | potential generations per year >1 | + | process/ functions |
| 21 | Buendia | 2013 | | fs | MI | shredders | - | process/ functions |
| 22 | Buendia | 2013 | | fs | MI | scrapers | + | process/ functions |
| 23 | Buendia | 2013 | | fs | MI | filter feeders | - | process/ functions |
| 24 | Buendia | 2013 | | fs | MI | deposit feeders | + | process/ functions |
| 25 | Buendia | 2013 | | fs | MI | respiration with gills | + | process/ functions |
| 26 | Buendia | 2013 | | fs | MI | swimmers | - | process/ functions |
| 27 | Buendia | 2013 | | fs | MI | crawlers | - | process/ functions |
| 28 | Buendia | 2013 | | fs | MI | burrowers | - | process/ functions |
| 29 | Buendia | 2013 | | fs | MI | EPT density | - | sensitivity/ tolerance |
| 30 | Buendia | 2013 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 31 | Buendia | 2013 | | fs | MI | %EPT | + | sensitivity/ tolerance |
| 32 | Clapcott | 2011 | | fs | MI | Biodiversity | - | diversity |
| 33 | Clapcott | 2011 | | fs | MI | Biodiversity | - | diversity |
| 34 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | % *Corynoneura* spp. | +/- | sensitivity/ tolerance |
| 35 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | % *Deleatidium* spp. | - | sensitivity/ tolerance |
| 36 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | EPT richness | - | sensitivity/ tolerance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 37 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | % EPT | - | sensitivity/ tolerance |
| 38 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | % Oligochaeta | + | composition/ abundance |
| 39 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | % *Potamopyrgus* spp. | + | composition/ abundance |
| 40 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | % Nematoda | + | composition/ abundance |
| 41 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | % Copepoda | +/- | composition/ abundance |
| 42 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | % *Sphaerium* spp. | +/- | composition/ abundance |
| 43 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | % Orthocladiinae | - | sensitivity/ tolerance |
| 44 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | MCI | - | composition/ abundance |
| 45 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | % Ostracoda | + | composition/ abundance |
| 46 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | % *Gyraulus* spp. | + | composition/ abundance |
| 47 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | % *Physella* spp. | + | composition/ abundance |
| 48 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | taxon richness | - | diversity |
| 49 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | evenness | + | diversity |
| 50 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | functional diversity | - | diversity |
| 51 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | max pot size ≤ 5 mm | + | process/ functions |
| 52 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | max pot size 5-10 mm | - | process/ functions |
| 53 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | max pot size 10-20 mm | + | process/ functions |
| 54 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | max pot size 20-40 mm | +/- | process/ functions |
| 55 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | semivoltine | +/- | process/ functions |
| 56 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | 1 reprod. cycle per individual | - | process/ functions |
| 57 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | >2 reprod. cycle per individual | +/- | process/ functions |
| 58 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | life duration of adults 1-10 days | +/- | process/ functions |
| 59 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | life duration of adults 10-30 days | +/- | process/ functions |
| 60 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | life duration of adults 30-365 days | +/- | process/ functions |
| 61 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | asexual reprod. | +/- | process/ functions |
| 62 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | hermaphrodism | +/- | process/ functions |
| 63 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | sexual reprod. | - | process/ functions |
| 64 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | oviposition water surface | - | process/ functions |
| 65 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | oviposition beneath surface | +/- | process/ functions |
| 66 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | oviposition terrestrial | +/- | process/ functions |
| 67 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | eggs free | - | process/ functions |
| 68 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | female bears eggs | +/- | process/ functions |
| 69 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | dissemination potential low (10m) | +/- | process/ functions |
| 70 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | dissemination potential high (>1km) | - | process/ functions |
| 71 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | swimmers | +/- | process/ functions |
| 72 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | attached to substrate | - | process/ functions |
| 73 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | no body flexibility | + | process/ functions |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 74 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | low body flexibility | - | process/ functions |
| 75 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | flattened body form | - | process/ functions |
| 76 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | ant TN & SIS | MI | cylindrical body form | + | process/ functions |
| 77 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | spherical body form | +/- | process/ functions |
| 78 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | aquatic stages: adult, larva | +/- | process/ functions |
| 79 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | aquatic stages: adult or larva | - | process/ functions |
| 80 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | syn TN & SIS | MI | aquatic stages: larva, pupa | +/- | process/ functions |
| 81 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | plurivoltine | - | process/ functions |
| 82 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | life duration of adults >365 days | +/- | process/ functions |
| 83 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | shredders | +/- | process/ functions |
| 84 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | filter feeders | + | process/ functions |
| 85 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | eggs cemented | - | process/ functions |
| 86 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | respiration: tegument | +/- | process/ functions |
| 87 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | burrowers | + | process/ functions |
| 88 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | fs | MI | high body flexibility | - | process/ functions |
| 89 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | add TN & SIS | MI | respiration: gills | +/- | process/ functions |
| 90 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | crawlers | - | process/ functions |
| 91 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | scrapers | - | process/ functions |
| 92 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | deposit feeders | + | process/ functions |
| 93 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | predators | + | process/ functions |
| 94 | Lange | 2014a | farming (fS, N, P), water abstraction (P) | N | MI | respiration: atmospheric O2 | - | process/ functions |
| 95 | Larsen | 2009 | | fs | MI | Oligochaeta relative abundance (%) | + | composition/ abundance |
| 96 | Larsen | 2009 | | fs | MI | total abundance | + | composition/ abundance |
| 97 | Larsen | 2009 | | fs | MI | % Chironomidae | - | sensitivity/ tolerance |
| 98 | Larsen | 2009 | | fs | MI | % Coleoptera | - | composition/ abundance |
| 99 | Larsen | 2009 | | fs | MI | total abundance | - | composition/ abundance |
| 100 | Larsen | 2009 | | fs | MI | taxon richness | - | diversity |
| 101 | Larsen | 2009 | | fs | MI | taxon richness | - | diversity |
| 102 | Larsen | 2009 | | fs | MI | Shannon index | + | diversity |
| 103 | Larsen | 2009 | | fs | MI | taxon richness | - | diversity |
| 104 | Larsen | 2009 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 105 | Larsen | 2009 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 106 | Larsen | 2009 | | fs | MI | % EPT | + | sensitivity/ tolerance |
| 107 | Larsen | 2009 | | fs | MI | total abundance | + | composition/ abundance |
| 108 | Larsen | 2009 | | fs | MI | % Chironomidae | - | sensitivity/ tolerance |
| 109 | Larsen | 2009 | | fs | MI | % Coleoptera | - | composition/ abundance |
| 110 | Larsen | 2009 | | fs | MI | total abundance | - | composition/ abundance |
| 111 | Larsen | 2009 | | fs | MI | taxon richness | - | diversity |
| 112 | Larsen | 2009 | | fs | MI | Shannon index | - | diversity |
| 113 | Larsen | 2009 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 114 | Larsen | 2009 | | fs | MI | % EPT | + | sensitivity/ tolerance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 115 | Matthaei | 2010 | | fs | MI | Total invertebrate density | - | biomass/ density |
| 116 | Matthaei | 2010 | | NP | MI | total density | + | biomass/ density |
| 117 | Matthaei | 2010 | | syn | MI | total density | +/- | biomass/ density |
| 118 | Matthaei | 2010 | | fs | MI | community composition | | composition/ abundance |
| 119 | Matthaei | 2010 | | fs | MI | Deleatidium spp. | | sensitivity/ tolerance |
| 120 | Matthaei | 2010 | | fs | MI | *Pycnocentrodes* spp. | | sensitivity/ tolerance |
| 121 | Matthaei | 2010 | | fs | MI | *Austrosimulium* spp. | | composition/ abundance |
| 122 | Matthaei | 2010 | | fs | MI | Deleatidium spp. | | sensitivity/ tolerance |
| 123 | Matthaei | 2010 | | fs | MI | Potamopyrgus antipodarum | | composition/ abundance |
| 124 | Matthaei | 2010 | | fs | MI | *Austrosimulium* spp. | | composition/ abundance |
| 125 | Matthaei | 2010 | | fs | MI | Copepoda | | composition/ abundance |
| 126 | Matthaei | 2010 | | fs | MI | community composition | | composition/ abundance |
| 127 | Matthaei | 2010 | | syn | MI | *Austrosimulium* spp. | +/- | composition/ abundance |
| 128 | Matthaei | 2010 | | NP | MI | Potamopyrgus antipodarum | | composition/ abundance |
| 129 | Matthaei | 2010 | | NP | MI | community composition | | composition/ abundance |
| 130 | Matthaei | 2010 | | fs | MI | taxon richness | - | diversity |
| 131 | Matthaei | 2010 | | NP | MI | Tanypodinae | | sensitivity/ tolerance |
| 132 | Matthaei | 2010 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 133 | Matthaei | 2010 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 134 | Matthaei | 2010 | | NP | MI | Chironomidae | | sensitivity/ tolerance |
| 135 | Matthaei | 2010 | | NP | MI | Deleatidium spp. | | sensitivity/ tolerance |
| 136 | Matthaei | 2010 | | syn | MI | Deleatidium spp. | +/- | sensitivity/ tolerance |
| 137 | Miltner | 1998 | | N | MI | ICI | - | composition/ abundance |
| 138 | Miltner | 1998 | | N | MI | ICI | - | composition/ abundance |
| 139 | Miltner | 1998 | | P | MI | ICI | - | composition/ abundance |
| 140 | Miltner | 1998 | | P | MI | ICI | - | composition/ abundance |
| 141 | Molinos | 2010 | | syn | MI | Shannon | - | diversity |
| 142 | Mondy | 2013 | agriculture | fs | MI | % filter feeder | + | process/ functions |
| 143 | Mondy | 2013 | agriculture | fs | MI | ovoviviparity | + | process/ functions |
| 144 | Mondy | 2013 | agriculture | fs | MI | isolated cemented eggs | - | process/ functions |
| 145 | Mondy | 2013 | agriculture | fs | MI | crawlers | - | process/ functions |
| 146 | Mondy | 2013 | agriculture | fs | MI | burrowers | + | process/ functions |
| 147 | Mondy | 2013 | agriculture | fs | MI | % scraper | - | process/ functions |
| 148 | Osmundson | 2002 | river regulation (reduced high flows) | fs | MI | Invertebrate dry mass | - | biomass/ density |
| 149 | Osmundson | 2002 | river regulation (reduced high flows) | fs | MI | Invertebrate dry mass | - | biomass/ density |
| 150 | Piggot | 2012 | | fs | MI | total invertebrate abundance | + | composition/ abundance |
| 151 | Piggot | 2012 | | fs | MI | community compostition | | composition/ abundance |
| 152 | Piggot | 2012 | | NP | MI | total invertebrate abundance | + | composition/ abundance |
| 153 | Piggot | 2012 | | fs | MI | Cladocera abundance | | composition/ abundance |
| 154 | Piggot | 2012 | | NP | MI | community compostition | | composition/ abundance |
| 155 | Piggot | 2012 | | NP | MI | P. *antipodarum* abundance | | composition/ abundance |
| 156 | Piggot | 2012 | | fs | MI | Copepoda abundance | | composition/ abundance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 157 | Piggot | 2012 | | fs | MI | Deleatidium spp. Abundance | - | sensitivity/ tolerance |
| 158 | Piggot | 2012 | | fs | MI | *Hydora* spp. Abundance | | composition/ abundance |
| 159 | Piggot | 2012 | | fs | MI | Nematoda abundance | + | composition/ abundance |
| 160 | Piggot | 2012 | | fs | MI | P. *antipodarum* abundance | | composition/ abundance |
| 161 | Piggot | 2012 | | fs | MI | Conoescidae abundance | - | sensitivity/ tolerance |
| 162 | Piggot | 2012 | | fs | MI | taxon richness | +/- | diversity |
| 163 | Piggot | 2012 | | NP | MI | Hydrobiosidae abundance | | sensitivity/ tolerance |
| 164 | Piggot | 2012 | | NP | MI | *Oxyethira* spp. Abundance | | sensitivity/ tolerance |
| 165 | Piggot | 2012 | | NP | MI | Conoescidae abundance | + | sensitivity/ tolerance |
| 166 | Piggot | 2012 | | fs | MI | sensitive EPT density | - | sensitivity/ tolerance |
| 167 | Piggot | 2012 | | fs | MI | total EPT abundance | | sensitivity/ tolerance |
| 168 | Piggot | 2012 | | fs | MI | EPT richness | | sensitivity/ tolerance |
| 169 | Piggot | 2012 | | add | MI | Conoescidae abundance | +/- | sensitivity/ tolerance |
| 170 | Piggot | 2012 | | NP | MI | Chironomidae abundance | + | sensitivity/ tolerance |
| 171 | Piggot | 2012 | | NP | MI | total EPT abundance | + | sensitivity/ tolerance |
| 172 | Piggot | 2012 | | add | MI | total EPT abundance | +/- | sensitivity/ tolerance |
| 173 | Piggot | 2012 | | add | MI | EPT richness | | sensitivity/ tolerance |
| 174 | Rabeni | 2005 | | fs | MI | taxa richness | - | diversity |
| 175 | Rabeni | 2005 | | fs | MI | % gatherers (taxa) | + | process/ functions |
| 176 | Rabeni | 2005 | | fs | MI | % shredders (taxa) | + | process/ functions |
| 177 | Rabeni | 2005 | | fs | MI | scrapers (richness) | - | process/ functions |
| 178 | Rabeni | 2005 | | fs | MI | gatherers (richness) | - | process/ functions |
| 179 | Rabeni | 2005 | | fs | MI | filterers (richness) | - | process/ functions |
| 180 | Rabeni | 2005 | | fs | MI | predators (richness) | - | process/ functions |
| 181 | Rabeni | 2005 | | fs | MI | % filteres | - | process/ functions |
| 182 | Rabeni | 2005 | | fs | MI | % scrapers | - | process/ functions |
| 183 | Rabeni | 2005 | | fs | MI | clingers (richness) | - | process/ functions |
| 184 | Rabeni | 2005 | | fs | MI | swimmers (richness) | - | process/ functions |
| 185 | Rabeni | 2005 | | fs | MI | sprawlers (richness) | - | process/ functions |
| 186 | Rabeni | 2005 | | fs | MI | % clingers (taxa) | - | process/ functions |
| 187 | Rabeni | 2005 | | fs | MI | % climbers (taxa) | + | process/ functions |
| 188 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | fs | MI | hbi | + | composition/ abundance |
| 189 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | fs | MI | species richness | - | diversity |
| 190 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | fs | MI | %ephem | - | sensitivity/ tolerance |
| 191 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | fs | MI | mean pollution tolerance value | + | sensitivity/ tolerance |
| 192 | Robertson | 2008 | agriculture, absence of forest | N | MI | hbi | + | composition/ abundance |
| 193 | Robertson | 2008 | | P | MI | hbi | + | composition/ abundance |
| 194 | Robertson | 2008 | | P | MI | hbi | + | composition/ abundance |
| 195 | Robertson | 2008 | agriculture | N | MI | species richness | - | diversity |
| 196 | Robertson | 2008 | | P | MI | species richness | - | diversity |
| 197 | Robertson | 2008 | | P | MI | species richness | - | diversity |
| 198 | Robertson | 2008 | | P | MI | species richness | - | diversity |
| 199 | Robertson | 2008 | agriculture | N | MI | species richness | - | diversity |
| 200 | Robertson | 2008 | agriculture | N | MI | %scrap | - | process/ functions |
| 201 | Robertson | 2008 | agriculture | N | MI | %scrap | - | process/ functions |
| 202 | Robertson | 2008 | agriculture | N | MI | %shred | + | process/ functions |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 203 | Robertson | 2008 | agriculture | P | MI | %ephem | - | sensitivity/ tolerance |
| 204 | Robertson | 2008 | agriculture | P | MI | %plec | - | sensitivity/ tolerance |
| 205 | Robertson | 2008 | agriculture | P | MI | mean pollution tolerance value | + | sensitivity/ tolerance |
| 206 | Robertson | 2008 | agriculture | P | MI | %ephem | - | sensitivity/ tolerance |
| 207 | Robertson | 2008 | agriculture | P | MI | %plec | - | sensitivity/ tolerance |
| 208 | Robertson | 2008 | agriculture | P | MI | mean pollution tolerance value | + | sensitivity/ tolerance |
| 209 | Robertson | 2008 | agriculture | N | MI | %ephem | - | sensitivity/ tolerance |
| 210 | Robertson | 2008 | agriculture | N | MI | %plec | - | sensitivity/ tolerance |
| 211 | Robertson | 2008 | agriculture | N | MI | %trichop | + | sensitivity/ tolerance |
| 212 | Robertson | 2008 | agriculture | N | MI | mean pollution tolerance value | + | sensitivity/ tolerance |
| 213 | Robertson | 2008 | agriculture | N | MI | %trichop | + | sensitivity/ tolerance |
| 214 | Robertson | 2008 | agriculture | N | MI | %plec | - | sensitivity/ tolerance |
| 215 | Robertson | 2008 | agriculture | N | MI | %ephem | - | sensitivity/ tolerance |
| 216 | Robertson | 2008 | agriculture | N | MI | %plec | - | sensitivity/ tolerance |
| 217 | Robertson | 2008 | agriculture | N | MI | %epttx | - | sensitivity/ tolerance |
| 218 | Robertson | 2008 | agriculture | N | MI | %depositional habitat tolerant individuals | - | sensitivity/ tolerance |
| 219 | Robertson | 2008 | agriculture | N | MI | mean pollution tolerance value | + | sensitivity/ tolerance |
| 220 | Townsend | 2008 | agriculture | fs | MI | Oligochaeta density | + | biomass/ density |
| 221 | Townsend | 2008 | | syn | MI | total taxon richness | - | diversity |
| 222 | Townsend | 2008 | | syn | MI | % 2+ cycles/ind. | + | process/ functions |
| 223 | Townsend | 2008 | | syn | MI | single individual reproduction | + | process/ functions |
| 224 | Townsend | 2008 | agriculture | fs | MI | % burrowers | + | process/ functions |
| 225 | Townsend | 2008 | agriculture | fs | MI | % respiration gills | - | process/ functions |
| 226 | Townsend | 2008 | agriculture | fs | MI | % surface egg laying | - | process/ functions |
| 227 | Townsend | 2008 | agriculture | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 228 | Townsend | 2008 | agriculture | fs | MI | EPT density | + | sensitivity/ tolerance |
| 229 | Townsend | 2008 | | syn | MI | EPT richness | - | sensitivity/ tolerance |
| 230 | Wagenhoff | 2011 | agriculture (fS, N) | add | MI | surface eggs % | - | process/ functions |
| 231 | Wagenhoff | 2011 | agriculture (fS, N) | syn | MI | % more than two reproductive cycles per ind. | + | process/ functions |
| 232 | Wagenhoff | 2011 | agriculture (fS, N) | fs | MI | % single indiv. Reprod. | + | process/ functions |
| 233 | Wagenhoff | 2011 | agriculture (fS, N) | add | MI | EPT richness | - | sensitivity/ tolerance |
| 234 | Wagenhoff | 2011 | agriculture (fS, N) | syn | MI | % Deleatidium | - | sensitivity/ tolerance |
| 235 | Wagenhoff | 2011 | agriculture (fS, N) | syn | MI | % EPT | - | sensitivity/ tolerance |
| 236 | Wagenhoff | 2011 | agriculture (fS, N) | add | MI | % *Pycnocentrodes* | - | sensitivity/ tolerance |
| 237 | Wagenhoff | 2011 | agriculture (fS, N) | add | MI | MCI (macroinv. Community index) | - | composition/ abundance |
| 238 | Wagenhoff | 2011 | agriculture (fS, N) | syn | MI | % Oligochaetes | + | composition/ abundance |
| 239 | Wagenhoff | 2011 | agriculture (fS, N) | syn | MI | % Elmidae | +/- | composition/ abundance |
| 240 | Wagenhoff | 2011 | agriculture (fS, N) | fs | MI | % P. antipodarum | + | composition/ abundance |
| 241 | Wagenhoff | 2012 | | fs | MI | cladocera density | - | biomass/ density |
| 242 | Wagenhoff | 2012 | | fs | MI | Hydora density | - | biomass/ density |
| 243 | Wagenhoff | 2012 | | fs | MI | Temnocephalus density | - | biomass/ density |
| 244 | Wagenhoff | 2012 | | fs | MI | Psilochorema density | - | biomass/ density |
| 245 | Wagenhoff | 2012 | | fs | MI | Oligochaeta density | +/- | biomass/ density |
| 246 | Wagenhoff | 2012 | | fs | MI | nematoda density | +/- | biomass/ density |
| 247 | Wagenhoff | 2012 | | fs | MI | copepoda density | +/- | biomass/ density |
| 248 | Wagenhoff | 2012 | | fs | MI | ostracoda density | +/- | biomass/ density |
| 249 | Wagenhoff | 2012 | | fs | MI | total density | +/- | biomass/ density |
| 250 | Wagenhoff | 2012 | | NP | MI | Oligochaeta density | - | biomass/ density |
| 251 | Wagenhoff | 2012 | | NP | MI | cladocera density | - | biomass/ density |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 252 | Wagenhoff | 2012 | | NP | MI | ostracoda density | - | biomass/ density |
| 253 | Wagenhoff | 2012 | | NP | MI | Psilochorema density | +/- | biomass/ density |
| 254 | Wagenhoff | 2012 | | NP | MI | total density | +/- | biomass/ density |
| 255 | Wagenhoff | 2012 | | NP | MI | evenness | + | diversity |
| 256 | Wagenhoff | 2012 | | NP | MI | total taxon richness | +/- | diversity |
| 257 | Wagenhoff | 2012 | | fs | MI | total taxon richness | - | diversity |
| 258 | Wagenhoff | 2012 | | fs | MI | evenness | +/- | diversity |
| 259 | Wagenhoff | 2012 | | add | MI | 19 variables (e.g. cladocera density, % spherical body shape, total EPT) | all | biomass/ density, processes, sensitive taxa |
| 260 | Wagenhoff | 2012 | | fs | MI | surface eggs % | - | process/ functions |
| 261 | Wagenhoff | 2012 | | fs | MI | clingers % | - | process/ functions |
| 262 | Wagenhoff | 2012 | | fs | MI | low body flexibility % | - | process/ functions |
| 263 | Wagenhoff | 2012 | | fs | MI | spherical body shape % | - | process/ functions |
| 264 | Wagenhoff | 2012 | | fs | MI | grazers % | - | process/ functions |
| 265 | Wagenhoff | 2012 | | fs | MI | filterers % | - | process/ functions |
| 266 | Wagenhoff | 2012 | | fs | MI | % single indiv. Reprod. | + | process/ functions |
| 267 | Wagenhoff | 2012 | | NP | MI | >2 reprod. Cycles/ind % | - | process/ functions |
| 268 | Wagenhoff | 2012 | | fs | MI | % burrowers | + | process/ functions |
| 269 | Wagenhoff | 2012 | | fs | MI | % deposit feeders | + | process/ functions |
| 270 | Wagenhoff | 2012 | | fs | MI | % predators | + | process/ functions |
| 271 | Wagenhoff | 2012 | | NP | MI | single individual reproduction % | - | process/ functions |
| 272 | Wagenhoff | 2012 | | NP | MI | spherical body shape % | - | process/ functions |
| 273 | Wagenhoff | 2012 | | fs | MI | % respires using gills | + | process/ functions |
| 274 | Wagenhoff | 2012 | | fs | MI | Average body size | + | process/ functions |
| 275 | Wagenhoff | 2012 | | NP | MI | % filterers | - | process/ functions |
| 276 | Wagenhoff | 2012 | | NP | MI | % surface eggs | + | process/ functions |
| 277 | Wagenhoff | 2012 | | NP | MI | % low body flexibility | + | process/ functions |
| 278 | Wagenhoff | 2012 | | fs | MI | >2 reprod. Cycles/ind % | +/- | process/ functions |
| 279 | Wagenhoff | 2012 | | NP | MI | % respires using gills | + | process/ functions |
| 280 | Wagenhoff | 2012 | | NP | MI | Average body size | + | process/ functions |
| 281 | Wagenhoff | 2012 | | fs | MI | Chironomidae density | - | sensitivity/ tolerance |
| 282 | Wagenhoff | 2012 | | fs | MI | Deleatidium density | - | sensitivity/ tolerance |
| 283 | Wagenhoff | 2012 | | fs | MI | Tanypodinae density | - | sensitivity/ tolerance |
| 284 | Wagenhoff | 2012 | | fs | MI | Oxyethira density | - | sensitivity/ tolerance |
| 285 | Wagenhoff | 2012 | | fs | MI | EPT density | - | sensitivity/ tolerance |
| 286 | Wagenhoff | 2012 | | fs | MI | % EPT | - | sensitivity/ tolerance |
| 287 | Wagenhoff | 2012 | | fs | MI | EPT richness | - | sensitivity/ tolerance |
| 288 | Wagenhoff | 2012 | | NP | MI | % EPT | + | sensitivity/ tolerance |
| 289 | Wagenhoff | 2012 | | NP | MI | Chironomidae density | +/- | sensitivity/ tolerance |
| 290 | Wagenhoff | 2012 | | NP | MI | Deleatidium density | +/- | sensitivity/ tolerance |
| 291 | Wagenhoff | 2012 | | NP | MI | Tanypodinae density | +/- | sensitivity/ tolerance |
| 292 | Wagenhoff | 2012 | | NP | MI | EPT density | +/- | sensitivity/ tolerance |
| 293 | Wagenhoff | 2012 | | NP | MI | EPT richness | +/- | sensitivity/ tolerance |
| 294 | Wagenhoff | 2012 | | syn | MI | EPT richness | - | sensitivity/ tolerance |
| 295 | Wagenhoff | 2012 | | syn | MI | Chironomidae density | - | sensitivity/ tolerance |
| 296 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | MIBI | - | composition/ abundance |
| 297 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | HBI | + | composition/ abundance |
| 298 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | ISOPONB% | + | composition/ abundance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 299 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | ISOPOTX% | + | composition/ abundance |
| 300 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | TOP2NB% | + | composition/ abundance |
| 301 | Wang | 2007 | agriculture, absence of forest | TP | MI | HBI | + | composition/ abundance |
| 302 | Wang | 2007 | agriculture, absence of forest | TP | MI | ISOPONB% | + | composition/ abundance |
| 303 | Wang | 2007 | agriculture, absence of forest | TP | MI | ISOPOTX% | + | composition/ abundance |
| 304 | Wang | 2007 | agriculture, absence of forest | NH4J | MI | HBI | + | composition/ abundance |
| 305 | Wang | 2007 | agriculture, absence of forest | NH4J | MI | MIDGENB% | + | composition/ abundance |
| 306 | Wang | 2007 | agriculture, absence of forest | TKN | MI | HBI | + | composition/ abundance |
| 307 | Wang | 2007 | agriculture, absence of forest | TKN | MI | ISOPONB% | + | composition/ abundance |
| 308 | Wang | 2007 | agriculture, absence of forest | TKN | MI | ISOPOTX% | + | composition/ abundance |
| 309 | Wang | 2007 | agriculture, absence of forest | TP | MI | MIDGETX% | + | composition/ abundance |
| 310 | Wang | 2007 | agriculture, absence of forest | TP | MI | TOP2NB% | + | composition/ abundance |
| 311 | Wang | 2007 | agriculture, absence of forest | TPJ | MI | HBI | + | composition/ abundance |
| 312 | Wang | 2007 | agriculture, absence of forest | TPJ | MI | ISOPOTX% | + | composition/ abundance |
| 313 | Wang | 2007 | agriculture, absence of forest | TPA | MI | HBI | + | composition/ abundance |
| 314 | Wang | 2007 | agriculture, absence of forest | TPA | MI | ISOPONB% | + | composition/ abundance |
| 315 | Wang | 2007 | agriculture, absence of forest | TKN | MI | MIDGENB% | + | composition/ abundance |
| 316 | Wang | 2007 | agriculture, absence of forest | TKNJ | MI | HBI | + | composition/ abundance |
| 317 | Wang | 2007 | agriculture, absence of forest | TKNJ | MI | MIDGENB% | + | composition/ abundance |
| 318 | Wang | 2007 | agriculture, absence of forest | TN | MI | HBI | + | composition/ abundance |
| 319 | Wang | 2007 | agriculture, absence of forest | TN | MI | MIBI | - | composition/ abundance |
| 320 | Wang | 2007 | agriculture, absence of forest | TN | MI | MIDGENB% | + | composition/ abundance |
| 321 | Wang | 2007 | agriculture, absence of forest | TN | MI | TOP2NB% | + | composition/ abundance |
| 322 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | HBI | + | composition/ abundance |
| 323 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | MIBI | - | composition/ abundance |
| 324 | Wang | 2007 | agriculture, absence of forest | TNA | MI | HBI | + | composition/ abundance |
| 325 | Wang | 2007 | agriculture, absence of forest | TNA | MI | MIBI | - | composition/ abundance |
| 326 | Wang | 2007 | agriculture, absence of forest | TNA | MI | MIDGENB% | + | composition/ abundance |
| 327 | Wang | 2007 | agriculture, absence of forest | TNA | MI | TOP2NB% | + | composition/ abundance |
| 328 | Wang | 2007 | agriculture, absence of forest | TPA | MI | ISOPOTX% | + | composition/ abundance |
| 329 | Wang | 2007 | agriculture, absence of forest | TPA | MI | MIDGETX% | + | composition/ abundance |
| 330 | Wang | 2007 | agriculture, absence of forest | DP | MI | HBI | + | composition/ abundance |
| 331 | Wang | 2007 | agriculture, absence of forest | DP | MI | ISOPONB% | + | composition/ abundance |
| 332 | Wang | 2007 | agriculture, absence of forest | DP | MI | ISOPOTX% | + | composition/ abundance |
| 333 | Wang | 2007 | agriculture, absence of forest | DPJ | MI | HBI | + | composition/ abundance |
| 334 | Wang | 2007 | agriculture, absence of forest | DPJ | MI | MIDGENB% | + | composition/ abundance |
| 335 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | SDIVERSI | - | diversity |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 336 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | TAXANB | - | diversity |
| 337 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | SDIVERSI | - | diversity |
| 338 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | TAXANB | - | diversity |
| 339 | Wang | 2007 | agriculture, absence of forest | TN | MI | SDIVERSI | - | diversity |
| 340 | Wang | 2007 | agriculture, absence of forest | TN | MI | TAXANB | - | diversity |
| 341 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | SDIVERSI | - | diversity |
| 342 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | TAXANB | - | diversity |
| 343 | Wang | 2007 | agriculture, absence of forest | TNA | MI | SDIVERSI | - | diversity |
| 344 | Wang | 2007 | agriculture, absence of forest | TNA | MI | TAXANB | - | diversity |
| 345 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | GATHETX% | + | process/ functions |
| 346 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | PREDANB% | - | process/ functions |
| 347 | Wang | 2007 | agriculture, absence of forest | NO3 | MI | PREDATX% | - | process/ functions |
| 348 | Wang | 2007 | agriculture, absence of forest | NO3J | MI | PREDANB% | - | process/ functions |
| 349 | Wang | 2007 | agriculture, absence of forest | NO3J | MI | PREDATX% | - | process/ functions |
| 350 | Wang | 2007 | agriculture, absence of forest | TKN | MI | FILTETX% | - | process/ functions |
| 351 | Wang | 2007 | agriculture, absence of forest | TKN | MI | SCRAPNB% | + | process/ functions |
| 352 | Wang | 2007 | agriculture, absence of forest | TKN | MI | SHREDNB% | + | process/ functions |
| 353 | Wang | 2007 | agriculture, absence of forest | TKN | MI | SHREDTX% | + | process/ functions |
| 354 | Wang | 2007 | agriculture, absence of forest | TN | MI | PREDANB% | - | process/ functions |
| 355 | Wang | 2007 | agriculture, absence of forest | TN | MI | PREDATX% | - | process/ functions |
| 356 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | PREDANB% | - | process/ functions |
| 357 | Wang | 2007 | agriculture, absence of forest | TNA | MI | PREDANB% | - | process/ functions |
| 358 | Wang | 2007 | agriculture, absence of forest | TNA | MI | PREDATX% | - | process/ functions |
| 359 | Wang | 2007 | agriculture, absence of forest | TP | MI | EPTNB% | - | sensitivity/ tolerance |
| 360 | Wang | 2007 | agriculture, absence of forest | TP | MI | EPTTX% | - | sensitivity/ tolerance |
| 361 | Wang | 2007 | agriculture, absence of forest | TP | MI | TOLVALUE | + | sensitivity/ tolerance |
| 362 | Wang | 2007 | agriculture, absence of forest | TPJ | MI | EPTNB% | - | sensitivity/ tolerance |
| 363 | Wang | 2007 | agriculture, absence of forest | TPJ | MI | EPTTX% | - | sensitivity/ tolerance |
| 364 | Wang | 2007 | agriculture, absence of forest | TPJ | MI | TOLVALUE | + | sensitivity/ tolerance |
| 365 | Wang | 2007 | agriculture, absence of forest | TPA | MI | EPTNB% | - | sensitivity/ tolerance |
| 366 | Wang | 2007 | agriculture, absence of forest | TPA | MI | EPTTX% | - | sensitivity/ tolerance |
| 367 | Wang | 2007 | agriculture, absence of forest | TPA | MI | TOLVALUE | + | sensitivity/ tolerance |
| 368 | Wang | 2007 | agriculture, absence of forest | DP | MI | EPTNB% | - | sensitivity/ tolerance |
| 369 | Wang | 2007 | agriculture, absence of forest | DP | MI | EPTTX% | - | sensitivity/ tolerance |
| 370 | Wang | 2007 | agriculture, absence of forest | DP | MI | TOLVALUE | + | sensitivity/ tolerance |
| 371 | Wang | 2007 | agriculture, absence of forest | DPJ | MI | EPTNB% | - | sensitivity/ tolerance |
| 372 | Wang | 2007 | agriculture, absence of forest | DPJ | MI | EPTTX% | - | sensitivity/ tolerance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 373 | Wang | 2007 | agriculture, absence of forest | DPJ | MI | TOLVALUE | + | sensitivity/ tolerance |
| 374 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | EPTNB% | - | sensitivity/ tolerance |
| 375 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | EPTTX% | - | sensitivity/ tolerance |
| 376 | Wang | 2007 | agriculture, absence of forest | NH4 | MI | TOLVALUE | + | sensitivity/ tolerance |
| 377 | Wang | 2007 | agriculture, absence of forest | NH4J | MI | EPTNB% | - | sensitivity/ tolerance |
| 378 | Wang | 2007 | agriculture, absence of forest | NH4J | MI | EPTTX% | - | sensitivity/ tolerance |
| 379 | Wang | 2007 | agriculture, absence of forest | NH4J | MI | TOLVALUE | + | sensitivity/ tolerance |
| 380 | Wang | 2007 | agriculture, absence of forest | TKN | MI | EPTNB% | - | sensitivity/ tolerance |
| 381 | Wang | 2007 | agriculture, absence of forest | TKN | MI | EPTTX% | - | sensitivity/ tolerance |
| 382 | Wang | 2007 | agriculture, absence of forest | TKN | MI | TOLVALUE | + | sensitivity/ tolerance |
| 383 | Wang | 2007 | agriculture, absence of forest | TKNJ | MI | EPTTX% | - | sensitivity/ tolerance |
| 384 | Wang | 2007 | agriculture, absence of forest | TKNJ | MI | TOLVALUE | + | sensitivity/ tolerance |
| 385 | Wang | 2007 | agriculture, absence of forest | TN | MI | EPTNB% | - | sensitivity/ tolerance |
| 386 | Wang | 2007 | agriculture, absence of forest | TN | MI | EPTTX% | - | sensitivity/ tolerance |
| 387 | Wang | 2007 | agriculture, absence of forest | TN | MI | TOLVALUE | + | sensitivity/ tolerance |
| 388 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | EPTNB% | - | sensitivity/ tolerance |
| 389 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | EPTTX% | - | sensitivity/ tolerance |
| 390 | Wang | 2007 | agriculture, absence of forest | TNJ | MI | TOLVALUE | + | sensitivity/ tolerance |
| 391 | Wang | 2007 | agriculture, absence of forest | TNA | MI | EPTNB% | - | sensitivity/ tolerance |
| 392 | Wang | 2007 | agriculture, absence of forest | TNA | MI | EPTTX% | - | sensitivity/ tolerance |
| 393 | Wang | 2007 | agriculture, absence of forest | TNA | MI | TOLVALUE | + | sensitivity/ tolerance |
| 394 | Zweig | 2001 | no access! | fs cover % | MI | EPT density | - | sensitivity/ tolerance |
| 395 | Zweig | 2001 | | fs cover % | MI | EPT richness | - | sensitivity/ tolerance |
| 396 | Zweig | 2001 | | fs cover % | MI | EPT/Chironomidae richness | - | sensitivity/ tolerance |
| 397 | Argent | 1999 | | fS weight % | FI | incubating Brook trout survival | - | sensitivity/ tolerance |
| 398 | Bryce | 2010 | | fS cover % | FI | 4 sensitive species | - | sensitivity/ tolerance |
| 399 | Bryce | 2010 | | fS cover % | FI | 4 sensitive species | - | sensitivity/ tolerance |
| 400 | Lange | 2014b | farming | add TN & fs | FI | trout density | - | sensitivity/ tolerance |
| 401 | Lange | 2014b | farming | TN | FI | Bully presence | +/- | biomass/ density |
| 402 | Lange | 2014b | farming | TN | FI | Bully density | +/- | biomass/ density |
| 403 | Lange | 2014b | farming | fSdepth mm | FI | trout presence | - | sensitivity/ tolerance |
| 404 | Lange | 2014b | farming | fSdepth mm | FI | trout density | - | sensitivity/ tolerance |
| 405 | Lange | 2014b | farming | TN | FI | trout density | - | sensitivity/ tolerance |
| 406 | Miltner | 1998 | | TIN | FI | IBI | - | composition/ abundance |
| 407 | Miltner | 1998 | | TIN | FI | IBI | - | composition/ abundance |
| 408 | Miltner | 1998 | | TP | FI | IBI | - | composition/ abundance |
| 409 | Miltner | 1998 | | TP | FI | IBI | - | composition/ abundance |
| 410 | Miltner | 1998 | | TIN | FI | IBI | - | composition/ abundance |
| 411 | Richardson | 2002 | natural exacerbated by forest clearance (agriculture) | SSC g/m3 | FI | fish abundance | - | composition/ abundance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 412 | Richardson | 2002 | natural exacerbated by forest clearance (agriculture) | SSC g/m3 | FI | fish diversity | - | diversity |
| 413 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | riverine species (nr) | - | composition/ abundance |
| 414 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | %riversp | - | composition/ abundance |
| 415 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | IBI | - | composition/ abundance |
| 416 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | %litspawn | - | process/ functions |
| 417 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | %sucker | - | process/ functions |
| 418 | Robertson | 2008 | agriculture | TP | FI | riverine species (nr) | - | composition/ abundance |
| 419 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | %insect | - | process/ functions |
| 420 | Robertson | 2008 | agriculture | TP | FI | %riversp | - | composition/ abundance |
| 421 | Robertson | 2008 | agriculture | TP | FI | IBI | - | composition/ abundance |
| 422 | Robertson | 2008 | agriculture | DP | FI | nativesp | - | composition/ abundance |
| 423 | Robertson | 2008 | agriculture | DP | FI | riverine species (nr) | - | composition/ abundance |
| 424 | Robertson | 2008 | agriculture | DP | FI | %riversp | - | composition/ abundance |
| 425 | Robertson | 2008 | agriculture | TN | FI | riverine species (nr) | - | composition/ abundance |
| 426 | Robertson | 2008 | agriculture | TN | FI | %riversp | - | composition/ abundance |
| 427 | Robertson | 2008 | agriculture | TN | FI | IBI | - | composition/ abundance |
| 428 | Robertson | 2008 | agriculture | NH4 | FI | nativesp | - | composition/ abundance |
| 429 | Robertson | 2008 | agriculture | NH4 | FI | riverine species (nr) | - | composition/ abundance |
| 430 | Robertson | 2008 | agriculture | NH4 | FI | %riversp | - | composition/ abundance |
| 431 | Robertson | 2008 | agriculture | NH4 | FI | IBI | - | composition/ abundance |
| 432 | Robertson | 2008 | agriculture | TKN | FI | riverine species (nr) | - | composition/ abundance |
| 433 | Robertson | 2008 | agriculture | TKN | FI | %riversp | - | composition/ abundance |
| 434 | Robertson | 2008 | agriculture | TKN | FI | IBI | - | composition/ abundance |
| 435 | Robertson | 2008 | agriculture | TP | FI | %disease | + | Disease and deformities |
| 436 | Robertson | 2008 | agriculture | TP | FI | sucker | - | process/ functions |
| 437 | Robertson | 2008 | agriculture | TP | FI | %litspawn | - | process/ functions |
| 438 | Robertson | 2008 | agriculture | TP | FI | %sucker | - | process/ functions |
| 439 | Robertson | 2008 | agriculture | TP | FI | %insect | - | process/ functions |
| 440 | Robertson | 2008 | agriculture, absence of forest, urban area (%) | SSC | FI | intol | - | sensitivity/ tolerance |
| 441 | Robertson | 2008 | agriculture, absence of forest | NO3 | FI | disease | + | Disease and deformities |
| 442 | Robertson | 2008 | agriculture | TN | FI | %litspawn | - | process/ functions |
| 443 | Robertson | 2008 | agriculture | TN | FI | %sucker | - | process/ functions |
| 444 | Robertson | 2008 | agriculture | TN | FI | %insect | - | process/ functions |
| 445 | Robertson | 2008 | agriculture | NO3 | FI | %litspawn | - | process/ functions |
| 446 | Robertson | 2008 | agriculture | NO3 | FI | %sucker | - | process/ functions |
| 447 | Robertson | 2008 | agriculture | NO3 | FI | %insect | - | process/ functions |
| 448 | Robertson | 2008 | agriculture | NH4 | FI | sucker | - | process/ functions |
| 449 | Robertson | 2008 | agriculture | NH4 | FI | %litspawn | - | process/ functions |
| 450 | Robertson | 2008 | agriculture | NH4 | FI | %sucker | - | process/ functions |
| 451 | Robertson | 2008 | agriculture | DP | FI | sucker | - | process/ functions |
| 452 | Robertson | 2008 | agriculture | DP | FI | %litspawn | - | process/ functions |
| 453 | Robertson | 2008 | agriculture | DP | FI | %sucker | - | process/ functions |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 454 | Robertson | 2008 | agriculture | NH4 | FI | %insect | - | process/ functions |
| 455 | Robertson | 2008 | agriculture | TKN | FI | sucker | - | process/ functions |
| 456 | Robertson | 2008 | agriculture | TKN | FI | %litspawn | - | process/ functions |
| 457 | Robertson | 2008 | agriculture | TKN | FI | %sucker | - | process/ functions |
| 458 | Robertson | 2008 | agriculture | TKN | FI | %insect | - | process/ functions |
| 459 | Robertson | 2008 | agriculture | TP | FI | intol | - | sensitivity/ tolerance |
| 460 | Robertson | 2008 | agriculture | DP | FI | intol | - | sensitivity/ tolerance |
| 461 | Robertson | 2008 | agriculture | TN | FI | intol | - | sensitivity/ tolerance |
| 462 | Robertson | 2008 | agriculture | NO3 | FI | intol | - | sensitivity/ tolerance |
| 463 | Robertson | 2008 | agriculture | TKN | FI | intol | - | sensitivity/ tolerance |
| 464 | Sutherland | 2002 | agriculture | baseflow turbidity (NTU) | FI | benthic crevice and gravel spawners (rel. Abundance of adult fishes) | - | process/ functions |
| 465 | Sutherland | 2002 | agriculture | baseflow turbidity (NTU) | FI | benthic excavators (rel. Abundance of adult fishes) | ns | process/ functions |
| 466 | Sutherland | 2002 | agriculture | baseflow turbidity (NTU) | FI | benthic nest builders and benthic nest associates (rel. Abundance of adult fishes) | - | process/ functions |
| 467 | Sutherland | 2002 | agriculture | Embeddedness % | FI | benthic crevice and gravel spawners (rel. Abundance of adult fishes) | - | process/ functions |
| 468 | Sutherland | 2002 | agriculture | Embeddedness % | FI | benthic excavators (rel. Abundance of adult fishes) | + | process/ functions |
| 469 | Sutherland | 2002 | agriculture | Embeddedness % | FI | benthic nest builders and benthic nest associates (rel. Abundance of adult fishes) | ns | process/ functions |
| 470 | Wang | 2007 | agriculture, absence of forest | NO3 | FI | FISBIOMA | + | biomass/ density |
| 471 | Wang | 2007 | agriculture, absence of forest | NO3J | FI | FISBIOMA | + | biomass/ density |
| 472 | Wang | 2007 | agriculture, absence of forest | TP | FI | FISIBI | - | composition/ abundance |
| 473 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | FISIBI | - | composition/ abundance |
| 474 | Wang | 2007 | agriculture, absence of forest | TPA | FI | FISIBI | - | composition/ abundance |
| 475 | Wang | 2007 | agriculture, absence of forest | DP | FI | FISIBI | - | composition/ abundance |
| 476 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | FISIBI | - | composition/ abundance |
| 477 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | FISIBI | - | composition/ abundance |
| 478 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | NATINB | - | composition/ abundance |
| 479 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | NATINB% | - | composition/ abundance |
| 480 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | NATISP% | - | composition/ abundance |
| 481 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | SUNFNB | + | composition/ abundance |
| 482 | Wang | 2007 | agriculture, absence of forest | TKN | FI | FISIBI | - | composition/ abundance |
| 483 | Wang | 2007 | agriculture, absence of forest | TKN | FI | NATINB | - | composition/ abundance |
| 484 | Wang | 2007 | agriculture, absence of forest | TKN | FI | NATINB% | - | composition/ abundance |
| 485 | Wang | 2007 | agriculture, absence of forest | TKN | FI | NATISP% | - | composition/ abundance |
| 486 | Wang | 2007 | agriculture, absence of forest | TKN | FI | SUNFNB | + | composition/ abundance |
| 487 | Wang | 2007 | agriculture, absence of forest | TKN | FI | SUNFNB% | + | composition/ abundance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 488 | Wang | 2007 | agriculture, absence of forest | TKN | FI | SUNFSP% | + | composition/ abundance |
| 489 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | SUNFNB | + | composition/ abundance |
| 490 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | SUNFNB% | + | composition/ abundance |
| 491 | Wang | 2007 | agriculture, absence of forest | TN | FI | FISIBI | - | composition/ abundance |
| 492 | Wang | 2007 | agriculture, absence of forest | TNJ | FI | FISIBI | - | composition/ abundance |
| 493 | Wang | 2007 | agriculture, absence of forest | TNA | FI | FISIBI | - | composition/ abundance |
| 494 | Wang | 2007 | agriculture, absence of forest | TP | FI | CARNNB | - | process/ functions |
| 495 | Wang | 2007 | agriculture, absence of forest | NO3 | FI | OMNINB% | + | process/ functions |
| 496 | Wang | 2007 | agriculture, absence of forest | NO3 | FI | OMNISP% | + | process/ functions |
| 497 | Wang | 2007 | agriculture, absence of forest | NO3J | FI | OMNINB% | + | process/ functions |
| 498 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | CARNNB | - | process/ functions |
| 499 | Wang | 2007 | agriculture, absence of forest | TP | FI | CARNNB% | - | process/ functions |
| 500 | Wang | 2007 | agriculture, absence of forest | TP | FI | CARNSP% | - | process/ functions |
| 501 | Wang | 2007 | agriculture, absence of forest | TP | FI | OMNISP% | + | process/ functions |
| 502 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | CARNNB | - | process/ functions |
| 503 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | CARNNB% | - | process/ functions |
| 504 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | CARNSP% | - | process/ functions |
| 505 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | OMNISP% | + | process/ functions |
| 506 | Wang | 2007 | agriculture, absence of forest | TPA | FI | CARNNB | - | process/ functions |
| 507 | Wang | 2007 | agriculture, absence of forest | TPA | FI | CARNNB% | - | process/ functions |
| 508 | Wang | 2007 | agriculture, absence of forest | TPA | FI | CARNSP% | - | process/ functions |
| 509 | Wang | 2007 | agriculture, absence of forest | TPA | FI | OMNISP% | + | process/ functions |
| 510 | Wang | 2007 | agriculture, absence of forest | DP | FI | CARNNB | - | process/ functions |
| 511 | Wang | 2007 | agriculture, absence of forest | DP | FI | CARNNB% | - | process/ functions |
| 512 | Wang | 2007 | agriculture, absence of forest | DP | FI | CARNSP% | - | process/ functions |
| 513 | Wang | 2007 | agriculture, absence of forest | DP | FI | OMNINB | + | process/ functions |
| 514 | Wang | 2007 | agriculture, absence of forest | DP | FI | OMNISP% | + | process/ functions |
| 515 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | CARNNB | - | process/ functions |
| 516 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | CARNNB% | - | process/ functions |
| 517 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | CARNSP% | - | process/ functions |
| 518 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | OMNISP% | + | process/ functions |
| 519 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | CARNNB% | - | process/ functions |
| 520 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | CARNSP% | - | process/ functions |
| 521 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | INSECSP% | + | process/ functions |
| 522 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | OMNINB | + | process/ functions |
| 523 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | OMNISP% | + | process/ functions |
| 524 | Wang | 2007 | agriculture, absence of forest | NH4J | FI | CARNNB | - | process/ functions |

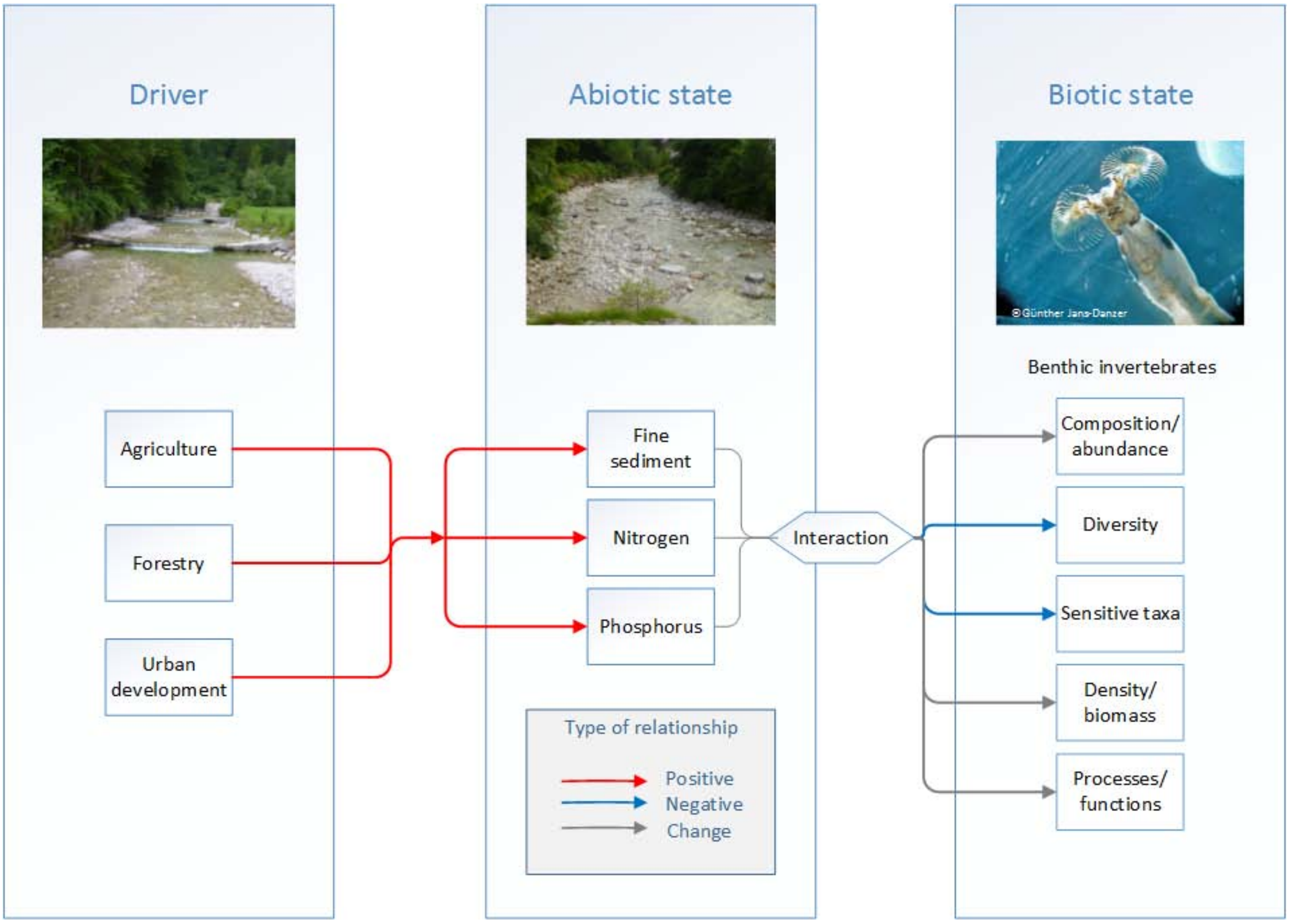
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 525 | Wang | 2007 | agriculture, absence of forest | NH4J | FI | CARNNB% | - | process/ functions |
| 526 | Wang | 2007 | agriculture, absence of forest | NH4J | FI | INSECNB% | + | process/ functions |
| 527 | Wang | 2007 | agriculture, absence of forest | NH4J | FI | INSECSP% | + | process/ functions |
| 528 | Wang | 2007 | agriculture, absence of forest | TKN | FI | CARNNB | - | process/ functions |
| 529 | Wang | 2007 | agriculture, absence of forest | TKN | FI | CARNNB% | - | process/ functions |
| 530 | Wang | 2007 | agriculture, absence of forest | TKN | FI | CARNSP% | - | process/ functions |
| 531 | Wang | 2007 | agriculture, absence of forest | TKN | FI | INSECNB% | + | process/ functions |
| 532 | Wang | 2007 | agriculture, absence of forest | TKN | FI | OMNISP% | + | process/ functions |
| 533 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | CARNNB | - | process/ functions |
| 534 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | CARNNB% | - | process/ functions |
| 535 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | INSECNB% | + | process/ functions |
| 536 | Wang | 2007 | agriculture, absence of forest | TN | FI | CARNNB | - | process/ functions |
| 537 | Wang | 2007 | agriculture, absence of forest | TN | FI | CARNNB% | - | process/ functions |
| 538 | Wang | 2007 | agriculture, absence of forest | TN | FI | CARNSP% | - | process/ functions |
| 539 | Wang | 2007 | agriculture, absence of forest | TN | FI | OMNINB% | + | process/ functions |
| 540 | Wang | 2007 | agriculture, absence of forest | TN | FI | OMNISP% | + | process/ functions |
| 541 | Wang | 2007 | agriculture, absence of forest | TNJ | FI | OMNINB% | + | process/ functions |
| 542 | Wang | 2007 | agriculture, absence of forest | TNJ | FI | OMNISP% | + | process/ functions |
| 543 | Wang | 2007 | agriculture, absence of forest | TNA | FI | CARNNB% | - | process/ functions |
| 544 | Wang | 2007 | agriculture, absence of forest | TNA | FI | OMNINB% | + | process/ functions |
| 545 | Wang | 2007 | agriculture, absence of forest | TNA | FI | OMNISP% | + | process/ functions |
| 546 | Wang | 2007 | agriculture, absence of forest | TP | FI | INTONB | - | sensitivity/ tolerance |
| 547 | Wang | 2007 | agriculture, absence of forest | TP | FI | INTONB% | - | sensitivity/ tolerance |
| 548 | Wang | 2007 | agriculture, absence of forest | TP | FI | INTOSP% | - | sensitivity/ tolerance |
| 549 | Wang | 2007 | agriculture, absence of forest | TP | FI | SALMONNB | - | sensitivity/ tolerance |
| 550 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | INTONB | - | sensitivity/ tolerance |
| 551 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | INTONB% | - | sensitivity/ tolerance |
| 552 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | INTOSP% | - | sensitivity/ tolerance |
| 553 | Wang | 2007 | agriculture, absence of forest | TPJ | FI | SALMONNB | - | sensitivity/ tolerance |
| 554 | Wang | 2007 | agriculture, absence of forest | TPA | FI | INTONB | - | sensitivity/ tolerance |
| 555 | Wang | 2007 | agriculture, absence of forest | TPA | FI | INTONB% | - | sensitivity/ tolerance |
| 556 | Wang | 2007 | agriculture, absence of forest | TPA | FI | INTOSP% | - | sensitivity/ tolerance |
| 557 | Wang | 2007 | agriculture, absence of forest | TPA | FI | SALMONNB | - | sensitivity/ tolerance |
| 558 | Wang | 2007 | agriculture, absence of forest | DP | FI | INTONB | - | sensitivity/ tolerance |
| 559 | Wang | 2007 | agriculture, absence of forest | DP | FI | INTONB% | - | sensitivity/ tolerance |
| 560 | Wang | 2007 | agriculture, absence of forest | DP | FI | INTOSP% | - | sensitivity/ tolerance |
| 561 | Wang | 2007 | agriculture, absence of forest | DP | FI | SALMONNB | - | sensitivity/ tolerance |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 562 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | INTONB% | - | sensitivity/ tolerance |
| 563 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | INTOSP% | - | sensitivity/ tolerance |
| 564 | Wang | 2007 | agriculture, absence of forest | DPJ | FI | SALMONNB | - | sensitivity/ tolerance |
| 565 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | INTONB | - | sensitivity/ tolerance |
| 566 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | INTONB% | - | sensitivity/ tolerance |
| 567 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | INTOSP% | - | sensitivity/ tolerance |
| 568 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | SALMONNB | - | sensitivity/ tolerance |
| 569 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | TOLENB | + | sensitivity/ tolerance |
| 570 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | TOLENB% | + | sensitivity/ tolerance |
| 571 | Wang | 2007 | agriculture, absence of forest | NH4 | FI | TOLESP% | + | sensitivity/ tolerance |
| 572 | Wang | 2007 | agriculture, absence of forest | NH4J | FI | SALMONNB | - | sensitivity/ tolerance |
| 573 | Wang | 2007 | agriculture, absence of forest | TKN | FI | INTONB | - | sensitivity/ tolerance |
| 574 | Wang | 2007 | agriculture, absence of forest | TKN | FI | INTONB% | - | sensitivity/ tolerance |
| 575 | Wang | 2007 | agriculture, absence of forest | TKN | FI | INTOSP% | - | sensitivity/ tolerance |
| 576 | Wang | 2007 | agriculture, absence of forest | TKN | FI | SALMONNB | - | sensitivity/ tolerance |
| 577 | Wang | 2007 | agriculture, absence of forest | TKN | FI | TOLENB% | + | sensitivity/ tolerance |
| 578 | Wang | 2007 | agriculture, absence of forest | TKN | FI | TOLESP% | + | sensitivity/ tolerance |
| 579 | Wang | 2007 | agriculture, absence of forest | TKNJ | FI | SALMONNB | - | sensitivity/ tolerance |
| 580 | Wang | 2007 | agriculture, absence of forest | TN | FI | INTONB | - | sensitivity/ tolerance |
| 581 | Wang | 2007 | agriculture, absence of forest | TN | FI | INTONB% | - | sensitivity/ tolerance |
| 582 | Wang | 2007 | agriculture, absence of forest | TN | FI | INTOSP% | - | sensitivity/ tolerance |
| 583 | Wang | 2007 | agriculture, absence of forest | TN | FI | SALMONNB | - | sensitivity/ tolerance |
| 584 | Wang | 2007 | agriculture, absence of forest | TNJ | FI | INTOSP% | - | sensitivity/ tolerance |
| 585 | Wang | 2007 | agriculture, absence of forest | TNA | FI | INTONB | - | sensitivity/ tolerance |
| 586 | Wang | 2007 | agriculture, absence of forest | TNA | FI | INTONB% | - | sensitivity/ tolerance |
| 587 | Wang | 2007 | agriculture, absence of forest | TNA | FI | INTOSP% | - | sensitivity/ tolerance |

# Appendix B

The factsheet for the MARS project

0. Picture




1. Stressor combination

   **Fine sediment and nutrients (nitrogen and phosphorus)**

2. Main driver(s)

   Agriculture, forestry (absence of forest), urban development

3. Pressure

   Diffuse pressure from agriculture

4. General description

Nutrient enrichment is widespread in European rivers. The main sources of nitrogen and phosphorus include diffuse emissions from agriculture, and point source emissions from urban wastewater treatment plants and industry. There has been a significant reduction in the levels of nutrients in European freshwaters over the past two decades. However, diffuse pollution from agriculture remains a significant pressure in more than 40% of Europe's rivers. Excessive nutrient inputs cause eutrophication, resulting in e.g. changes in species abundance and diversity (EEA 2015).

Fine sediment is a natural and essential component in running waters. Fine sediment delivery to rivers and sediment transport in rivers are increasing in catchments that are impacted by human activities, such as agriculture and deforestation (Owens et al. 2005). Increasing fine sediment affects the biological functioning in rivers by altering habitat quality and quantity.

Agriculture predominantly affects both nutrient and fine sediment inputs in rivers. Therefore these stressors often occur together, especially in agricultural streams. Nutrients can cause positive or subsidy-stress responses in the ecological indicators, while fine sediment acts mainly as a stressor. The majority of the biological responses to this stressor combination in rivers are additive multi-stressor effects. The best indicators are benthic invertebrates.

5. Effect/Impact on water system

Diffuse pressure from agriculture cause changes in abiotic states of the rivers by increasing nutrient and fine sediment concentrations. Excess nutrients and fine sediment have joint effects on biotic state variables, which are mainly additive multi-stressor effects.

Most scientific evidence supports effects on benthic invertebrates. Most of these effects are additive, but synergistic and antagonistic effects have been described as well (e.g. Townsend et al. 2008; Lange et al. 2014a).

The effects on fish (Lange et al. 2014b) and benthic algae and cyanobacteria (Wagenhoff et al. 2013) are mostly simple, additive effects. Exceptions are % cyanobacteria (Wagenhoff et al. 2013) and motile growth form of periphyton (Piggott et al. 2012; Wagenhoff et al. 2013), which responded synergistically to the joint increase of the stressors.

The most pronounced effects are changes in macroinvertebrate community structure. These effects are mainly additive, but include also more complex synergistic and antagonistic effects.

Prevalence of additive relationships suggests that nutrients and sediment often differ in their modes of action and affect independently many biological indicators.

Benthic invertebrate indicators and their responses to mutual increase in fine sediment and nutrients in rivers:

Decrease in diversity, synergistic effect (Townsend et al. 2008; García Molinos & Donohue 2010; Lange et al. 2014a)

Decrease in EPT taxa richness and relative abundance of EPT taxa, additive, synergistic and antagonistic effects (Wagenhoff et al. 2011; Lange et al. 2014a; Townsend et al. 2008; Wagenhoff et al. 2012)

Changes in species traits (feeding types, body size and shape, reproduction, respiration, life duration, locomotion), mainly additive effects (e.g. Lange et al. 2014a)

Decrease in Macroinvertebrate Community Index (MCI), additive effect (Lange et al. 2014; Wagenhoff et al. 2011)

6. Case studies where this pressure is present

García Molinos & Donohue 2010

Lange et al. 2014a

Lange et al. 2014b

Larsen & Ormerod 2010

Matthaei et al. 2010

Piggott et al. 2012

Townsend et al. 2008

Wagenhoff et al. 2011

Wagenhoff et al. 2012

Wagenhoff et al. 2013

7. Implication for management and ecosystem services

The interaction between the stressors most often causes additive multi-stress responses in the biotic indicators. Nevertheless it is especially important to recognize those circumstances where the joint action produces synergistic or antagonistic responses. In such cases the outcomes of the management actions cannot be predicted on the basis of the knowledge of single stressor effects.

Managing both fine sediment and nutrient inputs from agriculture is crucial to achieving good stream condition and maintaining ecosystem services, but priority should be given to minimizing inputs of fine sediment. In multi-stress situations the fine sediment seems to be more pervasive stressor than nutrients (Wagenhoff et al. 2011, 2012; Piggott et al. 2012).

8. Useful references

García Molinos, J. & Donohue, I., 2010. Interactions among temporal patterns determine the effects of multiple stressors. Ecological Applications, 20, 1794–1800.

EEA, 2015. The European environment — state and outlook 2015: synthesis report, European Environment Agency, Copenhagen.

Lange, K. Townsend C.R., Matthaei C.D., 2014a. Can biological traits of stream invertebrates help disentangle the effects of multiple stressors in an agricultural catchment? Freshwater Biology, 59, 2431–2485

Lange, K., Townsend, C.R., Gabrielsson, R., Chanut, P.C.M. & Matthaei, C.D., 2014b Responses of stream fish populations to farming intensity and water abstraction in an agricultural catchment. Freshwater Biology, 59, 286–299.

Larsen, S. & Ormerod, S.J., 2010. Combined effects of habitat modification on trait composition and species nestedness in river invertebrates. Biological Conservation, 143, 2638–2646. Available at: http://dx.doi.org/10.1016/j.biocon.2010.07.006.

Matthaei, C.D., Piggott, J.J. & Townsend, C.R., 2010. Multiple stressors in agricultural streams: Interactions among sediment addition, nutrient enrichment and water abstraction. Journal of Applied Ecology, 47, 639–649.

Owens, P.N., Batalla, R.J., Collins, A.J., Gomez, B., Hicks, D.M., Horowitz, A.J., Kondolf, G.M., Marden, M., Page, M.J., Peacock, D.H., Petticrew, E.L., Salomons, W. & Trustrum, N.A., 2005. Fine-grained sediment in river systems: environmental significance and management issues. River Research and Applications, 21, 693–717. Available at: http://doi.wiley.com/10.1002/rra.878.

Piggott, J.J., Lange, K., Townsend C.R. & Matthaei, C.D., 2012. Multiple Stressors in Agricultural Streams: A Mesocosm Study of Interactions among Raised Water Temperature, Sediment Addition and Nutrient Enrichment. *PLoS ONE*, 7(11): e49873. doi:10.1371/journal.pone.0049873

Townsend, C.R., Uhlmann, S.S. & Matthaei, C.D., 2008. Individual and combined responses of stream ecosystems to multiple stressors. Journal of Applied Ecology, 45, 1810–1819. Available at: http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2664.2007.01428.x.

Wagenhoff, A., Lange, K., Townsend, C.R. & Matthaei, C.D., 2013. Patterns of benthic algae and cyanobacteria along twin-stressor gradients of nutrients and fine sediment: A stream mesocosm experiment. Freshwater Biology, 58, 1849–1863.

Wagenhoff, A., Townsend, C.R. & Matthaei, C.D., 2012. Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: A stream mesocosm experiment. Journal of Applied Ecology, 49, 892–902.

Wagenhoff, A., Townsend, C.R., Phillips, N. & Matthaei, C.D., 2011. Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. Freshwater Biology, 56, 1916–1936.