Biomonitoring with Organism Traits and Impacts of Small Impoundments on Stream Ecological Integrity and Food Web

by

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Summary

Change of ecosystems and the associated loss of biodiversity is among the most important environmental issues. Climate change, pollution, and impoundments are considered as major drivers of biodiversity loss. Organism traits are an appealing tool for the assessment of these three stressors, due to their ability to provide mechanistic links between organism responses and stressors, and consistency over wide geographical areas. Additionally, traits such as feeding habits influence organismal performance and ecosystem processes. Although the response of traits of specific taxonomic groups to stressors is known, little is known about the response of traits of different taxonomic groups to stressors. Additionally, little is known about the effects of small impoundments on stream ecosystem processes, such as leaf litter decomposition, and food webs. After briefly introducing the theoretical background and objectives of the studies, this thesis begins by synthesizing the responses of traits of different taxonomic groups to climate change and pollution. Based on 558 peer-reviewed studies, the uniformity (i.e., convergence) in trait response across taxonomic groups was evaluated through meta-analysis (Chapter 2). Convergence was primarily limited to traits related to tolerance. In Chapter 3, the hypothesis that small impoundments would modify leaf litter decomposition rates at the sites located within the vicinity of impoundments, by altering habitat variables and invertebrate functional feeding groups (FFGs) (i.e., shredders), was tested. Leaf litter decomposition rates were significantly reduced at the study sites located immediately upstream (IU) of impoundments, and were significantly related to the abundance of invertebrate shredders. In Chapter 4, the invertebrate FFGs were used to evaluate the effect of small impoundments on stream ecosystem attributes. The results showed that heterotrophic production was significantly reduced at the sites IU. With regard to food webs, the contribution of methane gas derived carbon to the biomass of chironomid larvae was evaluated through correlation of stable carbon isotope values of chironomid larvae and methane gas concentrations. The results indicated that the contribution of methane gas derived carbon into stream benthic food web is low. In conclusion, traits are a useful tool in detecting ecological responses to stressors across taxonomic groups, and the effects of small impoundments on stream ecological integrity and food web are limited.

Contents

CHAPTER 1

Introduction and Objectives

1.1 Biomonitoring with organism traits

Biomonitoring refers to the use of living organisms to assess the condition of the environment (Markert et al., 2003). Biomonitoring is performed using organisms such as plants, fish, and invertebrates, and diverse methodologies and metrics have been developed (Jeffrey & Madden, 1991; Markert et al., 2003; Neville & Yen, 2007). Traditionally, biomonitoring programs often used the taxonomic composition (TC) of organisms as an indicator of ecological conditions (Karr, 1981; Wallace & Webster, 1996; Bradford et al., 1998). Following this biomonitoring process, samples are collected from sites impacted by stressors, and from reference sites, identified, and counted (Nestler et al., 2010). Differences in the TC of biota among samples are then compared by computing various biotic indices (Solimini et al., 2008; Aparicio, 2011; Young et al., 2013). A significant drawback of this approach is that it leads to loss of information on community structure, and does not reveal the mechanisms behind ecological responses to stressors (Van den brink et al., 2011). However, the traits of the identified species, such as ability to tolerate toxicants, provide this information, overcoming the problems related to approaches based on TC (Baird et al., 2008).

A trait refers to a characteristic that reflects the adaptation of a species to its environment (Goldstein & Meador, 2005). Organism traits can be classified into biological and ecological traits. Biological traits consist of life history characteristics and morphological adaptations of organisms, such as body size and shape, duration of life cycle, feeding habits, and reproduction. Ecological traits reflect habitat preferences of organisms, such as temperature, substratum type, trophic status, and salinity (McGill et al., 2006; Vieira et al., 2006). Some traits (e.g., functional feeding groups, Figure 1-1) influence ecosystem functions, and provide ideal tools for the assessment of the functional consequences of stressors (Díaz & Cabido, 1997; Lavorel & Garnier, 2002; Violle et al., 2007).

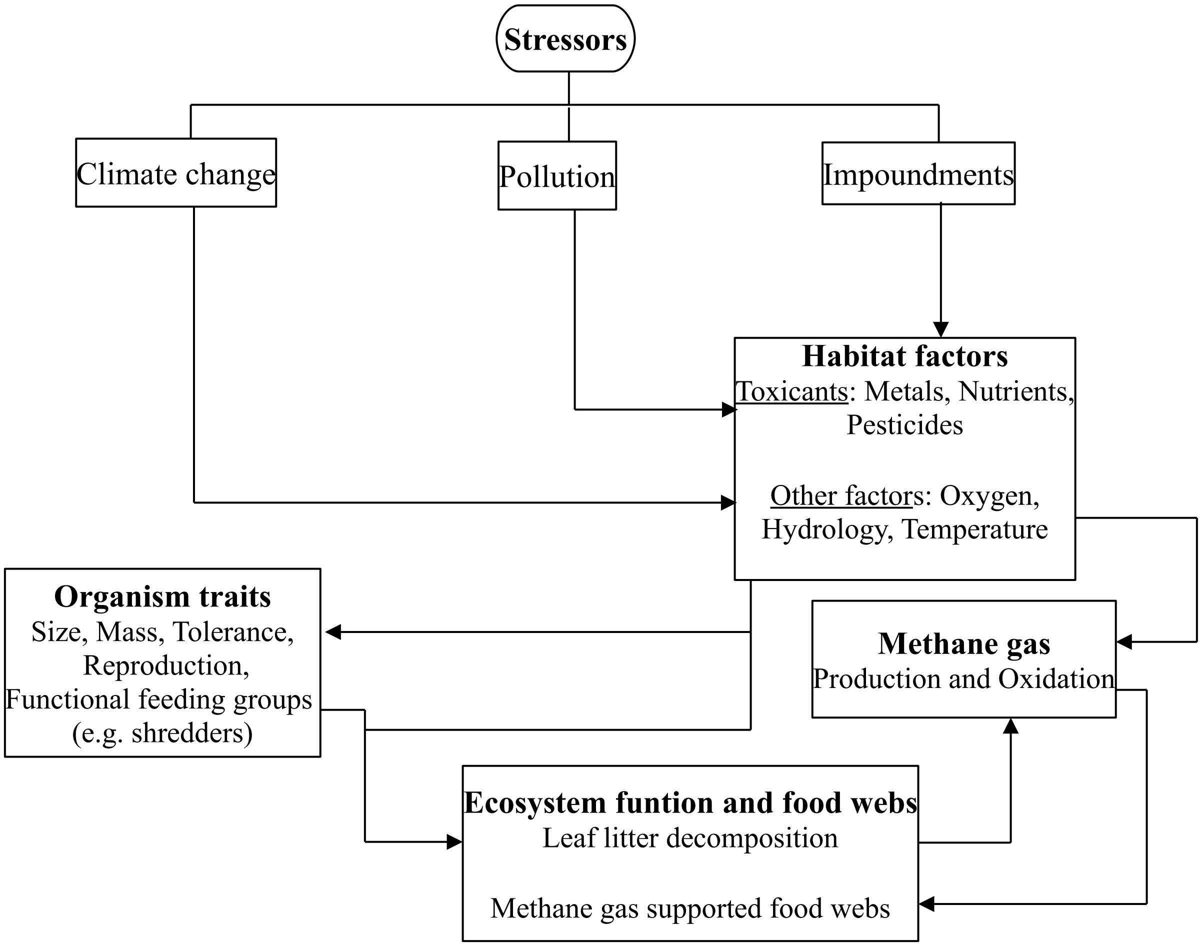

Figure 1-1: A conceptual framework showing examples of stressors that characterize ecosystems (i.e., climate change, pollution, and impoundments), examples of habitat factors affected, organism traits, methane gas cycling in food webs, and ecosystem function (i.e., leaf litter decomposition).

The concept of traits can be traced back to the 1800s, when Semper (1880) pointed out that specialist animal species are more susceptible to temporal habitat variations than generalist ones, and that small habitats normally contain small and more mobile animals than large ones. Since Semper, ecologists focused on various organism traits, and their relationship to environmental constraints. For example, according to Thienemann (1918) and Hesse (1924), the environment acts as a ‘filter’ for traits, and increasing environmental harshness causes communities to have increasingly similar traits. This assumption of trait convergence within communities is still an active field of research (Lamouroux et al., 2002; Cunicoa et al., 2011; Read et al., 2014). More recently, Grime (1974) hypothesized that competition and environmental stressors interactively determine herbaceous plants by invoking varying strategies. Thomas Southwood advanced the ‘habitat templet concept’, which postulates that spatio-temporal habitat variations provide a ‘templet’, which selects life history and other species traits, and results in differential survival and reproduction rates (Southwood, 1977). Building on this framework, Keddy (1992) put forward a conceptual framework where the environment functions like a ‘filter’, removing species lacking specific combinations of traits.

When compared with approaches based on TC, traits are advantageous because they may be less influenced by seasonal changes, and can disentangle the effects of different stressors (Bêche et al., 2006; Statzner & Bêche, 2010). In particular, traits permit comparison of biomonitoring data across biogeographic regions (Statzner et al., 2007; Violle & Jiang, 2009). This is important because the conservation and management of ecosystems and their function often require assessment at large spatial scales (Gayraud et al., 2003). At large scales, approaches based on TC may be less powerful (Baird et al., 2008). The ability of traits to collate data over large areas is also important in synthesizing the general response patterns of organisms to environmental gradients associated with stressors, such as climate change and pollution (Dormann & Woodin, 2002; Ingels et al., 2012; Temme et al., 2013). For example, Temme et al. (2013) performed a meta-analysis on the response of plant traits to reduced carbon dioxide concentrations and found that size and mass were increased and decreased, respectively, by up to two-fold. Dormann & Woodin (2002) synthesized the effect of climate change on arctic plants and found that increases in temperature and nutrients had positive effects on size, mass, and reproduction. Jeppesen et al. (2010) reviewed the effect of climate warming on fish. The authors found that there was increase in fish characterized by small body size, short life cycles, earlier reproduction, generalist feeding habit, and preference for littoral and benthic areas. The effect of carbon dioxide and nutrients on the biomass of grass was analyzed by Lee et al. (2010). It was observed that nitrogen inputs increased biomass stronger than carbon dioxide, and that the increments were more pronounced in high precipitation areas. The aforementioned studies primarily focused on specific taxonomic groups and ecosystems. A meta-analysis of the impacts of stressors across different ecosystems, and taxonomic groups, can reveal general response patterns across different natural systems. As a first objective, therefore, the Chapter 2 of the current study synthesized the responses of organism traits to climate change and pollution, to identify trait convergence across taxonomic groups.

1.2 Impoundments impacts stream ecological integrity and food webs

Ecological integrity (EI) refers to the ability of an ecosystem to maintain a community of organisms and functional processes comparable to those of a natural habitat (Bunn & Davies, 2000; Gessner & Chauvet, 2002; Allan, 2004). EI is assessed using indicators based on TC, such as species richness or community based indices (e.g., Index of Biotic Integrity, IBI) (Sládecek, 1973; Hilsenhoff, 1987; Karr, 1991). EI is also assessed through the use of organism traits (see above) and ecosystem processes, such as photosynthesis, respiration, and leaf litter decomposition (Gessner & Chauvet, 2002; Young et al., 2008).

The maintenance of EI in running waters is important because they act as sources of fresh water and food, and are habitats for plants and animals, among other ecosystem services and goods (Boulton, 1999; Baron et al., 2002; Postel & Richter, 2012). Despite the various benefits that are obtained from running waters, humans have historically had a close association with rivers, leading to deterioration of biodiversity (Cottrell, 1957; Vörösmarty et al., 2010). Indeed, on a global scale, the biodiversity has decreased at a much faster rate than the natural background rate (Chapin, 2000; Jenkins, 2003), and freshwater ecosystems habitats, organisms, and functions are among the most impacted (Malmqvist & Rundle, 2002; Strayer & Dudgeon, 2010; Dodds et al., 2013). It is approximated that up to 20,000 freshwater species have either become extinct or are seriously threatened (Thomsen et al., 2012). Freshwater habitats cover less than 1% of the earth's surface, and about 0.006% of this water is in streams and rivers (Malmqvist & Rundle, 2002; Strayer & Dudgeon, 2010). Streams and rivers constitute a wide range of habitats, ranging from small mountain brooks to big low land rivers. The relative narrowness of many lotic ecosystems imply that they have a close contact with the surrounding terrestrial areas and catchments (Hynes, 1975). This makes lotic ecosystems to be susceptible to many of the activities that take place within the catchment areas. Indeed, rivers and streams are one of the ecosystems that have been greatly impacted by human activities, such as logging, sedimentation, chemical contamination, and impoundment (Malmqvist & Rundle, 2002; Dodds et al., 2013). For example, Bowler et al. (2012) performed a meta-analysis on the effect of wooded riparian zones on stream temperature and found that removal of vegetation increased stream temperature. Beketov et al. (2013) analysed the effects of pesticides on stream invertebrate assemblages and found a regional decline (up to 2-fold) in biodiversity. Impoundment (Figure 1-2) is one of the most common anthropogenic habitat changes in rivers, and about two-thirds of worlds running waters are impounded (Nilsson & Berggren, 2000).

Figure 1-2: Example of a small instream dam that impounded one of the studied streams. The white arrow shows the direction of water movement.

Impoundment of rivers increased dramatically during the 20th century, reaching an all time high in the 1970s, when close to 5,000 large dams (i.e., impoundments > 3,000,000 m^3 in volume, WCD, 2000) were constructed. Although dams provide a variety of benefits, such as drinking water, electricity generation, flood control, irrigation, navigation, and recreational opportunities (Manatunge et al., 2008), they change the structure and functioning of running waters, causing detrimental ecological effects (Baxter, 1977; Ligon et al., 1995).

The impacts of dams, and their associated impoundments, include modification of the flooded upstream areas from river valleys to impoundments, sediment and organic matter accumulation, and modification of riverbed morphology and banks. Other ecological impacts include alteration of variables such as nutrients, temperature, dissolved gases, primary production, turbidity, and concentrations of heavy metals and minerals (Rosenberg et al., 1995; McCully, 2001) (Figure 1-1). These changes have negative effects on river biota and ecosystem functioning. Firstly, the presence of dams along rivers disrupt the migration of animals, such as fish (Liermann et al., 2012). Additionally, changes in habitat have deleterious effects on the abundance and composition of biotic communities, such as invertebrates, in the upstream reaches flooded by impoundments and downstream sections (Tiemann et al., 2004; Chaves-Ulloa et al., 2014). For example, Brittain & Saltveit (1989) reviewed the effect of river flow regulation on stream invertebrates. The authors found that modification of physico-chemical habitat conditions by dams altered the size, mass, habitat preferences, feeding habits, reproduction capacity, dispersal propensity, and abundance of invertebrates. Another study synthesized the effects of river flow regulation on stream habitat and biota, and found that the abundances of invertebrates and fish were decreased, and that the percentage of habitat generalists was increased (Haxton & Findlay, 2008).

As a result of dam-induced changes, a fundamental ecosystem function such as leaf litter decomposition may be modified, given that it is influenced by physico-chemistry and biotic communities, such as invertebrate shredders (Graça, 2001; Graça & Canhoto, 2006; Ferreira et al., 2014) (Figure 1-1). For example, González et al. (2013) investigated the effect of small impoundments, releasing surface water, on leaf litter decomposition rates and found a decrease at the downstream reaches. The decrease in leaf litter decomposition rates below impoundments was primarily attributed to the low abundances of invertebrate shredders. Mbaka & Schäfer (2015) also found that small impoundments that released surface water decreased leaf litter decomposition rates, though at the reaches located immediately upstream of impoundments. The authors suggested that the low abundances of invertebrate shredders, and flow, reduced leaf litter decomposition rates. By contrast, Casas et al. (2000) found that a small impoundment that released deep water had no significant effect on leaf litter decomposition rate. The authors suggested that high leaf litter decomposition rate at the downstream side, caused by increased nutrient content, was balanced out at the upstream side by flow-induced physical abrasion of leaves (Belančić et al., 2009). Alteration of the leaf litter decomposition process by impoundments can have a negative effect on stream food webs because allochthonous organic matter is a major source of carbon and energy in running waters, contributing up to 99% carbon in headwater streams (Fisher & Likens, 1973; Tank et al., 2010).

The organic matter accumulated in impoundments may undergo decomposition, under anoxic conditions, and increase the production of methane gas (e.g., up to 85-fold, Maeck et al., 2013; Maeck et al., 2014). Some of the produced methane gas may escape to the atmosphere, and contribute to the pool of greenhouse gases, while some methane gas may be oxidized by methane oxidizing bacteria (MOB) (Deines et al., 2007a; DelSontro et al., 2010). The methane gas integrated into the biomass of MOB can serve as a source of energy and carbon in the aquatic food webs, by supporting other aquatic organisms, such as invertebrates and fish (Sanseverino et al., 2012). In particular, chironomids has been shown to heavily rely on methane gas derived carbon (MGDC) (e.g., up to 70% of their biomass, Jones et al., 2008), when compared with the other invertebrates such as zooplankton (e.g., up to 15% of their biomass, Bastviken et al., 2003) (Jones & Grey, 2011). This relates to the chironomids mode of life, where their burrowing habit creates a gradient of oxygen gas and methane gas, promoting the development of MOB (Deines et al., 2007b). The importance of MGDC as an alternative source of carbon and energy for freshwater food webs has primarily been demonstrated for lakes, and few studies exist for streams, back water pools (see review in Jones & Grey, 2011), and impoundments (Mbaka et al., 2014).

Most impoundments (> 60%) are small in size (< 3,000,000 m^3 reservoir storage capacity, WCD, 2000), and are a common feature in low order streams (first to third Strahler order, Strahler, 1957) in many catchment areas (e.g., Van Looy et al., 2014). Despite the numerical significance of small impoundments, much of the empirical research and generalizations (e.g., Serial Discontinuity Concept (SDC), Ward & Stanford, 1983) about the impact of impoundments on the EI of streams are based on large impoundments (Benstead et al., 1999; Cumming, 2004). The SDC hypothesizes the downstream impacts of large impoundments, releasing deep water, on the physical, chemical, and biological conditions of rivers. It is uncertain whether the information obtained from studies dealing with large impoundments is applicable to small impoundments, because impoundments vary in factors such as water storage volumes, and mode of operation, and these factors have an effect on the magnitude of ecological impact on the river ecosystem (Poff & Hart, 2002). Thus, the Chapters 3 to 5 of the current study investigated the ecological, and food web, effects of small impoundments. In Chapter 3, the effect of small impoundments on stream ecosystem function was investigated, by evaluating leaf litter decomposition rates. The effect of small impoundments on stream ecosystem attributes was assessed in Chapter 4, using macroinvertebrate functional feeding group ratios. Finally, the relationship between methane gas concentrations and chironomids stable carbon isotope values was investigated in Chapter 5.

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CHAPTER 2

Meta-analysis on the Responses of Traits of Different Taxonomic Groups to Global and Local Stressors

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CHAPTER 3

Effect of Small Impoundments on Leaf Litter Decomposition in Streams

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CHAPTER 4

Macroinvertebrate Functional Feeding Group Ratios Reveal Local Impacts of Small Impoundments on Stream Ecosystem Attributes

4.1 Abstract

Impoundment is one of the most widespread human impacts in rivers. Functional approaches are increasingly used to assess the effect of stressors in aquatic ecosystems. We assessed the impact of small impoundments (80 m^3 to 720 m^3) on macroinvertebrate functional feeding groups (FFGs) in nine streams located in the Rhineland Palatinate region, south western Germany, and assessed ecosystem attributes. For each impoundment, two sites located within 10 m upstream of the area flooded by dam and downstream and two additional sites located further upstream and downstream (~ 300 m) were selected. A significant decrease in the mean abundance of scrapers was found at the immediate upstream sites. Most sites were heterotrophic, with the immediate downstream sites being most autotrophic. The amount of coarse particulate organic matter and linkage between riparian vegetation and stream ecosystem function were more reduced at the immediate upstream sites. The study sites located immediate downstream transported the highest amount of fine particulate organic matter and had the highest channel stability. In conclusion, small impoundments had only limited and local ecological effects, and the effects of larger dams and other hydro-morphological alterations may be more relevant.

4.2 Introduction

Pollution, invasive species, and impoundments have been documented in the Millenium Ecosystem Assessment (MEA) as some of the main causes of loss in ecosystem services and biodiversity (MEA, 2005). Rivers are often impounded to provide water for purposes such as irrigation, industrial use, flood control, and hydroelectric power generation. However, impoundments can change the structure and functioning of rivers by flooding the riparian zones, retention of sediments, particulate organic matter and nutrients, and modification of the natural flow regime, dissolved oxygen and nutrient content, primary production, and temperature among other modifications (Baxter, 1977; Poff et al., 2007; Bae et al., 2015). Consequently, these changes can lead to modification of the abundance and composition of macroinvertebrates at the impacted reaches because many taxa have specific habitat requirements (Horsák et al., 2009; Verdonschot et al., 2015; Lewin et al., 2015).

Biological assessments are typically conducted through taxonomic or functional approaches (Cumming & Child, 2009). The functional approach is a promising tool for ecological assessment due to its ability to link species responses to specific ecological processes (Cadotte et al., 2011). Additionally, the functional approach is based on easily identifiable morphological and behavioural features of macroinvertebrates, such as feeding behaviours (Schoenly et al., 1991). The use of functional feeding groups (FFGs) may be particularly useful in assessing perturbations that may affect the distribution of food resources (Vallania & Corigliano, 2007). Additionally, the FFGs can identify the effect of perturbations on stream ecosystem attributes (e.g., metabolism) (Rawer-Jost et al., 2000). The major types of food consumed by macroinvertebrates can be classified into coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), algae, and prey (Meritt & Cummins, 1996 a). The application of macroinvertebrate FFGs in the assessment of streams is based on the river continuum concept, which hypothesises a longitudinal change in macroinvertebrate FFGs and ecosystem attributes (Vannote et al., 1980). The FFG ratios uses the relative abundance of macroinvertebrate FFGs as a surrogate for stream ecosystem attributes, such as the ratio of shredders to collectors as an indicator of the functioning of the riparian zone (Cummins et al., 2005). For example, Couceiro et al. (2011) found a significant reduction in the ratio of shredders to collectors in streams impacted by anthropogenic sedimentation and suggested that this indicated a reduction in the amount of CPOM and linkage between riparian vegetation and stream ecosystem function. Although the FFG ratios approach has many merits when assessing ecosystem attributes in aquatic ecosystems, the effect of small impoundments (i.e., impoundments with water storage capacity less than 3,000,000 m^3, WCD, 2000) on streams is usually based on taxonomic approaches (e.g., Ogbeibu & Oribhabor, 2002; Principe, 2010; Miyake & Akiyama, 2012). Few studies have used FFGs to assess the effect of small impoundments on streams (e.g., Fleituch, 2003; Martínez et al., 2013). Martínez et al. (2013) compared paired upstream and downstream sites at each of 5 impoundments and found the impoundments to decrease the abundance of shredders and collector-gatherers at the downstream reaches. Decrease in macroinvertebrate FFGs abundance was attributed to factors such as change in flow regime and availability of food resources. Almodóvar & Nicola (1999) compared two reaches located below and above a small impoundment and found minimum impacts on stream bed habitat and macroinvertebrate FFGs.

The generalizations on the effect of impoundments on lotic ecosystems are mainly based on research dealing with the downstream effects of large dams that release deep water (e.g., Ward, 1982; Ward & Stanford, 1983). Impoundments vary in attributes such as water storage volume and water release mechanism, and this affects ecological conditions at the upstream reaches flooded by impoundment and downstream sections (Poff & Hart, 2002; Tiemann et al., 2004). In the present study, we investigated the effect of small impoundments on macroinvertebrate FFGs and related ecosystem attributes in four sites (i.e., 2 upstream and 2 downstream sites with different distances to the impoundment) at each of 9 surface-release impoundments in Rhineland Palatinate, south western Germany. We hypothesized that the impoundments would modify the macroinvertebrate FFGs and ecosystem attributes at the sites located within the vicinity of the impoundments (~ 10 m upstream and downstream) by altering habitat variables such as flow regime and substrates composition.

4.3 Materials and methods

4.3.1 Study area and sites

The study was conducted between 18 April and 20 May 2014 in nine low-order streams (1^{st}-2^{nd}, Strahler order, Strahler, 1957) affected by small water storage impoundments (volume, 80 m^3 to 720 m^3) in the Palatinate forest (coordinates: Latitude 48°76'– 49°53' N and Longitude 7°31'– 8°13' E), south western Germany. The study area is characterized by dry climate conditions in summer, is covered by sandstone, and the altitude varies from 100 m to 670 m above sea level. The impoundments released surface water, had water residence times of between 0.5 to 3 minutes, and were between 1 m to 2.5 m in height (Appendix C, Table C.1). Apart from impoundments, the study area did not have other human activities (e.g., agriculture) in the upstream areas. The study streams normally maintain base flow throughout the year and the impoundments have water bypasses that transport water to the downstream reaches (Appendix C, Figure C.1). Four sampling sites were selected at each impoundment. Two sampling sites were situated immediately (i.e., within 10 m of the dam wall and area flooded by impoundment) upstream (i.e., the flooded impoundment reach; IU) and downstream (i.e., the plunge zone, ID). A third site was situated 300 m further downstream (FD) from impoundment. A fourth site was situated further upstream (FU) from impoundment and had the same distance as the FD site.

4.3.2 Benthic samples collection and processing

Benthic samples were collected randomly using a Surber sampler (area: 0.12 m^2, mesh size: 250 μm, Surber, 1930). Sample collection always started from downstream at every study reach, moving upstream. The substrates located within the working area of the Surber sampler were disturbed by hand for 3 minutes to a depth of 10 cm. The samples retained by the net of the sampler were put in labelled 500 ml plastic bottles, preserved with 70% ethanol solution, and transported to the laboratory for further processing. In total, three samples were collected from each of the 36 study sites. In the laboratory, the samples were washed in a 0.5 mm mesh sieve to separate macroinvertebrates and coarse particulate organic matter (CPOM) from fine sediment. Macroinvertebrates were identified (Brohmer et al., 1964; Ludwig, 1989; Nilsson, 1996; Waringer & Graf, 1997) with a dissecting microscope to the lowest level feasible (mainly genus), counted, and classified into feeding groups (i.e., shredders, scrapers, collector-gatherers, predators, and filtering-collectors) following Tachet et al. (2002).

4.3.3 Functional feeding group ratios

The stream ecosystem attributes were based on FFG ratios (Cummins et al., 2005), which constituted four parameters (Table 4.1). The ratio of scrapers to shredders and collectors shows the comparative importance of autotrophic to heterotrophic production (P/R). The ratio of shredders to collectors shows the availability of food resources (CPOM/FPOM) for the shredders and the linkage between the riparian zone and stream ecosystem function. The ratio of filterers to gatherers indicates the amount of FPOM in transport (TFPOM), relative to benthic FPOM (BFPOM). The ratio of scrapers and filterers to shredders and gatherers indicates the level of stability of the stream channel in terms of availability of large substrates such as coarse woody debris.

Table 4.1: Characterization of stream ecosystem attributes based on FFG ratios (from Merritt and Cummins, 1996 b).

Ecosystem attribute	Label	FFG ratio	Criteria for FFG ratios
Autotrophic/ Heterotrophic index	P/R	Scrapers to (Shredders + Collectors)	Autotrophic, > 0.75
CPOM to FPOM	CPOM/ FPOM	Shredders to Collectors	High CPOM, > 0.25
Transport to benthic FPOM	TFPOM/ BFPOM	Filterers to Gatherers	High FPOM in transport, > 0.5
River channel stability index	Stability	(Scrapers + Filterers) to (Shredders + Gatherers)	Stable substrates (e.g. cobbles), > 0.5

P/R, photosynthesis to respiration; CPOM /FPOM, coarse to fine particulate organic matter; TFPOM /BFPOM, transport to benthic fine particulate organic matter.

4.3.4 Physico-chemical variables

Physico-chemical variables such as electrical conductivity, pH, temperature, dissolved oxygen, and nutrient concentrations (nitrate and phosphate) were measured using WTW multi-parametric sensors (Wissenschaftlich Werkstätten, Weilheim, Germany) and Macherey-Nagel viscolor kits (Macherey-Nagel, Düren, Germany). Benthic substrates were assessed visually and categorized as given in Table 4.2 (Bain & Stevenson, 1999; Mullner et al., 2000). Canopy cover and substrate embeddedness, a measure of the degree to which large particles (e.g., cobbles) are covered by fine sediment, were also assessed visually (Jennings et al., 1999). At each sampling site, FliesswasserStammTisch (FST) hemispheres (Stazner & Müller, 1989), hereafter referred to as FST, were used to assess near-bed flow forces where benthic samples were collected. The FST method involves the use of 21 standard hemispheres of identical size (diameter 7.8 cm) and surface texture, but different densities. The hemispheres were exposed sequentially on a small horizontal plate on the stream bottom and the heaviest hemisphere moved by the water flow taken to define the instantaneous flow condition near the stream bed. Each hemisphere is characterized by minimum bottom sheer stress causing its movement in flume calibrations (Statzner et al., 1991). The froude number (*Fr*), an index of flow turbulence (Bansal, 2008), was calculated from current velocity (*V*) and water depth (*D*) according to the following formula:

$$Fr = \frac{V}{(gD)^{0.5}} \tag{4.1}$$

where g is the acceleration of gravity. It indicates whether the flow is subcritical ($Fr < 1$), critical ($Fr = 1$) or supercritical ($Fr > 1$).

4.3.5 Data analysis

Linear Mixed-Effects Models (LMMs) were used to test the effect of site location (i.e., FU, FD, IU, and ID) on physico-chemical variables, with site location as a fixed factor and stream as a random factor. The effect of site location on the abundance of macroinvertebrate FFGs and ecosystem attributes was tested using Generalized Linear Mixed-Effects Models (GLMMs) (Zuur et al., 2009; Bolker et al., 2009). The *p*-values were adjusted for multiple comparisons using the Holm correction method (Holm, 1979) and we report the adjusted *p*-values. The assumptions of models were assessed visually as described by Zuur et al. (2009). Tukey contrasts were used for pairwise comparisons for statistically significant models (Hothorn et al., 2008). The LMMs and GLMMs were fitted using the 'nlme' (normal distribution; Pinheiro et al., 2013) and 'glmmADMB' (negative binomial distribution) (Skaug et al., 2011) packages in R (version 3.2.0; R Core Team, 2015).

4.4 Results

4.4.1 Functional feeding groups and ecosystem attributes

A total of 8169 macroinvertebrates belonging to 77 taxa were found. Only 10 taxa had abundances greater than 1% of the total abundance and represented 91% of all macroinvertebrates found in the samples (Table 4.2). Shredders were the major feeding group and were dominated by *Gammarus* sp. (72.2%). The filter-feeding *Hydropsyche* sp. was the second most dominant taxon (4.3%) and had a 12-fold higher mean abundance at the immediate downstream (ID) sites than further downstream (FD) sites (Table 4.2). The mean abundance of scrapers differed significantly among the study sites ($p = 0.03$ in GLMM). Tukey contrasts showed that the sites located immediate upstream (IU) had significantly lower (22.9 ± 17.8 individuals m^{-2}) scrapers abundance than further downstream (FD) sites ($p = 0.01$). Filter-feeders had up to 4-fold higher mean abundances at the ID sites.

The CBOM/FPOM and P/R ratios indicated that most sites were heterotrophic and the ID sites were the most autotrophic (Table 4.2). The CBOM/FPOM and P/R ratios differed significantly among the sites ($p < 0.05$ in GLMM). Tukey contrasts indicated that the IU sites had significantly lower CPOM content than the sites FD and FU ($p < 0.05$) and that the difference in P/R ratios between the ID and FD sites was close to statistical significance ($p = 0.09$). Although not statistically significant ($p = 0.08$ in GLMM), the TFPOM/BFPOM ratio indicated that the ID sites transported the highest amount of suspended FPOM. The channel stability index did not differ significantly among the sites ($p = 0.18$ in GLMM) and showed higher availability of coarse substrates (e.g., cobbles) at the ID sites (Table 4.2).

4.4.2 Physico-chemical variables

The mean percentages of pools/riffles, embeddedness, silt/sand and clay, and the FST-value differed significantly among the sites (all $p < 0.05$ in LMM). Tukey contrasts indicated that the sites located immediate upstream (IU) of the impoundments had higher mean percentage values of silt/sand and clay, pools and embeddedness, and lower FST-values (all $p < 0.05$). Although the other variables did not vary significantly among the sites, water velocity and Froude number tended to decrease at the IU sites, and CPOM was highest (75.6 ± 23.9 g m^{-2}) at the IU sites and lowest (29.8 ± 21.9 g m^{-2}) at the ID sites (Table 4.2).

4.5 Discussion

4.5.1 Impoundments and functional feeding groups

The mean abundances of scrapers and filter-feeders increased up to 4-fold at the immediate downstream (ID) sites, when compared with the further upstream (FU) sites. This finding is in agreement with our hypothesis that the macroinvertebrate FFGs abundances would be altered at the sites located close to the impoundments.

Table 4.2: Mean (± SE) abundances and percentages of the major benthic macroinvertebrate taxa, feeding groups (individuals m^{-2}), ecosystem attributes and habitat variables of the studied streams. Different capital letters indicate significant differences. Sites ordered from downstream to upstream.

			Sites				
		FFG	**FD**	**ID**	**IU**	**FU**	**%**
Taxa	*Gammarus* sp.	SHR	2406.7 (1069.7)	1236.9 (100.1)	574.8 (762.2)	1129.6 (207.4)	72.2
	Hydropsyche sp.	FF	23.8 (55.9)	279.1 (199.2)	14.5 (65.3)	1.8 (78.0)	4.3
	Elmis sp.	SCR	55.9 (8.9)	78.9 (31.9)	18.4 (28.6)	34.7 (12.2)	2.5
	Chironominae	CG	35.1 (5.9)	37.2 (3.8)	39.6 (1.4)	52.0 (11.0)	2.2
	Limnephilidae	SHR	42.0 (1.7)	71.4 (30.9)	18.1 (22.2)	29.9 (10.4)	2.2
	Baetis sp.	CG	55.9 (17.1)	44.4 (5.6)	25.7 (13.2)	29.3 (9.5)	2.1
	Stenelmis sp.	SCR	52.0 (18.9)	23.3 (9.7)	16.9 (16.1)	39.9 (6.9)	1.8
	Simuliidae[a]	FF	65.6 (39.2)^{A}	21.5 (1.9)^{B}	4.5 (18.8)^{B}	4.8 (18.5)^{B}	1.3
	Potamophilus sp.	SHR	14.2 (8.1)	44.8 (22.4)	10.9 (11.4)	19.4 (2.9)	1.2
	Pisidium sp.	CG	12.4 (8.3)	17.8 (2.9)	28.1 (7.3)	24.8 (4.0)	1.1
FFG	CG		34.3 (7.9)	43.8 (1.7)	52.8 (10.6)	37.8 (4.4)	
	SHR		719.5 (298.0)	405.9 (15.6)	238.1 (183.3)	322.3 (99.1)	
	SCR[a]		53.1 (12.3)^{A}	51.8 (11.0)^{AB}	22.9 (17.8)^{B}	35.1 (5.6)^{AB}	
	FF		35.6 (33.9)	174.8 (103.2)	32.2 (39.4)	41.7 (29.9)	
	PRE		5.9 (6.6)	9.8 (2.8)	23.7 (11.1)	10.8 (1.7)	
	Total FFG abundance[a]		121.9 (91.2)^{A}	98.4 (63.8)^{AB}	54.1 (32.5)^{B}	90.9 (64.2)^{AB}	
Ecosystem attributes	P/R[b]		0.2 (0.06)	0.6 (0.3)	0.1 (0.2)	0.3 (0.01)	
	CPOM/FPOM[a]		14.7 (3.7)^{A}	9.1 (1.9)^{AB}	4.9 (6.2)^{B}	15.6 (4.5)^{A}	
	TFPOM/BFOM		0.6 (0.9)	3.6 (2.1)	1.2 (0.3)	0.7 (0.8)	
	Channel stability		0.6 (0.2)	1.1 (0.4)	0.6 (0.2)	0.7 (0.1	

PRE, predator; FFG, functional feeding group; SHR, shredder; FF, filter-feeder; SCR, scraper; CG, collector-gatherer; P/R, photosynthesis to respiration; CPOM/FPOM, coarse to fine particulate organic matter; TFPOM/BFPOM, transport to benthic fine particulate organic matter; FD and FU, further downstream and further upstream; ID and IU, immediate downstream and immediate upstream; SE, standard error.

Table 4.2: Mean values (± SE) of physico-chemical variables measured across the sites of the studied streams. Sites ordered from downstream to upstream *(Continued).*

		Sites			
		FD	**ID**	**IU**	**FU**
Physico-chemical variables	Froude number	0.6 (0.09)	0.4 (0.08)	0.2 (0.06)	0.5 (0.08)
	Velocity (m s^{-1})	0.5 (0.1)	0.4 (0.05)	0.2 (0.06)	0.5 (0.1)
	FST-value^{c}	5.7 (1.2)^{A}	4.1 (0.6)^{AB}	3.3 (0.8)^{B}	7.0 (0.4)^{A}
	CPOM (g m^{-2})	58.6 (24.9)	29.7 (9.3)	75.6 (35.1)	42.7 (13.2)
	Width (cm)	149.7 (22.6)	138.6 (16.4)	166.2 (37.9)	120.2 (14.6)
	Depth (cm)	12.1 (2.6)	10.9 (3.0)	13.9 (3.7)	10.9 (2.4)
	Temperature (^{o}C)	10.1 (0.8)	10.2 (0.8)	9.6 (0.5)	9.7 (0.6)
	pH	7.5 (0.2)	7.3 (0.2)	7.3 (0.1)	7.4 (0.2)
	Nitrate (mg L^{-1})	2.4 (0.4)	2.2 (0.4)	2.1 (0.6)	1.5 (0.4)
	Phosphate (mg L^{-1})	0.04 (0.01)	0.07 (0.01)	0.1 (0.03)	0.06 (0.01)
	Conductivity (µS cm^{-1})	179.4 (51.9)	178.3 (51.4)	194.0 (56.3)	194.3 (57.1)
	Oxygen (mg L^{-1})	10.7 (0.3)	10.6 (0.3)	10.6 (0.2)	10.4 (0.3)
	Embeddedness^{c} (%)	22.2 (7.5)^{A}	40.0 (9.5)^{A}	72.8 (4.8)^{B}	36.1 (9.5)^{A}
	Bedrock (> 500 mm) (%)	2.0 (0.1)	0.9 (0.6)	1.7 (1.1)	2.7 (2.2)
	Boulders (> 250 mm) (%)	7.2 (5.4)	1.8 (0.9)	1.4 (1.1)	3.3 (1.4)
	Cobbles (60 – 250 mm) (%)	8.7 (2.9)	8.4 (3.1)	1.0 (0.6)	8.1 (2.5)
	Gravel (10 – 60 mm) (%)	19.7 (3.7)	18.7 (4.7)	4.9 (1.4)	17.2 (5.0)
	Fine gravel (2 – 10 mm) (%)	20.9 (4.7)	20.7 (5.0)	17.3 (5.4)	14.4 (3.3)
	Clay/silt/sand (< 0.06 – 2 mm)^{c} (%)	29.7 (6.2)^{A}	33.3 (6.6)^{A}	56.1 (4.6)^{B}	35.5 (5.8)^{A}
	Canopy cover (%)	31.4 (8.4)	40.6 (8.7)	35.6 (9.4)	37.2 (9.9)
	Riffle ^{c} (%)	84.4 (6.9)^{A}	54.8 (9.4)^{A}	28.3 (7.1)^{B}	76.7 (7.8)^{A}
	Pool ^{c} (%)	15.6 (6.9)^{A}	36.1 (8.0)^{A}	71.7 (7.1)^{B}	23.3 (7.8)^{A}

$^{a}p<0.05$ in GLMM; $^{b}p<0.05$ in GLMM, but no pairwise differences; $^{c}p<0.05$ in LMM.

Previous studies also found that the mean abundances of scrapers and filter-feeders increased at downstream reaches (0.4 to 1.5 km) of small impoundments (2,600 to 300,000 m^3) (e.g., Santucci et al., 2005; Camargo et al., 2005). This finding was attributed to factors such as downstream increase in primary production, stream channel stability, and fine particulate organic matter (FPOM) content. Indeed, an increase in primary production and stream channel stability below impoundments can increase the abundances of scrapers and filter-feeders, given higher food resources and stable substrates for attachment of filtration nets (Cardinale et al., 2004; Camargo et al., 2004).

The mean abundance of shredders was lowest at the immediate upstream (IU) sites. This finding is in agreement with other studies that found shredders abundance to be reduced at the sites located directly above small impoundments releasing surface water (e.g., Xiaocheng et al., 2008; Mueller et al., 2011). Nevertheless, several studies reported low abundances of shredders below impoundments releasing deep water (e.g., Camargo & De Jalon, 1990; Camargo & Voelz, 1998; Vallania & Corigliano, 2007). This discrepancy may be attributed to differences in the size of impoundments (15×10^6 to 665×10^6 m^3 compared to 80 to 720 m^3 in our study) and location of study sites. The size of impoundments has an effect on habitat variables (e.g., CPOM) (Poff & Hart, 2002; Kibler & Tullos, 2013), which consequently will affect macroinvertebrates FFGs composition. Regarding location of study sites, the above-mentioned studies compared sites which were located further upstream and downstream (0.2 to 15 km) from the impoundments, whereas sites from our study were located adjacent (~ 10 m) to the impoundments, allowing detection of small-scale alteration of macroinvertebrate FFGs.

Generally, the IU sites had low abundances for most macroinvertebrate FFGs. This may be due to reduced flow conditions (e.g., FST-value, Table 4.2), which are unfavourable for some macroinvertebrate FFGs (e.g., filter-feeders) requiring sustained flow (Palmer & Craig, 2000), and high fine sediment content (i.e., sand/silt and clay) at the IU sites. Fine sediment can impair respiration and feeding in macroinvertebrates by clogging the filter-feeding apparatus and gills (Jones et al., 2012). Fine sediment can also reduce the availability of food resources and habitat for macroinvertebrates by covering detritus and algae and clogging the interstitial spaces (Wood

& Armitage, 1997; Jones et al., 2012). Dissolved oxygen, canopy cover, water chemistry, and temperature are also important factors that influence the distribution of macroinvertebrates in streams (Hussain & Pandit, 2012). In the current study, the impoundments did not have a significant influence on these factors, and we therefore suggest that their contribution to the differences in macroinvertebrate FFGs abundances is minimal.

4.5.2 Impoundments and ecosystem attributes

The high heterotrophic production recorded at most study sites likely resulted from the predominantly forested land cover in the upstream catchment and riparian zone, which contributes large amounts of organic matter (Wipfli et al., 2007). The increased (i.e., 2-fold) autotrophic production at the ID sites has also been reported for other small impoundments releasing surface water (e.g., Avilés & Niell, 2006) and may be due to the impoundments retaining organic matter (Angradi & Kubly, 1994). By contrast, primary production did not increase in other studies (e.g., Tiemann & Gillette, 2004; Santucci et al., 2005). However, the impoundments have variable effects on habitat factors, such as water flow rate, water depth, fine sediment, and nutrients, all of which influence primary production (Larned, 2010). For example, the impoundments in our study significantly decreased the fine sediment (i.e., sand/silt and clay) content and embeddedness, and increased the percentage gravel, at the ID sites and may have increased primary production when compared with the IU sites (Izagirre et al., 2009).

The high CPOM content recorded at the IU sites is anticipated due to increased deposition under low flow conditions and retention by impoundments (Asaeda et al., 2013). By contrast, the FFG-based CPOM/FPOM ratio showed that the IU sites had a 3-fold reduction in CPOM (Table 4.2). This suggests that the IU sites had the highest measurable CPOM content but it was not available for the functioning of the ecosystem (e.g., availability to shredders, Couceiro et al., 2011). This finding can be explained by the fact that the IU sites had a significantly higher fine sediment content (i.e., sand/silt and clay), which may reduce CPOM at the sediment surface by covering it (Couceiro et al., 2011). Indeed, substratum particle size is an important determinant of CPOM storage and fine grained stream beds (e.g. sandy) may store most CPOM in interstices, when compared with coarse grained stream beds (e.g. gravelly) (e.g., Cornut et al., 2012). The T-

FPOM/BFPOM ratio showed that the ID sites had the highest (i.e., 5-fold) FPOM content. High FPOM content at the sites located immediate downstream has also been reported for other small impoundments releasing surface water (e.g., up to 2-fold, Mendoza-Lera et al., 2012). Impoundments can increase the downstream FPOM content by trapping CPOM and processing it into FPOM or through the release of suspended algae (Newbern et al., 1981; Touchette et al., 2007; Smolar-žvanut & Mikoš, 2014). Impoundments can also concentrate the FPOM produced further upstream and release it to the downstream reaches in high quantities (Angradi & Kubly, 1994). Stream channel stability was highest at the ID sites. This is attributed to an increase in the frequency of coarse substrates and has been reported for other small impoundments releasing surface water (e.g., Miyake & Akiyama, 2012). However, other studies could not find a downstream increase in channel stability (e.g., Bushaw-Newton et al., 2012; Thomson et al., 2005). This discrepancy can be attributed to the fact that some impoundments, e.g. run-of-river-dams, may have less influence on substratum particle size distribution due to their limited effect on downstream water flow (Csiki & Rhoads, 2010).

4.6 Conclusions

The results from our study indicate that small impoundments reduced the abundance of most macroinvertebrate FFGs at the study sites located immediately above the impoundments. Additionally, the impoundments altered ecosystem attributes at the study sites located within the vicinity of the impoundments. Thus, our results imply that small impoundments may rather have a local impact on macroinvertebrate FFGs and ecosystem attributes. Future studies should apply the FFG ratios approach in impoundments differing in size and water release depths to reveal the ecosystem impacts of different types of small impoundments.

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CHAPTER 5

Methane Derived Carbon in the Benthic Food web in Stream Impoundments

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CHAPTER 6

General Discussion

The responses of different taxonomic groups to two major stressors (i.e., climate change and pollution) that impact ecosystems were reviewed, and the convergence (i.e., uniformity) in trait responses assessed in Chapter 2. The current study contrasts with previous studies where the response of a specific trait (e.g., body size) to a stressor (e.g., climate change) was investigated (e.g., Daufresne et al., 2009). In the aforementioned study, it was reported that there was convergence in size (i.e., reduction) across aquatic organisms, such as fish, phytoplankton, bacteria, and zooplankton. In the current study, convergence was only found for tolerance traits (Rajpurohit et al., 2013). This discrepancy in trait response is attributed to the fact that traits respond differently to the various environmental gradients and extraneous factors that are found in different ecosystems. Nevertheless, the results are similar in that the present study also found a reduction in body size for fish and phytoplankton. It is suggested that the response of organisms to stressors through dispersal, and to multiple-stressors, should be further investigated because organisms have to respond to stress by adapting or dispersing (Berg et al., 2010), and there are interactions between stressors (Vinebrook et al., 2004; Moe et al., 2013). Ecosystems are characterized by multiple stressors, and an understanding of the combined effect of stressors on organisms can help to determine the environmental factors with the highest contribution to the observed responses (O'Gorman et al., 2012; Navarro-Ortega et al., 2015). For example, Przeslawski et al. (2015) synthesized the effects of temperature and acidification on the tolerance of marine organisms and found that acidification had a stronger negative effect on most taxonomic groups than temperature. The authors also found that the combined effect of stressors on organisms was greater than the sum of individual stressors in most (> 60%) cases. Harvey et al. (2013) also found that combining acidification and climate change increased the magnitude of trait responses. Indeed, the establishment of clear links between traits and stressors may also be hampered in case traits are related to each other in stressors response (Baird et al., 2008; Verberk et al., 2013). The issue of correlated traits is a current challenge in the trait-based approach, and can be solved by achieving a better understanding of co-evolved trait strategies (Verberk et al., 2013), and the relative sensitivity of individual and related traits to stress (e.g., Buchwalter et al., 2008). Determination of the molecular basis of organisms phenotypic diversities (for e.g., microorganisms, Pierlé, et al., 2012) will help to identify stressor-specific traits (Zhang et al., 2014; Krause et al., 2014), and further boost the application of traits in stressors assessment.

Impoundments are also prevalent stressors and their impact on ecosystem functioning (i.e., leaf litter decomposition) and attributes (based on macroinvertebrate functional feeding group ratios, Cummins et al., 2005), and on the contribution of methane gas (CH_4) derived carbon to stream benthic food web was investigated in Chapters 3 to 5. The results showed that the leaf litter decomposition rate and ecosystem attributes, such as primary production, were significantly reduced or increased at the study sites located immediately upstream (IU) or downstream (ID) of the impoundments. These findings are in agreement with the hypothesis that the impoundments would alter leaf litter decomposition rate and ecosystem attributes at the study sites located within the vicinity of impoundments, by modifying habitat variables such as flow and substrates composition. However, they differ from other studies involving small impoundments, where effects were detected further downstream (e.g., 60 m to 1500 m, Camargo et al., 2005; González et al., 2013). This discrepancy is attributed to variability in factors that regulate the magnitude of ecological effects of impoundments, such as size, water retention time, location in the catchment area, and mode of dam operation (e.g., water release mechanism) (Camargo & Voelz, 1998; Poff & Hart, 2002; denHeyer, 2007). For example, the impoundments investigated in the current study were smaller in size, when compared with the ones studied in the aforementioned studies (e.g., 720 m^3 versus 700,000 m^3), and had short water retention times (e.g., 3 minutes versus 20 days in Fairchild & Velinsky, 2006). Maxted et al. (2005) investigated the downstream effects of small impoundments (volume: 750 m^3 to 22,500 m^3), that released surface water, on physico-chemical variables and macroinvertebrate assemblages. The magnitude of effects was related to the size of impoundments, water retention time, season, and catchment land use. The greatest difference in temperature, between upstream and downstream reaches, was found for impoundments located in areas with less vegetation cover, during summer, and for the more retentive and bigger impoundments. The location of impoundments in headwaters in the current study, and the fact that the study area is largely devoid of human activities (e.g., farming) in upstream areas, may explain why no significant effects on water chemistry and most physical variables (e.g., temperature) were detected (Martínez et al., 2013). Impoundments located along streams that receive effluents from the surrounding areas can accumulate high quantities of nutrients and increase the downstream concentrations (Bosch, 2008). For example, Camargo (1992) reported that an impoundment located along a river that received industrial effluent caused the downstream concentration of nutrients (e.g., nitrates and fluorides) to increase significantly. The residence time of water in impoundments was also reported to have a significant effect on the downstream concentration of nutrients, with the more retentive impoundments releasing nutrients (e.g., nitrates), and fine particulate organic matter (FPOM), at higher concentrations (Fairchild & Velinsky, 2006).

In the current study, leaf litter decomposition rates were significantly reduced at the study sites located immediately upstream of impoundments. This was primarily attributed to the low abundance of invertebrate shredders, and reduced flow conditions. The decomposition rate of organic matter in streams is influenced by factors such as flow velocity, nutrient concentrations, microbial biomass, and abundance of invertebrate shredders (Graça, 2001). Small impoundments may decrease or increase leaf litter decomposition rates at the upstream reaches flooded by impoundments, or in downstream reaches, depending on their effects on the aforementioned biotic and abiotic factors. For example, Menéndez et al. (2012) reported that a small impoundment that released deep water caused a significant downstream increase in leaf litter decompositon rate, due to increases in the concentration of dissolved inorganic nitrogen, water temperature, and abundance of invertebrate shredders. However, leaf litter decomposition rates were reduced at the downstream sides of impoundments that released surface water, due to reduction in the abundance of invertebrate shredders. Short & Ward (1980) reported that although a small impoundment that released deep water caused the abundance of invertebrate shredders to decrease at the downstream side, the high temperature accelerated leaf litter decomposition rate, by enhancing microbial degradation. However, Mendoza-Lera et al. (2012)

found that small impoundments, that released surface water, had negligible effects on physico-chemical factors, such as temperature, and microbial abundance, and that the leaf litter decomposition rates were lowest downstream from impoundments, presumably due to the low abundances of invertebrate shredders.

The reported changes in the abundance of invertebrate functional feeding groups, such as shredders, in previous studies, and in the current study, are likely due to variability in other factors, such as the ratio of coarse to fine particulate organic matter (CPOM:FPOM), and not the minimal changes in water chemistry. For example, Martínez et al. (2013) reported that there were significant decreases in the mean abundances of invertebrate shredders and collector-gatherers at the downstream reaches of small impoundments. The authors suggested that this was likely due to a downstream decrease in the ratio of CPOM:FPOM, given that most physico-chemical variables did not differ between sites. However, Camargo et al. (2005) reported that increases in nutrient concentrations, and primary production, at the downstream sides of small impoundments caused the abundances of scrapers and collector-gatherers to increase. Modification in the abundance of invertebrate functional feeding groups attributed to gradients in food resources, and other habitat factors, was also recorded in other ecosystems similar to impoundments, such as lake outlets (Richardson & Mackay, 1991; Čmrlec et al., 2013). For example, Poepperl (1999) investigated macroinvertebrate assemblages below a lake outlet and found that filter-feeders had the highest biomass, due to the high content of FPOM.

With regard to methane gas (CH_4) derived carbon (MGDC), studies on impoundments are generally lacking and to my knowledge this is the first study. Therefore, most comparisons were made with lake studies. The results showed that there was no significant relationship between the stable carbon isotope values ($\delta^{13}C$) of chironomid larvae and CH_4 concentrations. Additionally, the $\delta^{13}C$ values (−27‰) of chironomid larvae were more similar to that of allochthonous organic matter (−30‰), than the previously reported $\delta^{13}C$ values (less than −40‰, Jones & Grey, 2011) of chironomid larvae, which indicated utilization of methane oxidizing bacteria (MOB) with very low $\delta^{13}C$ values. The current study contrasts with previous studies where significant negative correlations between CH_4 concentrations and $\delta^{13}C$ values of invertebrates indicated ingestion and assimilation of MOB (e.g., Deines & Grey, 2006; van Hardenbroek et al., 2012). For example, Deines & Grey (2006) investigated the contribution of CH_4 to the food web of a lake and found that CH_4 production increased, whereas the $\delta^{13}C$ values of chironomid larvae decreased with increasing water depth, suggesting that the rate of CH_4 production influenced the assimilation of MGDC by the chironomid larvae. Trimmer et al. (2009) evaluated the $\delta^{13}C$ values of invertebrates in a river with ground water sources and found that most invertebrates (e.g., *Gammarus* sp. and Simuliidae) had $\delta^{13}C$ values that were within the same range as those of potential food resources (e.g., algae) (i.e., ~ −32 to −36‰). However, the $\delta^{13}C$ values of caddisflies (*Agapetus* sp. and *Silo* sp.) were markedly decreased, when compared with the lowest $\delta^{13}C$ values (−38‰) of potential food resources, such as macrophytes (e.g., *Ranunculus* sp.). The authors suggested that the caddisflies most probably fed on MOB while foraging beneath the rocks and gravels, where appreciably high CH_4 oxidation rates were recorded. Kohzu et al. (2004) measured the $\delta^{13}C$ values of invertebrates, CH_4, and potential food resources, such as leaf litter and algae in backwater pools. The authors found that the invertebrates (e.g.,*Gammarus* sp.) collected from substrate surfaces had $\delta^{13}C$ values (−33 to −31‰) that were similar to those of their photosynthetic food resources (e.g., leaf litter) (−30 to −25‰). Nevertheless, the invertebrates collected from inside the organic matter accumulations, such as the coleopterans (e.g., *Helodes* sp. and *Agabus* sp.), had $\delta^{13}C$ values that were strikingly low (−40 to −68‰), and similar to that of CH_4 (− 66‰). Chironomids and bivalves collected from the same habitat as the coleopterans also had $\delta^{13}C$ values that were low (i.e., −30 to −40‰). The low $\delta^{13}C$ values of invertebrates collected from areas with organic matter accumulations was primarily attributed to consumption of MOB, or chemoautotrophic bacteria, whose development was boosted by the high CH_4 production, and oxidation of CH_4 by MOB, under a gradient of CH_4 and oxygen gas (Kajan & Frenzel, 1999; Colaco et al., 2002). Indeed, variability in the concentrations of oxygen gas and CH_4, and biomass of MOB, may also be the culprits for variability in the $\delta^{13}C$ values of chironomid larvae in lakes (Kiyashko et al. 2001; Jones et al., 2008). For example, Kiyashko et al. (2001) and Jones et al. (2008) investigated the contribution of MGDC to the food web of lakes and found chironomid $\delta^{13}C$ values to be as low as−70‰. However, the authors also recorded high stable carbon isotope values (e.g., −8‰) in some of the studied lakes. The differences in $\delta^{13}C$ values were attributed to variability in factors such as oxygen concentrations, which influence CH_4 production and oxidation rates, and biomass of MOB. This was also corroborated in other lake studies, where zoobenthos collected from well oxygenated shallow areas had higher $\delta^{13}C$ values than those collected from offshore areas with low oxygen concentrations (e.g., Deines & Grey, 2006; Hershey et al., 2006). Therefore, habitat conditions influence the contribution of MGDC to the benthic food webs and the effect of large impoundments may differ from that observed in the current study.

Overall, the results indicated that trait convergence is limited to few traits, and that the effect of small impoundments on the stream ecosystem is rather limited in magnitude and spatially. Despite the fact that several trends emerged from the synthesis of trait responses to climate change and pollution, the challenge now is how to extrapolate the findings to the field. Firstly, there were few studies that assessed trait responses at large spatial-scales, and to the multiple-stressors that characterize ecosystems (Matzelle et al., 2015). This is probably due to the costs involved and challenges involving field monitoring studies, such as the challenge of applying the appropriate stressors and tracking biological changes (Dobson, 2005). Certainly, laboratory experiments provide crucial information on the responses of traits to multiple stressors (Piggott et al., 2012; Wagenhoff et al., 2012). However, local and short-term studies cannot account for regional and global-scale environmental changes, which have been gradually changing over long time scales. Indeed, there is a difference between trait responses under laboratory experiments and in field natural conditions (e.g., Sandel et al., 2010). Therefore, there is an urgent need for further comparisons of organism trait responses under natural conditions, and in experiments, for ecological realism (Harvey et al., 2015). Future studies synthesizing trait responses to stressors should examine the multiple life stages of organisms, including larvae and adults, because sensitivities to stressors differ during the life-cycle of organisms (Dupont et al., 2010). With regard to impoundments, future studies should compare impoundments with different characteristics, such as size and water release depths, to identify the ecological effects of different types of small impoundments. The effects of small impoundments on other ecological aspects, such as migration of fish, should be assessed. Moreover, investigations on the contribution of MGDC to the stream benthic food web should scrutinize different types of invertebrates, CH_4 oxidation rates, and the microbial community. From a management perspective, the ecological effect of impoundments in this study may require less attention. However, for bigger impoundments, and other hydromorphological alterations such as dredging, the impacts may exceed the ones of the current study and management actions may be necessitated.

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APPENDIX A

Supplementary information for: Meta-analysis on the Responses of Traits of Different Taxonomic Groups to Global and Local Stressors

A.1 Supplementary Tables

Table A.1: Examples of trait databases for organisms, with a brief description, examples of previous applications and geographic coverage. Cov = coverage.

Organisms	Brief description	Examples of applications	Cov	Reference
Terrestrial Plants	Has over 3 million trait records	Development of models, hypotheses testing	Global	Kattge and et al (2011)
Terrestrial invertebrates	Considers 7 lepidopteran traits	Relation of traits to occupancy patterns	Europe	Franzén et al. (2012)
	Contains trait information on 1183 moth and butterfly species	Relationships between traits and feeding relationships e.g., larval trophic specificity	Global	Garcia-Barros (2008)
	Describes 5 nematodes traits	Evolution of traits in nematodes	UK	Morand (1996)
	Contains information for 128 collembolan species (12 traits)	Relationship between traits and environmental variables	Europe	Salmon and Ponge (2012)
Terrestrial vertebrates	Describes 4 primate traits	Relating population to habitat disturbances	Global	Cowlishaw et al. (2009)
	Has 25 mammal traits	Analysis of life history, ecology, and geography	Global	Jones et al. (2009)
	4 birds traits included	Mapping birds functional traits	America	Newbold et al. (2012)
	Describes 4 frog traits	Examination of macro-ecological relationships a	Australia	Murray and Hose(2005)

Table A.1: continued

Organisms	Brief description	Examples of applications	Cov	Reference
Aquatic plants	Has 31 phytoplankton functional categories	Description of phytoplankton distribution patterns in aquatic ecosystems	UK	Reynolds et al. (2002)
	A Morphological Based Functional Grouping (MBFG) of phytoplankton	Relating phytoplankton and environment	Europe and America	Kruk et al. (2010)
	Divides riparian vegetation into 5 flow response guilds	Proposes the organisation of riparian plants based on species with shared traits	USA	Merritt et al. (2010)
	Has traits information of more than 12,000 organisms	Assessment of ecological quality of rivers	Europe	Schmidt-Kloiber and Hering (2015)
	120 species of macrophytes are assigned to 20 functional groups	Relationship between macrophytes functional groups and habitat utilisation	Europe	Willby et al. (2000)
Aquatic invertebrates	SPEAR (species At Risk) provides specific indicators for assessment of stressors in aquatic systems	Assessment of impacts of stressors (e.g. pesticides, organic pollutants) in streams ($\text{SPEAR}_{\text{pesticides/organic}}$)	Australia, Europe, Russia	Liess and Von der Ohe (2005)
	Includes 20 invertebrates traits	Assessment of trait correlations, evolutionary associations	North America	Poff et al. (2006)
	Consists over 2,200 invertebrate species on 7 traits	Relationship between traits, environmental gradients	North America	Vieira et al. (2006)
	15 biological traits from 60 invertebrate species	Comparison of taxonomy and trait based approaches to determine land use effects	New Zealand	Dolédec et al. (2006)
	Describes 11 biological traits	Responses to several environmental gradients	Europe	Tachet et al. (2002)

Table A.1: continued

Organisms	Brief description	Examples of applications	Cov	Reference
Aquatic invertebrates	Contains 8 macroinvertebrate biological traits from 82 neotropical taxa	Assessment of invertebrate community traits in relation to habitat variability	South America	Tomanova and Usseglio-Polatera (2007)
	9 invertebrates traits are included	Development of SPEAR indices for assessment of salinity and pesticides	Australia	Schäfer et al. (2011)
	Describes 6 fish traits. It includes more than 120 fish species	Modeling assemblages convergence at large spatial scales along geomorphic and hydraulic gradients	USA and Europe	Lamouroux et al. (2002)
	FishBase presents trait information in form of 9 functional groupings	Modeling, testing of hypotheses, and fish distribution patterns over large spatial scales	Global	Froese and Pauly (2012)
	Has more than 100 traits for 809 fish species	Large scale analyses of both native and non-native fish species	North America	Frimpong and Angermeier (2009)

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Table A.2: Papers found applying organism traits to assess climate change and pollution. Climate = climate change, other biol/ecol = other biological/ecological, study = study type, field expt/mon = field experiment/monitoring, lab = lab study.

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field mon	Japan	Local	Alpine/fell field plants	Reproduction	Flowering respond habitat specific	Kudo and Hirao (2006)
Terrestrial plants	Climate	Field expt	Netherlands, Norway	Regional	3 plant species	Mass, size, reproduction	Increase in shoot growth rate/biomass, advanced flowering	Buizer et al. (2012)
Terrestrial plants	Climate	Field expt	China	Local	*Picea* sp.	Mass, size, reproduction	Increased growth rate of seedlings, biomass	Xu et al. (2012)
Terrestrial plants	Climate	Field expt	Japan	Local	5 alpine shrub species	Mass, size, reproduction, other biol	Advanced phenology (*Vaccinium*). High leaf biomass and survival, flower production and shoot growth, low leaf nitrogen (species dependent)	Suzuki and Kudo (2000)
Terrestrial plants	Climate	Field expt	Japan	Local	*Sieversia* sp.	Mass, size, other biol	Increase in leaf size, biomass & reduced nitrogen (in experiment)	Taguchi and Wada (2001)
Terrestrial plants	Climate	Field mon	Faroe islands	Regional	12 plant sp.	Tolerance	Negative effect on plants with low tolerance (e.g. *Calluna* sp.)	Fosaa et al. (2004)
Terrestrial plants	Climate	Field mon	Spain	Local	*Abies* sp.	Mass, size	Reduced biomass, size	Peguero-Pina et al. (2007)
Terrestrial plants	Climate	Field expt	Switzerland	Local	Oak	Mass	No clear warming effect on biomass	Kuster et al. (2013)
Terrestrial plants	Climate	Field expt	China	Local	Epiphytes	Mass	Reduced biomass	Song et al. (2012)
Terrestrial plants	Climate	Field expt	USA	Local	Forbs	Mass, reproduction	Increased biomass, reproduction (species dependent)	Blumenthal et al. (2013)
Terrestrial	Climate	Field	China	Local	Alpine sp.	Mass	Negative effect on biomass	Wu et al. (2013)
plants	Climate	mon	China	Local	4 Shrub species	Mass, size, reproduction, other biol	Advanced reproduction, increased size, mass, leaf life span. Reduced leaf nitrogen (species dependent)	Xu et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field mon	Spain	Local	2 shrub species	Mass, size reproduction	Reduced biomass, advanced growth phenology in *Erica sp.*	Bernal et al. (2011)
Terrestrial plants	Climate	Field mon	Spain	Local	Shrubs	Reproduction, other biol	Reduced reproduction (mainly for short lived species)	del Cacho et al. (2012)
Terrestrial plants	Climate	Field expt	Germany	Local	Grass	Mass	Reduced biomass	Vogel et al. (2013)
Terrestrial plants	Climate	Field expt	Sweden	Local	Cushion plants	Mass, size, reproduction	Short term increase in biomass and size	Alatalo and Little (2014)
Terrestrial plants	Climate	Field mon	Norway	Local	Plants	Tolerance	Northerly shift of species adapted to cold	Felde et al. (2012)
Terrestrial plants	Climate	Field mon	UK	Local	*Hypericum* sp.	Reproduction, Size	Reduced height, reproduction	Fox et al. (1999)
Terrestrial plants	Climate	Field expt	Spain	Local	Shrubs	Size, Mass	Contrasting effects on mass and size	Llorens et al. (2004)
Terrestrial plants	Climate	Field expt	China	Local	Plants	Size, Mass	Mixed response of size, biomass declined	Yang et al. (2005)
Terrestrial plants	Climate	Field expt	China	Local	Grass, Shrubs	Size, mass, other biol	Mixed response of biomass, leaf traits (e.g. area) (species dependent)	Xu et al. (2014)
Terrestrial plants	Climate	Field mon	USA	Local	Grass	Tolerance, function diversity, other biol	Reduction of sensitive species and functional diversity	Craine et al. (2011)
Terrestrial plants	Climate	Field expt	Germany	Local	2 shrub species	Reproduction	Altered reproduction (species dependent)	Nagy et al. (2013)
Terrestrial plants	Climate	Field expt	French	Local	Grass	Reproduction, mass	Mixed responses	Bloor et al. (2010)
			USA	Local	Grass	Mass	Long term decrease in biomass	Zhou et al. (2012)
Terrestrial plants	Climate	Field expt	Europe	Regional	Shrubs	Reproduction, Mass	Mixed response of biomass, reproduction	Peñuelas et al. (2004)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	Spain	Local	3 shrub species	Reproduction	Mixed response of reproduction	del Cacho et al. (2013)
Terrestrial plants	Climate	Field expt	Russia	Local	Shrubs, Lichens	Mass	Increased biomass	Biasi et al. (2008)
Terrestrial plants	Climate	Field mon	Switzerland	Local	2 oak species	Mass, size Reproduction	Advanced biomass and reproduction	Kuster et al. (2014)
Terrestrial plants	Climate	Field expt	Spain	Local	2 shrub species	Mass, Size	Mixed response of size and mass	Prieto et al. (2009) a
Terrestrial plants	Climate	Field mon	Switzerland	Local	Plants	Mass, reproduction	Mixed response of biomass, reproduction	Sheppard et al. (2012)
Terrestrial plants	Climate	Field expt	Belgium	Local	3 plant species	Mass, size	Increased biomass for some species	Verlinden et al. (2013)
Terrestrial plants	Climate	Field expt	Switzerland	Local	*Polygonum* sp.	Mass, Size, Reproduction	Weak responses of biomass and reproduction	Gugerli and Bauert (2001)
Terrestrial plants	Climate	Field expt	Australia	Local	Alpine plants	Size	Increase in height	Wahren et al. (2013)
Terrestrial plants	Climate	Field expt	USA	Local	*Bromus* sp.	Reproduction, Mass	Advanced reproduction, biomass increase	Zelikova et al. (2013)
Terrestrial plants	Climate	Field expt	Norway	Local	6 plant species	Reproduction	Reduced reproductive success (species dependent)	Semenchuk et al. (2013)
	Climate		USA	Local	Grass	Mass	Mixed response	Wan et al. (2005)
Terrestrial plants	Climate	Field expt	USA	Local	plants	Functional diversity, mass, size	Decreased biomass, increase in size and change in functional diversity	Hoeppner and Dukes (2012)
Terrestrial plants	Climate	Field mon	USA	Local	Forbs	Reproduction, Size	Mixed response of size, reproduction	Leger (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field mon	Austria	Local	10 alpine species	Reproduction	Altered reproduction	Hülber et al. (2010)
	Climate	Field mon	UK, USA	Local	Plants	Reproduction	Altered reproduction	Hulme (2011)
Terrestrial plants	Climate	Field expt	USA	Local	Forbs	Size, other biol, reproduction	No clear effect on size and other biol traits. Altered reproduction	Starr et al. (2000)
Terrestrial plants	Climate	Field expt	Sweden	Local	Mosses	Size, mass	Increased size, mass	Dorrepaal et al. (2003)
	Climate		Sweden	Local	2 species	Reproduction	Advanced reproduction	Aerts et al. (2004)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Size, mass	Increased height, biomass	Wahren et al. (2005)
Terrestrial plants	Climate	Field expt	Iceland	Local	Plants	Size	Increased height	Jónsdóttir et al. (2005)
Terrestrial plants	Climate	Field expt	Europe	Regional	Plants	Mass, tolerance	Increased biomass of tolerant oaks	Penuelas et al. (2007)
Terrestrial plants	Climate	Field mon	Central Europe	Regional	Lichens	Tolerance	Decrease in less tolerant species	Hauck (2009)
Terrestrial plants	Climate	Field mon	Canada	Local	Plants	Mass	Increased biomass	Hill and Henry (2011)
Terrestrial plants	Climate	Field expt	Spain	Local	Plants	Mass	Increased biomass	Sebastia (2007)
	Climate		China	Local	Plants	Mass	Increased biomass	Li et al. (2011)
Terrestrial plants	Climate	Field expt	Australia	Local	6 species	Reproduction	Variable alteration of reproduction	Hoffmann et al. (2010)
Terrestrial plants	Climate	Field mon	Switzerland	Local	Plants	Tolerance	Reduction of sensitive species	Scherrer and Körner (2011)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	Canada	Local	Plants	Size, mass	No clear effect on height, biomass	Hudson and Henry (2010)
Terrestrial plants	Climate	Field expt	Europe	Regional	Grass	Mass, Tolerance	Mixed responses of tolerance and biomass	Beierkuhnlein et al. (2011)
Terrestrial plants	Climate	Field expt	Sweden	Local	Plants	Mass, size	Reduced biomass (species dependent)	Bjerke et al. (2011)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Reproduction, Mass	Increased biomass, advanced reproduction	Natali et al. (2012)
	Climate	Field expt	Japan	Local	Oak	Mass, size, reproduction	Increased biomass and size, advanced reproduction	Usami et al. (2001)
Terrestrial plants	Climate	Field expt	Canada	Local	*Brassica* sp.	Size, Mass	Reduced height and biomass	Qaderi et al. (2006)
Terrestrial plants	Climate	Field expt	Australia	Local	Grass	Reproduction, mass, size	Altered reproduction, size, mass	Hovenden et al. (2008)
Terrestrial plants	Climate	Field expt/mon	Global	Global	Plants	Mass	Increased biomass for some species	Lin et al. (2010)
Terrestrial plants	Climate	Field expt	Switzerland	Local	Shrubs	Mass, size	Increased size,mass for some species	Dawes et al. (2011)
Terrestrial plants	Climate	Field expt	China	Local	Plants	Reproduction	Altered reproduction	Liu et al. (2011)
	Climate	Field expt	China	Local	Grass	Mass	Increased biomass	Li et al. (2014)
Terrestrial plants	Climate	Field expt	Switzerland	Local	Shrubs	Mass, Size	Increased mass, length	Anadon-Rosell et al. (2014)
	Climate	Field expt	UK	Local	Shrubs	Size, tolerance, other biol	No clear effect	Llorens et al. (2002)
	Climate	Field expt	Europe	Local	Shrubs/ grass	Reproduction	Altered reproduction	Prieto et al. (2009)b

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	Chile	Local	*Nothofagus* sp.	Mass, Size, other biol	Increased biomass, size, seed survival, low carbon isotope composition	Piper et al. (2013)
Terrestrial plants	Climate	Field expt	Switzerland	Local	Oak	Mass, Size	Reduced biomass, size	Fonti et al. (2013)
Terrestrial plants	Climate	Field expt	UK	Local	Plants	Reproduction, tolerance	Advanced reproduction and sensitivity responses	Bokhorst et al. (2010)
	Climate		USA	Local	Plants	Mass	Increased biomass	Day et al. (2008)
Terrestrial plants	Climate		Canada	Local	Shrubs	Mass	Increased biomass	Zamin et al. (2014)
Terrestrial plants	Climate		UK	Local	Shrubs	Mass, Reproduction	Altered reproduction and reduced biomass	Bokhorst et al. (2011)
Terrestrial plants	Climate		UK	Local	Shrubs	Reproduction	Altered reproduction	Bokhorst et al. (2008)
Terrestrial plants	Climate	Field mon	Korea	Local	Plants	Reproduction	Altered reproduction	Jeong et al. (2011)
Terrestrial plants	Climate	Field expt	Canada	Local	Plants	Reproduction	Increased reproduction	Klady et al. (2011)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Size	Increased height	Hollister et al. (2005)
Terrestrial plants	Climate	Field expt	Europe/USA	Regional	Plants	Mass	Increased biomass	Baldwin et al. (2014)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Reproduction	Altered reproduction	Lambrecht et al. (2007)
Terrestrial plants	Climate	Field expt	Europe/USA	Regional	Plants	Tolerance	Reduction in sensitive lichens	Lang et al. (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	France	Local	Grass	Mass, Reproduction	Increased biomass, reproduction	Chuine et al. (2012)
	Climate		Chile	Local	Plants	Reproduction	Altered reproduction	Arroyo et al. (2013)
	Climate		Europe	Regional	Plants	Reproduction	Altered reproduction	Jentsch et al. (2009)
Terrestrial plants	Climate	Field mon	USA	Local	Plants	Reproduction	Altered reproduction	Park (2014)
Terrestrial plants	Climate	Field expt	Canada	Local	Plants	Reproduction, Size	Advanced reproduction, increased height	Bronson et al. (2009)
Terrestrial plants	Climate	Field expt	Canada	Local	*Picea sp.*	Size	Increased height	Danby and Hik (2007)
Terrestrial plants	Climate	Field expt	France	Local	Grass	Mass	Negative effect on biomass	Zwicke et al. (2013)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Reproduction	Altered reproduction	Norby et al. (2003)
Terrestrial plants	Climate	Field expt	Belgium	Local	Grass	Mass	Reduced biomass	De Boeck et al. (2007)
	Climate		Finland	Local	Plants	Reproduction	Altered reproduction	Strømme et al. (2014)
Terrestrial plants	Climate	Field mon	China	Local	Plants	Reproduction	Altered reproduction	Shi et al. (2014)
Terrestrial plants	Climate	Field expt	China	Local	Plants	Functional diversity, size,mass, other biol	Altered functional diversity, biomass, size and leaf traits	Liu and Ma (2012)
Terrestrial plants	Climate	Field mon	Japan	Local	Plants	Reproduction	Altered reproduction	Kudo and Ida (2013)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Tolerance	Indirect effects on plant stress	Marquis et al. (2014)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Mass	Increased biomass	Day et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	Japan	Local	Shrubs	Reproduction, size, other biol	Earlier flowering for some sp. Reduced nitrogen and increased shoot growth rate for some sp.	Suzuki and Kudo (1997)
Terrestrial plants	Climate	Field expt	USA	Local	Grass, shrubs	Size, other biol	Increase in sp. with small seeds, short life span and high nitrogen	Sandel et al. (2010)
Terrestrial plants	Climate	Field mon	USA	Local	Forbs	Reproduction, size, other biol	Effects mainly on recruitment than survival for sp. with short generation	Dalgleish et al. (2010)
Terrestrial plants	Climate	Field expt	France	Local	Grass	Size, Mass, Functional diversity	Increased dry matter. Initial increase in biomass, but decline afterwards	Cantarel et al. (2013)
Terrestrial plants	Climate	Field mon	Canada	Local	Plants	Size, Mass, tolerance, other biol	Increase in sp. with high growth rate, height and short life span	Lacourse (2009)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Reproduction	Advanced leafing/flowering	Borner et al. (2008)
Terrestrial plants	Climate	Field expt/ mon	Global	Global	Plants	Reproduction	Advanced leafing/flowering	Wolkovich et al. (2012)
Terrestrial plants	Climate	Field mon	Australia	Local	*Dononaeav iscosa sp.*	Size	Decreased leaf area/width	Guerin et al. (2012)
Terrestrial plants	Climate	Field mon	USA	Local	Plants	Reproduction	Altered reproduction	Wipf (2010)
Terrestrial plants	Climate	Field expt	Tibet	Local	4 plant species	Reproduction	Delayed reproduction. Advanced reproduction for some species (sp.)	Dorji et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	China	Local	Grass	Mass, size	Regrowth less pronounced in plants previously affected by drought	Xu et al. (2009)
Terrestrial plants	Climate	Field mon	China	Local	Plants	Reproduction	Altered reproduction	Luo et al. (2007)
Terrestrial plants	Climate	Field mon	Switzerland	Local	Plants	Size, other biol	Replacement of snow bed specialists with short grass sp.	Schöb et al. (2009)
Terrestrial plants	Climate	Field mon	Portugal	Local	Shrubs	Size, Mass, tolerance, other biol	Increased shoot/leaves growth, leaf area and life span for some sp.	Simoes et al. (2008)
Terrestrial plants	Climate	Field mon	Middle east, North Africa, Europe	Regional	Trees, shrubs, forbs	Size, Reproduction, other biol	Increased short shurbs/forbs. Plants traits (e.g. texture) variable based on plant type	Barboni et al. (2004)
Terrestrial plants	Climate	Field mon	Local	Australia	Plants	Size, Mass	Increase in leaf area/height	Venn et al. (2011)
Terrestrial plants	Climate	Field expt	Mongolia	Local	8 plant species	Reproduction	Advanced flowering and fruiting time	Xia and Wan (2013)
Terrestrial plants	Climate	Field expt	Canada	Local	Shrubs/forbs/sedges	Size, other biol	Increase in size, decrease in specific leaf area, carbon concentration (sp. dependent)	Hudson et al. (2011)
Terrestrial plants	Climate	Field mon	USA	Local	Plants	Reproduction	Altered reproduction	McKinney et al. (2012)
	Climate		USA	Local	Plants	Reproduction	Altered reproduction	Marra et al. (2005)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial plants	Climate	Field expt	Japan	Local	Shrubs/ forbs	Size, Mass	Increased growth and biomass (shrubs), reduced growth (shrub/forbs)	Wada et al. (2002)
Terrestrial plants	Climate	Field expt	Sardinia	Local	Plants	Mass, Size	No clear effect on size and biomass	De Dato et al. (2008)
Terrestrial plants	Climate	Field expt	Spain	Local	Shrubs	Reproduction	Altered reproduction	Llorens and Penuelas (2005)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Reproduction	Negative effect on reproduction	Saavedra et al. (2003)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Mass	Increased biomass	Sherry et al. (2008)
Terrestrial plants	Climate	Field expt	Europe	Regional	Herbs	Reproduction, Size, Mass	Increased height, biomass and reproduction	De Frenne et al. (2011)
Terrestrial plants	Climate	Field expt	USA	Local	Plants	Mass	Increased biomass	Hollister and Flaherty (2010)
Terrestrial plants	Pollution	Field mon	Local	Portugal	Lichens	Other Ecol	Decrease in sensitive groups	Llop et al. (2012)
Terrestrial plants	Pollution	Field mon	Local	Portugal	Lichens	Other Ecol	Replacement of oligotrophic sp.	Pinho et al. (2012)
Terrestrial plants	Pollution	Field mon	Local	Netherlands	Lichens	Other Ecol	Increase in nitrophytic groups	Van Dobben and Ter Braak (1998)
Terrestrial plants	Pollution	Field mon	Local	Canada	Lichens	Tolerance	Insensitive sp. widely distributed	Nieboer et al. (1972)
Terrestrial plants	Pollution	Field mon	Local	Finland	Plants	Tolerance	Reduced intolerant sp.	Salemaa et al. (2004)
Terrestrial arthropods	Climate	Field expt	Local	Sweden	Collembolans	Size, tolerance, other ecol/ biol	Increase in drought tolerant, epiedaphic large sp.	Makkonen et al. (2011)

Table A.2: Continued

Organism	Stressor	study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial arthropods	Climate	Field expt	Canada	Local	Arthropods	Reproduction, other ecol/biol	Increase in tolerant/ small sp.	Lindo et al. (2012)
			Germany	Local	Spiders	Other ecol, size	No clear relationship	Buchholz (2010)
	Climate	Field expt	Norway	Local	Arthropods	Reproduction, functional group	Increase in short lived/predatory sp.	Hågvar and Klanderud (2009)
	Climate	Field expt	USA	Local	Arthropods	Mass	No direct effect	Whitney-Johnson et al. (2005)
	Climate	Field mon	USA	Local	Arthropods	Reproduction	Advanced reproduction	Schulte et al. (2008)
	Climate	Field expt	Netherlands	Local	Arthropods	Tolerance	Increased tolerance	van Dooremalen et al. (2011)
Terrestrial arthropods	Climate	Field mon	USA	Local	Arthropods	Reproduction	Increased voltinism	Mitton and Ferrenberg (2012)
	Climate	Field expt	USA	Local	Ants	Size, mass, tolerance	Increased tolerance	Wiescher et al. (2012)
	Climate	Field mon	Australia	Local	Arthropods	Reproduction	Altered reproduction	Kearney et al. (2010)
	Climate	Field mon/expt	Global	Global	Arthropods	Reproduction	Altered reproduction	Karuppaiah and Sujayanad (2012)
	Climate	Field expt	USA	Local	Arthropods	Reproduction	Advanced reproduction	Fielding and Defoliart (2010)
	Climate	Field mon	USA	Local		Reproduction	Change to bi-voltinism	Nufio et al. (2010)
	Climate	Field expt	China	Local	Arthropods	Reproduction	Negative effects on reproduction	Zhang et al. (2013)
	Climate	Field mon	Canada	Local	Arthropods	Dispersal, other ecol	Less mobile species more sensitive	Kharouba et al. (2014)
	Climate	Field expt/mon	Belgium	Local	Arthropods	Reproduction	Positive effects on reproduction	Radchuk et al. (2013)
	Climate	Field expt	China	Local	Arthropods	Reproduction	Advanced reproduction	Guo et al. (2009)

Table A.2: Continued

Organism	**Stressor**	**Study**	**Location**	**Scale**	**Species**	**Traits**	**Traits response**	**Reference**
Terrestrial arthropods	Climate	Field expt	Japan	Local	Arthropods	Reproduction, size	Altered reproduction/size	Musolin et al. (2010)
	Climate	Field expt	USA	Local	Arthropods	Functional diversity	Reduction in herbivores/parasitoids	Villalpando et al. (2009)
	Climate	Field expt	Ireland	Local	Arthropods	Reproduction	Advanced reproduction	O'Neill et al. (2012)
	Climate	Field expt	China	Local	Arthropods	Reproduction	Altered reproduction	Guo et al. (2013)
	Climate	Field expt	China	Local	Arthropods	Reproduction		Guo et al. (2012)
	Climate	Field mon	Japan	Local	Arthropods	Reproduction		Moriyama and Numata (2011)
	Climate	Field expt	Korea	Local	Arthropods	Reproduction		Bang et al. (2011)
	Climate	Field mon	Tunisia	Local	Arthropods	Reproduction		Neila et al. (2012)
	Climate	Field expt	Marion island	Local	Arthropods	Mass	Reduced biomass	McGeoch et al. (2006)
	Climate	Field expt	Japan	Local	Arthropods	Reproduction	Altered reproduction	Takeda et al. (2010)
	Climate	Field expt	USA	Local	Ants	Tolerance	Increase in tolerant sp.	Diamond et al. (2012)
	Climate	Field expt	Local	USA	Arthropods	Size	Mixed response in body size	Klok and Harrison (2013)
	Climate	Field expt	Local	USA	Arthropods	Size, mass, other biol	Decrease in mass/size	Simmons et al. (2009)
	Climate	Field expt	Denmark and Italy	Regional	Collembolans	Tolerance, Size, Mass	Desiccation resistance increased towards the most southern and northern populations	Bahrndorff et al. (2006)
	Climate	Field mon	UK	Local	Butterflies	Dispersal, Reproduction, other ecol	Phenological advancement (species dependent)	Diamond et al. (2011)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial arthropods	Climate	Field expt	Sweden	Local	Collembolans	Size, mass, other biol/ecol	Negative effect on small sp. Increased hemi-edaphic sp.	Bokhorst et al. (2012)
	Climate	Field expt	Switzerland	Local	Collembolans, mites	Size, Mass	Reduced biomass of arthropods. Increase in small mites	Xu et al. (2012)
	Climate	Field mon	USA	Local	Bees	Size, other other ecol, reproduction	Increase in small sp., with large dietary/phenological breadth	Bartomeus et al. (2013)
	Climate	Field mon	Spain	Local	Moth	Reproduction	Advanced phenology/voltinism	Martín-Vertedor et al. (2010)
	Climate	Field mon	Korea	Local	Moth	Reproduction	Change to bivoltinism from univoltinism	Choi et al. (2011)
	Climate	Field mon	Europe	Regional	Moth/butterfly	Reproduction	Increased voltinism	Altermatt (2009)
	Climate	Field mon	Switzerland	Local	Moth	Reproduction	Increased voltinism	Stoeckli et al. (2012)
	Climate	Field expt	USA	Local	Ant sp.	Tolerance	Increase in tolerant sp.	Warren and Chick (2013)
	Climate	Field mon	Italy	Local	Beetles	Reproduction	Advanced phenology/voltinism	Faccoli (2009)
	Climate		Finland	Local	Moths	Reproduction	Increased voltinism	Pöyry et al. (2011)
	Climate	Field mon	Norway	Local	Beetles	Reproduction	Increased voltinism	Jönsson et al. (2009)
	Climate	Field expt	Sweden	Local	Collembolans	Reproduction, size, mass	Reduced growth rates, reproduction and juveniles	Tranvik et al. (1993)
	Climate	Field expt	North America	Local	Ants	Tolerance	Increase in sp. with high thermal maxima in southern side	Stuble et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Terrestrial arthropods	Pollution	Field mon/expt	UK	Local	Earthworms	Tolerance	No clarity between zinc tolerance/distribution	Spurgeon and Hopkin (1999)
	Pollution	Field mon	Australia	Local	Ants	Other ecol	Little change of functional groups	Hoffmann et al. (2000)
	Pollution	Field mon	Poland	Local	Aphids	Reproduction, size, mass	Reduced fecundity/population growth rate	Görür (2007)
	Pollution	Field mon/expt	Netherlands	Local	Micro-arthropod	Dispersal, reproduction, other ecological	Increased dispersal, thelytokously reproduction and synchronisation tactics	Siepel (1995)
Birds	Climate	Field mon	France	Local	Mallard	Size, mass	Body mass increased	Guillemain et al. (2010)
	Climate	Field mon	North America	Regional	Bird sp.	Size, mass	Body size/ mass declined	Van Buskirk et al. (2010)
	Climate	Field mon	UK/France	Regional	Bird sp.	Size, mass	No relationship between size/migratory capacity	Guillemain et al. (2009)
	Climate	Field mon	Barents/Baltic/North seas	Regional	Bird sp.	Reproduction	Altered reproduction phenology	Van Der Jeugd et al. (2009)
	Climate	Field mon	Germany	Local	Bird sp.	Size	No consistency in body size response	Salewski et al. (2014)
	Climate	Field mon	South Africa	Local	Bird sp.	Size, Mass, Reproduction	Reduced mass, size/reproduction	Cunningham et al. (2013)
	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Altered reproductive phenology	Townsend et al. (2013)
	Climate	Field mon	Finland	Local	Bird sp.	Reproduction	Change in breeding range	Brommer et al. (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon/ exp	Global	Global	Great tits	Reproduction	Altered reproduction phenology	Caro et al. (2013)
	Climate	Field mon	USA	Local	Bird sp.	Size	More northerly distribution for large birds	Repasky (1991)
	Climate	Field mon	West Europe	Local	Bird sp.	Reproduction	Altered reproduction phenology	Jenni and Kéry (2003)
	Climate	Field mon	USA	Local	Bird sp.	Tolerance	Decline in thermal sensitive sp.	Butler et al. (2007)
	Climate	Field mon	Finland	Local	Bird sp.	Reproduction	Altered reproduction phenology	Lehikoinen et al. (2011)
	Climate	Field mon	Svalbard	Local	Bird sp.	Reproduction	Reduced reproduction	Clausen and Clausen (2013)
	Climate	Field mon	Germany	Local	Bird sp.	Size	Altered body size	Salewski et al. (2014)
	Climate	Field mon	Europe/Russia	Regional	Pied fly catcher	Reproduction	Altered reproduction phenology	Burger et al. (2012)
	Climate	Field mon	Macquarie island	Local	Penguins	Reproduction	Altered reproduction phenology	Hindell et al. (2012)
	Climate	Field mon	Netherlands	Local	Great tits	Reproduction	Altered reproduction	Visser et al. (1998)
	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Change in breeding range	Hitch and Leberg (2007)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon	Hungary	Local	Bird sp.	Size, mass, reproduction	Increased body mass, reduced size and northerly expansion of breeding range	Kovács et al. (2011)
Birds	Climate	Field mon	Possession island	Local	Penguins	Reproduction	Altered reproduction phenology	Le Bohec et al. (2008)
Birds	Climate	Field mon	UK	Local	Bird sp.	Reproduction	Altered reproduction phenology	Whitehouse et al. (2013)
Birds	Climate	Lab study	Netherlands	Local	Bird sp.	Reproduction	Altered reproduction phenology	Visser et al. (2009)
Birds	Climate	Field mon	Crozet islands	Local	Bird sp.	Reproduction	Altered breeding range	Péron et al. (2012)
Birds	Climate	Field mon	Canada	Local	Bird sp.	Size	Altered bill size	Burness et al. (2013)
Birds	Climate	Field mon	Finland	Local	*Tetrao tetrix* sp.	Reproduction	Altered reproduction phenology	Ludwig et al. (2006)
Birds	Climate	Field mon	Finland	Local	Bird sp.	Tolerance	Reduction in sensitive sp.	Virkkala and Rajasärkkä (2011)
Birds	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Reduced reproduction in some sp.	Cox et al. (2013)
Birds	Climate	Field mon	USA	Local	Geese	Mass, size	Reduced size, mass	Aubry et al. (2013)
Birds	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Shift in breeding range	McDonald et al. (2012)
Birds	Climate	Field mon	South Indian ocean	Regional	Bird sp.	Reproduction	Shift in reproduction success	Barbraud et al. (2011)
Birds	Climate	Field mon	Germany	Local	Bird sp.	Reproduction	Altered reproduction	Smallegange et al. (2010)

Table A.2: Continued

Organism	**Stressor**	**Study**	**Location**	**Scale**	**Species**	**Traits**	**Traits response**	**Reference**
Birds	Climate	Field	USA	Local	Bird sp.	Size	No clear body size response	Goodman et al. (2012)
Birds	Climate	mon	Slovakia	Local	Bird sp.	Reproduction	Increase in breeding success	Gordo et al. (2013)
Birds	Climate	Field mon	Canada	Local	Bird sp.	Reproduction	Reduced breeding success	Martin and Wiebe (2004)
Birds	Climate	Field mon	Canada	Local	Bird sp.	Reproduction	Altered reproduction	Wilson and Arcese (2003)
Birds	Climate	Field mon	Italy	Local	Bird sp.	Reproduction	Altered reproduction phenology	Sergio (2003)
Birds	Climate	Field mon	Canada	Local	Bird sp.	Reproduction	Indirect effects on reproduction phenology	Hipfner and Elner (2013)
Birds	Climate	Field mon	Finland	Local	Pied fly catcher	Reproduction	Altered reproduction	Laaksonen et al. (2006)
Birds	Climate		Switzerland	Local	Eurasian dipper	Reproduction	Altered reproduction	Hegelbach (2001)
Birds	Climate	Field mon	France	Local	*Accipiter* sp.	Reproduction	Altered reproduction	Nielsen and Møller (2006)
Birds	Climate	Field mon	Britain	Local	Bird sp.	Functional diversity	Increase in generalist taxa	Davey et al. (2012)
Birds	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Positive effects on reproduction	Giuliano and Daves (2002)
Birds	Climate	Field	Panama	Local	Bird sp.	Reproduction	Altered reproduction	Robinson et al. (2014)
Birds	Climate	mon	UK	Local	Bird sp.	Size, mass	Mixed responses	Yom-Tov et al. (2006)
Birds	Climate		France	Local	Teal	Size, mass	Decreased body size	Guillemain et al. (2005)
Birds	Climate	Field	Slovakia	Local	Warbler	Size, mass	Increase in size/biomass	Kanuscak et al. (2004)
Birds	Climate	mon	Poland	Local	Bird sp.	Reproduction	Altered reproduction	Tryjanowski et al.(2004)
Birds	Climate	Field mon	Australia	Local	Passerines	Size	Decline in size for some 4 sp.	Gardner et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon	Israel	Local	Passerines	Size, mass	4 sp. declined in body mass,2 in body size	Yom-Tov (2001)
Birds	Climate	Field mon	North America	Local	Swallows	Reproduction	Increased clutch size/advanced egg laying	Winkler et al. (2002)
Birds	Climate	Field mon	Israel	Local	Chukar patridges	Size, mass	Decline in body mass/size	Yom-Tov et al. (2002)
Birds	Climate	Field mon	Finland	Local	Pied flycatcher	Reproduction	Increased egg volume	Jarvinen (1994)
Birds	Climate	Field mon	USA	Local	Lark Bunting	Reproduction	Increased clutch size/nest survival	Skagen and Adams (2012)
Birds	Climate	Field mon	Denmark	Local	Bird sp.	Reproduction	Multibrooded sp. increased duration of breeding season and single brooded sp. decreased theirs	MØller et al. (2010)
Birds	Climate	Field mon	Netherlands	Local	Water fowl sp.	Reproduction, size, mass	Decline in growth rate of insectivorous sp./ground breeders	Cormont et al. (2011)
Birds	Climate	Field mon	Europe	Regional	Bird sp.	Size, mass, tolerance	Lower growth rate at thermal maxima	Jiguet et al. (2010)
Birds	Climate	Field mon	France	Local	Bird sp.	Tolerance, other ecol	Decline in sp. with low thermal maximum/habitat specialists at a faster rate	Jiguet et al. (2007)
Birds	Climate	Field mon	North America	Local	Tree swallows	Reproduction	Advanced egg laying	Dunn and Winkler (1999)
Birds	Climate	Field mon	Netherlands	Local	Pied fly catcher	Reproduction	Advanced egg laying date	Both and Visser (2005)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon	Asia	Regional	Warblers	Reproduction	Advanced breeding	Scordato et al. (2012)
Birds	Climate	Field mon	Europe	Regional	Bird sp.	Tolerance	Decline in sp. with lower thermal maximum	Jiguet et al. (2010)
Birds	Climate	Field mon	Italy	Local	Kestrels	Reproduction	Delayed egg laying/smaller clutches/higher hatching & fledging success	Costantini et al. (2009)
Birds	Climate	Field mon	Croatia	Local	Bird sp.	Reproduction	Advanced breeding date	Dolenec and Dolenec (2011)
Birds	Climate		Spain	Local	Songbirds	Reproduction	Egg breadth decreased	Potti (2008)
Birds	Climate	Field mon	Netherlands	Local	Great tits	Size, mass	Decrease in mass in all populations. Decrease in size of one population	Husby et al. (2011)
Birds	Climate		Germany	Local	Passerines	Size, mass	Decrease in mass/size for 5 sp.	Salewski et al. (2010)
Birds	Climate	Field mon	USA	Local	Mexican Jay	Reproduction	Advanced clutch appearance/nests	Brown et al. (1999)
Birds	Climate	Field mon	Spain	Local	Passerines	Reproduction, mass	Decline in mass/clutch size with climate zones	Vaclav and Sanchez (2008)
Birds	Climate		Spain	Local	Blue tits	Reproduction	Advanced breeding date	Potti (2009)
Birds	Climate	Field mon	Finland	Local	Great tits	Reproduction	Increase in fledging success/variation in clutch size/egg laying dates	Ahola et al. (2009)
Birds	Climate	Field mon	Germany	Local	Bird sp.	Reproduction	Advanced 1st singing date in less migratory/multibrooded sp.	Rubolini et al. (2010)
Birds	Climate	Field mon	UK	Local	Great tits	Reproduction	Advanced egg laying date	Charmantier et al. (2008)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon	Czech Republic	Local	Bird sp.	Reproduction	Earlier breeding/increased brood size	Hušek and Adamik (2008)
Birds	Climate	Field mon	USA	Regional	Swallows	Size	Increased large birds	Brown and Brown (1998)
Birds	Climate	Field mon	Canada	Local	Geese	Reproduction, size, mass	Increased nest density/early egg laying and hatching/reduction in size and mass	Dickey et al. (2008)
Birds	Climate	Field mon	Brazil	Local	Bird sp.	Size	Reduced bill size for 4 groups	Symonds and Tattersall (2010)
Birds	Climate	Field	Croatia	Local	Tits	Reproduction	Advanced egg laying	Dolenec (2006)
Birds	Climate	mon	Iceland	Local	Common eiders	Reproduction	Advanced egg laying/variability in number of nests	D’alba et al. (2010)
Birds	Climate	Field mon	Europe	Regional	*Ficedula* sp.	Reproduction	Advanced egg laying	Both et al. (2004)
Birds	Climate		USA	Regional	Swallows	Size	Increased wing size/tail/bill	Brown et al. (2013)
Birds	Climate	Field mon	Greenland	Local	*Alle* sp.	Size, mass	Increased size	Wojczulanis-Jakubas et al. (2011)
Birds	Climate	Field mon	Western Europe	Regional	Pied fly catcher	Reproduction	Advanced egg laying date	Sanz (2003)
Birds	Climate	Field mon	Europe	Regional	Pelicans	Reproduction	Advanced egg laying date for 1 sp. Reduced egg laying period for 1 sp.	Doxa et al. (2012)
Birds	Climate	Field mon	North America	Local	Northern flicker	Reproduction	Advanced egg laying date	Wiebe and Gerstmar (2010)
Birds	Climate	Field mon	Morocco	Local	*Galerida* sp.	Size	Decrease in body size for 2 sp. Increase in body size for 1 sp.	Guillaumet et al. (2008)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Climate	Field mon	Netherlands	Local	Great tits	Reproduction	Decline in birds that produce 2 clutches	Husby et al. (2009)
Birds	Climate	Field mon	Netherlands	Local	Great tits	Reproduction	Advanced egg laying date	Visser et al. (2006)
Birds	Climate	Field mon	Netherlands	Local	Bird sp.	Reproduction	Advanced egg laying date	Both et al. (2006)
Birds	Climate	Field mon	Hungary	Local	Warblers	Size, mass	Decline in mass (reed/marsh warblers)/increase in size (all sp.	Kovács et al. (2012)
Birds	Climate	Field mon	Norway	Local	2 bird sp.	Reproduction	Advanced egg laying (*Alle* sp.)/low clutch size and breeding success (*Rissa* sp.)	Moe et al. (2009)
Birds	Climate	Field mon	USA	Local	Bird sp.	Reproduction	Advanced clutch initiation dates	Lynch et al. (2012)
Birds	Climate		Scotland	Local	Red grouse	Reproduction	Advanced egg laying date	Fletcher et al. (2013)
Birds	Pollution	Field mon	Finland	Local	Great tits	Reproduction	Decrease in clutch size	Eeva and Lehikoinen (2013)
Birds	Pollution	Field mon	Finland	Local	Pied fly catcher	Reproduction	Reduced size/egg shell thickness/clutch size/hatching	Eeva and Lehikoinen (1995)
Birds	Pollution	Field mon	Finland	Local	Pied fly catcher	Size, mass	No clear relationship between pollution/size and mass	Eeva et al. (1997)
Birds	Pollution		Belgium	Local	Blue tits	Reproduction	No clear relationship	Dauwe et al. (2005)
Birds	Pollution	Field mon	Belgium	Local	Great tits	Reproduction	Reduced breeding performance	Jansens et al. (2003)
Birds	Pollution	Field mon	Finland	Local	Blue tits	Reproduction	Decreased clutch size/hatching in *Parus* sp.	Eeva et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Pollution	Field mon	Finland	Local	Bird sp.	Reproduction	Increased egg laying dates	Eeva and Lehikoinen (2010)
Birds	Pollution		Spain	Local	Bird sp.	Reproduction	Birds skipped breeding	Zabala et al. (2011)
Microorganisms	Climate	Field expt	Austria	Local	Microbes	Mass, tolerance	Increased stress tolerance biomarkers	Schindlbacher et al. (2011)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Mass	Decreased microbial biomass	Arnold et al. (1999)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Mass	No clear relationship between warming/mass	Zhang et al. (2005)
Microorganisms	Climate	Field expt	Finland	Local	Microbes	Mass	Reduction in microbial biomass	Rinnan et al. (2009)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Functional diversity	Reduction in functional genetic diversity	Castro et al. (2010)
Microorganisms	Climate	Field expt	China	Local	Microbes	Mass	No clear relationship between warming/mass	Zhang et al. (2013)
Microorganisms	Climate	Field expt	Switzerland	Local	Microbes	Mass	Reduced fungal biomass	Flury and Gessner (2011)
Microorganisms	Climate	Field expt	China	Local	Microbes	Mass	No clear relationship between warming/mass	Fu et al. (2012)
Microorganisms	Climate	Field expt	Sweden	Local	Microbes	Mass	Increased microbial biomass	Ruess et al. (1999)
Microorganisms	Climate	Field expt	Canada	Local	Microbes	Mass	Increased fungal biomass	Deslippe et al. (2011)
Microorganisms	Climate	Field expt	Denmark	Local	Microbes	Mass	Small effect on biomass	Özen et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Microorganisms	Climate	Field expt	Denmark	Local	Microbes	Mass	Increased biomass	Haugwitz et al. (2014)
Microorganisms	Climate	Field expt	Falklands/ Signy/Anchorage islands	Local	Microbes	Functional diversity	Increased generalist taxa	Yergeau et al. (2012)
Microorganisms	Climate	Field expt	Germany	Local	Microbes	Mass	Altered biomass	Poll et al. (2013)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Mass	Altered biomass	Frey et al. (2008)
Microorganisms	Climate	Field expt	China	Local	Microbes	Tolerance	Increased thermal stress	Chang et al. (2012)
Microorganisms	Climate	Field expt	Australia	Local	Microbes	Tolerance	Increased tolerance	Kantachote et al. (2001)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Tolerance	Increased tolerant taxa	Garcia-Pichel et al. (2013)
Microorganisms	Climate	Field expt	China	Local	Microbes	Mass	Decline in biomass	Wang et al. (2007)
Microorganisms	Climate	Field expt	Australia	Local	Microbes	Mass	No clear effect on biomass	Schindlbacher et al. (2012)
Microorganisms	Climate	Field expt	Netherlands	Local	Microbes	Mass	Increased biomass	Van Meeteren et al. (2008)
Microorganisms	Climate	Field expt	USA	Local	Microbes	Functional diversity	Decreased functional genetic diversity	Zogg et al. (1997)
Microorganisms	Pollution	Field expt	China	Local	Microbes	Tolerance, functional diversity	Increase in oil tolerant genes/decreased functional diversity	Liang et al. (2011)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Birds	Pollution	Field mon	Portugal	Local	Great tits	Reproduction	No direct effect of pollution	Costa et al. (2011)
Birds	Pollution	Field mon	USA	Local	Bird sp.	Other ecol	Negative effects on intertidal feeders	Day et al. (1997)
Birds	Climate	Field mon	Italy	Local	Crows	Size, mass	Increased body size/mass	Acquarone et al. (2004)
Birds	Climate	Field mon	Hungary	Local	Bird sp.	Reproduction	Advanced 1st arrival dates for generalist/multibrooded and less extensive pre-breeding molt sp.	Végvári et al. (2010)
Birds	Climate	Field mon	Germany	Local	Reed warblers	Reproduction	Advanced breeding/shortened breeding time window/clutch initiation. Change in breeding period	Schaefer et al. (2006)
Microorganisms	Climate	Field expt	Australia	Local	Microbes	Mass	Biomass increased	Fuchslueger et al. (2014)
Microorganisms	Climate	Field expt	China	Local	Microbes	Mass	Biomass decreased	Wu et al. (2010)
Microorganisms	Pollution	Field expt	China	Local	Microbes	Tolerance, functional diversity	Decrease in functional gene diversity/oil degradation genes	Liang et al. (2009)
Microorganisms	Pollution	Field expt	Austria	Local	Microbes	Mass	Decreased microbial biomass	Kandeler et al. (1996)
Microorganisms	Pollution	Field expt	Denmark	Local	Microbes	Mass,tolerance, functional diversity	Decreased biomass /functional diversity, increased tolerance	Müller et al. (2001)
Microorganisms	Pollution	Field expt	China	Local	Bacteria	Mass	Decreased biomass	Zhang et al. (2006)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Climate	Lab	UK	Local	Phytoplankton	Size, mass	Reduced size/biomass	Yvon-Durocher et al. (2011)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, reproduction	Advanced reproduction/size reduction	Winder et al. (2012)
Phytoplankton	Climate	Field mon	French	Local	Phytoplankton	Size	Little impact on size	Larroudé et al. (2013)
Phytoplankton	Climate	Field mon	Sweden	Local	Phytoplankton	Mass	Reduced biomass	Markensten (2006)
Phytoplankton	Climate	Field mon	USA	Local	Phytoplankton	Size	Decreased size	Winder et al. (2009)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Mass	Increased biomass	Sommer et al. (2012)
Phytoplankton	Climate	Lab	Argentina	Local	Pytoplankton	Mass, size	Decrease in size/increase in some sp. biomass	Halac et al. (2013)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Reproduction, mass, size	Decreased mass/size/ advanced spring bloom	Sommer and Lewandowska (2011)
Phytoplankton	Climate	Lab	UK	Local	Phytoplankton	Mass	Increased biomass/advanced phenology	Feuchtmayr et al. (2010)
Phytoplankton	Climate	Field mon	USA	Local	Phytoplankton	Size	Decrease in cell size	Finkel et al. (2005)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Decreased biomass/size	Sommer and Lengfellner (2008)
Phytoplankton	Climate	Field mon	Denmark	Local	Phytoplankton	Size	Decrease in size	Hilligsøe et al. (2011)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Reproduction	Advanced phytoplankton break up dates	Adrian et al. (2006)
Phytoplankton	Climate	Lab	Canada	Local	Phytoplankton	Mass	No clear effect on biomass	Strecker et al. (2004)
Phytoplankton	Climate	Lab	UK	Local	Phytoplankton	Mass	Limited effect on biomass	Moss et al. (2003)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Mass, size	Increased biomass (for small sized sp.)	Aberle et al. (2012)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Mass, tolerance	Increased biomass (cyanobacteria)/decline in biomass of diatoms with low tolerance	Wagner and Adrian (2011)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Mass	Biomass decreased/increased	Horn et al. (2011)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Increased biomass/decrease in size	Sommer et al. (2007)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size	Decrease in cell size	Peter and Sommer (2012)
Phytoplankton	Climate	Field mon	France	Local	Phytoplankton	Size, other biol	Decrease in size	David et al. (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Mass	Decreased biomass	Gaedke et al. (2010)
Phytoplankton	Climate	Field mon	Northwest pacific	Regional	Phytoplankton	Size	Reduced size	Ishida et al. (2009)
Phytoplankton	Climate	Field mon	Arctic ocean	Regional	Phytoplankton	Mass	Increased biomass	Kahru et al. (2011)
Phytoplankton	Climate	Lab	Austria	Local	Phytoplankton	Mass	Increased biomass (cyanobacteria)	Schabhuttl et al. (2013)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size	Reduced size	Peter and Sommer (2013)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Increased biomass/and increase or decrease in size	Aberle et al. (2007)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Mass	Increased biomass	Lewandowska et al. (2014)
Phytoplankton	Climate	Lab	Sweden	Local	Diatoms	Mass	Increased biomass	Torstensson et al. (2012)
Phytoplankton	Climate	Field mon	Denmark	Local	Phytoplankton	Mass	Increased biomass	Jeppesen et al. (2009)
Phytoplankton	Climate	Field mon	Baltic sea	Regional	Phytoplankton	Mass	Increased biomass	Jaanus et al. (2011)
Phytoplankton	Climate	Field mon	Canada	Local	Phytoplankton	Size	Decrease in size	Craig et al. (2013)
Phytoplankton	Climate	Field mon	Seas (e.g. Arabian)	Regional	Phytoplankton	Size	No clear effect	Maranón et al. (2012)
Phytoplankton	Climate	Lab	USA	Local	Algae	Mass	No clear response	Hargrave et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Climate	Field mon	North Atlantic	Regional	Phytoplankton	Mass	Decreased biomass	Oviatt (2004)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Decreased size/reduced biomass	Klauschies et al. (2012)
Phytoplankton	Climate	Field mon	Japan	Local	Phytoplankton	Mass	Increased biomass	Hsieh et al. (2011)
Phytoplankton	Climate	Field mon	UK	Local	Phytoplankton	Mass	Advanced spring biomass	Thackeray et al. (2008)
Phytoplankton	Climate	Lab	Spain	Local	Phytoplankton	Tolerance	Differences in tolerances/adaptation	Huertas et al. (2011)
Phytoplankton	Climate	Field mon	Global	Global	Phytoplankton	Size, mass	Decreased biomass of small sp.	Marinov et al. (2010)
Phytoplankton	Climate	Field	Spain	Local	Phytoplankton	Size	Decreased size	Morán et al. (2010)
Phytoplankton	Climate	mon	Canada	Local	Phytoplankton	Mass	Increased biomass	Findlay et al. (2001)
Phytoplankton	Climate	Lab	UK	Local	Phytoplankton	Mass	No clear effect	McKee et al. (2003)
Phytoplankton	Climate	Field mon	USA	Local	Phytoplankton	Size	Decrease in size	Polovina and Woodworth (2012)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Mass	Decrease in biomass	Lewandowska et al. (2012)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Reproduction	Advanced spring bloom	Peeters et al. (2007)
Phytoplankton	Climate	Lab	Brazil	Local	Phytoplankton	Mass	Increased biomass	Hennemann and Petrucio (2011)
Phytoplankton	Climate	Field mon	Sweden	Local	Phytoplankton	Tolerance, mass	Increased biomass for sensitive sp.	Weyhenmeyer (2001)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Climate	Field mon	Austria	Local	Phytoplankton	Mass	Decrease in biomass	Thies et al. (2012)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Reproduction, mass	Advanced blooming/increased biomass	Gerten and Adrian (2000)
Phytoplankton	Climate	Field mon	Germany	Local	Phytoplankton	Reproduction	Advanced blooming	Huber et al. (2008)
Phytoplankton	Climate	Field mon	North sea	Regional	Phytoplankton	Reproduction	Delayed blooming	Wiltshire and Manly (2004)
Phytoplankton	Climate	Lab	Netherlands	Local	Phytoplankton	Mass	Increased biomass (cyanobacteria)	Domis et al. (2007)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Reduced biomass/size	Lewandowska and Sommer (2010)
Phytoplankton	Climate	Field mon	Argentina	Local	Phytoplankton	Size, other biol	Decreased size (e.g. *Cyclotella* sp)/increased short lived diatoms	Guinder et al. (2010)
Phytoplankton	Climate	Field mon	North Baltic sea	Regional	Phytoplankton	Mass, size	Decreased cell size/increased biomass for some sp.	Suikkanen et al. (2013)
Phytoplankton	Climate	Lab	Germany	Local	Phytoplankton	Size, mass	Reduced biomass, size	Sommer et al. (2012)
Phytoplankton	Climate	Field mon	Global	Global	Phytoplankton	Size	Reduced size	Finkel et al. (2007)
Phytoplankton	Climate	Lab	Argentina	Local	Phytoplankton	Size, mass	Decreased size (diatoms)/biomass	Moreau et al. (2014)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Pollution	Field mon	Spain	Local	Phytoplankton	Mass	Increased biomass	Sebastiá and Rodilla (2013)
Phytoplankton	Pollution		Germany	Local	Phytoplankton	Mass	Increased biomass	Stich and Brinker (2010)
Phytoplankton	Pollution	Lab	India	Local	Phytoplankton	Mass	Increased biomass	Mochemadkar et al. (2013)
Phytoplankton	Pollution	Field mon	Hungary	Local	Phytoplankton	Functional diversity, mass	Reduced functional diversity/increased biomass	Pálffy et al. (2013)
Phytoplankton	Pollution	Field mon/ Lab	USA	Local	Phytoplankton	Size	Decreased size	Oviatt et al. (1989)
Phytoplankton	Pollution	Field mon	Spain	Regional	Phytoplankton	Mass	Decrease in biomass	Jordi et al. (2012)
Phytoplankton	Pollution	Field mon	Baltic sea	Regional	Phytoplankton	Mass	Increased biomass	Worm and Lotze (2006)
Phytoplankton	Pollution	Field mon	Brazil	Local	Phytoplankton	Mass	Increased biomass	Rangel et al. (2012)
Phytoplankton	Pollution	Field mon	England	Local	Phytoplankton	Mass	Increased biomass	Bowes et al. (2012)
Phytoplankton	Pollution	Field mon	USA	Local	Phytoplankton	Other ecol	Responses habitat specific	Passy (2007)
Phytoplankton	Pollution	Lab	French	Local	Phytoplankton	Mass	No clear effect	Seguin et al. (2001)
Phytoplankton	Pollution	Lab	Brazil	Local	Phytoplankton	Mass	Reduced biomass	Crossetti and Bicudo (2005)
Phytoplankton	Pollution	Field mon	Europe	Regional	Phytoplankton	Mass	Increased biomass	Lyche-Solheim et al. (2012)
Phytoplankton	Pollution	Lab	USA	Local	Phytoplankton	Mass	Increased biomass	Higlyey et al. (2001)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Pollution	Field mon	Spain	Local	Phytoplankton	Mass	Increased biomass	Carrillo et al. (2008)
Phytoplankton	Pollution	Lab	Norway	Local	Phytoplankton	Mass	No clear effect on biomass	Jacobsen et al. (1995)
Phytoplankton	Pollution	Lab	Tanzania	Local	Phytoplankton	Mass	No clear response	Hazenoot (2012)
Phytoplankton	Pollution	Field mon	Sweden	Local	Phytoplankton	Mass	No clear effect on biomass	Willén (1992)
Phytoplankton	Pollution	Field mon	Argentina	Local	Phytoplankton	Mass	Increased biomass	Devercelli and Peruchet (2008)
Phytoplankton	Pollution	Field mon	USA	Local	Phytoplankton	Mass	Increased biomass	Cottingham et al. (1998)
			Canada	Regional	Phytoplankton	Size, mass	Increased biomass/size	Ardyna et al. (2011)
			Korea	Local	Phytoplankton	Mass	Increased biomass	Jang et al. (2011)
			Portugal	Local	Phytoplankton	Mass	Reduced biomass	Oliveira (1985)
Phytoplankton	Pollution	Lab	French	Local	Phytoplankton	Other biol	Increased motile/low profile guilds and mucous tubules	Rimet and Bouchez (2011)
Phytoplankton	Pollution	Lab	USA	Local	Phytoplankton	Tolerance, size, other biol	Reduced sensitive sp. Increased small and chain forming diatoms	Sanders and Cibik (1988)
Phytoplankton	Pollution	Lab	Spain	Local	Phytoplankton	Mass	Increased biomass	Duarte et al. (2000)
Phytoplankton	Pollution	Lab	Denmark	Local	Phytoplankton	Mass	Increased biomass	Schlüter (1998)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Pollution	Field mon	Switzerland, France	Regional	Phytoplankton	Mass	No clear relationship	Anneville and Pelletier (2000)
Phytoplankton	Pollution	Field expt/Lab	Canada	Local	Phytoplankton	Mass	Decline in growth rate	Das et al. (2014)
Phytoplankton	Pollution	Lab	Australia	Local	Phytoplankton	Mass	Increased biomass	Muhid et al. (2013)
Phytoplankton	Pollution	Lab	USA	Local	Phytoplankton	Mass	Increased biomass	Cymbola et al. (2008)
Phytoplankton	Pollution	Field mon	Finland	Local	Phytoplankton	Mass	Increased biomass	Toming and Jaanus (2007)
Phytoplankton	Pollution	Field mon	Poland	Local	Phytoplankton	Mass	Increased biomass	Grabowska (2012)
Phytoplankton	Pollution	Lab	England	Local	Phytoplankton	Mass	No clear effect on biomass	Feuchtmayr et al. (2009)
Phytoplankton	Pollution	Field mon	India	Local	Phytoplankton	Mass, size	Increased mass of small sp.	Madhu et al. (2010)
Phytoplankton	Pollution	Field mon/expt	Taiwan	Local	Phytoplankton	Mass	Increased biomass	Wu and Chou (2003)
Phytoplankton	Pollution	Field	China	Local	Phytoplankton	Mass	Decreased biomass	Lie et al. (2011)
Phytoplankton	Pollution	mon	USA	Local	Phytoplankton	Size	Decreased size	Finkel et al. (2009)
Phytoplankton	Pollution	Field mon	France	Local	Phytoplankton	Reproduction, size, functional diversity	Increased small sp. without storage organs/sexual reproduction (low productivity)	Arthaud et al. (2012)
Phytoplankton	Pollution	Field mon	Australia	Local	Phytoplankton	Mass	Increased biomass	Catford et al. (2007)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Phytoplankton	Pollution	Lab	Canada	Local	Phytoplankton	Mass	Increased biomass	Davies and Bothwell (2012)
Phytoplankton	Pollution	Field mon	USA	Local	Phytoplankton	Mass	Increased biomass	Godfrey (1982)
Phytoplankton	Pollution	Lab	Argentina	Local	Phytoplankton	Mass	Increased biomass	Marcoval et al. (2008)
Phytoplankton	Pollution	Lab	Bering sea	Regional	Phytoplankton	Mass	Increased biomass	Strom and Fredrickson (2008)
Phytoplankton	Pollution	Field mon	France	Local	Phytoplankton	Mass	Increased/decreased biomass	Pesce et al. (2008)
Phytoplankton	Pollution	Lab	Canada	Local	Phytoplankton	Mass	No clear effect	Baxter et al. (2013)
Phytoplankton	Pollution	Field mon	Australia	Local	Phytoplankton	Mass	Increased biomass	Burford et al. (2012)
Phytoplankton	Pollution	Field mon	France	Local	Phytoplankton	Size, other biol/ecol	Increased low/high profile guilds at low pollution levels	Berthon et al. (2011)
Phytoplankton	Pollution	Field mon	Spain	Local	Phytoplankton	Functional diversity, mass	Increased biomass/C and S strategists sp. depending on eutrophication	Caputo et al. (2008)
Phytoplankton	Pollution	Field mon	Argentina	Local	Phytoplankton	Mass	Decreased biomass	Fernández et al. (2011)
Aquatic invertebrates	Climate	Field mon	Taiwan	Local	Aquatic invertebrates	Tolerance, size, mass, other ecol/biol	Increase in tolerant taxa with slow growth/large size	Chiu and Kuo (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Climate	Field mon	Iceland	Local	Aquatic invertebrates	Functional diversity	Increased filter-feeders mainly	Friberg et al. (2009)
	Climate	Field mon	Italy	Local	Aquatic invertebrates	Functional diversity, size, reproduction, dispersal, other biol/ecol	Increase in collectors, decrease in scrapers/shredders, increase in small fast growing crawlers reproducing severally	Fenoglio et al. (2007)
	Climate	Field mon	Europe	Regional	Diving beetles	Tolerance	Widespread sp. most thermal tolerant	Calosi et al. (2008)
Aquatic invertebrates	Climate	Field mon	Serbia	Local	Aquatic invertebrates	Tolerance	Reduction in sensitive taxa	Živić et al. (2014)
Aquatic invertebrates	Climate	Field mon	Europe	Local	Aquatic invertebrates	Tolerance, Other ecol	Reduced sensitive sp./habitat loss for endemic sp.	Domisch et al. (2013)
Aquatic invertebrates	Climate	Field mon	Global	Global	Aquatic invertebrates	Size, dispersal, tolerance, other biol/ecol	Increased body size/lower specialised body shape and mobility, sensitivity	Milner et al. (2009)
			Australia	Local	Aquatic invertebrates	Other ecol, tolerance	Increased in taxa tolerant to high temperature/preferring low flow	Chessman (2012)
			Spain	Local	Aquatic invertebrates	Tolerance, other ecol	Reduced flow sensitive sp.	Belmar et al. (2013)
			Portugal	Local	Amphipods	Tolerance	Reduced sensitive sp.	Guerra et al. (2014)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Climate	Field mon	USA	Local	Aquatic invertebrates	Functional diversity,Tolerance	Decrease in sensitive sp.	Milner et al. (2011)
	Climate	Lab	USA	Local	Ephemeropterans	Mass, size	Increased size, mass	Scherr et al. (2010)
	Climate	Lab	UK	Local	Aquatic invertebrates	Mass, size	Decreased biomass/size	Dossena et al. (2012)
	Climate	Field	Korea	Local	Aquatic	Tolerance	Reduction in sensitive sp.	Li et al. (2013)
	Climate	mon	Korea	Local	invertebrates	Tolerance	Reduction in sensitive sp.	Li et al. (2014)
	Climate		Sweden	Local	Aquatic invertebrates	Tolerance, other ecol/biol	Reduced sensitive sp.	Sandin et al. (2014)
	Climate	Field mon	UK	Local	Aquatic invertebrates	Reproduction, mass, size, functional diversity	Reduced size, mass/fast growing sp., reduced predators/herbivores	Ledger et al. (2013)
	Climate	Field mon	UK	Local	Aquatic invertebrates	Reproduction, mass, functional diversity, size	Reduced biomass/shredders and predators. Increase in fast reproducing and small sp.	Ledger et al. (2011)
	Pollution	Field mon	Czech	Local	Aquatic invertebrates	Other ecol, tolerance	Increase in taxa that prefer pelal habitat/filterers and gatherers	Brabec et al. (2004)
	Climate		French	Local	Aquatic invertebrates	Tolerance	Reduced sensitive sp.	Brown et al. (2007)
	Climate	Field mon	South africa	Local	Aquatic invertebrates	Tolerance	Specialist had wide temperature range	Eady et al. (2013)
	Climate	Field mon	New Guinea	Local	Aquatic invertebrates	Dispersal, tolerance	Reduced sensitive and mobile sp	Fabricius et al. (2014)
	Pollution	Field mon	Czech	Local	Aquatic invertebrates	Functional diversity, tolerance	Reduced sensitive sp. /increased mud dwellers	Orendt et al. (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Climate	Field mon	USA	Local	Aquatic invertebrates	Size, other biol, functional diversity, tolerance	Reduced body size/sp. with long life span	Lawrence et al. (2010)
Aquatic invertebrates	Climate	Field mon	USA	Local	Aquatic invertebrates	Reproduction, tolerance, dispersal, other ecol/biol	Increased multivoltinism, cool/warm eurythermal, depositional obligates, burrowers, high drift	Poff et al. (2010)
Aquatic invertebrates	Climate	Field mon	Spain	Local	Aquatic invertebrates	Size, reproductive, dispersal, tolerance, other ecol/biol	Differences in body size, dispersal capacity, respiration and feeding mode, life cycles	Bonada et al. (2007)
Aquatic invertebrates	Climate	Field expt	Canada	Local	Aquatic invertebrates	Reproduction, size, mass	Earlier emergence, increased growth rates/ breeding/ reduced size	Hogg and Williams (1996)
	Climate	Field expt	Canada	Local	Aquatic invertebrates	Reproduction, size	Altered reproduction, size	Hogg et al. (1995)
	Climate	Field mo	Australia	Local	Aquatic invertebrates	Other Ecol, tolerance	Decrease in sensitive sp.	Chessman (2009)
	Climate	Field mon	Europe	Regional	Aquatic invertebrates	Other ecol, tolerance	Loss of taxa that prefer fast/cold waters	Floury et al. (2013)
	Climate	Field mon	USA	Local	Aquatic invertebrates	Dispersal, other ecol/biol, tolerance, size, reproduction,	Increase in sp. with resilient traits/short life cycles/resistant/small sized	Griswold et al. (2008)
	Climate	Field mon	Germany	Local	Aquatic invertebrates	Reproduction	Earlier emergence	Adrian et al. (2006)
	Climate	Field mon	USA	Local	Aquatic invertebrates	Dispersal, other ecol, reproduction, tolerance	Reduced dispersal, temperature sensitive sp./sprawling habit and univoltine life cycle	Brown and Milner (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Climate	Field mon	Italy, France	Local	Aquatic invertebrates	Tolerance	Reduction of sensitive taxa	Khamis et al. (2014)
	Climate	Field mon	USA	Local		Tolerance, mass, reproduction	Less sensitive taxa. Influence on growth rate and reproduction	Hawkins et al. (1997)
	Climate	Field mon	USA	Local		Other ecol, tolerance	Reduction of sensitive sp.	Stamp et al. (2010)
	Climate		USA	Local		Other ecol	Increase in taxa preferring low flow during drought condition	Bêche and Resh (2007)
	Climate		Australia	Local		Tolerance	Reduced sensitive sp.	Boulton (2003)
	Climate	Lab	UK	Local		Tolerance	Reduction of sensitive taxa	Verberk and Bilton (2013)
	Climate	Field mon	China	Local		Tolerance	Reduction of sensitive sp.	Li et al. (2012)
	Pollution	Field mon	Portugal	Local		Functional diversity, tolerance	Reduced sensitive sp./increased filter-feeders	Cabral-Oliveira et al. (2014)
	Pollution	Field mon	France	Local		Size, tolerance, other ecol/biol, reproduction, dispersal	Responses in traits such as reproduction, lifecycles, feeding groups, dispersal, locomotion, size, tolerance, dispersal etc	Ducrot et al. (2005)
	Pollution	Field mon	Germany	Local	Aquatic invertebrates	Reproduction, dispersal, tolerance	Decrease in sensitive sp.	Bunzel et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Pollution	Field mon	Denmark	Local	Aquatic invertebrates	Reproduction, dispersal, tolerance	Decrease in sensitive sp. based on Species At Risk Index (SPEAR)	Rasmussen et al. (2013)
	Pollution	Field mon	USA	Local	Aquatic invertebrates	Tolerance	Reduction in sensitive sp.	Clements et al. (2000)
	Pollution	Field mon	USA	Local	Aquatic invertebrates	Tolerance, mass, size, functional diversity	Increased biomass of tolerant and small sp./collectors	Woodcock and Huryn (2007)
	Pollution	Field mon	USA	Local	Aquatic invertebrates	Tolerance	Reduction in sensitive sp.	Bazinet et al. (2010)
	Pollution	Field mon	UK	Local	Aquatic invertebrates	Tolerance	Reduction of sensitive sp.	Beasley and Kneale (1999)
	Pollution	Field mon	USA	Local	Aquatic invertebrates	Tolerance, functional diversity	Increase in tolerant taxa/deposit feeders	Pelletier et al. (2010)
	Pollution	Field mon	Sweden	Local	Aquatic invertebrates	Size, reproduction, functional diversity, other biol	Altered size, reproduction, functional diversity	Petrin (2011)
	Pollution	Field mon	USA	Local	Aquatic invertebrates	Tolerance, functional diversity	Altered tolerance and functional diversity	Mccormick et al. (2004)
	Pollution	Field mon	South Africa	Local	Aquatic invertebrates	Tolerance	Increased tolerant taxa	Selala et al. (2013)
	Pollution	Field mon, lab	Siberia, Australia, Europe	Regional	Aquatic invertebrates	Reproduction, dispersal, tolerance	Reduction in sensitive sp.	Schäfer et al. (2012)
	Pollution	Lab	Germany	Local	Aquatic invertebrates	Reproduction, tolerance	Semi and univoltine species most affected	Beketov et al. (2008)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Pollution	Field mon	Australia	Local	Aquatic invertebrates	Tolerance	Increased tolerance	Sloane and Norris (2003)
	Pollution	Field mon	China	Local		Dispersal, functional diversity	Increased motile deposit feeders/omnivores	Cheung et al. (2008)
	Pollution	Field mon	Spain	Local		Tolerance	Decrease in sensitive sp.	Solà et al. (2004)
	Pollution	Field mon	Germany	Local		Reproduction, dispersal, tolerance	SPEAR indicated a reduction in sensitive sp.	Bunzel et al. (2014)
	Pollution	Field mon	Denmark	Local		Reproduction, dispersal, tolerance	SPEAR values low in polluted areas	Rasmussen et al. (2012)
	Pollution	Field mon	Finland, Germany France	Regional		Reproduction, dispersal, tolerance	Increase in mobile species with short generation times (i.e. species not at risk)	Beketov et al. (2009)
	Pollution	Field mon	Finland/France	Regional		Reproduction, dispersal, tolerance	SPEAR indicated a reduction in sensitive species in polluted streams	Schäfer et al. (2007)
	Pollution	Lab	USA	Local		Tolerance	Cadmium uptake and elimination correlated with bioaccumulation	Buchwalter et al. (2008)
	Pollution	Lab	Germany	Local		Tolerance, reproduction	Multivoltine sensitive taxa affected by toxicants at lower concentrations	Liess and Beketov (2011)
	Pollution	Lab	Russia	Local		Tolerance	Decline in sensitive species	Beketov and Liess (2008)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Aquatic invertebrates	Pollution	Field mon	France	Local	Aquatic invertebrates	Size, reproduction, other biol/ecol, dispersal, tolerance	Increase in body size, transverse distribution, sediment preferences, saprobity, temperature, resistance forms and high dispersal forms	Colas et al. (2013b)
	Pollution	Field mon	France	Local		Size, reproduction, other biol/ecol, dispersal, tolerance	Response traits included large body size, several generations/year, asexual reproduction and high drift	Colas et al. (2013a)
	Pollution	Lab	Italy	Local		Size, reproduction, other biol/ecol, tolerance	Behavioural complexity, body length and shape responded to toxicants	Ippolito et al. (2012)
	Pollution	Field mon	France	Local		Reproduction, dispersal, tolerance, other ecol, size	Polyvoltine/ovoviviparous taxa detected toxicants	Mondy et al. (2013)
	Pollution	Field mon	Europe	Regional		Reproduction, dispersal, tolerance	SPEAR correlated negatively with toxic stress. Sensitive taxa had low mobility, long generation times	Liess and Von der Ohe (2005)
	Pollution	Field mon	Australia	Local		Reproduction, other biol/ecol, tolerance, dispersal	SPEARsalinity index correlated strongly to salinity	Schäfer et al. (2011)
	Pollution	Field mon	France	Local		Size, reproduction, other biol/ecol, dispersal, tolerance	Reproduction types, life duration and life forms detected pollution	Péru and Dolédec (2010)
Fish	Climate	Field mon	Europe	Regional	Fish	Reproduction, other biol/ecol	Reproduction traits of sp. with specific habitat requirements most affected. Life stage determined response of Norwegian cod and Biscay anchovy	Petitgas et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Climate	Field mon	France	Local	Fish	Tolerance	Decrease in sensitive species	Buisson et al. (2008)
Fish	Climate	Field mon	North sea	Regional	Fish	Size, reproduction	Shift in boundary of fish with faster reproduction and small size	Perry et al. (2005)
Fish	Climate	Field mon	Portugal	Local	Fish	Tolerance	Reduction in sensitive taxa	Teixeira et al. (2014)
Fish	Climate	Field mon	North west pacific	Regional	Fish	Tolerance	Shift in distribution of temperature tolerant species	Okunishi et al. (2012)
Fish	Climate	Field mon	Atlantic Ocean	Regional	Fish	Tolerance	Increase tolerant sp.	Ter Hofstede et al. (2010)
Fish	Pollution	Field mon	China	Local	5 fish species	Functional diversity	Omnivorous fishes had highest metal concentrations	Cheng et al. (2013)
Fish	Climate	Field mon	USA	Local	Fish	Mass, tolerance	Increased biomass and reduction of sensitive sp.	Al-Chokhachy et al. (2013)
Fish	Climate	Field mon	USA	Local	Fish	Mass, size	Altered size, mass	Ries and Perry (1995)
Fish	Climate	Lab	Belgium	Local	*Cottus* sp.	Reproduction	Advanced reproduction/negative effects at high temperature	Dorts et al. (2012)
Fish	Climate	Field mon	Europe	Regional	Fish	Size, mass, tolerance	Increase in tolerant sp. Decrease in size and biomass	Jeppesen et al. (2012)
Fish	Climate	Field mon	North Atlantic	Regional	Fish	Size, tolerance, functional diversity, reproduction	Reduction of small fish. Response in benthivores, reproduction	Rose (2005)
Fish	Climate	Field mon	Germany	Local	Fish	Tolerance, mass	Reduction of biomass	Busch et al. (2012)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Climate	Lab	USA	Local	Fish	Tolerance, mass, size	Biomass and size increase and shift to cooler waters	Sogard and Olla (2001)
Fish	Climate	Field mon	USA	Local	Fish	Tolerance	Increase in tolerant sp.	Jones et al. (2013)
Fish	Climate	Field mon	USA	Local	Fish	Tolerance	Distributional shift to cool and deeper waters for sensitive sp.	Sharma et al. (2011)
Fish	Climate		Bohai Sea	Regional	Fish	Size	Increase in small fish	Jin (2004)
Fish	Climate		USA	Local	Fish	Tolerance	Tolerant sp. increased	Lyons et al. (2010)
Fish	Climate	Field mon/ expt	Global	Global	Fish	Size, functional diversity, mass, reproduction	Reduced body size/increased mass and diversity and shorter reproduction spans	Meerhoff et al. (2012)
Fish	Climate	Field mon	USA	Local	Fish	Size, mass	Size decrease /biomass increase	Carey and Zimmerman (2014)
Fish	Climate	Lab	Australia	Local	Fish	Mass, reproduction, size	Increased reproduction	Miller et al. (2013)
Fish	Climate	Lab	North coast of Sicily	Regional	Fish	Tolerance	Dominance of tolerant species	Milazzo et al. (2013)
Fish	Climate	Lab	Great barrier reef	Regional	Fish	Size, tolerance, mass	Smaller fish more tolerant and had lower mass	Donelson et al. (2011)
Fish	Climate	Field mon	North sea	Regional	Fish	Tolerance	Effect of thermal regime not clear	Neat and Righton (2007)
Fish			East sea			Tolerance	Reduction of cold water taxa	Jung (2014)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Climate	Field mon	Denmark Uruguay	Regional	Fish	Decreased biomass/size	Decreased biomass/size	Teixeira-de Mello et al. (2012)
Fish	Climate	Field mon	Laurentian great lakes	Regional	Fish	Tolerance	Northerly shift in cold water sp.	Lynch et al. (2010)
Fish	Climate	Field mon	Global	Global	Fish	Tolerance	Reduction in cold water sp. and contraction/expansion for habitats for warm water sp.	Comte et al. (2013)
Fish	Climate	Field mon	North Atlantic	Regional	Fish	Reproduction, mass	Reduction in northerly sites and biomass increase	Drinkwater (2005)
Fish	Climate	Lab	Australia	Local	Fish	Tolerance	Reduction in sensitive sp.	Munday et al. (2009)
Fish	Climate	Field mon	Global	Global	Fish	Mass	Both increase and decrease in biomass	Sherman et al. (2009)
Fish	Climate	Field mon	Russia and Estonia	Regional	Fish	Tolerance, functional diversity	Decrease in cold water sp. and benthivores	Kangur et al. (2013)
Fish	Climate		French	Local	Fish	Size	Decrease in size	Edeline et al. (2013)
Fish	Climate		Finland	Local	Fish	Tolerance	Dominance of Arctic charr in areas of low temperature	Lehtonen (1998)
Fish	Climate		Persian gulf	Regional	Fish	Size, diversity, mass	Decrease in size, herbivorous fish. Increased biomass	Feary et al. (2010)
Fish	Climate		North Atlantic	Regional	Fish	Mass, tolerance	Increased growth rates/wide tolerances	Righton et al. (2010)
Fish	Climate		Great reef barrier	Regional	Fish	Reproduction	Reduced breeding and production of small eggs at high temperature	Donelson et al. (2010)
Fish	Climate		USA	Local	Fish	Tolerance	Increase in tolerant taxa	Hsieh et al. (2009)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Climate	Field mon,lab	Japan	Local	Fish	Size, mass	Increased growth rate	Shoji et al. (2011)
Fish	Climate	Field mon	UK	Local	Fish	Size, other ecol	Decrease in size, low and mid trophic ecotypes. Decline in large sized/high trophic level ecotypes and pelagic sp.	Engelhard et al. (2011)
Fish	Climate		France	Local	Fish	Size	Decline in body size	Daufresne et al. (2009)
Fish	Climate		North America	Local	Fish	Tolerance	Increase in tolerant sp.	Cline et al. (2013)
Fish	Climate		Australia	Local	Fish	Tolerance	Reduction in sensitive sp.	Morrongiello et al. (2011)
Fish	Climate		USA	Local	Fish	Tolerance, other ecol	Reduction in habitat for fish with less tolerance	Eaton and Scheller (1996)
Fish	Climate		Australia	Local	Fish	Reproduction	Influence on fish reproduction	Pankhurst and Munday (2011)
Fish	Climate		Europe	Regional	Fish	Reproduction, tolerance, other ecol	Decline in habitat specialists, rheophiles, with broad tolerance to flow	Logez and Pont (2012)
Fish	Climate		UK	Local	Fish	Size	Decreased size	Genner et al. (2010)
Fish	Climate		UK	Local	Fish	Size, other ecol	Shifts in distribution of cold and warm water fishes varying in size and habitat preferences	Dulvy et al. (2008)
Fish	Climate		North sea	Regional	Fish	Reproduction	Northerly shift in distribution of spawners	Rindorf and Lewy (2006)
Fish	Climate	Lab	Portugal	Local	Fish	Tolerance, mass	Reduction of sensitive young fish and biomass	Vinagre et al. (2013)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Climate	Field mon	Australia	Local	Fish	Size, reproduction, other biol/ecol, tolerance	Reduction in invertivorous feeders, large size taxa, low fecundity and demersal eggs and less tolerant sp.	Chessman (2013)
Fish	Climate	Field mon	Japan	Local	Fish	Size, mass	Increased growth rate	Shoji et al. (2011)
Fish	Pollution		Brazil	Local	3 fish species	Functional diversity	Predators had highest heavy metals followed by omnivores, generalists	Terra et al. (2008)
Fish	Pollution		Australia	Local	Fish	Size	Positive and negative effects on body size	McKinley et al. (2012)
Fish	Pollution		Slovakia	Local	Fish	Functional diversity, mass	High concentrations in carnivores, detritivores. Small effect on biomass	Brázová et al. (2012)
Fish	Pollution		Spain	Local	6 fish species	Size	Negative relationship between metals and body size	Merciai et al. (2014)
Fish	Pollution		China	Local	7 fish species	Mass, size, functional diversity	Concentrations highest in carnivores and correlated to size, mass	Zhu et al. (2012)
Fish	Pollution		China	Local	Fish	Size	Positive correlation between metals and size in many cases	Yi and Zhang (2012)
Fish	Pollution		Finland, Norway, Russia	Regional	Fish	Functional diversity, size, mass	High metal concentrations in planktivores and benthivores. Reduction in size and biomass	Amundsen et al. (2011)
Fish	Pollution		India	Local	Fish	Size	Positive correlation between body size and metals	Pal et al. (2012)
Fish	Pollution		Brazil	Local	Fish	Mass, functional diversity	Carnivores had highest metal concentrations	Kehrig and Malm (1999)

Table A.2: Continued

Organism	Stressor	Study	Location	Scale	Species	Traits	Traits response	Reference
Fish	Pollution	Field mon	Portugal	Local	Fish	Functional diversity, size	High accumulations in detritivores. Positive effect on body size	Fernandes et al. (2008)
Fish	Pollution		Netherlands	Local	Fish	Tolerance	No clear relationship between tolerance and distribution of invasive sp.	Fedorenkova et al. (2013)
Fish	Pollution		Canada	Local	Fish	Reproduction	Increased testicular asymmetry, sperm with short heads and fewer live eggs	Sopinka et al. (2012)
Fish	Pollution		USA	Local	Fish	Size, other ecol	Body size and trophic guild best descriptors of mercuric contamination	Walters et al. (2010)

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APPENDIX B

Supplementary information for: Effect of Small Impoundments on Leaf Litter Decomposition in Streams

B.1 Supplementary Table

Table B.1: Location and physico-chemical characteristics of each site of the 9 studied forest streams. n.d, not detected.

	Rambach				**Eisbach**				**Ruthenbach**			
Latitude, N	49º27.4´27´´				49º23´84´´				49º23´08´´			
Longitude, E	8º00´27´´				7º99´01´´				7º98´43´´			
Altitude (m)	328				269				261			
Discharge ($m^3 s^{-1}$)	1.1				6.4				2.0			
Reservoir volume (m^3)	84				273				380			
Height (m)	1.4				2.3				2.0			
Water residence time (min)	1.3				0.7				3.2			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Depth (cm)	10	10	6	8	5	3	4	4	2	2	2	96
Forest (%)	100	100	100	100	100	100	100	100	100	100	100	100
Water temperature (ºC)	9	10	9	9	10	14	11	14	12	13	13	12
Velocity ($m s^{-1}$)	0.2	0.3	0.2	0.8	0.4	0.4	0.6	0.5	0.1	0.4	0.3	0.3
Nitrates ($mg L^{-1}$)	1	0	0.5	3	5	3	0.5	3	0	3	3	3
Phosphates ($mg L^{-1}$)	0.05	0.05	0.07	0.075	0.05	0.07	0.1	0.07	0.1	0.05	0.05	0
Conductivity ($\mu S cm^{-1}$)	135	134	116	135	454	436	452	437	431	417	430	424
Oxygen concentration ($mg L^{-1}$)	11	11	11	11	10	9	10	9	9	9	9	10
Embeddedness (%)	70	25	10	10	50	50	50	5	70	60	70	70
Canopy cover (%)	0	20	0	0	65	80	35	45	35	45	60	65

Table B.1: Continued

	Rambach				Eisbach				Ruthenbach			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Embeddedness (%)	70	25	10	10	50	50	50	5	70	60	70	70
Bedrock (500 mm) (%)	0	0	0	0	0	0	0	0	0	0	0	0
Boulders (250 mm) (%)	0	0	0	0	0	0	0	0	0	0	0	0
Cobbles (60-250 mm) (%)	0	2	5	10	2	15	5	0	0	5	5	0
Gravel (10-64 mm) (%)	10	10	20	30	10	20	30	25	5	20	10	3
Fine gravel (2-10 mm) (%)	20	15	25	30	40	30	25	40	30	30	15	3
Clay/silt/sand (< 0.06 mm) (%)	65	60	45	30	48	20	40	35	65	25	70	4
Coarse organic matter (%)	5	13	5	0	0	15	0	0	0	20	0	0
Riffle (%)	40	90	50	100	70	60	80	100	10	15	20	50
Pool (%)	60	10	50	0	30	40	20	0	90	85	80	50

FU and FD, further upstream and further downstream; IU and ID, immediate upstream and immediate downstream.

Table B.1: Continued

	Dernbach				**Modenbach**				**Kaltenbach**			
Latitude, N	49º22´94´´				49º24´04´´				49º24´64´´			
Longitude, E	8º01´10´´				7º87´69´´				7º88´14´´			
Discharge ($m^3 s^{-1}$)	n.d				9.4				4.8			
Reservoir volume (m^3)	330				299				720			
Altitude (m)	255				303				275			
Height (m)	2.5				1.7				2.4			
Water residence time (min)	n.d				0.5				2.5			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Width (cm)	73	86	106	66	183	220	160	170	346	210	215	213
Depth (cm)	2	5	2	3	5	14	37	12	16	21	19	14
Forest (%)	100	100	100	100	100	100	100	100	100	100	100	100
Water temperature (ºC)	9	11	9	11	7	7	7	7	8	7	7	8
Velocity ($m s^{-1}$)	n.d	0.2	n.d	0.4	0.5	0.4	0.7	0.5	0.2	0.5	0.8	1
Nitrates ($mg L^{-1}$)	0.5	0.0	0	0.0	1.0	3.0	3.0	3	3.0	1.0	1.0	3
Phosphates ($mg L^{-1}$)	0.2	0.0	0	0.05	0.3	0.1	0.1	0	0.05	0.05	0.05	0
Conductivity ($\mu S cm^{-1}$)	352	254	371	255	61	61	61	61	57	57	57	59
Oxygen concentration ($mg L^{-1}$)	10	9	10	9	11	11	11	11	11	11	11	11
Embeddedness (%)	70	20	80	10	90	25	40	15	80	5	10	2
Bedrock (500 mm) (%)	0	0	0	0	1	5	0	5	9	0	2	5
Boulders (250 mm) (%)	0	0	0	0	1	5	5	7	10	8	10	5
Cobbles (60-250 mm) (%)	0	10	0	25	1	5	10	15	5	30	20	1
Gravel (10-64 mm) (%)	10	15	0	25	2	50	5	30	2	30	45	5
Fine gravel (2-10 mm) (%)	35	30	20	30	2	10	5	16	4.0	5	10	5
Clay/silt/sand (< 0.06 mm) (%)	35	20	40	20	60	15	40	10	40	20	10	10
Coarse organic matter (%)	20	25	40	0	33	10	35	17	30	7	3	10
Canopy cover (%)	65	60	75	60	10	80	30	30	50	60	10	8
Riffle (%)	30	35	0	50	55	85	85	90	20	90	90	100
Pool (%)	70	65	70	50	45	15	15	10	80	10	10	0

Table B.1: Continued

	Eiderbach				**Flachsbach**				**Wellsbach**			
Latitude, N	49º26´78´´				49º28´45´´				49º28´74´´			
Longitude, E	7º86´64´´				7º85´68´´				7º86´94´´			
Discharge ($m^3 s^{-1}$)	n.d				10.5				4.1			
Reservoir volume (m^3)	99				704				324			
Altitude (m)	328				269				261			
Height (m)	1.1				2.2				1.5			
Water residence time (min)	n.d				1.1				1.3			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Width (cm)	313	78	26	166	136	160	156	140	133	150	126	135
Depth (cm)	7	10	7	13	12	21	11	17	17	14	7	13.0
Forest (%)	100	100	100	100	100	100	100	100	100	100	100	100
Water temperature (ºC)	10	7	9	8	9	8	9	8	9	10	9	10
Velocity ($m s^{-1}$)	n.d	0.7	0.4	0.07	0.3	0.2	0.7	0.2	0.3	0.4	0.5	0.3
Nitrates ($mg L^{-1}$)	5	3	3	1	0.5	3	1	3	5	3	1.5	2
Phosphates ($mg L^{-1}$)	0.1	0.1	0.0	0.05	0.08	0.08	0.0	0.0	0.0	0.1	0.05	0.05
Conductivity ($\mu S cm^{-1}$)	59	62	60	60	61	60	59	59	136	124	143	125
Oxygen concentration ($mg L^{-1}$)	10	11	8	11	10	10	10	10	10	10	10	10
Embeddedness (%)	90	50	50	10	60	70	5	10	75	90	10	80
Bedrock (500 mm) (%)	0	2	0	0	5	0	2	0	0	1	20	8
Boulders (250 mm) (%)	0	2.0	0	5	2	0.0	5	1	0	1	10	2
Cobbles (60-250 mm) (%)	0	5.0	0	1	1	2	8	2	0	2	15	10
Gravel (10-64 mm) (%)	0	10	0	2	5	8	25	10	0	5	15	20
Fine gravel (2-10 mm) (%)	0	8	0	2	25	8	25	30	0	50	5	5
Clay/silt/sand (< 0.06 mm) (%)	40	30	20	10	62	72	35	57	80	38	30	55
Coarse organic matter (%)	60	43	80	80	0	10	0	0	20	3	5	0
Canopy cover (%)	0	50	0	50	25	2	5	0	70	25	75	25
Riffle (%)	10	30	100	90	50	50	100	100	10	80	90	80
Pool (%)	90	70	0	10	50	50	0	0	90	20	10	20

APPENDIX C

Supplementary information for: Macroinvertebrate Functional Feeding Group Ratios Reveal Local impacts of small impoundments on stream ecosystem Attributes

C.1 Supplementary Figure

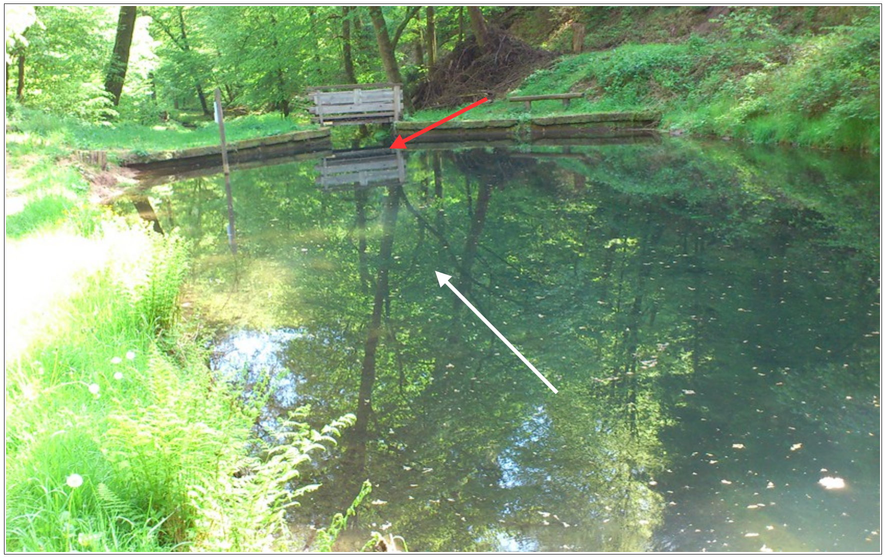

Figure C.1: Example of a small impoundment that impounded one of the studied streams. The white arrow shows the direction of water movement, and the red arrow shows surface-water release to the downstream reach. An immediate upstream area flooded by dam is shown.

C.2 Supplementary Table

Table C.1: Physical characteristics and location of the studied impoundments.

	Rambach				**Eischbach**				**Ruthenbach**			
Latitude, N	49º27.4´27´´				49º23´84´´				49º23´08´´			
Longitude, E	8º00´27´´				7º99´01´´				7º98´43´´			
Discharge (m^3 s^{-1})	1.1				6.4				2.0			
Reservoir volume (m^3)	84				273				380			
Height (m)	1.4				2.3				2.0			
Water residence time (min)	1.3				0.7				3.2			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Width (cm)	110	116	123	93	113	160	113	136	56	90	83	2
	Dernbach				**Modenbach**				**Kaltenbach**			
Latitude, N	49º22´94´´				49º24´04´´				49º24´64´´			
Longitude, E	8º01´10´´				7º87´69´´				7º88´14´´			
Discharge (m^3 s^{-1})	n.d				9.4				4.8			
Reservoir volume (m^3)	330				299				720			
Height (m)	2.5				1.7				2.4			
Water residence time (min)	n.d				0.5				2.5			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Width (cm)	73	86	106	66	183	220	160	170	346	210	215	213
	Eiderbach				**Flachsbach**				**Wellsbach**			
Latitude, N	49º26´78´´				49º28´45´´				49º28´74´´			
Longitude, E	7º86´64´´				7º85´68´´				7º86´94´´			
Discharge (m^3 s^{-1})	n.d				10.5				4.1			
Reservoir volume (m^3)	99				704				324			
Height (m)	1.1				2.2				1.5			
Water residence time (min)	n.d				1.1				1.3			
Site code	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**	**IU**	**ID**	**FU**	**FD**
Width (cm)	313	78	26	166	136	160	156	140	133	150	126	135

FU and FD, further upstream and further downstream; IU and ID, immediate upstream and immediate downstream; n.d, not detected.

APPENDIX D

Supplementary information for: Methane Derived Carbon in the Benthic Food web in Stream Impoundments

D.1 Supplementary Tables

Table D.1: Environmental characteristics recorded from the studied impoundments. n.d = not detected.

Impoundment name	**Code**	**pH**	**Discharge (m^3 s^{-1})**	**O_2 (mg L^{-1})**	**Water residence time (min)**	**Temperature (ºC)**	**Conductivity (μS cm^{-1})**	**NO^{-3} (mg L^{-1})**	**PO^{-4} (mg L^{-1})**
Germersheim	1	7.7	7.8	9.4	0.10	15.3	329	5.0	0.2
Fuchsbach	2	6.9	0.5	8.8	0.63	18.6	376	5.0	0.3
Godramstein	3	7.5	2.6	9.6	0.50	13.0	234	3.5	0.2
Siebeldingen	4	7.7	0.9	11.9	5.00	13.8	229	5.0	0.3
Albersweiler pfalz	5	7.4	1.4	11.6	0.66	13.1	191	4.5	0.2
Rosenfeldt Mill	6	7.5	2.2	11.3	0.41	15.5	267	5.0	0.2
Eußerbach	7	7.2	0.1	11.9	0.83	10.2	81	5.0	0.1
Eisbach	8	7.8	n.d	10.2	n.d	17.4	380	5.0	0.3
Annweiler AmTrifels	9	7.2	1.6	10.7	0.66	14.0	234	5.0	0.3
Langenbächel	10	7.0	n.d	8.5	n.d	15.4	89	3.5	0.1
Modenbach	11	6.4	1.6	11.7	5.83	13.1	61	5.0	0.

Table D.2: δ^{13}C values (‰) of chironomid larvae from the studied impoundments. For each of the impoundments, between 1 and 9 replicates (*n*) were made from pooled samples. S.D, standard deviation; min and max, minimum and maximum values.

Impoundment	Code	Species and instar (by size)	n	Mean	S.D.	Min	Max
Germersheim	1	Chironomini 4th instar	3	–26.9	0.48	–26.4	–27.3
		Chironomini 3rd instar	3	–26.6	0.16	–26.4	–26.7
		Tanypodinae 4th instar	1	–26.3			
Fuchsbach	2	Chironomini 4th instar	1	–27.7			
		Chironomini 3rd instar	1	–27.1			
Godramstein	3	Chironomini 4th instar	1	–28.1			
Siebeldingen	4	Chironomini 4th instar	9	–26.7	0.19	–26.4	–27.1
		Chironomini 3rd instar	3	–26.4	0.04	–26.4	–26.5
		Tanypodinae 4th instar	4	–26.2	0.11	–26.1	–26.4
Albersweiler	5	Chironomini 4th instar	4	–28.2	0.19	–28.1	–28.5
		Chironomini 3rd instar	3	–28.5	0.22	–28.2	–28.7
		Tanypodinae 4th instar	3	–26.9	0.02	–26.9	–26.9
Rosenfeldt	6	Chironomini 4th instar	3	–27.9	0.04	–27.8	–27.9
		Chironomini 3rd instar	3	–27.2	0.34	–26.9	–27.5
Eußerbach	7	Tanypodinae 4th instar	1	–26.2			
Eisbach	8	Tanypodinae 4th instar	1	–26.7			
		Chironomini 3rd instar	1	–29.2			
Annweiler	9	Chironomini 4th instar	3	–25.8	0.04	–25.8	–25.9
		Chironomini 3rd instar	3	–25.5	0.16	–25.3	–25.6
		Tanypodinae 4th instar	1	–25.6			
		Tanypodinae 3rd instar	1	–25.3			
Längenbachel	10	Chironomini 4th instar	1	–28.1			
Modenbach	11	Chironomini 4th instar	3	–26.1	0.14	–25.9	–26.2
		Chironomini 3rd instar	3	–25.6	0.06	–25.6	–25.7
		Tanypodinae 4th instar	3	–25.4	0.16	–25.3	–25.5
		Tanypodinae 3rd instar	1	–25.3			

Author´s Contributions

Paper I

TITLE:	Meta-analysis on the responses of traits of different taxonomic groups to global and local stressors
AUTHORS:	John Mbaka, Eduard Szöcs & Ralf Schäfer
STATUS:	Published in Acta Oecologica, 2015, Vol 69, 65-70
CONTRIBUTION:	Mbaka (70%) Designed research, Performed literature search, Reviewed papers, Discussed results, Wrote manuscript, Edited manuscript Schäfer (20%) Designed research, Wrote manuscript, Discussed Results, Edited manuscript Szöcs (10%) Analysed data, Edited manuscript

Paper II

TITLE:	Effect of small impoundments on leaf litter decomposition in streams
AUTHORS:	John Mbaka & Ralf Schäfer
STATUS:	Published in River Research and Applications, 2015. doi 10.1002/rra.2924
CONTRIBUTION:	Mbaka (70%) Designed research, Performed field and laboratory work, Analysed data, Wrote manuscript, Discussed Results, Edited manuscript Schäfer (30%) Designed research, Analysed data, Edited manuscript, Discussed Results, Wrote manuscript

Paper III

TITLE:	Macroinvertebrate functional feeding group ratios reveal local impacts of small impoundments on stream ecosystem attributes
AUTHORS:	John Mbaka & Ralf Schäfer
STATUS:	In Review in Limnology
CONTRIBUTION:	Mbaka (70%) Designed research, Performed field and laboratory work,

Analysed data, Wrote manuscript, Discussed Results, Edited manuscript

Schäfer (30%) Designed research, Analysed data, Edited manuscript, Discussed Results, Wrote manuscript

Paper IV

TITLE: Methane derived carbon in the benthic food web in stream impoundments

AUTHORS: John Mbaka, Celia Somlai, Dennis Koepfer, Andreas Maeck, Andreas Lorke & Ralf Schäfer

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CONTRIBUTION: Mbaka (55%) Designed research, Performed field and laboratory work, Analysed data, Wrote manuscript, Discussed Results, Edited manuscript

Somlai (8%) Performed field and laboratory work

Koepfer (2%) Performed field work

Maeck (10%) Performed field and laboratory work, Edited manuscript

Lorke (10%) Designed research, Edited manuscript, Wrote manuscript

Schäfer (15%) Designed research, Edited manuscript, Wrote manuscript, Analysed data

John Gichimu Mbaka

Resume

Personal

PLACE AND DATE OF BIRTH: Muranga, Kenya – December 16, 1981

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Research Interests

Aquatic ecosystems biomonitoring and management

Geophysical processes in freshwater ecosystems

Functional indicators in freshwater ecosystems

Research Activities

Current	**PhD Candidate**
OCT 2012	**Koblenz-Landau University, Germany** Institute for Environmental Sciences Landau, Germany DISSERTATION: Biomonitoring with organism traits and impacts of small impoundments on stream ecological integrity and food web
SEP-DEC 2010	**Research Assistant** **Egerton University, Kenya** Biological Sciences Department MAIN TASK: Collection of invertebrate samples from rivers, including specimen identification and data analysis

Education

SEP 2008 **International Post Graduate training in Limnology (IPGL)**
Egerton, University, Kenya

CORE SUBJECTS: River and Lake Ecology, Microbiology, Wetlands, Integrated Water Resource Management, Fish Biology, Water Supply and Sanitation

DEC 2007 **MSc in Environmental Science**
DEC 2010 Egerton University, Kenya

CORE SUBJECTS: Ecology and Environment, Environmental Pollution and Management, Environmental Policy and Advocacy, Environment and Development, Environmental Law

DISSERTATION: Impacts of canopy cover variation and organic matter dynamics on benthic invertebrate community in the Njoro River, Kenya

BSc in Applied Aquatic Science
Egerton University, Kenya

CORE SUBJECTS: Invertebrate and Vertebrate Zoology, Freshwater Ecology, Aquatic Techniques, Marine Ecology, Research Methods, Aquaculture, Watershed Management, Law of the Sea and Inland Waters

Scholarships

2002 BSc scholarship by Higher Education Loans Board (HELB) of Kenya
2007

APR 2012 German language scholarship by German Academic Exchange
OCT 2012 Service (DAAD)

OCT 2012 PhD scholarship at Koblenz-Landau University, Germany, by
OCT 2015 National Council for Science and Technology (NCST) and German Academic Exchange Service (DAAD)

Publications

Journal Articles

Mbaka J. & Schäfer, R. (2015) Effect of small impoundments on leaf litter decomposition in streams. *River Research and Applications,* doi: 10.1002/rra.2924.

Mbaka J., Szöcs E. & Schäfer R. (2015) Meta-analysis on the responses of traits of different taxonomic groups to global and local stressors. *Acta Oecologica* **69**: 65-70.

Mbaka J. & Schäfer, R. (2015) Macroinvertebrate functional feeding group ratios reveal local impacts of small impoundments on stream ecosystem attributes. *In Review in Limnology.*

Mbaka J., Somlai C., Koepfer D., Maeck A., Lorke A. & Schäfer R. (2014) Methane-derived carbon in the benthic food web in stream impoundments. *PLOS ONE* **9** (10): e111392.

Declaration

I hereby declare that I personally conducted the work presented in this Ph.D thesis entitled *"Biomonitoring with organism traits and impact of small impoundments on stream ecological integrity and food web"*. All people who assisted me during the study are mentioned and the parts involving other contributors and co-authors are indicated. This thesis or parts of it have not been submitted elsewhere as a dissertation for the award of an academic degree in Germany or abroad either in the same form or a similar form. I am aware that a violation of the aforementioned conditions can have legal consequences.

Landau, 16. October 2015

John Mbaka