StartClim2013.E

Wie und wo verändern sich die österreichischen Flüsse durch den Klimawandel?

Interdisziplinäre Analyse im Hinblick auf Fischfauna und Nährstoffe

Institut für Hydrobiologie und Gewässermanagement (IHG)

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Inhaltsverzeichnis

E-1 Kurzfassung

Klimawandel und Landnutzungsveränderungen wirken in vielfältiger Weise auf die Lebensgemeinschaften in unseren Fließgewässern. In dieser Arbeit wird vor allem auf die kombinierte Auswirkung von Klimawandel und Landnutzung auf die Wasserführung, Nährstoffkonzentration und Fischfauna in Bächen und Flüssen eingegangen. Viele Bäche und kleinere Flüsse gehören in Österreich über weite Strecken zur sogenannten Forellen- oder Äschenregion, und dort dominieren kälteliebende Fischarten (zu denen auch die namengebenden Arten gehören). Gehen diese kälteliebenden Formen in Folge des Klimawandels zurück, so bedroht dies nicht nur den Artenbestand, sondern es kann auch zu nicht vorhersehbaren Änderungen im ökologischen Wirkungsgefüge führen.

Für repräsentative Fließgewässer in Österreich wurden die Zusammenhänge zwischen Temperatur / Landnutzung / Wasserführung / Nitritkonzentration quantitativ erfasst (Pfadanalyse). Nitrit ist ein wichtiges Zwischenprodukt im Stickstoffkreislauf, das normalerweise in Fließgewässern nur in geringsten Mengen vorkommt und bereits in leicht erhöhten Konzentrationen toxisch wirken kann. Außerdem wurde versucht, das Vorkommen wichtiger Fischarten in einem Fließgewässerabschnitt mit den gerade erwähnten Umweltparametern sowie der Gewässerstruktur zu erklären (logistische Regressionsanalysen). Auf Grund der gefundenen Zusammenhänge wurden Szenarien für 2050 im Hinblick auf mittlere Nitritkonzentrationen und Abflussraten im Sommer, aber auch das Vorkommen von Schlüsselfischarten entwickelt. Die Sommerwerte wurden herangezogen, weil die Sommersituation für die durch den Klimawandel speziell bedrohten kaltwasser-adaptierten Fische besonders kritisch ist. Um Unsicherheiten in Zusammenhang mit Schnee- und Gletscherschmelze zu vermeiden, wurden für die Zukunftsszenarien nur Fließgewässerabschnitte mit stark Regen-beeinflusstem Abflussregime unterhalb 700 m Seehöhe betrachtet. Es wurde jeweils ein worst-case Szenario, und zwei Szenarien mit einem erhöhtem Feuchtgebietsanteil im Einzugsgebiet untersucht. Die Entwicklung der Lufttemperaturen wurde aus einem etablierten Klimamodell für das in der Klimawandelforschung oft verwendete, mit hohen Treibhausgasemissionen verbundenen IPCC-Szenarios A1b abgeleitet.

Dieses Szenario sieht bis 2050 für die meisten Einzugsgebiete Erhöhungen der mittleren sommerlichen Lufttemperaturen um 3-4°C (max. 5°C) voraus. Diese Temperaturen liegen in vielen Bereichen über den für Kaltwasserarten tolerierbaren Werten.

Neben dem direkten Temperatureffekt sind auch indirekte Effekte wie die Zunahme der landwirtschaftlichen Nutzung in mittleren Höhenlagen zu erwarten. Eine Ausweitung der landwirtschaftlichen Nutzung in den untersuchten Einzugsgebieten würde zu einer deutlichen Reduktion der sommerlichen Durchflussraten führen, nach den vorliegenden Szenarien besonders in mittelgroßen und großen Flüssen. Die Reduktion der Durchflussraten bewirkt wiederum erhöhte Nitritkonzentrationen und verstärkt anderen potenziellen Stressfaktoren. Geringe Durchflussraten verringern den verfügbaren Lebensraum für die gesamte Lebensgemeinschaft, wobei Fische schon aufgrund ihrer Größe am stärksten betroffen sein dürften. Weitere Stressfaktoren, die durch geringe Durchflussraten verstärkt werden: die Wassertemperatur steigt überproportional, der Sauerstoffgehalt sinkt nicht nur wegen der erhöhten Wassertemperaturen, sondern auch wegen des geringeren Gasaustauschs zwischen Luft und Wasser bei geringen Abflüssen und der erhöhten Stoffwechselaktivität der Fluss- bzw. Bachbewohner.

Das potentielle Vorkommen von 7 Fischarten (4 typischen Vertretern der Forellen- und Äschenregion, 2 Vertretern der Barbenregion und des Blaubandbärbling, eine nicht heimische Fischartmit potentiellen negativen Wirkungen auf die heimische Fischfauna) konnte anhand der oben erwähnten Umweltfaktoren gut vorausgesagt werden. Temperatur und Durchflussraten hatten den stärksten Einfluss, wobei die Bachforelle, Regenbogenforelle und die Äsche als Vertreter der oberen Fließgewässerabschnitte, die kühlere sommerliche Wassertemperaturen bevorzugen. Im Gegensatz dazu wird das poten-

tielle Vorkommen von Barbe, Nase und Blaubandbärbling durch wärmere Temperaturen gefördert. Je höher die sommerlichen Durchflussraten, desto höher die Vorkommenswahrscheinlichkeiten für 6 der 7 Arten (nur der Blaubandbärbling bevorzugte niedrigere Durchflussraten). Interessanterweise zeigte sich bei allen 7 Arten, nicht nur bei den Salmoniden, zusätzlich ein negativer Einfluss erhöhter sommerlicher Nitritkonzentrationen.

Die Szenarios zeigten, dass jedenfalls für die Äsche und andere Kaltwasser bevorzugende Arten eine erhebliche Reduktion des Lebensraums zu erwarten ist. Für andere Fischarten, die an wärmere Temperaturen angepasst sind, könnte diese Erwärmung eine deutliche Ausweitung ihres Lebensraums ermöglichen. Bei der exotischen Fischart Blaubandbärbling dürfte eine derartige verstärkte Ausbreitung deutliche, negative Konsequenzen jedenfalls auf die einheimischen Kleinfischarten haben.

Bei raumplanerischen Maßnahmen in Zukunft sollte stärker auf die Auswirkungen der Landnutzung auf den sommerlichen Durchfluss berücksichtigt werden. Auch die zu erwartenden erhöhten Nitritkonzentrationen wie andere Stoffkonzentrationen sollten in Zukunft im Gewässermanagement stärker berücksichtigt werden.

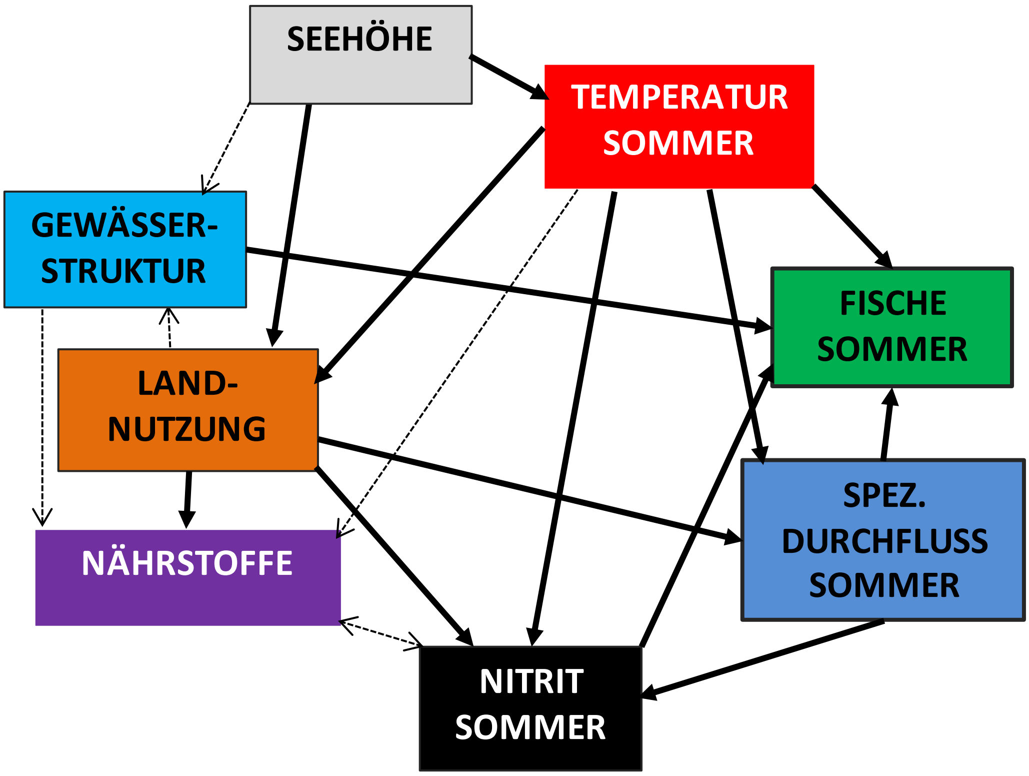

Abbildung E- 1: Schematische Übersicht der beobachteten und erwarteten Zusammenhänge

Durchgehende Pfeile: in der Arbeit belegte Zusammenhänge (Analysen: Pfadanalyse, logistische Regression), punktierte Pfeile: erwartete (aber nicht untersuchte) Zusammenhänge

Abbildungslegende:

Temperatur – mittlere Lufttemperatur, Gewässerstruktur – Anteil Flusslauf ohne Stau bzw. ohne Wasserentnahme und Schätzskala Güte Gewässermorphologie, Landnutzung – Anteil Landwirtschaft / Wald / Feuchtgebiete am Einzugsgebiet, Nitrit – Mediane und Spitzenwerte (=Anteil der Beobachtungen über 50µg/l NO2-N), spez. Durchfluss entspricht der hydraulischen Spende (=Durchfluss pro km² Einzugsgebiet), Fische - Vorkommen von 7 Fischarten, Sommer – Zeitraum Juni, Juli, August, September

E-2 Introduction

Riverine ecosystems are affected by a variety of interacting anthropogenic pressures. Besides water pollution, hydro-morphological alterations, connectivity disruptions, loss of habitat and other abiotic factors, climate change jeopardizes the fish-ecological integrity of river ecosystems (Schmutz & Mielach 2011). The rise of temperature is the best known phenomenon of global climate change and has been documented for Austria as well (Kromp-Kolb 2003; Matulla & Haas 2003). Since water temperature is mainly determined by heat exchange with the atmosphere, higher air temperatures lead to higher water temperatures. For rivers, strong correlations between water and air temperature have been documented (Webb & Nobilis, 1997; Moshini & Stefan, 1999; Hari et al. 2005; Solheim et al. 2010).

Water temperature affects river biota both directly and indirectly. Direct effects are increased activity levels of organisms, as long as water temperature is within their respective physiological tolerance. The ecological consequences of this enhanced activity level vary considerably depending on situation and organism affected. For warm water adapted organisms the net energy gain is likely to increase with temperature, whereas cold water adapted organisms may come close to their physiological limits, being more susceptible to parasites or abiotic stress factors, e.g. their energy balance is likely to deteriorate. The energy reserves obtained during optimum growth conditions in summer are crucial for survival in winter, thus summer conditions pave the way to death or survival at a later period. This phenomenon is well documented for fish: fat reserves are a key factor for the survival of many fish in winter (review in Shuter et al, 2012). So temperature may exclude organisms from river stretches before physiological temperature limits are reached. These mechanisms may be valid for a variety of riverine organisms, but they have been studied in detail only for fishes.

Microbial processes are crucial to many steps in nutrient cycling. The nitrogen cycle depends almost entirely on the activity of microorganisms. Therefore the nitrogen fractions ought to be strongly temperature dependent. Indeed, nitrate concentrations have been shown to be temperature dependent in some studies (for example in the Danube near Vienna; Zweimüller et al, 2008), but in other studies no close link between temperature and nitrate was found. When strong temperature dependence is found, nitrate concentrations decrease with temperature (Zweimüller et al, in prep.). Nitrate (NO3-N) represents the dominant inorganic nitrogen fraction in rivers (Zessner et al., 2003 - examples from Austria) and therefore governs nitrogen transport along the river continuum. Nitrite (NO2-N), an intermediate product of the nitrogen cycle, does not reach high concentrations in rivers, but it is toxic to aquatic life and may gain an important role in structuring the aquatic community, when it reaches high concentrations due to climate change. Relatively high concentrations of nitrite have been reported for nutrient-rich rivers during summer (Brehm & Mejiering, 1983).

A variety of indirect temperature effects also exists. Warmer water typically contains less oxygen than cold water. This partly due to a physical effect: warmer water has a lower solubility for oxygen (approx. 7 mg/l O2 at 35°C compared to 10 mg/l at 4°C, Wetzel, 1982). Secondly, increasing temperature triggers increasing community respiration in running water – just as in other ecosystems (Yvon-Durocher et al., 2012). These two factors may be enhanced by relatively low discharge rates in summer. Besides, lower discharge rates are typically associated with reduced turbulence, e.g. reduced gas exchange between river water and the atmosphere – a potential cause for reduced oxygen concentrations. When discharge rates are low, the river water is heated up quicker (f.e. Webb et al., 2003).

Discharge rates are also likely to be strongly affected by climate change. In middle Europe precipitation patterns are expected to shift seasonally – winters are likely to see more, summers less precipitation (Vautard et al., 2014). These changes are likely to result in flow rate reductions during summer, especially in river sites with pluvial hydraulic regime.

Reduced flow rates may lead to increasing concentrations of nutrients, when the same amount of nutrients (=load) is dissolved in a smaller water volume. This may have a fertilizen effect on in-stream productivity. However, the various nutrients fractions differ in their main control factors. While phosphorous concentrations are mainly driven by discharge rates (f.e. Jarvie et al., 2002), temperature influences the concentration of nitrate, the dominant inorganic nitrogen fraction in rivers and streams, (f.e. Zweimüller et al., 2008) due to the dominate role of microbiota in the nitrogen cycle. As water temperature increases and discharge rates change, N:P ratios may undergo considerable changes in the future. Today phosphorous is the limiting factor in most freshwater ecosystems, but nitrogen may become limiting under conditions of high water temperature and low discharge rates. Shifts in limiting factors may not only influence in-stream productivity, but could also affect ecosystem services of rivers and streams, such as water self-purification.

A major driver of nutrient concentrations in rivers is land use: agriculturally used land is fertilized and a variable proportion of the applied fertilizer can reach aquatic systems leading to multiple effects such as toxic effects by pesticides and eutrophication by nutrients. Land use pattern is not only impacting the river systems, but will be influenced by climate change and thus, interactions between pressures need to be considered. On one hand droughts may reduce intensive agriculture in some catchment areas or lead to increasing water demand by irrigation, on the other hand increasing temperatures may allow to expand agricultural land use to regions less intensively used at present. Land use is likely to be another key factor in the changes associated with climate change.

Interactions between changes in temperature regimes and alteration in the discharge regime and land use due to changes in precipitation patterns are likely to affect key ecosystem components and thus, also the delivery of ecosystem services of riverine systems.

Water-temperature is one of the most significant factors for the survival of aquatic biota (flora and fauna) in freshwater ecosystems and one of the most important key parameters driving fish species distribution (Fry 1967, 1971; Varley 1967; Hutchinson 1976, Armour, 1991). The temperature regime influences various aspects of life history, including migratory behavior, egg development, spawning process, fertilization and growth rates as well as metabolism, respiration and tolerance towards parasites. Therefore, temperature has to be considered a key environmental factor and should be increasingly important in structuring river fish assemblages, especially in regulated and water quality degraded river systems. This is closely related to the loss of fluvial habitats therein (Wolter 2007).

A relatively small increase in water-temperature may alter the entire fish community. Minor modifications often limit the survival of single species or life stages and consequently species distribution (Jungwirth & Winkler 1984; Schmutz & Jungwirth 2003). Especially cold-stenothermic species prefer significantly lower temperatures during summer than eury- or mesothermic species. Accordingly, interventions in the temperature regime of a water body can lead to advantages for one species and disadvantages for others.

In a changing environment the fish has two options to survive: (1) adapt, or (2) migrate. Different studies focus on the second option to evaluate distribution changes and different future scenarios. The possibilities for upstream migration are often limited, at first through diminishing discharge rates, secondly by migration barriers and/or reduced connectivity between river stretches (Matulla et al. 2007). Different types of stressors affecting the fish community are interacting with potentially multiplicative negative effects. Therefore it is possible that the European grayling (*Thymallus thymallus*) or Danube salmon (*Hucho hucho*), both endangered and flagship species, may be extirpated in Austria.

Several indications of climate impact on the fish community of freshwater ecosystems have already been observed in Europe, such as northward movement, phenology changes and invasive alien species (Daufresne & Boët, 2007; Buisson et al., 2008; Buisson & Grenouillet, 2009, Solheim et al., 2010, Comte et al., 2013).

Austrian streams and river cover a wide range of elevations, which leads to a great variety of fish zones. Indices have been assigned to these different fish communities. The Austrian fish-zone-index (FiZI) generally ranges from 3.8 (trout zone) through 5 (grayling zone) to 6 (barbel zone) and 6.8 (bream zone). The difference in water temperatures between the trout and grayling zones is smaller (2-3°C) than between grayling and barbel zones (4°C).Temperature changes associated with climate change lead to a shift of assemblage composition toward a species composition preferring warmer thermal regimes (Melcher et al. 2013).

Our study aims to improve the understanding of how rising temperatures and changes in discharge may alter the quality and functioning of freshwater ecosystems providing a scientific basis for adaptation strategies concerning the management of Austrian rivers. The water quality of most rivers in Austria is relatively good, except for a few smaller rivers draining catchment areas with a large proportion of arable land-use. These rivers are mainly located in pre-Alpine or lowland regions. High nitrate concentrations in the groundwater cause risks for the drinking water supply in several regions, which are hot spots of intensive agriculture. The EU nitrate directive has been implemented in Austria from 2000 onwards and the situation may improve on an intermediate time scale, while climate change effects might pose new risks in the future.

E-2.1 Current knowledge concerning climate change effects in Austrian rivers

Long-term trends of water temperature show clearly increasing trends of water temperatures especially since the 1990s (Webb and Nobilis, 1997; Zweimüller et al., 2008; Melcher et al. 2009; Markovic et al., 2013). The temperature rise over the last 30 years, especially in river sections downstream of lakes, induced a shift in fish species composition from cold-water to warm-water species. Rivers downstream of a lake show around 4 to 5°C higher temperatures than comparable reaches of rivers without lake influence. The European grayling (*Thymallus thymallus*) almost disappeared from many of these sections where it formerly occurred abundant (e.g. Traun River). Today more temperature tolerant species like barbel (*Barbus barbus*) and chub (*Squalius cephalus*) are abundant. Another biological indicator for temperature change is the increasing number of fish species (Melcher et al. 2013).

E-2.2 Expected changes due to climate change

The summer of 2013 has been one of the hottest summers on record in Austria, but comparable situations are expected to recur more often in future. The recent report of the IPCC (AR5, 2013) has relativized the intensity of future climate change but underlines expected changes concerning air temperature increases. Already in the fourth assessment report (IPCC, 2007) and according Special Report on Emissions Scenarios, different future pathways of economic growth describe different changes in the global climate. Several studies showed that the global economy currently follows the trends of the A1 emission scenario which therefore builds a reasonable basis. This scenario assumes an economic focused world with rapid growth accompanied by technical progress. Nonetheless, temperature increases up to 6.4 °C are projected. Future changes of precipitation are more unclear. River discharge is triggered by type and intensity of precipitation. The amount of annual precipitation is expected to remain similar to the present state, changes in type and timing of precipitation are assumed. On the one hand precipitation during summer will decrease whereas in winter more precipitation is expected (Vautard et al., 2014). These changes in precipitation will be reflected this in the hydrological regimes of most rivers. Low flows in summer and beginning autumn will occur with more intensity and water level during winter will increase. Furthermore, climate change impacts may be different in discharge systems triggered by snowmelt (e.g. Steyr) or glacier runoff (e.g. Isel).

Fish species which are not constrained by increasing temperatures may profit from climate change and higher temperatures as new habitats which were formerly restricted by minimum temperature thresholds get available. In respect of fish zonation this means a reduction of river reaches with rhithral conditions and an extension of potamal thermal conditions.

The effects of climate change on the nutrient concentrations in rivers have attracted much less attention so far, but far reaching consequences as an increase in algal blooms can be expected (Mauser et al., 2012). Agriculture is a major source for nutrients in rivers and streams. If areas with arable land use spread into formerly unused land with climate change, this can be seen as indirect effect of climate change on nutrient concentrations.

In Austria water quality is not considered a major threat to fish population in general (exceptions: point sources of pollution and small rivers near intensive agricultural areas). Still, nitrite as an intermediary product in the nitrogen cycle has to be taken into account, as nitrite is poisonous to aquatic life – including fish - at higher concentrations. Moreover, nitrite concentrations have been observed to increase during summer months in many lowland rivers, when metabolic activity is typically highest in fish. With increasing water temperatures nitrite concentrations may reach dangerous levels in the future. Eddy & Williams (1987) found likely threshold levels of 50 µg/l NO2-N for negative effects on fish populations in the salmonid region and 100 µg/l mean concentration for fish species in the cyprinid fish region (long-term average).

E-2.3 Research approach

The first step was to establish links between potential environmental drivers and response variables from existing data ("status quo"). The aim was to detect patterns in the data indicating first changes due to climate change and to identify the most likely environmental drivers for future changes.

Path analysis was used to model specific discharge rates and nitrite concentrations in the summer based on the (inter)relations between explanatory variables and response variable. These explanatory variables included land use data, specific discharge rates as well as air temperature.

The presence/absence of 7 fish species was predicted by logistic regressions using three factors describing river morphology, air temperature, specific discharge rates and two factors related to nitrite concentrations during the summer as covariates (=explanatory variables). The seven target species were chosen as typical representatives of fish zones (brown trout, grayling, barbell, nase carp) or as species of special interest (rainbow trout, Danube salmon, topmouth gudgeon). Four species (brown trout, rainbow trout, Danube salmon and grayling) are cold-water adapted species, e.g. they are expected to suffer from climate change due to increasing temperatures. Besides, salmonids preferring clear and oxygen saturated water are likely to be more vulnerable to elevated nitrite concentrations (Eddy & Williamson, 1987). The barbel and the nase are cyprinid species, which are found in the warmer, downstream sections of rivers. They are suspected to increase their distribution area due to climate changes. The non-native topmouth gudgeon has a potential to become invasive and threaten native fish species by transmitting fish diseases (Gozlan et al., 2010; Gozlan et al., 2005)

Linking fish and water quality data was achieved by addressing the question, whether nitrite concentrations in summer do already affect the probability of fish species occurrence today. As nitrite is strongly influenced by water temperature and discharge rates, residuals from regression analyses were used to assess the effect attributable to nitrite alone. Any effect of nitrite detected in the analysis is presumably due to exceptionally high nitrite concentrations.

In a second step we used the relationships discovered in the first analytic step to model changes to be expected with changing temperatures ("future – 2050"). For example, the path analysis for specific discharge rates in the summer allowed us to model discharge rates for the air temperature values for expected 2050 based on climate change scenario A1b. This can be seen as a classical space for time approach, e.g. it is expected that in future a river site with mean summer temperatures of 25°C in 2050 has similar conditions as a river site with same temperatures at present. This assumption is plausible, as long as responses of the ecosystem towards climate change are fairly linear. River sites with glacial or nival discharge regime (sensu Mader et al. 1996) could show unexpected changes in summer discharge rates, due to shifts in glacial run-off and/or snow melt patterns. Therefore scenarios were only established for river sites where rain had a strong influence on hydrology (pluvial regimes).

Three land use scenarios were established for specific discharge rates and nitrite concentrations in the summer based on summer air temperatures derived for climate model A1b. Based on these values, 3 sets of probability values for the occurrence of 6 fish species in 2050 were established. These scenarios were used to show potential changes in fish species distribution due to climate change.

E-3 Material and study area

E-3.1 Climate data

All climate data were represented by raster surfaces with emphasis on high resolution (~1x1km). The use of raster surfaces guaranteed a full coverage of the investigation area. Current climate conditions were described by data from the Integrated Nowcasting through Comprehensive Analysis (INCA, Haiden et al., 2011) system covering the period from 2003-2008. The INCA system basically is used for short term meteorological forecasts. Additionally, the system can be used to generate climate raster for selected periods. Future climate conditions were derived from a statistically downscaled GCM model output. The future climate is described according to the scenario A1b according to the fourth assessment report of the IPCC (2007).

E-3.1 River environment data

The riverine environment was described on the basis of the Austrian river network which is part of the national water management plan (NGP 2009) which was established in the light of the Water Framework Directive (WFD). The water management plan comprises all Austrian rivers with a catchment size larger than 10 km². The river courses are divided into surface water bodies (SWB) which build the WFD evaluation units. The SWB provide the information on fish zonation, i.e. classification into Epi-, Meta-, Hyporhithral Epi- or Metapotamal, respectively (Schmutz et al., 2000) as basis for a fish-relevant typology of rivers.

Location and size of river stretches with impoundments and residual flows are documented in distinct data sets. Furthermore, the morphological status is available on the basis of 500 m river stretches. The morphological status is given in five classes (from 1 “high” to 5 “bad”). All data were available in a geospatial vector format (i.e. line shapefile)

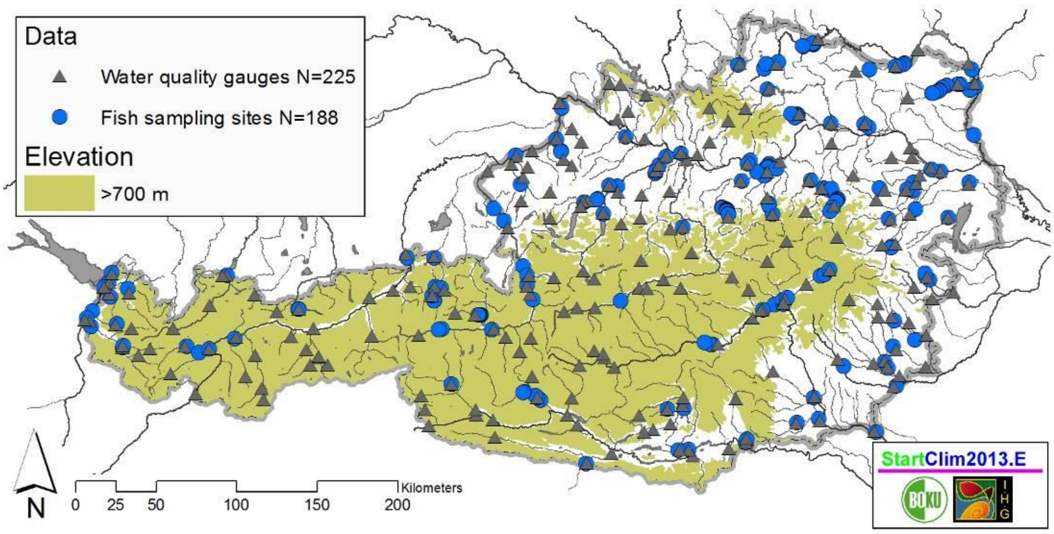

Figure E- 1: Water quality and fish species – locations of river sites used

E-3.2 Water quality, discharge and river site characteristics

Water quality data from 225 river sites were used (Fig. E-2). This comprises the majority of the official water quality monitoring sites. However, sites on the same river had to have at least twice the catchment area and/or a stream order at least one grade higher than the closest upstream site to be included in the dataset. Besides, only river sites with relatively easily available discharge data were included. 6 different nutrient-related parameters were analysed, 2 organic carbon related ones (BOD5 and DOC), 3 nitrogen-related (NO3-N, NO2-N, NH4-N) and orthophosphate (PO4-P). The data came from routine water quality monitoring. The water quality monitoring programmes are carried out under the responsibility of the provincial governments, the data are collected and monitored by the federal Environmental Protection Agency (UBA) and made available via Internet:

http://wisa.lebensministerium.at/h2o/state.do;jsessionid=7C89728EF753E2D7D7E8427C4E499244?stateId=FIVE_STEP_QUALITY

Detailed information on the water quality monitoring locations (elevation at the monitoring site, size of catchment area, type of hydrological regime (sensu Mader et al. 1996), exact geographical location, etc.) is available from the following web-site:

http://www.umweltbundesamt.at/umweltsituation/wasser/wasser_daten/wgev/jb2006/datenband_fw2006/datenband_fw2006_download/

For a few sites (18 sites) informations on hydrological regime were obtained from Mader et al. 1996 or by examining long-term average discharge rates of the respective river sites (3 sites)

Discharge data (daily mean discharge for the water quality monitoring stations) were obtained from the eHYD platform established by the ministry of agriculture (available at http://ehyd.gv.at/). Information on the geographic location including elevation and the size of the upstream catchment area at the gauge are also available.

Specific discharge (discharge per catchment area) is useful for comparing discharge rates between rivers of different size. When specific discharge is high, the river receives comparably more water per km² of the catchment. Discharge is strongly related to elevation. At high elevation, terrain slopes are steep and rainfall is quickly channeled into the riverbed. Furthermore, the type of land cover has an effect on discharge: e.g. vegetation stores water but transpiration may lead to water loss.

E-3.3 Land use data

Land use data were obtained from the M. Zessner, TU Wien (CORINE, EUROPEAN ENVIRONMENT AGENCY, 2009). They were based on the spatial framework of 376 MONERIS ((sub)catchment) in Austria (Gabriel et al., 2011). If the catchment of a river site included several MONERIS subcatchments, the land use information of these units was summed up. Land use information was expressed as percentage of total catchment area. For several very large catchments the land use information of the approx. 50km river stretch upstream the water quality monitoring site was used.

E-3.4 Fish data

Seven fish species were chosen to analyse the role of nitrite in fish species distributions. These species are flagship species of the fish zonation therefore representing different river types or they are of special ecological interest (e.g. invasive species).

The data describing the occurrence of the fish species as well as the structure of the fish assemblage were queried from the database of the Institute of Hydrobiology and Aquatic Ecosystem Management for locations close to the selected water quality sites. This database comprises data from standardised field sampling protocols either by wading or boat depending on river depth (CEN 2003). Fish sampling data was queried for the period of 2000 to 2010. Additional information was obtained from BAW-IGF Scharfling, Fischdatenbank Austria, as of 07.02.2014. Finally the data of fish occurrence include information from 2000 to 2013. For 93 river sites information it was possible to combine information on fish occurrence with nitrite data. For the Danube salmon only sites in rivers with historical (or recent) reports of Danube salmon occurrence were used for the analysis(n=29).

The presence of a species was defined differently for abundant and rare species. For the abundant species brown trout, rainbow trout, grayling, barbel and nase carp median value for each species on each river site was calculated. If the median was larger than 0 (e.g. fish were present at least during half of the observations at the respective river site), the fish species was considered to be present.

The rarer species Danube salmon and topmouth gudgeon were considered to be present in all sites with recordings density or frequency.

Target species

The target fish species are shortly characterized as follows:

Brown trout (*Salmo trutta*): character species of the trout zone; feeding on invertebrates and small fish; spawning takes place in autumn/winter

Rainbow trout (*Oncorhynchus mykiss*): introduced from North America; by stocking; feeding and reproduction similar to brown trout

Danube salmon (*Hucho hucho*): endemic to the Danube basin, restricted distribution area (mainly Danube tributaries of intermediate size). Threatened; fish predator (often preying on nase carp), spawning in spring after migrations

Grayling (*Thymallus thymallus*): character species of the grayling zone; endangered; feeding on invertebrates; spawning takes place on gravel substrate in spring, migrates before spawning

Barbel (*Barbus barbus*): character species of the barbel zone; e.g. prefers rivers of intermediate to large size; feeding on invertebrates, spawning takes place in spring on gravel banks, migrates before spawning

Nase carp (*Chondrostoma nasus*): abundant in the barbel zone, feeds on epilithic algae, spawning takes place in spring on gravel banks; migrates before spawning

Topmouth gudgeon (*Pseudoraspora parva*): small south-east Asian species, which is considered invasive; reports from Gozlan et al. (2010) indicate, that the species has expanded its range within the last decades. It may carry pathogens and thus threaten native fish (Gozlan et al., 2005). feeds on invertebrates; reproduction in spring

E-3.5 Future scenarios

The summer air temperature was modeled for 2050 using scenario A1b for all 225 river sites. These temperature values were used in further modelling specific discharge, nitrite concentrations and nitrite peaks in the summer and the presence of fish species.

These models were only applied to river sites which were located below 700m elevation and were strongly affected by rainfall in their hydraulic regime.

Three scenarios were used for this subset of river sites, scenario A represents our “worst case” scenario, whereas scenario B and C can be seen as mitigation scenarios

Specific discharge rates and nitrite concentrations were modeled according to land use and temperature values expected for 2050 (mean air temperatures for JJAS) using the regression coefficients from the path analysis. However, the scenarios differed with respect to land use. In scenario I to III different assumptions with respect to arable land use and woodland / forest in 2050 were applied. Secondly, the share of wetlands in the catchment was altered for scenarios A to C, resulting in 9 different scenarios (I_A to III_C). Two data sets were used to represent the “status quo”: the observed values and results from scenario I_A with present day temperature. The differences between these data sets do illustrate the difference between “real” data and data derived from model calculations and help to interpret for example the variability in the data.

Scenario I: the share of arable land and woodland / forest was considered to be the same as presently,

Scenario II: arable land use and woodland / forest were expected to change in accordance with air temperature using the coefficients from the path analysis.

Scenario III: the share of arable land was increased by 10% and the share of woodland / forest was reduced by 10% in every catchment. Maximum values for arable land were not allowed to exceed 95% and minimum values for woodland / forest were not allowed to drop below 1%.

Scenario A: share of wetlands in 2050 the same as today

Scenario B: share of wetlands is 0.76% for all catchments.

Scenario C: share of wetlands is 2% for catchment with much arable land use (more than 50%) and 0.15% for all other catchments

The percentages used in scenarios B and C correspond to the following quantils for share of wetlands in the present data set: 95%, 99% and 75%, respectively (e.g. only 1% of the catchments have more than 2% land covered by wetlands)

Based on the air temperature values derived for 2050 by the climate model and the relations between the environmental variables described by the path analysis specific discharge rates and median nitrite concentrations were modeled for the scenarios described above.

The presence of six fish species was also modeled based on the relations found by the logistic regression models. Hydro-morphological parameters were assumed to be average. No models were established for Danube salmon, as the logistic regression model is based on relatively few observations.

Tab. E-1 gives an overview, how many data points were available for the different types of variables and which (sub)sets were used for which analysis.

E-4 Methods

E-4.1 Spatial intersection of data

A major issue in the setting of this project was the intersection of the available data. Data concerning water quality, fish assemblage structure, climate conditions and river characteristics were necessary to fulfil the aims of the study. Accordingly, an important aspect was the spatial and temporal congruence of the different data sources. The temporal coherence of the data was simply given by the limitation in the data query on a specific period, i.e. 2000-2013. The spatial coherence of the data was achieved by intersections between the different data sources in a geographic information system (GIS, ESRI 2011).

The MGI/Austria Lambert projection was used for all analyses in the GIS.

The water quality monitoring as well as the fish sampling sites were imported to the GIS as points by their geographic coordinates and transformed into a spatial data format (point shapefile). Consecutively, to guarantee full spatial congruence, the points were exactly assigned to the river network and to the according SWB. Correctness of location was checked by given river names. Redundant information for single SWB was eliminated, i.e. for one SWB the information of only one water quality gauge and one fish sampling site was retained in the dataset.

The line shapefiles of impoundment, residual flows and hydro-peaking were intersected with the line shapefile of the SWB. The resulting features were used to calculate the balancing proportion of impacted length per SWB. Similarly, the 500m stretches of river morphology were intersected with the SWB. A mean morphological index was calculated as a weighted mean (by length) of each morphology class.

E-4.2 Statistical analysis

E-4.2.1 Interrelations land use / nitrite / specific discharge

Path analysis is a tool, where the interrelations between factors are described by a series of regression and correlations. In contrast to usual regression models the validity of the whole structure can be tested. This is done using a Chi-2 test, where the results of the model are tested against a saturated model including all possible effects. If the test is not significant, the path analysis established does not explain significantly less variance than the saturated model, e.g. it cannot be rejected. Additionally various indices of fit can be calculated. In this study the widely used index NFI was applied. If it is above 0.95 the model is acceptable, above 0.99, it is very good.

Path analyses were used to model specific discharge and nitrite concentrations and to establish scenarios. To obtain predicted values within a meaningful range (e.g. between above 0 and below 100% for land use and above 0 for specific discharge rates) variables were transformed: specific discharge rates and median nitrite concentrations were log2-transformed. Land use data were transformed into logits.

Unidirectional arrows indicate regression, while arrows with two arrow heads indicate correlation. No intercepts were included in the analysis. Numbers close to arrow heads indicate standardised regression coefficients, numbers close to boxes represent explained variance (r^2) for the respective variable. The number near the middle of the double-headed arrow indicates the correlation coefficient r.

E-4.2.1 Occurrence of fish species

Binary logistic regression: in contrast to linear regression binary data (in our case presence/absence of a fish species) can be used as response variable. The analysis does model the probability of occurrence for a specific event. If this probability is higher than 0.5 it is assumed, that the event takes place (e.g. a fish species is present). The regression coefficients for this analysis are not expressed in standardized form, e.g. they are scale dependent. To make interpretations easier, explanatory variable were transformed (e.g. all scales were set to average = 0 and standard error = 1). The response variable was the presence/absence of fish (coded by 0 and 1).

The occurrence of fish species was modelled with logistic regressions using three variables describing river hydro-morphology (status of river morphology multiplied by -1, see below, portion of un-impounded stretch length, portion of stretch length without water abstraction) summer discharge rates, summer air temperature and median nitrite concentrations in summer (see material and methods) as explanatory variables. The three hydro-morphology variables were scaled with higher number indicating better habitat conditions for fish (e.g. river morphology scores were multiplied by -1). A stepwise approach was used (backwards LR), allowing the analysis to choose the important explanatory variables.

When explanatory variables are correlated, the regression analysis “chooses” the better predictor of these pairs of variables. The other variable is not included, as it does not contribute enough additional information to the analysis. However, this does not mean, that the respective variable does not have an effect.

E-4.2.2 Differences between groups

A non-parametric test (Kruskal-Wallis) was used for comparisons between groups to avoid problems with a lack of normal distribution in the data.

E-4.2.3 Scenarios

For the scenarios modeling specific discharge rates and nitrite concentrations the results of the path analyses were used. For air temperature the results of the regionalized A1b scenario were used. 9 scenarios with different land use were established, 6 of which can be seen as mitigation scenarios (see below).

E-4.2.4 Software

The statistical analyses were carried out in SPSS (15) and AMOS. Excel was used to calculate scenarios.

E-4.2.5 Data used for the various analysis

Table E- 1: Available data and their use in the various analyses

elevation	below 700m		above 700m	
discharge regime	pluvial	glacio/ nival	pluvial	glacio/ nival
land use	225			
specific discharge	224			
mean nutrient conc	225			
nitrite summer since 2000	225			
fish distribution	93			
hydro-morphology	approx. 190			
status quo				
LR nutrients - arable LU	225			
path analysis	166			
log Reg fish 6 species	81			
log Reg Danube salmon	29			
future - 2050				
scenario air temperature	225			
scenario I - III	112			

numbers - n observations

Dark areas: data available / data used for the respective analysis
Numbers in shaded areas: number of observations = river sites

E-5 Results

E-5.1 Status quo of air temperature, specific discharge rates and land use

The river sites used in this study cover a wide range of environmental conditions: rhithral river sections are characterised by high specific discharge rates and low temperature as well as a low percentage of arable land use. Only a small fraction of the catchment areas is covered by glaciers. Even for small and intermediate streams (epirhithral and metarhithral) the average share of glaciers in the catchment is less than 2%. Wetlands make up less than 1% on average in all catchment in the different fish zones. Forest is a dominant land cover type in all river types. The differences of environmental variables between the fish zones are highly significant for nearly all environmental factors given in tab. E-2 (Kruskal-Wallis-test, $p<0.000$). Only the share of wetlands and glaciers does not differ significantly between fish zones (Kruskal-Wallis-test, $p>0.05$).

Elevation has a considerable effect on environmental factors. Fig. E-2 shows the strong link between elevation and air temperature, resulting on a broad range of temperature conditions within distinct fish zones. The temperature range is much wider in streams compared to rivers (for example metarhithral vs. epipotamal). Mean specific discharge rates (fig. E-3) are highest at sites over 700m. The effect is most pronounced in small streams, probably due to the steep slopes typical for streams in high elevation regions. In low elevation regions a wide scatter of mean specific discharge can be observed. For two fish zones (hyporhithral small and epipotamal small) specific discharge rates are extremely low.

Land use types are also correlated with elevation. Especially arable land use and the share of forest in a catchment are related to elevation (fig. E-4 and fig. E-5). There is a clear negative linear relationship between elevation and the share of arable land use in the catchment. The share of forest shows a unimodal relationship to elevation: first it increases simultaneous with elevation and above 700m the share of forest starts to decrease with elevation.

Table E- 2: Mean values (± standard deviation) for various environmental factors at the different fish zones

		Epirhithral			Metarhithral			Hyporhithral small			Hyporhithral large			Epipotamal small			Epipotamal middle			Epipotamal large / metapotamal		
n		36			61			8			58			7			37			17		
spec. Q	l / s / km²	39.62	±	28.30	38.11	±	32.51	3.97	±	3.09	29.48	±	21.99	2.68	±	1.64	14.66	±	11.98	22.94	±	18.47
air temp	°C	14.39	±	1.87	15.59	±	1.67	17.85	±	0.79	16.76	±	1.45	18.75	±	1.33	18.09	±	0.66	18.39	±	0.68
arable LU	%	7.94	±	15.13	9.51	±	16.69	50.08	±	17.20	11.37	±	16.53	57.97	±	26.06	35.51	±	22.48	28.81	±	25.04
forest	%	61.57	±	16.00	65.02	±	18.70	42.05	±	15.20	63.83	±	16.57	30.06	±	16.67	44.08	±	18.60	51.23	±	17.92
wetland	%	0.17	±	0.39	0.10	±	0.16	0.14	±	0.29	0.23	±	0.59	0.03	±	0.06	0.13	±	0.32	0.21	±	0.48
urban	%	2.44	±	2.04	2.90	±	2.89	4.45	±	1.41	3.70	±	3.28	9.42	±	8.67	5.00	±	2.67	4.73	±	1.97
grass	%	8.20	±	8.01	9.39	±	7.63	3.13	±	4.58	11.69	±	8.08	2.38	±	2.43	12.73	±	9.03	9.03	±	6.21
open	%	18.29	±	17.07	11.61	±	14.81	0.00	±	0.00	8.42	±	11.12	0.00	±	0.00	1.45	±	4.57	5.24	±	7.88
glaciers	%	1.18	±	5.10	1.27	±	3.99	0.00	±	0.00	0.32	±	1.17	0.00	±	0.00	0.04	±	0.26	0.18	±	0.40

n – number of observations, spec. Q - specific discharge in summer (JJAS), air temperature – mean air temperature in summer (JJAS), arable LU .. glaciers - land use parameters expressed as percentage of catchment

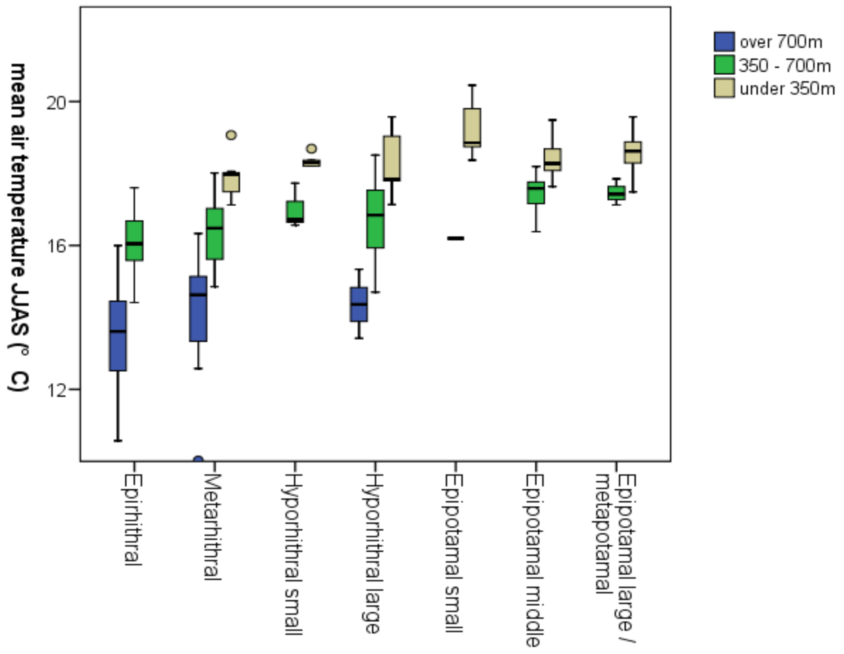

Figure E- 2: Mean air temperature for the period June to September in the different fish zones and for three elevation classes

Dark line in the middle of the box indicate medians, boxes include 50% of the observations, whiskers mark the range of the observations, expect for outliers (points or asterisks)

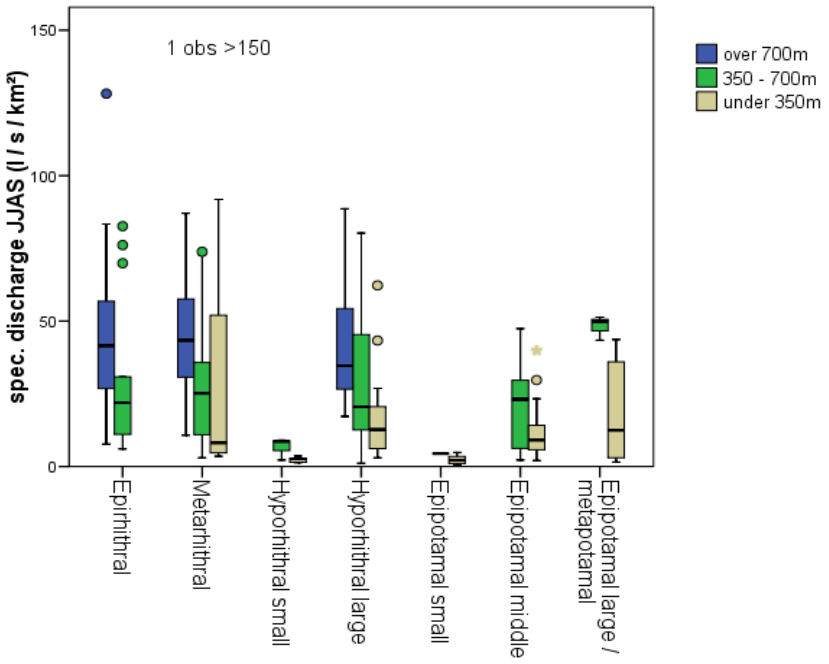

Figure E- 3: median specific discharge in summer at the different fish zones for 3 elevation classes

Legend as in fig. 2

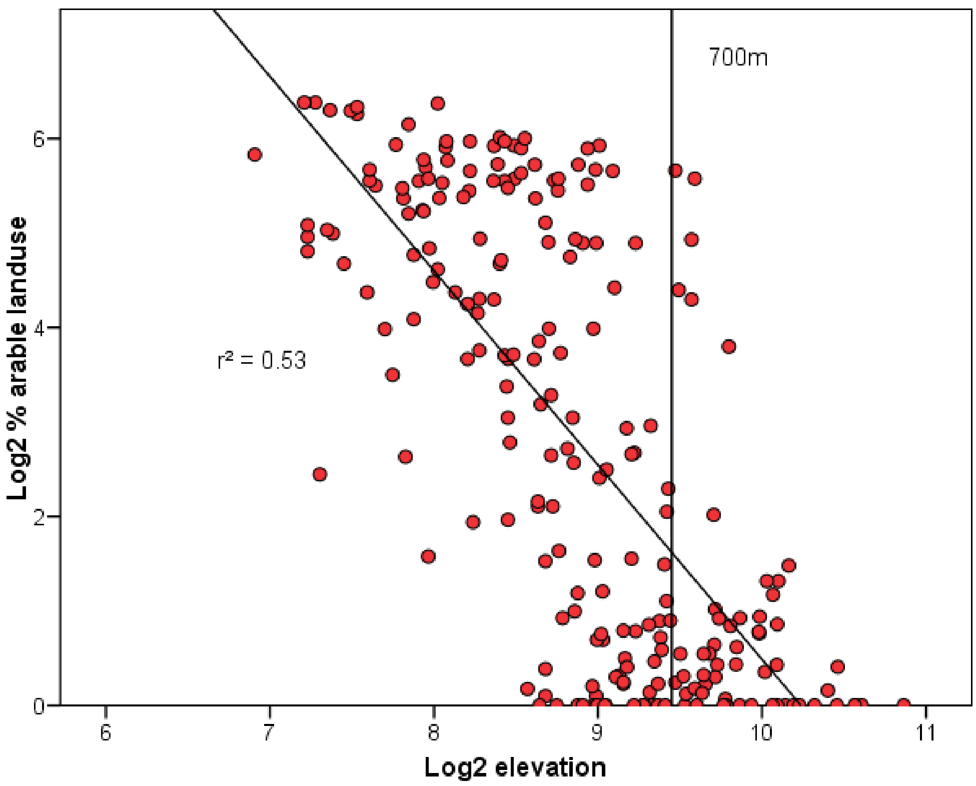

Figure E- 4: Elevation and arable land use

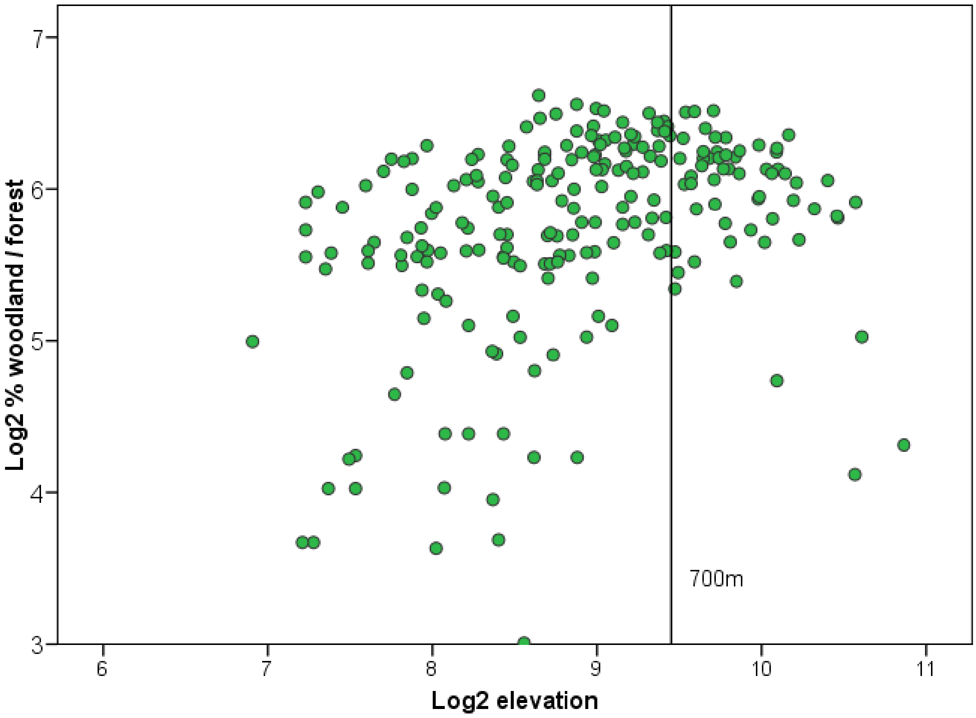

Figure E- 5: Elevation and woodland / forest

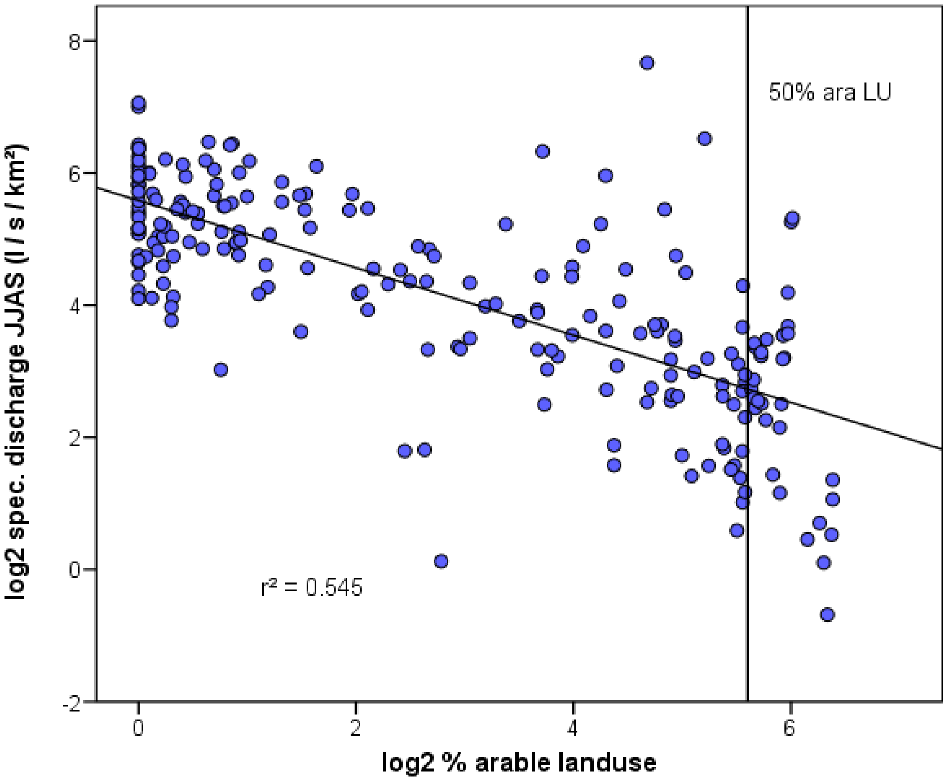

Figure E- 6: Relation between arable land-use and specific discharge in summer

The specific discharge rate (summer values) for a river site correlates strongly with the percentage of arable land-use characteristic for the catchment. The relation shown in fig. E-6 is based on log2-transformed values, e.g. arable land-use has a very strong impact on the specific discharge rate.

E-5.2 Status quo of nutrients

In a first step median nutrient concentration of all available data were used to characterize the overall situation. The concentrations of all six nutrients investigated increased with increasing river size, as shown in tab. E-3. The differences between fish zones were highly significant for all nutrients (Kruskal-Wallis-test, $p<0.000$). Interestingly the concentrations were highest in sites of medium-sized rivers ('Epipotamal small'), not in the largest rivers. This fish zone is the only one, where the median concentration for NO2-N is already dangerously close to the 50µg/l threshold reported by Eddy & Williams (1987) for salmonid rivers. The generally high concentrations found in Epipotamal small are in agreement with the higher percentage of arable land-use for the respective river sites (58% for Epipotamal small compared to less than 40% for the two groups of larger rivers, tab. E-3). For most nutrients and most fish zones the standard deviations are similar to the respective mean values. Only the standard deviations for nitrate were considerably smaller than the means; this trend became stronger for larger river types (potamal fish zones).

Table E- 3: Mean values (± standard deviation) for 6 nutrient concentrations in mg / l at the different fish zones

	Epirhithral			Metarhithral			Hyporhithral small			Hyporhithral large			Epipotamal small			Epipotamal middle			Epipotamal large / metapotamal		
n	36			61			8			58			7			37			17		
BOD5	0.639	±	0.402	0.825	±	0.432	1.448	±	0.289	1.170	±	0.435	2.336	±	0.735	1.529	±	0.434	1.665	±	0.741
DOC	0.910	±	1.062	1.242	±	1.183	2.601	±	0.762	1.250	±	0.739	4.029	±	1.263	2.447	±	1.383	2.508	±	1.661
NH4-N	0.007	±	0.008	0.016	±	0.025	0.034	±	0.020	0.025	±	0.028	0.202	±	0.207	0.051	±	0.051	0.081	±	0.067
NO2-N	0.002	±	0.002	0.004	±	0.005	0.016	±	0.011	0.007	±	0.008	0.047	±	0.027	0.018	±	0.014	0.019	±	0.014
NO3-N	0.737	±	0.620	0.926	±	0.792	2.509	±	1.370	1.168	±	0.847	3.927	±	1.097	2.256	±	1.259	1.666	±	0.854
PO4-P	0.008	±	0.011	0.011	±	0.016	0.054	±	0.047	0.017	±	0.024	0.088	±	0.065	0.042	±	0.033	0.043	±	0.053

Table E- 4: Parameters for regressions of median nutrient concentration versus percentage arable land in the catchment (log2)

	BOD5	DOC	NH4-N	NO2-N	NO3-N	PO4-P
intercept	0.801	0.862	0.0122	0.00267	0.621	0.0032
p for intercept	0.000	0.000	0.008	0.002	0.000	0.095
slope	0.018	0.041	0.0012	0.00037	0.041	0.0011
p for slope	0.000	0.000	0.000	0.000	0.000	0.000
r^2	0.448	0.491	0.208	0.415	0.675	0.565

Linear regressions of the nutrient concentrations with arable land use were highly significant in all cases (tab. E-4). The link between arable land-use and nutrient concentration was strongest for nitrate (r^2=0.68) and weakest for ammonia (r^2=0.21). For PO4-P the regression suggests, that without arable land-use the median concentration would be below the detection limits (intercept not significant), whereas for BOD5, DOC and nitrate median concentrations above 0.5 mg / l could be expected even without any arable land-use. When 50% of the catchment is used for agriculture nitrite-N levels are expected to slightly exceed 20µg / l, e.g. the high nitrite concentrations observed for epipotamal small may have additional reasons besides arable land-use.

The nutrient concentrations in tab. E-3 refer to all nutrient concentrations observed up to 2009. Fig. E-8 and Fig. E-9 present summer values for nitrite since 2000, e.g. the values most critical for the present day river biota. The median nitrite concentration exceeded the 50µg/l NO2-N threshold at fish zone “epipotamal small”, where values reached a maximum close to 150µg/l NO2-N. For the larger rivers the situation was less critical, but values close to or above 50µg/l were observed in all fish zones except small and middle-sized streams (epi- and metarhithral). High values were much more common in the lowest elevation class, but several exceptionally high values could be also observed in the intermediate elevation class. Median nitrite concentrations stayed close to zero for all river sites above 700m.

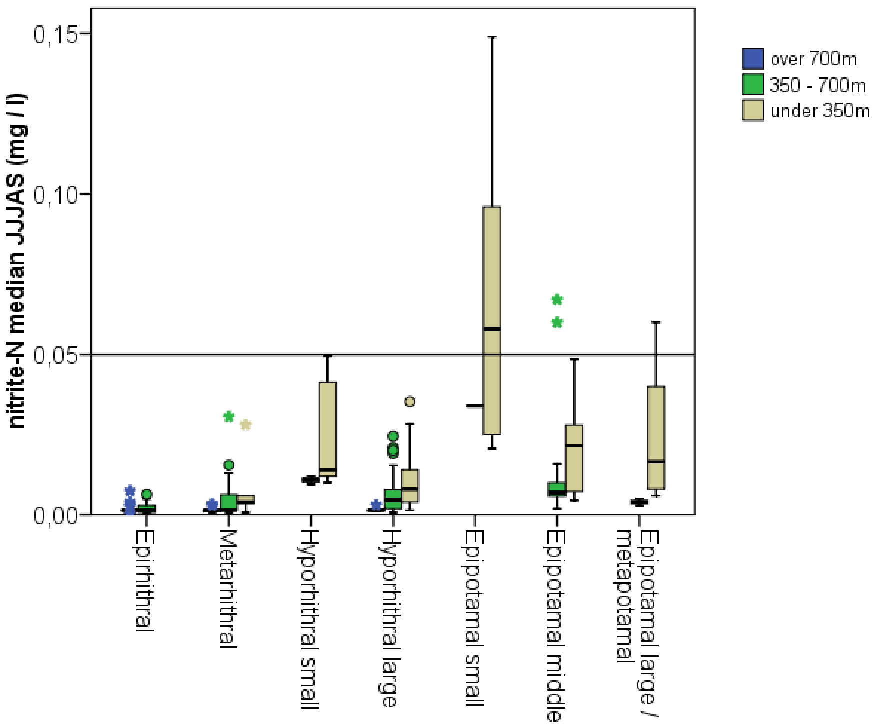

Figure E- 7: Median nitrite concentrations in summer in the different fish zones and for three elevation classes

Legend as in fig. 3

E-5.3 Path analysis for specific discharge and nitrite

Air temperature strongly affects land use: arable land use increases with increasing temperature, whereas the share of woodland shows the opposite trend. Arable land use has a very strong negative effect on discharge, the effect of woodland on discharge is also negative, but much weaker. Wetlands tend to increase specific discharge rates. This effect is weak, but interesting, as it suggests, that wetlands may have a mitigation potential with respect to discharge. The direct effects of air temperature on specific discharge or nitrite concentration are weak, but point in the expected directions (negative effect on discharge, positive effect on nitrite concentration).

Nitrite concentrations are driven by nearly all the variables included in the analysis, and three of the four variables tend to reduce nitrite concentrations.

The path analysis indicates strong indirect effects of air temperature mediated through land use. As arable land use increases in warmer conditions, specific discharge rates drop, while nitrite concentrations increase.

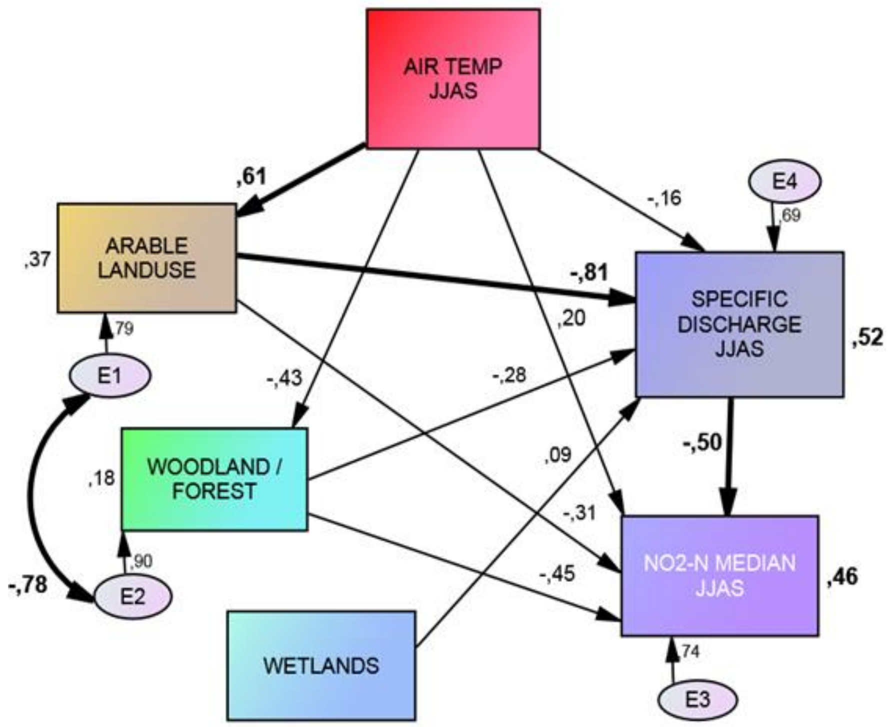

Figure E- 8: Path analysis specific discharge rates and nitrite in summer (below 700m)

specific discharge during summer (log2) - ‘SPECIFIC DISCHARGE JJAS’, air temperature ‘AIR TEMP JJAS’, portion of woodland (logit) – WOODLAND / FOREST’, arable land (logit)-‘ARABLE LANDUSE’ and wetlands - ‘WETLANDS in the catchment; E1 to E4 refer to residuals; numbers near arrows refer to standardized regression coefficients or correlation; see also explanations in methods section

E-5.4 Distribution of target fish species

E-5.4.1 Status quo of fish distribution

The seven species investigated were encountered at 24% to 70% of the river sites (N=93). Their distribution patterns match the expected trends: salmonids can be found in the majority of rhithral (=stream) stretches, whereas the cyprinids are mainly encountered in potamal (=river) regions. The brown trout is exceptional: while it is mainly found in streams, as expected, it can also be found in a high percentage of the larger rivers. The Danube salmon was found in a quarter of the river sites within its reported historic biogeographic distribution range (Hinterhofer, 2011). The grayling occupied 37% of the river sites, including sites in larger rivers.

The fish zone 'Epipotamal small' showed an impoverished fish fauna, as the topmouth gudgeon was found in four out of five river locations, whereas the barbel was found only at one site and the nase carp in none of these sites

Table E- 5: Percentage of river sites with fish species present at the various fish zones

	n	brown trout	rainbow trout	grayling	Danube salmon * ²	barbel	nase carp	topmouth gudgeon *
Epirhithral	6	100	17	17		0	0	0
Metarhithral	17	82	76	41	0	0	0	6
Hyporhithral small	3	67	0	33		0	33	33
Hyporhithral large	26	85	77	58	25	27	8	4
Epipotamal small	5	0	0	0		20	0	80
Epipotamal middle	21	71	24	24	17	81	71	48
Epipotamal large / metapotamal	15	40	33	33	38	73	73	33
total	**93**	**70**	**47**	**37**	**24**	**39**	**31**	**24**

Danube salmon + topmouth gudgeon: species present = at least one individual observed *

Definition for species presence for other species = see materials and methods

Danube salmon – percentages refer to the 29 river sites within its historic distribution range ²

The logistic regression models were based on the framework shown in Fig. E-8. The portion of un-impounded river stretch and portion of river stretch without water abstraction were highly correlated. Accordingly, only one variable of each pair is likely be used as explanatory variable in the model. For specific discharge and nitrite concentration residuals from regressions were used to make sure, that the effect of specific discharge or nitrite concentration, respectively, was documented in the analysis and not the effect of another strongly correlated environmental variables (e.g. temperature for specific discharge or specific discharge for nitrite concentration).

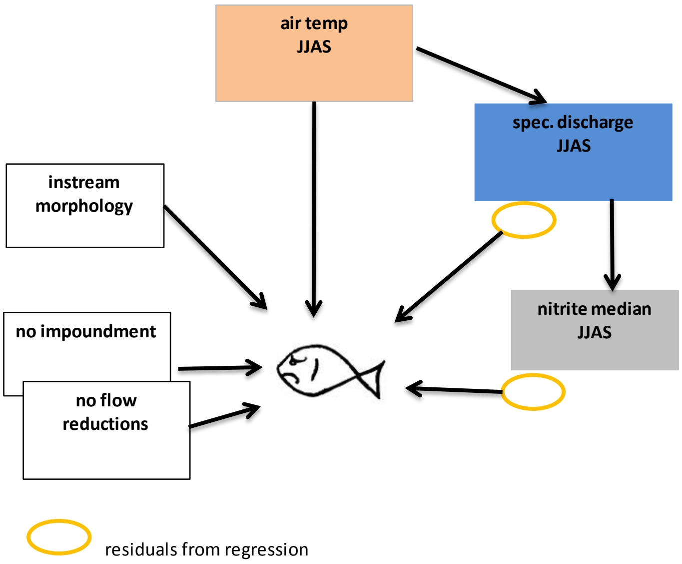

Figure E- 8: Explanatory variables used for logistic regression analysis of 7 fish species

All explanatory variables were transformed to make the resulting regression coefficients comparable. Residuals from regressions with air temperature (specific discharge) or specific discharge (median nitrite) were used.

The logistic regressions were able to explain the occurrence of all seven species. Air temperature showed the expected effects: lower temperatures favor the occurrence of brown trout, rainbow trout and grayling, whereas higher temperatures favor the occurrence of the cyprinids. No temperature effect could be detected for the Danube salmon, but this may be due to the much lower number of sampling sites and their restricted distribution range.

The specific discharge rates are important for all species. All species except the topmouth gudgeon prefer river sites with relatively high specific discharge rates. All four species exhibiting spawning migrations (grayling, Danube salmon, barbel and nase carp) are obviously affected by the hydro-morphological alterations (e.g. impoundments and/or water abstraction). The topmouth gudgeon also showed a negative effect of hydro-morphological alterations.

The brown trout and grayling are positively affected by natural in-stream river morphology which is in agreement with expectations. Interestingly the topmouth gudgeon was also affected by river morphology.

Table E- 6: Regression coefficients for logistic regressions explaining fish species presence/absence

species	n	% correct	p	air temp JJAS	spec. discharge JJAS	nitrite median JJAS	no impoundment	no flow restrictions	instream morphology	constant
brown trout	81	84	**0.000**	**-6.653**	**8.273**	-163.7			7.239	**1.602**
rainbow trout	81	74	**0.000**	**-4.562**	**8.183**					**-0.173**
grayling	81	72	**0.000**	-3.387	**9.378**	**-539.9**		**1.917**	4.388	**-0.749**
Danube salmon	29	83	**0.036**		20.679	-1258.2	5.4411			**-2.21**
barbel	81	78	**0.000**	**15.681**	**6.005**	-213.4	1.271			**-1.129**
nase carp	81	79	**0.000**	**9.540**	2.789	-246.0		**3.387**		**-1.220**
topmouth gudgeon	81	86	**0.000**	**17.007**	-3.803			**5.214**	9.403	**-2.511**

n – number of observations, % correct - % of observations correctly assigned by analysis; p – probability for respective logistic regression; numbers - regression coefficients; explanatory variables were transformed for easier interpretation of results; spec. discharge and nitrite median are residuals (as in fig. E 8); bold numbers indicate $p<0.05$ for respective parameter / regression

The majority of the species shows a negative effect of nitrite concentrations (as residuals from discharge) on the probability of occurrence. The effect is clearest for the grayling, but even the typical riverine species barbel and nase carp may be affected.

Fish species negatively affected by air temperature and/or nitrite concentrations and positively affected by specific discharge rates are likely to suffer from direct effects of climate change. Among the cold-water fish brown trout and grayling are negatively affected by all 3 environmental factors, rainbow trout and the Danube salmon by two factors.

Barbel and nase carp may or may not profit from climate changes, depending on whether increasing water temperature or decreasing specific discharge rates and increasing nitrite concentrations are more important. The topmouth gudgeon is very likely to profit from climate change.

Fig. E-9 highlights the sensitivity of the species to the interplay of specific discharge and summer temperatures. The regression parameters for temperature and specific discharge rates given in tab. E-6 were used to plot probability of occurrence for one situation with relatively low specific discharge rate and one situation with relatively high specific discharge rate (Quartile25% and Quartile75% of specific discharge rates for river sites where the respective species does occur). All other environmental factors were assumed to have mean values (=0). Clearly specific discharge strongly affects the critical summer temperature values for the cold-water fish, especially grayling. When specific discharge is low, summer temperatures below 15°C could be critical for the grayling (= its probability of occurrence is predicted to be below 0.5 by the logistic regression), whereas temperatures up to 18°C are not critical, when specific discharge rates are high. Similar results are obtained for the brown trout and for the rainbow trout. On the other hand, specific discharge has only a small effect on critical summer temperature for all 3 cyprinid species.

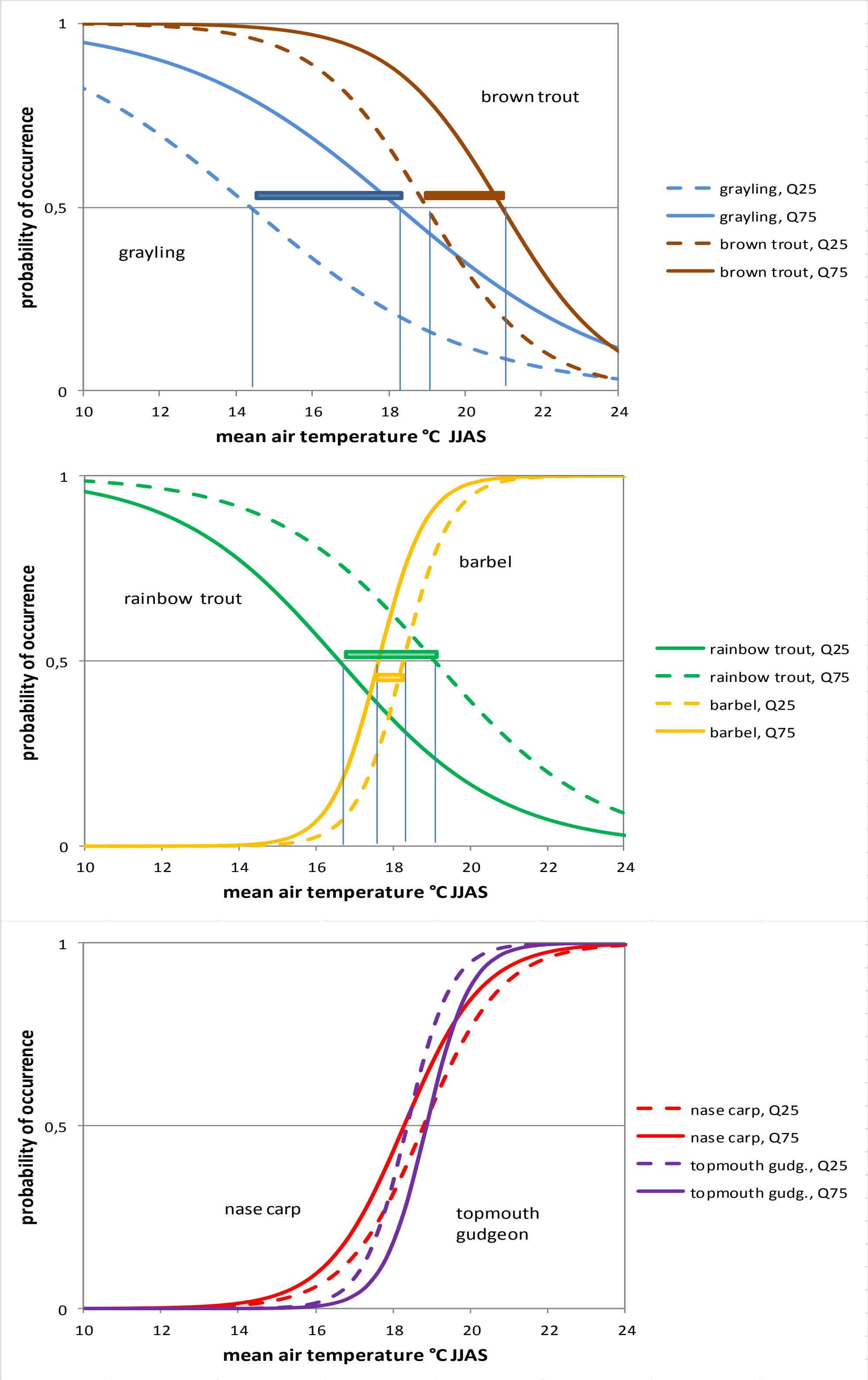

Figure E- 9: Species specific critical summer temperature and specific discharge

Colored bars indicate the temperature range between upper and lower critical summer temperature; 75% Q, 25% Q – 75% and 25% quartile of spec. discharge for the respective species; probability below 0.5 indicates species not present according to logistic regression; all influential variables except temperature and spec. discharge set to 0 (=average value); colored bars not drawn in lowest panel for clarity

Due to the analytical approach it was not possible to determine critical values for nitrite concentrations from the results presented in tab. E-6 (use of residuals). Therefore a logistic regression using nitrite concentration as explanatory variable was established for the grayling. Based on this regression analysis, a threshold of 5 µg / l NO2-N was established for the presence of grayling; at a nitrite concentration of 10 µg / l NO2-N the probability to find graylings drops below 40%. These values are well below the 50 µg / l NO2-N Eddy & Williams (1987) reported for salmonids.

E-5.5 Future projections

E-5.5.1 Summer temperature

The increases in summer temperature based on the A1b scenario were mainly within a range of +3 to +4 °C. For individual locations increases up to 5°C were modeled. The modeled increases exhibit wider ranges in streams (especially Epi- and Metarhithal),. The temperature increase showed similar patterns for high elevation (>700m) compared to lower elevation.

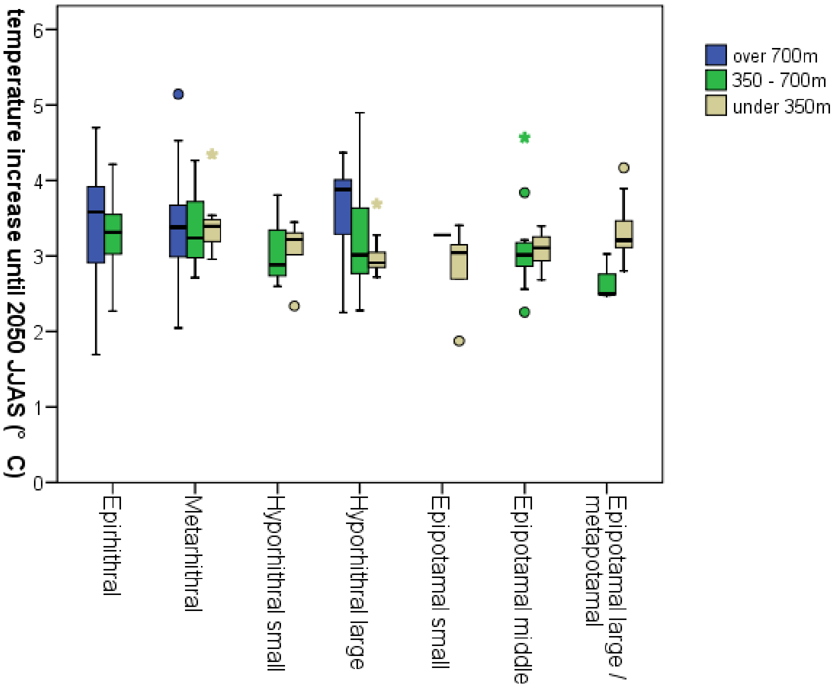

Figure E- 10: Modelled temperature increases for 2050 (A1b)

Legend as in fig. 2

Water temperature in streams and rivers follows air temperature, when an appropriate time scale is applied (for example monthly means, Caissie, 2006), but the slope of a regression air temperature (explanatory variable) versus water temperature (response variable) is lower than 1. Morrell et al. (2005) found the relation water temperature = 2.56 + 0.71 x air temperature, combining information from over 40 streams, e.g. mean air temperature values of 20°C result in 16.7 °C water temperature; for air temperature values of 25°C a water temperature of approx. 20°C can be postulated.

E-5.5.2 Specific discharge rates in summer

Scenario I, II and III differ strikingly in their outcome, especially in smaller streams: here discharge rates may not change dramatically, unless land use changes. The results for scenario I do hardly differ from the status quo in small streams (Fig. E-11). As rivers get larger, the results for all scenarios indicate a reduction in discharge rates compared to the status quo. Large rivers will experience a considerable loss in discharge rate according to all scenarios (fig. E-12).

Scenario II is consistently reporting the lowest discharge rates within a fish region.

Comparing A, B and C scenarios indicates the mitigation potential of wetlands: under most conditions, the B-scenario has better results than scenario C and A, but in larger rivers scenario C is clearly the best option.

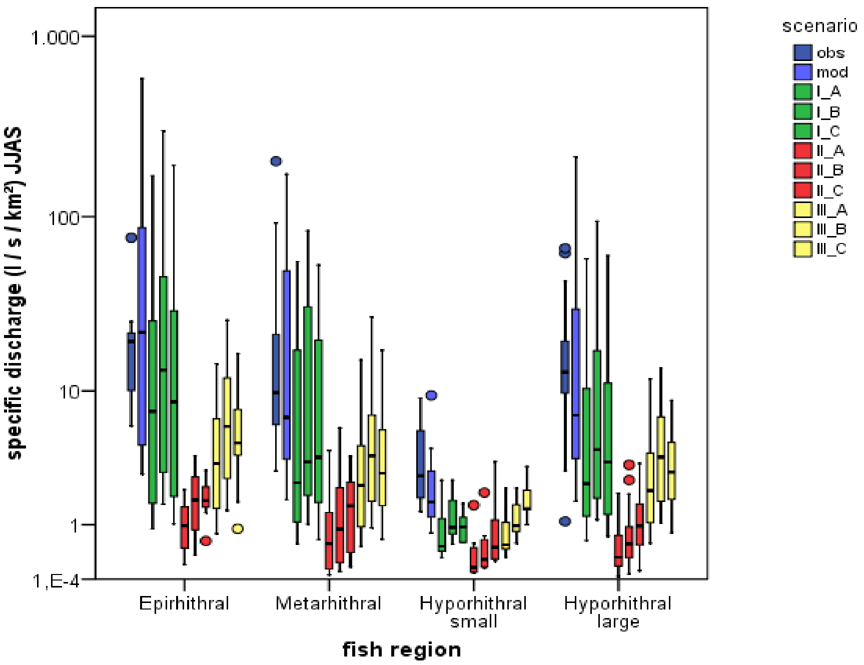

Figure E- 11: Modelled specific discharge rates in summer (JJAS): status quo and future (2050) in streams

river sites below 700m elevation and with rain-dominated hydraulic regime

obs – observed values, mod – modeled according to I_A, temperature as in status quo, I_A to III_C – scenarios for 2050

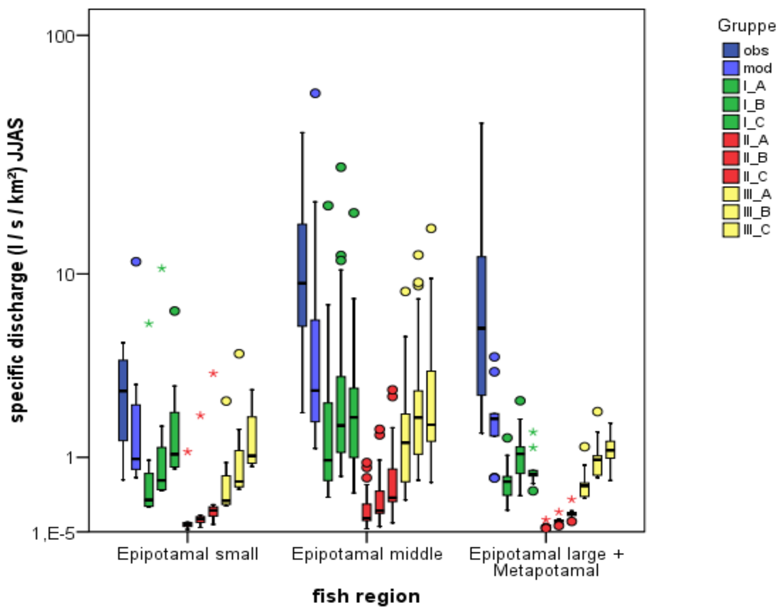

Figure E- 12: Modelled specific discharge rates in summer (JJAS): status quo and future (2050) in rivers

river sites below 700m elevation and with rain-dominated hydraulic regime

obs – observed values, mod – modeled according to I_A, temperature as in status quo, I_A to III_C – scenarios for 2050

Nitrite concentrations in summer

Fig. E-13 und E14 reveal, that nitrite concentrations in summer will increase considerably according to all scenarios. However, the expected changes in nitrite will be substantially different between fish zones: while rhithral zones show little overlap between the present situation and the scenarios for the 2050s (e.g. the rise in nitrite concentrations will be substantial), two potamal zones (epipotamal small and large) do already show elevated median nitrite concentrations in the present day situation (observed values). This makes it harder to interpret the nitrite concentrations modeled for the future.

Scenarios II and III showed consistently higher nitrite concentrations than scenario I, e.g. a higher share of arable land use in the catchment results in substantially increased nitrite concentrations in all catchment areas, whereas temperature increase without changes in land use has less effect.

The nitrite concentrations derived from all scenarios are rarely above the 50 µg / l threshold reported for salmonids, but nitrite concentrations, where grayling may survive (10µg/ l NO2-N) are only found under the assumptions of scenario I and are restricted to the fish regions epirhithral and metarhithral.

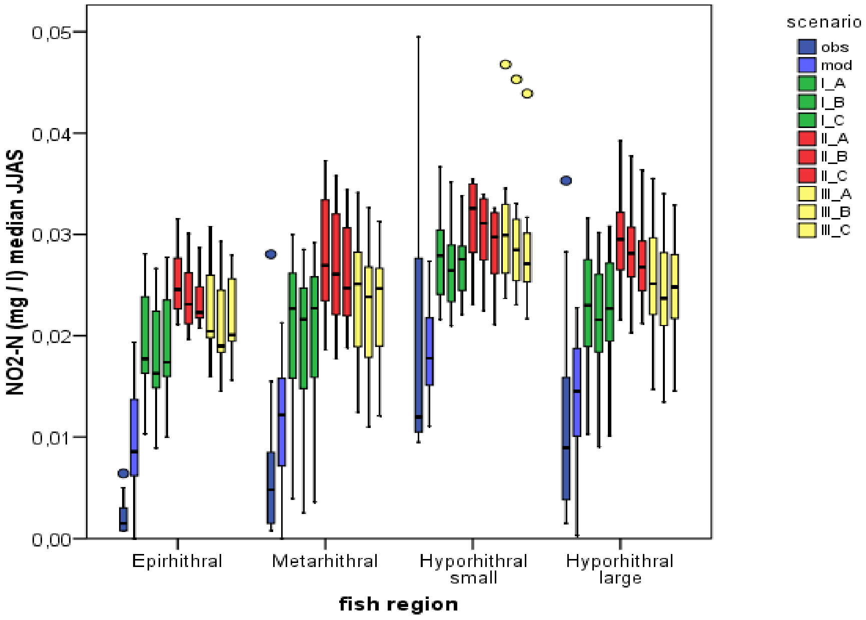

Figure E- 13: Modelled nitrite concentrations in summer (JJAS): comparing status quo and future (2050) in streams

river sites below 700m elevation and with rain-dominated hydraulic regime; see also legends fig. 2 and 12

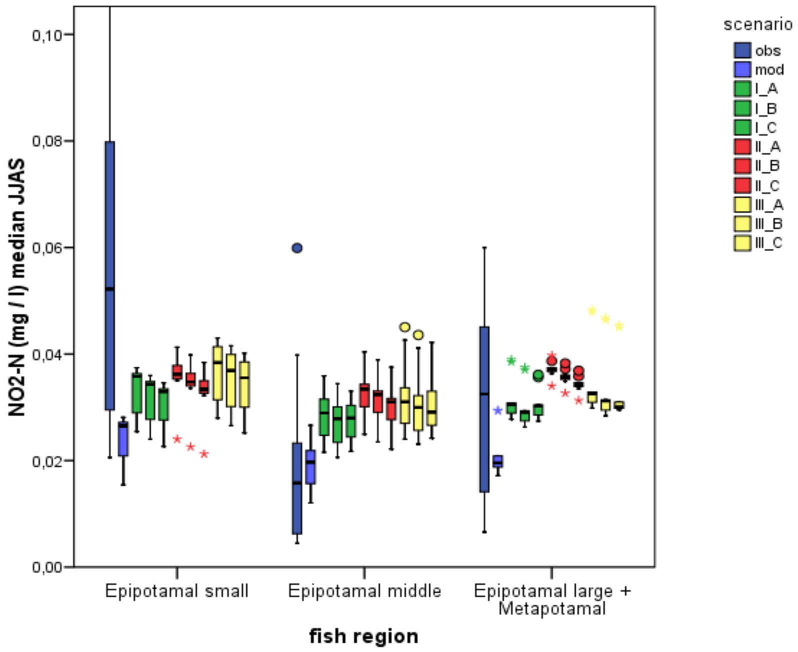

Figure E- 14: : Modelled nitrite concentrations in summer (JJAS): comparing status quo and future (2050) in rivers

river sites below 700m elevation and with rain-dominated hydraulic regime; see also legend fig. E-2 and E-12

E-5.5.3 Future distribution of fish species

E-5.5.3.1 Criterium: air temperature

Based on the different species specific temperature thresholds for low and high discharge situations presented in fig. E-9 presence/absence was calculated for the 6 fish species for the status quo and for the future. In tab. E-7 the results are summarized. The status quo situation - expressed as proportion of river sites where the species ought to occur according to temperature conditions – is presented in the right hand columns (grey background) to allow easy comparison with the results for 2050. According to these findings grayling and rainbow trout will be lost from the river sites investigated (below 700m, pluvial discharge regime) regardless of flow rates. The situation is less dramatic for the brown trout, which will be found in the small streams, when discharge conditions are favorable.

For the eurytopic cyprinids the trends are also spectacular: there are only very few river sites, from which cyprinids are excluded due to temperature in the future, whereas all three species are excluded from small streams by low summer temperatures (according to the model).

Table E- 7: Presence of fish species modeled from summer air temperature for

A) Cold-water fish and B) eurytopic species

A)	GRAYLING				BROWN TROUT				RAINBOW TROUT			
	LOW Q		HIGH Q		LOW Q		HIGH Q		LOW Q		HIGH Q	
epirhithral	0.00	0.00	1.00	0.00	1.00	0.00	1.00	0.89	0.67	0.00	1.00	0.00
metarhithral	0.00	0.00	0.75	0.00	0.95	0.10	1.00	0.65	0.25	0.00	0.95	0.10
hyporhithral small	0.00	0.00	0.38	0.00	1.00	0.00	1.00	0.38	0.00	0.00	1.00	0.00
hyporhithral large	0.00	0.00	0.54	0.00	0.89	0.00	1.00	0.61	0.14	0.00	0.89	0.00
epipotamal small	0.00	0.00	0.14	0.00	0.43	0.00	1.00	0.14	0.14	0.00	0.43	0.00
epipotamal middle	0.00	0.00	0.29	0.00	0.90	0.00	1.00	0.23	0.00	0.00	0.90	0.00
epipot. large + meta	0.00	0.00	0.00	0.00	0.44	0.00	1.00	0.00	0.00	0.00	0.44	0.00

B)	BARBEL				NASE CARP				TOPMOUTH G.			
	LOW Q		HIGH Q		LOW Q		HIGH Q		LOW Q		HIGH Q	
epirhithral	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	0.89
metarhithral	0.05	1.00	0.25	1.00	0.05	0.90	0.05	1.00	0.05	1.00	0.05	0.85
hyporhithral small	0.38	1.00	0.63	1.00	0.00	1.00	0.38	1.00	0.13	1.00	0.00	1.00
hyporhithral large	0.18	1.00	0.32	1.00	0.11	1.00	0.18	1.00	0.18	1.00	0.11	1.00
epipotamal small	0.86	1.00	0.86	1.00	0.43	1.00	0.86	1.00	0.71	1.00	0.43	1.00
epipotamal middle	0.35	1.00	0.71	1.00	0.10	1.00	0.35	1.00	0.29	1.00	0.10	1.00
epipot. large + meta	1.00	1.00	1.00	1.00	0.56	1.00	1.00	1.00	0.89	1.00	0.22	1.00

Grey areas – models based on present day temperatures, white background – models based on temperatures from scenario A1b; low / high Q – low / high discharge, respectively

Interestingly the model predictions for the status quo is overall agreement with the actual species distribution patterns (tab. E-5), except for the epipotamal small fish region, where only 2 fish species were actually recorded; the temperature-based model shows, that only the grayling may be missing from this region due to temperature. The topmouth gudgeon should be virtually absent from hyporhithral small due to the temperature conditions, but it is actually found in 33% of the river sites of this category.

E-5.5.3.2 Criteria: nitrite and specific discharge

The situation presented in tab. E-7 does not take into account the effects of summer nitrite concentrations on fish. According to logistic regression a median summer concentration of 5 µg / l NO_2-N is enough to reduce the probability of occurrence for the grayling below 50%. Using 10µg / l NO_2-N (which is equivalent to an approximately 40% probability of occurrence for grayling) as a more realistic threshold, it became clear, that only a few river sites will not have higher nitrite concentrations in the future. If only scenarios with increasing arable land use are considered, none of the river sites in the data set could harbor a grayling population in the future. Increasing the share of wetlands in the catchment area does not help much with respect to nitrite.

When the 50 µ /l NO_2-N threshold suggested for salmonid species by Eddy & Williams (1987) is applied to the data the results are completely different. No scenario came up with nitrite concentrations exceeding this value for any river sites. A few river sites do exceed the 50µ / l NO_2-N threshold at present, but these findings could not be explained by the environmental factors used in the model (path analysis).

It was not possible to obtain species specific threshold values for specific discharge rates (basically a collinearity problem). This is unfortunate, as for all species investigated specific discharge rates are very likely to have at least some effect on their occurrence probability (logistic regression, tab. E-6). Thus, low discharge rates may in fact strongly restrict the distribution of species, which could have expanded their habitat with increasing temperature.

E-6 Discussion

This study used information from a large number of river sites covering a wide range of environmental conditions. The analyses established parsimonious models to predict specific discharge rates, nutrient concentrations and the occurrence of fish species based on a few environmental parameters. For example the variance in median nitrite concentrations during summer could be explained to more than 50% by land use parameters and air temperature. Land use proved to be the key parameter for specific discharge rates in summer. Despite their very small share in the catchment areas wetlands do nevertheless have a noticeable positive effect on summer discharge. Just as arable land wetlands are hot spots of intense evapo-transpiration (f.e. Wetzel, 1983). Their potential in keeping up discharge rates during summer point to their function as natural water storage sites. In middle Europe precipitation is expected to become more intense during winter and to decrease during summer (f.e. Vautard et a., 2014). Therefore the ecosystem services of wetlands will become increasingly critical as climate change intensifies.

Two categories of land use – agriculture and forest - strongly dominate most catchment areas in Austria. However, it is mainly arable land use, which is governing discharge rates in summer according to our analysis. The strong effect of arable land use on discharge rates is unexpected, as direct irrigation is not widely used in Austrian agriculture. However, rapidly growing crop plants may have transpiration rates high enough to seriously affect discharge rates. During the main growing season this effect may be so strong, that the discharge rates of the rivers are affected. Besides, in hot spots of intensive agriculture water can be used for irrigation, especially during summer. This expansion of arable land due to increasing temperature could prove to be a key factor for environmental changes in the course of climate change, as arable land does not only affect discharge rates, but also nutrients.

Nutrient concentrations (long-term median values) in rivers are closely correlated with arable land use. More than 2/3 of the variance in nitrate concentrations and more than half of the variance in PO4-P-concentrations is explained by the percentage of arable land in the catchment are. The values for the other nutrient fractions investigated were less spectacular, but were not below 20% explained variance. When arable land use increases due to climate change, higher nutrient supply to the rivers can be seen as an indirect effect of climate change. While this “eutrophication effect” is not directly harmful to aquatic life, increasing nitrite concentrations can directly harm river biota.

Especially nitrite concentrations during summer are potentially harmful to aquatic life in general, salmonids being especially susceptible. Woodland proved to have a strong negative effect on nitrite concentrations, most likely due to the retention of nitrogen in woodland soil during summer. Agriculture has an indirect positive effect on nitrite concentrations through lowering discharge rates in summer. Interestingly there is also a weak negative effect of arable land use on nitrite during summer, e.g. arable land may act as a nitrogen sink during the main vegetation period. All scenarios modelling summer nitrite concentrations in 2050 revealed considerably increasing concentrations. The modeled maximum nitrite concentrations differ somewhat scenarios, but it river stretches with low nitrite concentrations (< 10µg / l NO2-N) will become exceedingly rare, especially in larger rivers. Interestingly the fish region with the highest nitrite concentration at present - epipotamal small - shows already strong signs of a depleted fish fauna.

The occurrence of fish species is directly linked to the temperature conditions. From the 1990´s onwards negative effects of climate change on cold-water fish species have been postulated, but only recently direct evidence was found in Austria. Melcher et al. (2013) found dramatic changes in the fish community of the Traun below the – increasingly warm – Traunsee. Evidence from the Mur-catchment indicates, that the salmon-zone has already begun to retreat to higher elevations (Mattulla et al., 2007).

The results of this study support evidence for negative effects of climate change on the fish fauna. Logistic regression analysis established for 7 fish species revealed the expected effects of summer temperature on the occurrence of fish: the cold-water species were clearly negatively affected by increasing temperature, whereas the cyprinid species typical for potamal regions are favored by warmer temperatures. Interestingly discharge rates proved to be also extremely important for the occurrence of fish species: for most species more water increases the likelihood of occurrence. Discharge rates do also modify the critical temperature values for cold-water fish: when discharge is higher, higher air temperatures can be tolerated. When discharge rates are low, water temperature adjusts more quickly to hot summer air temperatures. Besides, rivers with low discharge rates are likely to have less regions of turbulent water and thus less gas exchange with the atmosphere. Together with increased respiration rates due to high temperatures this might even result in a strong reduction of oxygen concentrations in the river. Elliott (2000) found reduced oxygen contents (1.2-2.5 mg/l O2) and high water temperature (24-29°C) in small pool habitats in a small English river during drought conditions. Brown trout did not inhabit the smallest – e.g. warmest – pools during this period. These conditions are likely to be a preview of the future under climate change. Reduced discharge rates in summer do not only reduce the aquatic habitat, they also make a large portion of this habitat unfavorable for cold-water fish.

The critical temperature values (air temperature) for the fish species detected by our analysis were close to water temperatures known to be physiologically limiting to early (subadult) stages of the respective species, but far away from lethal temperatures. For example: the grayling stops growth at temperatures above 17° (mean summer temperatures, Persat & Pattee, 1981), our critical values were between 14.5 and 17.8°C air temperature depending on discharge. Subadult brown trout do not exhibit physiological difficulties below 19°C (Elliott & Elliott, 2010), which is near to the upper critical value of our analysis (20.7°C). Temperature requirements for young-of-the-year nase carp have been investigated in detail (Kamler et al., 1998): the juvenile stage (dominating in summer) grows best at temperatures above 18°C, but has no difficulties to grow at 16°C. According to our analysis the probability of occurrence for nase carp drops considerably just below 18°C. Assuming, that water temperature is approx. 2 °C lower than air temperatures, the cold-water species do not seem to completely exploit the habitats, where temperature conditions are favorable for growth. This may be an indication of additional stress factors for trout and grayling. Additional stress factors may eliminate a fish species from an area, where temperature conditions might be still tolerable. Nitrite may be such an additional stress factor. On the other hand, the critical temperature values for the nase carp is likely to be close to temperature limits for optimal growth of juvenile fishes.

The temperature-based models developed for the occurrence of 6 fish species was in close agreement with expectations: brown trout and rainbow trout will lose habitat. Unfortunately the future for grayling looks bleak, at least in the rivers used for the detailed analysis (e.g. mainly lowland rivers with pluvial hydrological regime). In contrast, barbel and the nase carp will gain habitat. In fact the analysis suggests, that all the river sites in our investigation will be available for the species in 2050. However, our study did not investigate limitations by low discharge rates and critical upper temperature values for barbel and the nase carp. With maximum increases in air temperatures up to approx. 5°C summer temperatures may become even too hot for barbel and the nase carp. Besides, not all potamal species are warm-water adapted. For example, a common predatory species, the burbot *(Lota lota*) is a coldwater species, which passes the summer in an state of low activity. It seems doubtful, that this potentially important species does survive in warmer rivers. Shifts and replacements within the potamal fish assemblage can be expected.

Our results highlighted that in the present situation specific discharge rates as well nitrite concentrations are mainly driven by land-use, e.g. temperature is mainly effective through its influence on land use. Two third of our scenarios (B and C) investigate the effect of wetland land use. Wetlands presently make up only tiny fragments of the catchment areas. The maximum percentage observed is less than 4%. Despite its low share in the discharge area wetlands can have a positive effect on specific discharge rates in the summer – with effects potentially cascading to nitrite concentration and fish species distribution. Tab. E-10 gives a summary of effects expected from climate change, where they will occur and whether increasing the share of wetland could help.

Table E- 8: Expected changes due to climate change and mitigation potential of wetlands

Type of river	Expected change	Mitigation potential of wetlands
Epi- & metarhithral	Reduction of discharge in summer	Yes, especially for SC B
Epi- & metarhithral	Increasing nitrite concentrations in summer	Slight improvement with SC B
Epi- & metarhithral	Loss of fish species	Not detected
hyporhithral	Reduction of discharge in summer	Yes, SC B or C
hyporhithral	Increasing nitrite concentrations in summer	Yes, SC B or C
hyporhithral	Loss of fish species	Not detected
Epipotamal small & middle	Reduction of discharge in summer	Yes, SC B or C
Epipotamal small &middle	Increase in nitrite in summer	improvement with SC C
Epipotamal large	Reduction in specific discharge in summer	Yes, SC B or C
Epipotamal large	high nitrite concentrations in summer	Slight improvement with SC B or C

Scenarios B and C assume a considerable expansion of wetlands compared to the current situation, but they are not unrealistic: shares of wetlands of up to 2% for the respective catchment area. These values are on the upper end with respect to the extent of wetlands observed today. Tab. E-10 summarizes the results derived from the scenarios: no type of stream or river will remain unaffected by climate change, but the problems are not the same. Reductions in specific discharge rates seem to be most dramatic for the largest running water systems. According to the scenarios increasing the extent of wetlands is an interesting option for mitigation, especially for discharge rates in large rivers. On the other hand, increasing nitrite concentrations are most likely a problem for all types of rivers. Increasing the share of wetlands will lead to slightly lower nitrite concentrations, but will not keep nitrite the low level currently typical for most running water systems. This is unfortunate, as even low nitrite concentrations may cause serious problems to sensitive species, if the findings for grayling are typical for other species. Generally wetlands are unlikely to save the threatened cold-water fish fauna. Other strategies have to be applied for these problems.

Our study indicates strong and sometimes unexpected links between land use, nutrient concentrations and discharge rates. Air temperature is an obvious ecological driver for fish, but may be even more important due to its indirect effects (for example on discharge rates). Further studies are urgently needed in this field, which may help to find mitigation measures for ongoing climate change.

E-7 Conclusions

- Rhithral fish species are likely to lose habitat, while potamal species are likely to gain habitat.
- Nitrite concentrations in summer will increase due to climate change
- Increased nitrite concentrations will have negative effects, but more so on rhithral species; high nitrite concentrations in summer can be expected, especially in larger rivers
- The effect of these higher nitrite concentrations remains unclear. While logistic regressions showed an impact of nitrite even on cyprinid fish, nitrite concentrations will be below the threshold values reported for salmonid fish communities.
- Arable land use may enhance effects of climate change by reducing summer discharge rates and increased nutrient concentrations
- Increasing the share of wetlands could counteract some of the negative climate change effects, but detailed planning is necessary
- Indirect effects of climate change – usually involving land use changes were detected. Further studies are urgently needed

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E-9 Abbildungs- und Tabellenverzeichnis

E-9.1 Abbildungen

E-9.2 Tabellen