University of Natural Resources
and Life Sciences, Vienna

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH, NEW ZEALAND

DEVELOPMENT OF EMPIRICAL WATER-TEMPERATURE MODELS FOR AUSTRIAN RIVERS IN ORDER TO PREDICT EFFECTS OF CLIMATE CHANGE ON FISH POPULATIONS

Master Thesis in part fulfilment of the international Master Degree Natural Resource Management and Ecological Engineering submitted by:

Lisa Andrea Steurer

Supervisors:

Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Stefan Schmutz
Institute of Hydrobiology and Aquatic Ecosystem Management
University of Natural Resources and Life Sciences, Vienna, Austria

Ken Hughey B.A. M.Sc. Dip.Tchg. Ph.D. (Cant)
Faculty of Environment, Society and Design
Lincoln University, Canterbury, New Zealand

Co-supervisor:

Dipl.-Ing. Florian Pletterbauer
Institute of Hydrobiology and Aquatic Ecosystem Management
University of Natural Resources and Life Sciences, Vienna, Austria

Student ID Boku: 0941670

Vienna, January 2012

Acknowledgements

The following pages would not be filled if I had not been supported by a number of people, who I would like to show my appreciation with the following lines.

At the University of Natural Resources and Life Sciences, I would like to thank my co-supervisor Florian Pletterbauer for his tremendous and valuable support and advice, which went way beyond the self-evident. Furthermore, I would like thank my supervisor Stefan Schmutz for his crucial suggestions as well as Erwin Lautsch for the time he invested in helping me with the statistical analysis and methodology. Franziska Schmuttermeier and Martin Seebacher are to be thanked for the administrative and computer related support, without whom this thesis would not have been finished in the time it was. And for the friendly acceptance and support I would like to show my great appreciation to the entire ground floor office of the Institute for Hydrobiology and Aquatic Ecosystems Management.

At the Lincoln University, I would like to thank my advisor Ken Hughey for his support and time invested, and express my appreciation to Graham Barell and Ian Spellerberg for the advice and administrative support during and after my time at Lincoln.

For providing the water and air temperature, as well as discharge data, I would like to thank the Hydrographisches Zentralbüro and the Zentralanstalt für Meteorologie und Geodynamik, in particular Herbert Formayr at the Institute of Meteorology (BOKU).

Without their support, the timely completion of my thesis and consequently my Master Degree would not have been possible.

As these pages also constitute the end of my University career, I would like to take this opportunity to express special thanks to the two people without whom I would not have been able to get to this point: my parents, Madeleine and Roland Steurer, as they are the ones who made it possible for me to study and who always reassured me in my ideas and decisions. Last but not least I would like to thank Johannes Frey in particular for his amazing support and patience as well as my friends for their encouraging words and actions.

Abstract

Abiotic factors such as air temperature and catchment size define stream temperature, which in turn delineates fish species composition. Climate change is expected to result in increasing water temperatures and therefore an altered biocoenotic distribution and eventual species extinction. On the basis of water temperature data from 1997 to 2008 and influential abiotic factors, water temperature models for Austrian rivers were developed. Two approaches were followed: the first being a multiple regression analysis incorporating mean catchment air temperature, altitude, distance from the source and catchment size, and the second being a cross tabulation matrix based on air temperature, altitude and distance from the source, explaining up to 83% and 62% of the stream temperature's variance in the summer months respectively. The estimated water temperatures showed a significant correlation with the Fish Zone Indices as well as Salmonidae/Cyprinidae proportions, allowing defined temperatures to be assigned to the individual fish regions and families. Modeled future air temperatures for the IPCC scenarios were used to predict water temperatures and subsequent fish assemblages under the influence of climate change. A mean stream temperature increase of at least 4°C by the 2080s was estimated, and a distinct shift from a Salmonidae to a Cyprinidae dominance in Austria's waters predicted.

Kurzzusammenfassung

Fließgewässertemperatur ist von abiotischen Faktoren wie Lufttemperatur, Einzugsgebietsgröße und Durchfluss abhängig, und prägt unter anderem die Fischfauna in Flüssen. Daher ist zu erwarten, dass erhöte Temperaturen als Folge des Klimawandels zu Veränderungen in der Fischbiozönose führen. Auf Basis von Wassertemperaturdaten von 1997 bis 2008 sowie abiotischen Kenngrößen, wie Einzugsgebietsgröße und Seehöhe, wurden Wassertemperaturmodelle für Österreichs Flüsse entwickelt. Dabei wurden zwei Ansätze verfolgt: (1) die Entwicklung eines multiplen Regressionsmodells mit der mittleren Lufttemperatur im flussaufgelegenen Einzugsgebiet, Seehöhe, Distanz zur Quelle und Einzugsgebietgröße als unabhängige Variablen, und (2) die Entwicklung einer Kreuztabellenmatrix basierend auf mittlerer Lufttemperatur, Seehöhe und Distanz zur Quelle. Dabei konnten 83% und 62% der Variabilität der mittleren Wassertemperatur in den Sommermonaten Juni, Juli und August erklärt werden. Die prognostizierten Wassertemperaturen weisen eine signifikante Korrelation mit dem Fischregionsindex sowie dem Salmoniden/Cypriniden Verhältnis auf, wodurch charakteristische Wassertemperaturwerte für die einzelnen Fischregionen und -familien ermittelt werden konnten. Durch die Verwendung von modellierten zukünftigen Lufttemperaturen für verschiedene IPCC Szenarien wurde in Folge eine Erhöhung der mittleren Wassertemperatur im Sommer von mindestens 4℃, sowie eine deutliche Verschiebung der bestehenden Salmoniden- zu einer Cyprinidendominanz in der Artenzusammensetzung österreichischer Fließgewässer in den nächsten 80 Jahren prognostiziert.

Table of Contents

List of Abbreviations

$adjR^2$	Adjusted coefficient of determination
CCM	Catchment Characterization and Modeling
CFA	Confirmatory factor analysis
CIAT	Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture)
DEM	Digital Elevation Model
EFA	Extrapolatory factor analysis
EP	Epipotamal
ER	Epirhithral
EUK	Eucrenal
FI_{sp}	Species specific fish index
FiZI	Fish Zone Index
GCM	Global Circulation Model
GHG	Green-House-Gas
HP	Hypopotamal
HR	Hyporhithral
HYK	Hypocrenal
HZB	Hydrographisches Zentralbüro
IGF	Institut für Gewässerökologie, Fischereibiologie und Seenkunde
IHG	Insitut für Hydrobiologie und Gewässerökologie (Institute of Hydrobiology and Aquatic Ecosystem Management)
IPCC	Intergovernmental Panel on Climate Change
MP	Metapotamal
MR	Metarhithral
NGP	Nationaler Gewässerbewirtschaftungsplan (National Water Management Plan)
R^2	Coefficient of determination
RCM	Regional Climate Model
SCI	Salmonidae/Cyprinidae Index
SDM	Statistical Downscaling Method
SRES	Special Report on Emission Scenarios
UNFCCC	United Nations Framework Convention on Climate Change
WFD	EU Water Framework Directive
WISA	Water Information System Austria
ZAMG	Zentralanstalt für Meteorologie und Geodynamik

1. INTRODUCTION AND PROBLEM DEFINITION

Water temperature is one of the important abiotic factors determining riverine conditions and therefore greatly influences growth rates and the distribution of aquatic organisms (COUTANT, 1990; FICKE *et al.*, 2007). Water temperature itself correlates strongly with air temperature (MOHSENI & STEFAN, 1999) and is therefore predicted to increase with rising global temperatures due to climate change (DAUFRESNE *et al.*, 2003), resulting in a shift of aquatic ecosystems (DAUFRESNE & BOET, 2007) and eventual species extinction (MATULLA *et al.*, 2007).

Empirical water-temperature models have been developed by, among others, WEBB and NOBILIS (1997) and DIAGLE *et al.* (2010) in order to predict stream temperatures for different parts of the world. An empirical model in this sense is defined as a model based on empirical data, which itself is defined as data gained through observation as opposed to theoretical computation. Different kinds of empirical stream temperature model approaches have been used for diverse time scales and geographic distributions where regression models have proven to be most practical for monthly and weekly temperature modeling (BENYAHYA *et al.*, 2007). Other studies have focused on investigating the effect of rising water temperatures on ecosystem composition (MORRILL *et al.*, 2005; FICKE *et al.*, 2007; MATULLA *et al.*, 2007; BUISSON & GRENOUILLET, 2009; BURKHARDT-HOLM, 2009), stressing the point that high temperatures during the summer months are most likely to be the limiting factor in relation to fish distribution.

These points are further explained in the following section, after the objective and theoretical background of this thesis have been defined. The second part then elaborates on the data and methods used, followed by an outline of the results in section three and a discussion thereof in section four.

1.1. OBJECTIVE

The objective of this thesis is to develop an applicable empirical water temperature model for Austrian rivers in order to predict current and future water temperatures taking possible climate change scenarios into account and thereafter predict the effects on fish populations.

After testing and defining abiotic factors which correlate strongly with water temperature, a statistically robust model is to be developed that predicts water temperatures with little deviation and is also practicable in predicting future stream temperatures. Data from measuring points along Austrian rivers will be used to develop and calibrate the model. The model is then to be applied to predict future water temperatures under different climate change scenarios at certain fish sampling points, and to determine the expected fish species compositions at the sites.

Hence the research questions for this thesis are defined as follows:

1. Which abiotic factors influence water temperatures in Austrian rivers?
2. Which abiotic factors, of influence to water temperature, are likely to be affected by climate change, and are there realistic predictions as to what way they are likely to change?
3. What does a statistically robust model to predict water temperatures in Austrian rivers look like?
4. How would the fish assemblages at given fish sampling points change in the future with the predicted water temperatures under the influence of different climate change scenarios?

1.2. WATER TEMPERATURE AND ABIOTIC FACTORS

Abiotic "non-living" and biotic "living" factors influence riverine ecosystems. Abiotic factors are thereby described as the chemical, physical and hydro-morphological factors in water bodies (JUNGWIRTH, 2003) such as temperature, exposition, discharge, elevation or distance from the source.

Stream temperature is in turn influenced by a number of abiotic factors. CAISSIE (2006) classified them into four groups, as shown in figure 1.1:

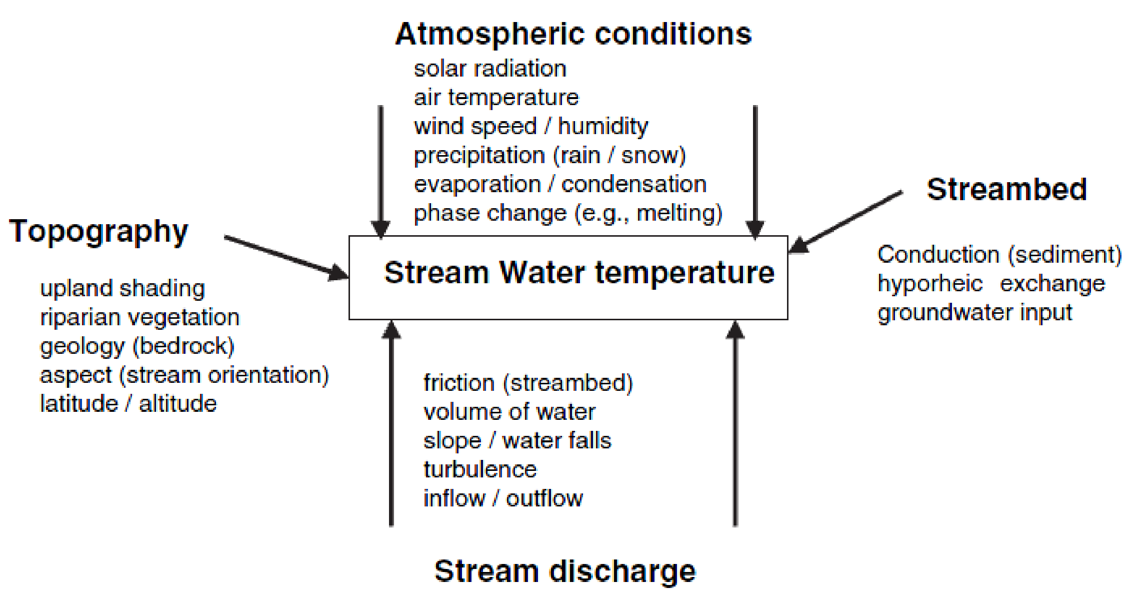


Figure 1.1: Factors influencing the thermal regime of rivers. (CAISSIE, 2006, p. 1391)

He attributes the highest importance to the atmospheric conditions influenced by topography, due to the effect on the heat exchange processes that take place at the surface. Stream discharge in turn mainly influences the heating and cooling capacity of rivers. Due to the nature of these factors which are visualized in figure 1.2 in relation to the longitudinal gradient, streams exhibit a natural temperature variation.

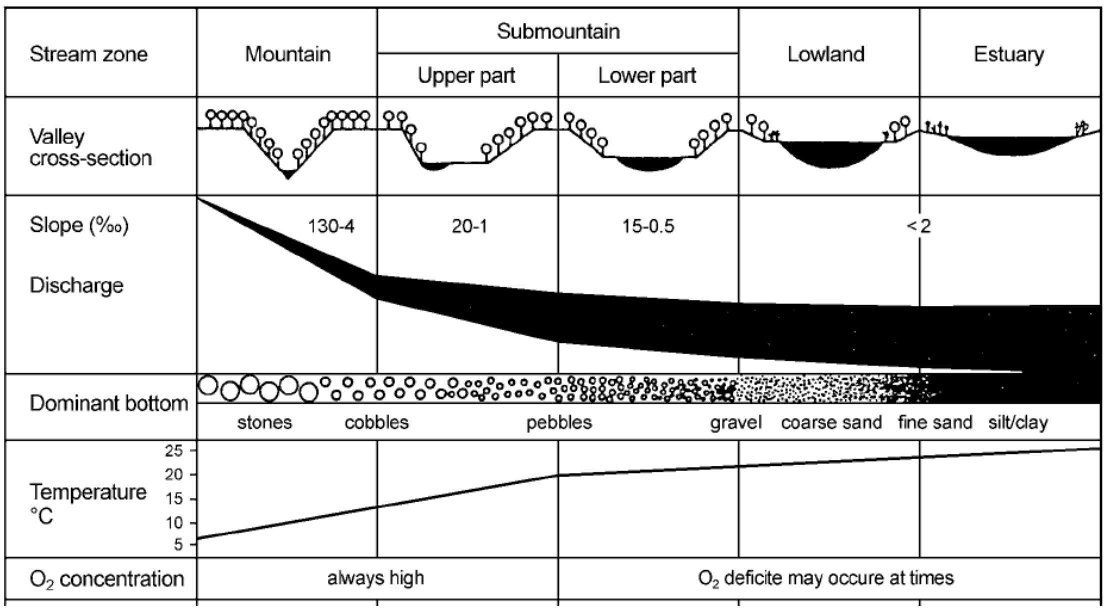


Figure 1.2: Schematic depiction of the river-region-concept under consideration of the main abiotic factors after Witkovsky (Holcik 1989 in: SPINDLER, 1997, p. 32)

River temperature at the source is close to groundwater temperature, which approximately accords to the annual mean air temperature, and increases in a downstream direction (CAISSIE, 2006). However, the increase is not linear but greater for smaller water bodies than for larger ones and factors such as shore vegetation, glacial melt water and lakes have an influence. Canopy cover reduces the downstream water temperature increase, however the influence is again greater on small streams than on large rivers (RUTHERFORD *et al.*, 2004). The water temperature of glacial melt water influenced streams rises during warmer periods, but the downstream temperature increase is reduced due to greater melt water production and consequently a larger total stream flow volume for atmospheric heating and a proportional reduction in groundwater contributions (CADBURY *et al.*, 2008). Lake outlets, on the other hand, have been shown to discharge relatively warm water from the lake's upper water layers and therefore result in an inverted temperature profile in summer: warm water which cools in a downstream direction (PETZ-GLECHER & PETZ, 2005).

Daily fluctuations also increase with distance from the source as ground water influence decreases and exposure to meteorological conditions increases (CAISSIE, 2006). Generally, water temperature reaches its minimum in the early morning and its maximum in the late afternoon (PRATS *et al.*, 2010). Annual temperature fluctuations follow a sinusoidal function with maximum values in summer (CAISSIE, 2006), for central Europe this translates to July and August.

1.3. WATER FRAMEWORK DIRECTIVE

The Water Framework Directive (WFD) is a piece of legislation released by the European Union in October 2000 "establishing a framework for the community action in the field of water policy" (EUROPEAN COMMISSION, 2000, p. 1). It defines quality objectives and methods to reach these aims of the framework and maintain a good ecological status. By replacing seven previous directives it forms one sole legal foundation for all EU-member countries, including Austria, as well as a basis for data harmonization across the continent.

The main goal is to achieve a good ecological status for all European waters within 15 years, with an absolute ban on deterioration of the current ecological statuses. A central point is the river basin approach which, based on a current state analysis, calls for the establishment of guidelines to reach the environmental goals within the given timeline. In this manner each natural geographical and hydrological unit is managed jointly, instead of according to administrative or political boundaries. The basis of this lies in the recognition that "drainage networks and associated drainage networks and basins form complex functional entities not only for hydrological processes but also for environmental processes at large" (VOGT, 2010, p. 1). Comprehensive digital data relating to river networks, drainage basins and their characteristics are required in order to study and manage the underlying processes and effects. For this reason a pan-European database of river networks and catchments, Catchment Characterization and Modeling (CCM) 1.0, was established in 2003 and subsequently updated to CCM 2.0 in 2007 and to CCM 2.1 in 2008. The CCM River Catchment Database 2 (V.2.1) is derived from a Digital Elevation Model (DEM), land cover and climate data and covers the entire pan-European continent. It includes a fully connected hierarchical network of rivers, a nested set of catchments with associated characteristics and the option of locating hydrological monitoring stations (VOGT *et al.*, 2007).

The WFD was written into Austrian law and enforced in December 2003. In order to reach the directive's goals and to fulfill its requirements, every six years the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management releases the National Water Management Plan (NGP). It constitutes a planning manual for a river basin approach and includes a detailed current state analysis as well as the goals to be reached and the measures necessary to do so. The Water Information System Austria (WISA) is the connection between the planning and executing agencies and the public. It distributes information such as the NGP and calls for participation.

1.4. FISH REGIONS AND FISH ZONE INDEX

The composition of fish fauna changes in the course of a river, and over 130 years ago FRITSCH (1872, IN SPINDLER, 1997) introduced the concept of stream zonation based on the longitudinal distribution of riverine organisms. ILLIES (1961) as well as MOOG and WIMMER (1994) refined this biocoenotic zonation and characterized the zones though abiotic factors which include current, substrate and, most importantly, water temperature and slope (HUET, 1959; FINK *et al.*, 2000; MOOG, 2002). Generally, it can be said that the slope decreases from the upper regions (i.e. upper trout region) to the lower regions (i.e. bream region) while temperature and species diversity increase.

Table 1.1 below lists the eight biocoenotic zones relevant for riverine ecosystems, where the first two, the Euceral and Hypoceral, do not carry any fish but are important for benthos organisms (ILLIES, 1961). As there are no Hypopotamal rivers that flow through Austria, the Epirhithral, Mearhithral, Hyporithral, Epipotamal and Metapotamal are the most important biocoenotic regions in relation to fish species and a list of the corresponding species can be found in Annex I. Austrian literature separates large and small Hyporhithral, as well as large, medium and small Epipotamal respectively; however for this thesis the sub classifications will be disregarded.

Table 1.1: Biocoenotic regions, their corresponding dominant fish communities, Fish Region Index and water temperatures (MOOG, 2002, edited; MATULLA et al., 2007).

Bioceoenotic region	Abbreviation	Fish zone	FiZI	Summer mean Temperature (℃)
Euceral	EUK	Mountain spring	1	-
Hypocrenal	HYK	Mountain stream	2	-
Epirhithral	ER	Upper-Trout Region	3	5-10
Metarhithral	MR	Lower-Trout Region	4	5-10
Hyporhithral	HR	Grayling Region	5	8-14
Epipotamal	EP	Barbel Region	6	12-18
Metapotamal	MP	Bream Region	7	16-20
Hypopotamal	HP	Brackish-Water		16-20

Different fish species often occur in more than one of the regions or have their distribution focus in a transition zone between two regions. To describe fish species composition along a stream in a more accurate manner and be able to integrate them into statistical analysis, SCHMUTZ *et al. (2000a)* converted the nominal fish regions into the "Fish Zone Index" (FiZI). The index consists of values from 1 to 7, corresponding to the biocoenotic regions Eucrenal to Metapotamal (see table 1.1), where, as mentioned above, only the regions 3 to 7 are relevant for fish species.

The FiZI is based on a species specific fish index (FI_{sp}) which expresses a fish species' preference for a certain fish region along a water body and which is calculated as follows:

$$FI_{sp}=\frac{3 \times p_3 + 4\times p_4 + 5 \times p_5 + 6 \times p_6 + 7 \times p_7}{100} \qquad [1]$$

FI_{sp}= Species specific fish index

p_i= Frequency of a species in percent where $\sum p_i= 100$

Theoretically the FI_{sp} could take any value between 3 and 7, but in practice there are no species which occur only in one region. The FI_{sp} for the brown trout, for example, is 3,8 since this species prevails in the Rhithral (lower and upper trout region). 60% of graylings, on the other hand, are found in the Hyporhithral, with 20% in the Mearhithral and Epipotamal respectively. The grayling therefore has a FI_{sp} of 5. The roach and the bream both have a FI_{sp} of 6,7, which is the highest in Austria (HUBER, 2008).

Consequently, the FiZI at each point in a river is calculated as follows (MATULLA *et al.*, 2007):

$$FRI= \frac{\sum(\boldsymbol{Nsp} \times \boldsymbol{FIsp})}{\boldsymbol{Ntotal}} \qquad [2]$$

FRI= Fish region index

N_{sp}= Number of individuals of a species

N_{total}= Total number of individuals

1.5. CLIMATE CHANGE AND FISH DISTRIBUTION

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a "change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (IPPC, 2007, p. 30). Human induced or natural changes are thereby not differentiated between, as they are in the United Nations Framework Convention on Climate Change (UNFCCC), where only direct or indirect human induced change is referred to as climate change. Hereafter climate change will be used in the sense as defined by the IPCC.

The main causes of climate change are Green-House-Gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as shown in figure 1.4, which increase the globe's self-heating capacity by absorbing and reflecting outgoing infrared radiation (IPPC, 2007). Even though some factors with an influence on climate change are negative, such as stratospheric ozone or aerosols, and hence exhibit a cooling effect, the overall balance is positive which has led to a general increase in temperature.

Global mean surface temperatures have risen by 0.8℃ over the last 100 years, while the rate of warming over the past 50 years was double that of the previous 100 years (IPPC, 2007). In Austria this temperature rise was more than twice as high, with a 1.8℃ increase at all levels of elevation (KROMP-KOLB, 2003). Global temperatures are expected to continue to rise over the following decades. Since water temperature is, to a certain degree, proportional to air temperature, a water temperature rise has also taken place and is expected to continue analogously (SOLHEIM *et al.*, 2010). However, temperature is not the only factor affected by climate change. Precipitation patterns are also changing and are expected to change further, with a subsequent effect on temperature regimes within streams and therefore fish population (SOLHEIM *et al.*, 2010).

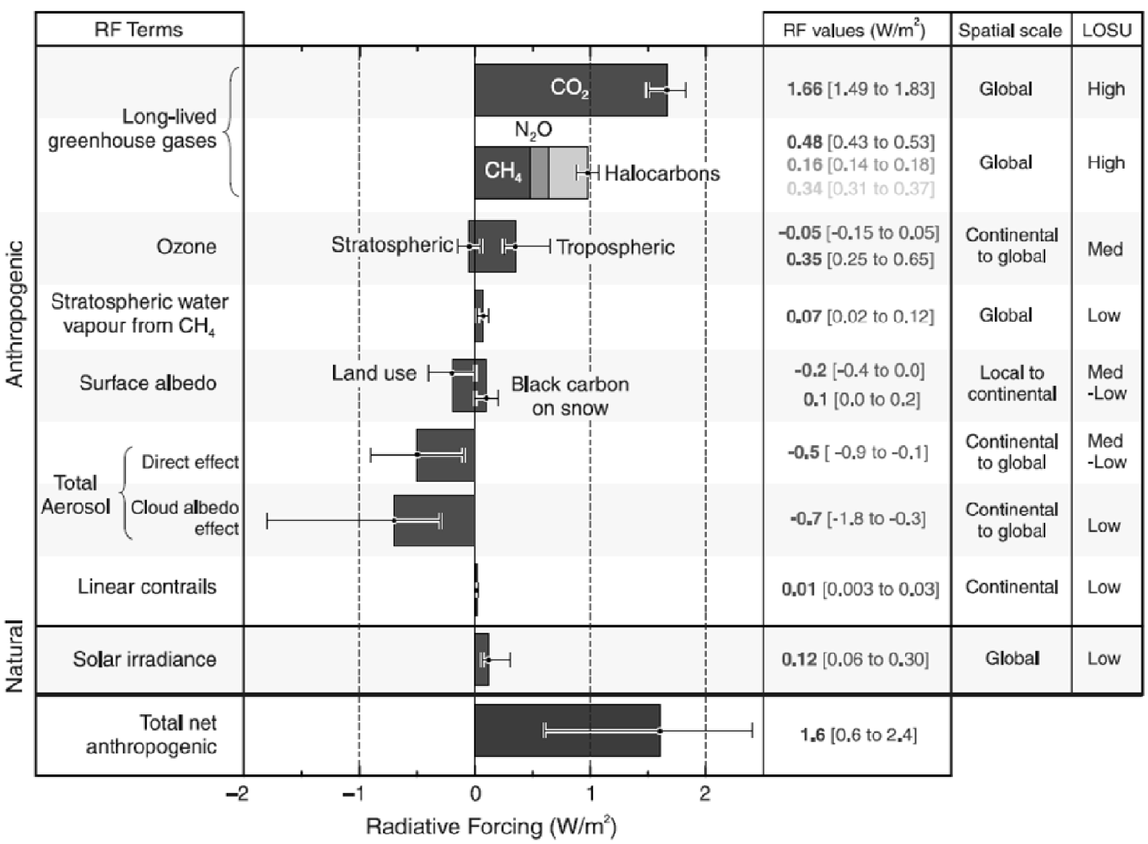


Figure1.4: Radiative forcings in climate between 1750 and 2005 (IPPC, 2007, p. 39)

Freshwater fish are exothermic and cannot regulate their body temperature physiologically, which means that their body temperatures are identical to their environmental temperature (FICKE *et al.*, 2007). They have certain temperature ranges they can tolerate, which determines their distribution (SOLHEIM *et al.*, 2010) and influences their biochemical reaction rates, which subsequently affect growth and reproduction rates (SCHMIDT-NIELSEN, 1997). Even though a certain degree of adaption is possible, rising temperatures affect species distribution and certain species, especially those with a narrow tolerance range, e.g. coldstenothermic, may die out (SCHMIDT-NIELSEN, 1997; FICKE *et al.*, 2007; MATULLA *et al.*, 2007).

Studies that address the issue of fish distribution in relation to climate change have been conducted by, among others, DAUFRESNE *et al.* (2003), BUISSON & GRENOUILLET (2009) and SOLHEIM *et al.* (2010). They conclude that a change in assemblage and distribution is expected, especially on an upstream-downstream gradient. BUISSON and GRENOUILLET (2009) further expect a general increase in fish species diversity, with a decrease in cold water adapted species.

1.6. STREAM TEMPERATURE MODELING APPROACHES

A wide variety of stream temperature models have been developed for different geographic locations. Generally they can all be categorized into two major groups:

1. Deterministic models
2. Statistical models

According to BENYAHYA *et al.* (2007, p. 4) “Deterministic models are based on [the] mathematical representation of the underlying physics of heat exchange between the river and the surrounding environment.” These models require detailed and expansive input data and are generally used when analyzing different impact scenarios. An example of a deterministic model developed and recently modified is the CEQUEAU hydrological and water temperature model (for more information see: CHARBONNEAU *et al.*, 1977).

Statistical models are simpler than deterministic models and thus require less data. They can further be classified as follows:

- 2.1. Parametric models
  - 2.1.1. Regression models
  - 2.1.2. Stochastic models
- 2.2. Non-Parametric models

Regression models are usually used to simulate and predict water temperatures at monthly or weekly time scales while stochastic models are used for shorter time scales. Non-parametric models are not as widely used due to their limited reliability (BENYAHYA *et al.*, 2007).

Regression models are used to predict one variable based on one or more other variables. Stream temperature has often been modeled dependent on air temperature (MOHSENI & STEFAN, 1999; CAISSIE *ET AL.*, 2001). WEBB and NOBILIS (1997), for example, developed a regression model based on monthly mean air temperature with a determination coefficient of 95%. Other studies use two or more parameters such as elevation, discharge or catchment size to predict water temperature with similar determination coefficients (HUBER, 2008; DAIGLE *et al.*, 2010).

Most studies, especially those that use predicted stream temperature to predict fish- or other population distributions, focus on the warm months of the year. The main reason for this is that one of the major limiting factors in species distribution is the maximum tolerated temperature for reproduction (SCHMIDT-NIELSEN, 1997). Furthermore, it has been shown that the air temperature/stream temperature relationship is stronger during the summer months, i.e. with high air temperatures, and weaker in winter, especially if the air temperature drops below zero degrees Celsius (MOHSENI & STEFAN, 1999).

2. DATA AND METHODS

The following section describes the data, it's source and the methods used to fulfill the objective of this thesis. Statistical methods were used to answer research questions one, three and four: (1) which abiotic factors influence water temperature in Austrian rivers?; (3) what does a statistically robust model to predict water temperature in Austrian rivers look like?; (4) how would the fish assemblages at given sampling points change in future with the predicted water temperatures under the influence of different climate change scenarios? Literature research was used to answer research question two: which abiotic factors, of influence to water temperature, are likely to be affected by climate change and are there realistic predictions as to what way they are likely to change?

Since this thesis focuses on available data in large quantities, data management was important. Microsoft Access (MICROSOFT, 2007a) and Excel 2007 (MICROSOFT, 2007b) were used as a database and to review the data, while SPSS©15 (SPSS, 2006) was used for the statistical analysis.

2.1. DATA SOURCES

This thesis is based on data which was made available by a number of institutions or was acquired through literature research and geographical information system (GIS) queries performed in ArcGis 9.3 (ESRI, 2008). Two main categories of data were used: (1) abiotic data which included water temperature, climate records and stream discharge, including corresponding metadata and (2) biotic data which consisted of data describing fish assemblages.

2.1.1. ABIOTIC DATA

Water temperature and stream discharge data was made available by the *Hydrographisches Zentralbüro* (HZB), which is part of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and in charge of surveying the hydrological cycle. The measurement of water temperature, stream discharge and ground water levels is part of this survey. For this thesis, the HZB supplied water temperature data from 117 gauging sites distributed around Austria for the time period of 1976 to 2008. Information regarding the geographic location of each measurement station, including elevation above sea level, the coordinates and the catchment size were also given for each site. Furthermore, a table of measurement times was supplied as temperature had not been gauged at the exact same time at every station over the years. The HZB also supplied discharge data for 96 of the 117 sites in the form of daily mean values for the same time period.

Information on the hydro-morphology of each river section is presented in the NGP made available through the WISA. The report is accessible online and discloses information on, amongst other data, each river section’s chemical, biological and ecological status resulting in an overall condition described by a number between one and five where the lowest number represents the best (i.e. natural) state. Information on whether each section is influenced by impoundment or water abstraction is also available through this report and was extracted together with the hydro-morphology classification for every river section for which water temperature and discharge information was available.

Climate data consisting of monthly mean air temperatures for every year was made available by the *Zentralanstalt für Meteorologie und Geodynamik* (ZAMG), which is the Austrian Central Institute for Meteorology and Geodynamics. The measurement sites of the ZAMG do not always match the HZB-measurement sites. For cases where there was no ZAMG-station at the exact location of an HZB-station, the nearest ZAMG station within up to ten kilometers distance and less than 50m altitude difference was chosen. However, this was not possible for all sites, ultimately only 34. Additional temperature data from the WorldClim database was therefore used (HIJMANS *et al.*, 2005). WorldClim is a freely available set of global climate grids with a spatial resolution of 30 arc seconds (~1km at Equator), which were generated through interpolation of average monthly climate data from weather stations (HIJMANS *et al.*, 2005). The data consists of monthly mean values for the time period 1961-2000 (one value per month and location). In the GIS, monthly mean temperatures were queried for each HZB-site as well as the mean temperature for each site’s upstream catchment. Through the location of the HZB-gauges in the CCM2 (V2.1), the primary catchment of each site could be defined as well as the extent of the upstream basin. Consequently, the mean temperatures for each primary catchment were queried, after which the mean value for all primary catchments comprising the upstream basin was calculated. In this manner the monthly mean WorldClim temperature for each gauge’s catchment was generated.

Additional information relating to river width and stream order (Strahler order) as well as the eco-, bio- and fish regions at the sites of interest, was gathered. Furthermore, those streams that were lake outlets were determined, and the distance to and size of each lake were noted. This information was gathered through literature research and GIS queries based on data available from the WFD, the HZB’s online GIS portal eHYD (accessible at: http://gis.lebensministerium.at/eHYD) and the CCM database. A detailed list of all abiotic data used along with the corresponding sources is available in Annex II.

In order to model stream temperatures under the influence of climate change, predicted future climate data, in particular air temperatures, was required. This data was obtained from the International Center for Tropical Agriculture (Centro Internacional de Agricultura Tropica, CIAT at: http://ccafs-climate.org/download_sres.html), available as 30 arc-second resolution raster grids from which monthly mean air temperature values could be obtained through a GIS query. Different datasets based on different Global Circulation Models (GCMs) (see section 3.3.3) are available for seven future periods between the 2020s and 2080s. For this thesis, data for the 30 year period of the 2050s (2040-2069) and 2080s (2070-2099) for three future scenarios (A1b, A2 and B2) based on the HADCM3 GCM was used (RAMIREZ-VILLEGAS & JARVIS, 2010).

2.1.2. *BIOTIC DATA*

Fish data was available through the IHG-database (Institute for Hydrobiology and Aquatic Ecosystem Management) at the University of Natural Resources and Life Sciences, Vienna. The data consisted of 1700 fish samplings at over 1500 sampling sites within Austria for which the number of the caught fish species and individuals was available. For each site, additional data describing the environmental characteristics (e.g. altitude, size of catchment, distance from the source etc.) was available (see section 3.2. for detail).

2.2. ERROR ELIMINATION, DATA PREPARATION AND REVIEW

Water temperature data for 117 measuring sites within Austria was available as daily measurements from 1979 until 2008. For each site and year, the time of temperature measurement was given as it was consistent neither across nor within measurement sites.

	A	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	ID	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	
2	200329	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
3	201095	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	Lü	DS	DS	DS	DS
4	201194	TM	TM	TM	TM	Lü	Lü	Lü	Lü	Lü	Lü	Lü	Lü	Lü	Lü	Lü	DS	DS	DS
5	201459	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS
6	201525	TM	TM	TM	Lü	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	Lü	DS
7	201558	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	DS	DS	DS	DS	DS	DS
8	201624	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	Lü	DS	DS	DS	DS
9	201681	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
10	201749	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	Lü	Lü	DS	DS	DS
11	201905	10:00	10:00	10:00	10:00	10:00	10:00	10:00	10:00	10:00	10:00	10:00	08:00	08:00	08:00	DS	DS	DS	DS
12	203075	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
13	203208	15:00	15:00	15:00	15:00	15:00	15:00	15:00	15:00	15:00	15:00	16:00	16:00	16:00	DS	DS	DS	DS	DS
14	203323	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	DS	DS	DS
15	203398	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
16	203497	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
17	203539	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	DS	DS	DS	DS	DS	DS
18	203570	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	DS	DS	DS	DS	DS
19	203752	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	DS	DS	DS	DS	DS	DS	DS
20	203794	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	DS	DS	DS	DS	DS	DS	DS	DS
21	204677	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	12:00	12:00	07:00	07:00	07:00	07:00	07:00	07:00
22	204719	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	08:00	12:00	08:00	07:00	07:00	07:00	07:00	07:00	07:00
23	204875	12:00	12:00	12:00	12:00	12:00	12:00	12:00	12:00	12:00	12:00	13:00	13:00	13:00	13:00	13:00	13:00	13:00	08:00
24	204883	TM	TM	TM	TM	TM	TM	TM	TM	TM	TM	12:00	DS	DS	DS	09:00	DS	DS	DS

Figure 2.1: Measurement times over the years for each site where TM= daily average, DS= data writers (hourly measurement), Lü= missing data and the numbers= time of measurement (e.g. 08:00= measurement at 8am)

The measurement times ranged from single measurements at a certain hour between 6am and 6pm, to daily averages and hourly measurements throughout the day taken by a digital logger. Since stream temperature exhibits daily variations as described in section 1.2, different sites with different measurement times cannot be compared and compatible sites in relation to measurement times had to be selected. Figure 2.1 shows a selection of different measuring sites in the leftmost column, the year in the topmost row and the times of measurement in between.

2.2.1. ERROR ELIMINATION AND DATA PREPARATION

Once the sites were selected, data was reviewed for errors and associated with the available metadata. There were two types of missing data within the temperature and discharge data: (1) For some measuring sites, it was clear that data was missing for certain years (see figure 2.1), in which case the missing time periods were absent from the data, or (2) single measurements were missing, in which case “Lü” filled the cell instead of a number. In the first case the missing time periods were added to the time series and in both cases missing data was labeled with a dummy value (namely “999”).

Once the data for each HZB-site was complete and contained a measurement or error code for each day, all data was aggregated into one data sheet. The available metadata was then allocated to each measurement site, resulting in a spreadsheet containing the following information:

- HZB ID
- Date
- Water temperature
- Altitude
- Catchment size
- Length of river
- Distance to mouth
- Distance from source
- River width
- Stream order
- Ecoregion
- Bioregion
- Fishregion
- WorldClim air temperature
- WorldClim catchment air temperature
- ZAMG air temperature
- ZAMG maximum air temperature
- ZAMG minimum air temperature
- Discharge

Since monthly averages were to be used for the analysis, the date was split into year and month through an Access query before monthly mean water temperature and mean discharge values were calculated in a pivot table. The rest of the information was either nominal or already available as monthly mean values (i.e. climate data). In order to ensure comparability with the WorldClim air temperatures, monthly mean water temperature and discharge values for the period of 1997 to 2008[1] were calculated. Two datasets were therefore available: one with monthly mean values for every year using ZAMG air temperature data, and a second with long-term monthly mean values using WorldClim air temperature data.

[1] See section 3.1.1 for further explanation as to why this time period was chosen

2.2.2. DATA REVIEW

Descriptive statistics were used to get an overview of the distribution of the data and determine outliers and trends. All available information ranging from water and air temperature to discharge and the available environmental characteristics were analyzed using box plots and histograms.

Box plots are used to describe the location and distribution of a dataset. It consists of a “box” and two lines called “whiskers” left and right of the box. The two ends of the box display the upper $_{(x=0.75)}$ and lower $_{(x= 0.25)}$ quartile of the data. The line inside a box symbolizes the median and the two whiskers the highest and lowest value within the inter-quartile range. Single circles beyond the whiskers symbolize outliers and stars represent extreme values. If a value is between 1.5 and 3 or more than 3 times the inter-quartile range they are considered to be outliers and extreme values respectively. Box plots can be used to describe a single variable, e.g. temperature with one box plot, or to compare values of one variable using another, nominal, variable as a category, e.g. temperature in each month with twelve box plots displayed side by side, each describing one month’s values.

In addition to box plots, histograms were used to describe the data. Histograms graphically illustrate the distribution of the data. The frequency for specific categories represented by vertical bars is displayed, where the frequency is labeled on the y-axis and the category on the x-axis. They can be used to display nominal data, such as species or classifications, as well as metric data. In the case of nominal data, the frequencies are shown for each defined category, whereas with metric data, categories are formed and then displayed as ranges.

2.3. ABIOTIC FACTORS OF INFLUENCE TO STREAM TEMPERATURE

In order to answer the first research question, relating to which abiotic factors may be of influence to stream temperature, correlation analysis and factor analysis were used. The first was used to determine the relationship between each abiotic factor and stream temperature and the latter to explore the nature of this relationship.

2.3.1. CORRELATION ANALYSIS

Correlation analysis explores the strength of a relationship between two variables, where the index of this relationship is referred to as the correlation coefficient. This coefficient can range from -1 to 1, where 0 signifies a very weak relationship, 1 a strong positive and -1 a strong negative relationship. All available variables were correlated with stream temperature after Pearson:

- Air temperature at site
- Air temperature in catchment
- Catchment size
- Discharge
- Altitude
- Length of river
- Width of river
- Distance from source
- Distance to the next confluence
- Ecoregion
- Bioregion
- Stream order

2.3.2. FACTOR ANALYSIS

Factor analysis is a “collection of methods used to examine how underlying constructs influence the responses on a number of measured variables” (DECOSTER, 1998, p. 3) and was used to identify a small number of factors that explain as much of the variance associated with the variables as possible. Factor analysis can be divided into (1) extrapolatory factor analysis (EFA) and (2) confirmatory factor analysis (CFA), where the first attempts to find constructs and the second attempts to prove a given hypothesis. Both types are based on the Common Factor Model which proposes that each observed response is influenced by common and unique factors. The correlation (or covariance) between the response and it’s influential factors is analyzed (DECOSTER, 1998).

For this thesis, EFA was used with the objective of determining the number of common factors influencing a variable as well as the strength of the relationship. However, it is a symmetric method meaning that it does not analyze the relationship between one dependent variable and a number of independent ones, but the relationship between all variables. The result is groups of variables which exhibit one or more latent attributes.

The interpretation of the results is similar to the interpretation of a regression coefficient, which can be scored, resulting in a loading value between 1 and -1, where 1 is a strong positive, -1 a strong negative and 0 no loading. The loadings are the correlation coefficients between the variable(s) and the factors and should theoretically be 0.7 or higher in order for the variable to be strongly represented by a particular factor, although 0.45 is also accepted.

In this case, all factors that were available in a metric scale were tested in order to explain the variance of measured stream temperature. The tested factors were:

- Air temperature at site
- Air temperature in catchment
- Catchment size
- Discharge
- Altitude
- Length of river
- River width
- Distance from source
- Distance to mouth

2.4. ABIOTIC FACTORS INFLUENCED BY CLIMATE CHANGE

Current literature was reviewed in order to determine which abiotic factors of influence to stream temperature are likely to vary under the influence of climate change and whether there are any accurate predictions as to how these factors may vary (research question 2). A broad spectrum of literature was reviewed, with one focus on literature published by the IPCC regarding predictions and scenarios of climate change, and a second on stream and fish ecological publications, in particular studies that investigated future stream temperatures and fish assemblages under the influence of climate change. The climate change literature was analyzed regarding which abiotic factors are likely to change and how these changes will look like according to future predictions. The information was subsequently used to answer the second research question and to choose one of the available methods to generate small scale future climate predictions and to select a corresponding datasets. The fish ecological literature was used to compare the results to and verify them.

2.5. STREAM TEMPERATURE MODEL

In order to develop an accurate and robust stream temperature model, two approaches were followed: the development of a regression model and, additionally, the development of a cross tabulation model. Due to the large inhomogeneity of the river typography across the measurement sites (see section 3.1), it was necessary to cluster the sites in order to develop a number of accurate models which could be used to predict the water temperature of Austrian rivers.

2.5.1. DATA CLUSTERING

Data clustering is a method of data transformation and was used to homogenize the dataset in order to develop an accurate stream-temperature model. Different methods of classification were applied which can be categorized into (1) hierarchical cluster analysis, (2) visual classification and (3) profiling.

Hierarchical cluster analysis

Hierarchical clustering is a form of multi-dimensional clustering and can either be agglomerative or divisive, where the first starts with every case being a cluster in itself and then similar clusters are merged, while the second starts with all cases in one cluster and then split into similar clusters.

Four different variables, three of which the factor analysis had shown to be influential on water temperature, and water temperature itself were chosen to define the clusters. Five different runs were conducted, each requesting a different number of clusters between two and ten. Even though the results were satisfactory, it was noted that there was no clear definition of the clusters in the sense that general rules about which HZB-site was included in which cluster could not be defined. Since the to-be-developed model is not only to be used to predict current and future water temperature at the HZB-sites used in its development, but also for other sites within Austria, this type of clustering was determined to be unfeasible since extrapolation would not be possible. It was therefore decided that visual classification and profiling were to be used to form clusters.

Visual classification

Visual classification may be said to be the simplest of all classification or clustering methods. Each variable which is to be classified or clustered is displayed as a histogram and then divided into the number of desired classes. This method, unlike hierarchical clustering, does not allow for clusters to be built on the basis of a number of variables (multi-dimensional cluster), but on the basis of one (one dimensional clustering). For the given analysis, all available variables that were shown to have an impact on stream temperature were each classified into two, three or four groups. The classification was done either subject specific or based on the frequency distribution.

This way, the entire dataset could be divided into one dimensional clusters, each on the basis of one variable, e.g. different classes of catchment size. This method proved to be useful for the development of the regression model, for the crosstabs model, however, further homogenization was necessary and for this reason different clusters were profiled.

Profiling

Through the calculation of mega-variables (profiles) more dimensional clusters can be built manually. This was done, as described by LAUTSCH and TÖHLE (2003), through the combination of one dimensional clusters which had been obtained through visual classification as described above. Two, three, four or more categorized variables can be summed up in order to obtain new, homogeneous more dimensional clusters. The equation below describes the profiling technique, taking a three variable profile as an example:

$$Profile_{xyz} = cat_x * 100 + cat_y * 10 + cat_z \quad [3]$$

$Profile_{xyz}$= the created profile
cat_x= classified variable x
cat_y= classified variable y
cat_z= classified variable z

In the above case the resulting profile is a three digit number combining different variables to a new mega-variable.

In this manner, thousands of different profiles could be calculated, each clustering the data in a different way. In order for the most accurate and valid model to be developed, with wide application, a number of different profiles were calculated and analyzed. Since not all possible combinations could be attempted, subject specific attributes were considered during profiling.

2.5.2. REGRESSION ANALYSIS

Regression analysis describes a cause-effect relationship between dependent and independent variables. Unlike factor analysis, regression analysis is an asymmetric model which can be used to calculate the influence of each independent on one or more dependent variables as well as to predict tributary variables. Two types of linear regression functions were used in this thesis: simple and multiple regressions, where the first represents the relationship between one independent and one dependent variable and the latter of one dependent and multiple independent variables.

Simple Regression: $Y = a + b * x + e$ [4]

Multiple Regression: $Y = a + b_1 * x_1 + b_2 * x_2 + \ldots b_n * x_n + e$ [5]

Y= estimation of dependent variable
a= constant
b= coefficient
x= independent variable
e= error term

In this thesis, regression analysis was one of the two approaches used to develop a stream temperature model, as a number of earlier studies have shown it to be a simple yet accurate way of predicting water temperature (see section 1.4). Stream temperature is therefore the dependent variable and all other variables identified by the factor analysis to have an effect on it are independent variables. Since stream temperature is not only influenced by one sole variable, simple regression analysis was not expected to deliver satisfactory results. Therefore multiple regression analysis was used. However, regression analysis was also used to predict future fish distributions and this was done using a simple regression analysis.

Different types[2] of multiple regression analysis exist which differ in the way the independent variables are included or excluded from the equation: (1) *Enter*, includes all selected variables in the equation while (2) *Forward*, adds one variable at a time until all relevant variables are included and (3) *Backward*, includes all variables at first and excludes them stepwise. The problem with the *Backward*-method is that once a variable is excluded it is not eligible for entry anymore and any interaction with other variables is not considered. All methods were tested and *Enter* was shown to deliver the best results.

When using regression analysis to calculate the influence of one or more variables on another, the independent variables used should not correlate with each other since then the influence of each one can no longer be determined. However, in this case the regression equation is to be used to predict stream temperature and hence the exact influence of each variable is not important but rather is a valid and significant result. Therefore, it was legitimate to include redundant variables, such as altitude and air temperature, which correlate strongly with each other, in the equation.

Even though a regression model gives a tangible value as a result, the error margin still has to be kept in mind. Firstly, the coefficient of determination (R^2) indicates the amount of total variability explained by the regression model. Hence, when the coefficient of determination is low, the model is not very accurate as there are still a number of other factors influencing the dependent variable, which are not included in the model. However, the R^2 has been found to

[2] Multivariate regression types as available and labeled in SPSS©15

be a biased estimate of the variance explained especially when a large number of independent variables are included in the model (ROBERTS & HENSON, 2002). For this reason it can be adjusted (adjusted coefficient of determination= adjR^2) to include effect size and hence be a more accurate indication of the variance explained. AdjR^2 is never higher than R^2 since it increases only if the significance increases not when additional regressors are added. Even with a high adjR^2 the estimated values will always disperse around the line of regression and unless it equals 1, which means that the regression model explains 100% of the variance, there will always be a margin of error for every predicted value.

Classification tree

Classification or decision trees are hierarchically ordered diagrams that map observations and therefore a type of graphical regression that clusters data. The basis on which a dataset is categorized through a tree classification is defined by a dependent variable and a number of independent variables. In this case, the dependent variable is stream temperature, since the objective is to develop an accurate water temperature model, and the independent variables are the factors which influence the dependent variable, the created mega-variables (profiles) in particular were used here. The result of each tree classification is a new variable which classifies the dataset and was used as the basis for the crosstabs model.

2.5.3. CROSS TABULATION

Cross tabulation or crosstab is a procedure that displays a relationship between two variables in tabular form. Different ways of displaying the relationship between the two variables can be chosen: (1) absolute numbers, (2) percentages and (3) standardized residues, amongst others. Furthermore, the decision can be taken to display either the expected or the observed frequencies. This procedure is mostly used to describe a dataset and can hence be referred to as a method of descriptive statistics; however, in the case of this thesis, crosstab was used as the second method to develop a stream temperature model.

As the relationship of two variables is calculated, cross tabulation can be considered to be a simple regression analysis and through the use of mega-variables (profiles) as independent variables it functions in a similar manner to a multivariate regression analysis.

Clustered profiles and categorized stream temperatures were used as independent and dependent variables respectively, and observed frequencies of absolute values and standardized residues were chosen to be displayed in the table. Through the use of the following formulas (LAUTSCH & VONWEBER, 1995, pp. 42, 53-55) the so-called test-statistics or standardized residues and the adjusted alpha (e.g. α= 0.05) could be calculated:

$$u_{ij} = \frac{(b_{ij} - e_{ij})}{\sqrt{e_{ij}} * KF} \quad [6]$$

u_{ij}= standardized residues

b_{ij}= observed frequencies

e_{ij}= expected frequencies

KF = corrected factor

i= 1

j= 1

$$\alpha^* = \frac{\alpha}{\text{number of rows} * \text{number of columns}}. \quad [7]$$

α*= adjusted alpha

The adjusted alpha was then used to extract $u_{(\alpha^*;2\text{-sided})}$ from the corresponding tables developed by LAUTSCH and VON WEBER (1995, pp. 192-195) and consequently to determine the test statistics: if a cell in the crosstab matrix exhibits $u_{ij} > u_{(\alpha^*;2\text{-sided})}$ then this cell is statistically significant (VONEYE, 2002).

2.5.4. *VALIDATION*

In order to validate the stream temperature model, the estimated values were compared to the observed values and the residues were calculated. The residues show the divergence of the estimated values in relation to the observed values. Furthermore, standardized residues were calculated and Person's chi squared test as well as the Kolmogorov-Smirnov-Test were conducted to further examine whether there is a large differentiation between the observed and estimated values and whether the residues were distributed normally.

2.6. PREDICTION OF FUTURE STREAM TEMPERATURE AND FISH ASSEMBLAGE

Regression analysis was again used to answer the fourth research question as to how stream temperatures and fish assemblages are likely to change under the influence of climate change. After a number of fish sampling sites were selected, for which the species assemblages are known, the stream temperature for these sites was estimated using the developed stream temperature model. The relationship between water temperature and fish assemblage at current temperatures was then analyzed using correlation and regression analysis as described above. Finally, the developed stream temperature and fish assemblage models were used to predict future water temperatures and fish assemblages under the influence of climate change.

In addition to the fish regions and the FiZI, the Salmonidae/Cyprinidae proportion was used to describe the fish assemblage at the sampling sites as well as to develop a regression model in order to predict future composition. Salmonids mainly inhabit colder waters with a steep gradient and hence dominate the upper fish regions, while Cyprinids prefer warmer streams with little incline and dominate the lower fish regions (see Annex I). Due to their opposing habitat preferences along the longitudinal gradient of a river, these families were chosen to characterize the fish sampling sites along the river continuum. Through the calculation of a Salmonidae/Cyprinidae Index (see formula 8 below) their relative occurrence can be displayed with values between 0 (= highly dominated by Salmonidae) and 1 (= highly dominated by Cyprinidae), therefore characterizing upstream/downstream river sections.

$$SCI_{(s)} = \frac{C_s}{(C_s + S)_s} \qquad 0 \leq SCI \geq 1 \tag{8}$$

$SCI_{(s)}$ = Salmonidae/Cyprinidae Index at site *s*

C_s = Number of Cyprinidae caught at site *s*

S_s = Number of Salmonidae caught at site *s*

3. RESULTS

3.1. DATA REVIEW AND SELECTION: HZB GAUGES

The following section describes the results of the descriptive data analysis which forms the basis for the selection of gauging stations from which the stream temperature model for Austrian rivers was developed. A summary of reasons for site exclusion can be found in section 3.1.12.

3.1.1. PRELIMINARY SELECTION AND MEASUREMENT TIMES

Out of the 117 sites, nine are located on the banks of lakes rather than streams and were therefore excluded. One site is located on a canal, the *Werkskanal Fischa,* and another along the *Warme Fischa* which results from the discharge of thermal baths. Both sites do not show a natural river temperature regime and were therefore also excluded.

The remaining 106 sites were then analyzed as to their time of measurement in order to create a valid dataset, the selection of which proved to be difficult due the great diversity of times. In order to be able to conduct a time series analysis, the data needs to be homogeneous, which meant that only sites with constant and comparable measurement times throughout all years could be used. Accordingly, the time of measurement has to be constant between sites, and only sites with equal or very similar measurement times could be used together.

If sites with daily averages were to be analyzed only 20 sites remained in the dataset. Similarly, if sites with morning measurements (before 9am) were included only 22 sites were available. The small number of homogeneous sites would not be enough to develop a water temperature model for Austria, but would rather be sufficient for local models, which does not fulfill the objective of this thesis.

As since 1997 many sites were equipped with digital data loggers, which measure water temperatures at hourly intervals throughout the day, it was therefore decided to only use the data after 1997 which allowed for a greater number of sites to be selected. Furthermore, it was decided to use morning measurements, either 7am or 8am, as this would allow for 92 sites to be used, the maximum number possible. In order to legitimate this decision, the temperature difference between 7am and 8am was analyzed for eight random sites in years where a data writer was used. As shown in figure 3.1, the difference in water temperature between 7am and 8am was below 0.4℃ and therefore negligible. The maximum difference was two degrees but this value proved to be a single outlier

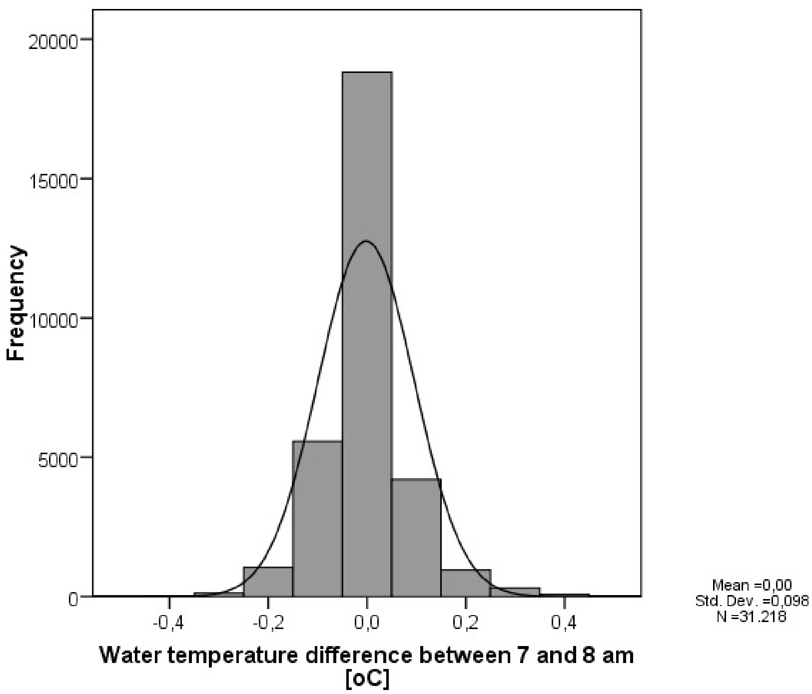


Figure 3.1: Frequency of water temperature difference between 7am and 8am as calculated from eight random measurement sites for the time period 1997-2008 (N=31218).

Out of the 92 sites, four further sites had to be excluded because no discharge data was available. In the end, 88 sites were used to begin the analysis, during which 25 further sites were excluded (see table 3.2 in section 3.1.12 for a summary) before the model was developed.

3.1.2. HYDROPOWER INFLUENCE AND RIVER MORPHOLOGY

Human alterations often result in a shift of fish regions or an altered age structure as well as guild composition (SCHMUTZ, *et al.*, 2000b). Hydropower influence, impoundment and water abstraction alter the natural stream-temperature regime (see section 1.2); Rivers supplied with water from hydropower stations often exhibit colder water temperatures in summer and warmer temperatures in winter (Jacob, 2001). Furthermore, there is a greater temperature variation as the hydropower facilities are not operating constantly and stream temperature is influenced by discharge (Jacob *et al.*, 2010). In regard to riverine habitat condition, river reaches under the influence of impoundment and hydropeaking show altered nutrition and oxygen availability (Endler & Matzarakis, 2011). Similarly, water abstraction has an altering effect on discharge, stream depth, and therefore the temperature.

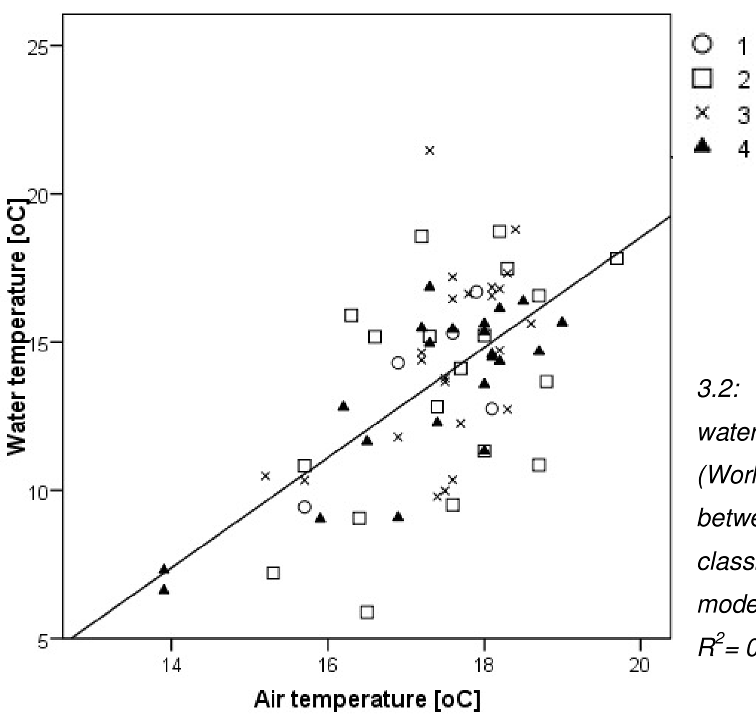
Since one of the objectives of this thesis is to predict fish species composition under the influence of climate change, the impact of other factors, affecting the stream temperature regime, was minimized. Therefore, all sections under the influence of impoundment or water abstraction were excluded from further analysis. Out of the 88 measurement sites, 14 are influenced by hydropeaking, four by impoundment and a further four by water abstraction, leaving 66 sites for further analysis.

Each river section in Austria is classified by the Federal Ministry of Agriculture, Forestry, Environment and Water Management in the National Water Management Plan (NGP). The basis for this classification is the biological, chemical and hydro-morphological condition, representing the ecological integrity of each section. The ecological status of a river reach is expressed by a number between one and five, with one being the best and five the worst, as shown in table 3.1.

Table 3.1: Morphological classification scheme as used by the NGP

Classification	**Condition**
1	High
2	Good
3	Moderate
4	Poor
5	Bad

Since the morphological condition of most Austrian rivers is modified by human activities, it can be argued that river sections classified as poor or worse no longer represent near-natural stream-temperature regimes.



3.2: Scatter graph plotting mean water and air temperature (WorldClim) for July differentiating between the four morphological classifications (1= high, 2= good, 3= moderate and 4= poor). N=66 and R^2= 0.39.

Out of the 66 sites, four had been classified as exhibiting in a very good morphological condition, 18 as good and 23 as demonstrating a moderate morphology. However, 31 % of the 66 sites had been classified as having a dissatisfactory biological, chemical and ecological condition. In order to find out whether the morphology has an influence on the air temperature, stream temperature relationship, it was plotted on a scatter graph shown in figure 3.2. As it can be seen, the black triangles representing a morphological classification of four are dispersed evenly among all other values, proving that there is no major difference in the air- and stream temperature relationship. Therefore, it was decided not to exclude measurement sites located along river sections classified as having a dissatisfactory morphology.

3.1.3. Lake influence

As discussed in section 1.2, discharged lake water is often warmer than conventional river water, and therefore gauging stations downstream of lakes might have to be excluded from the analysis as they would distort the model. However, figure 3.3 shows that not all sites downstream of a lake exhibit the expected effect of higher temperatures, only HZB site 204586, a station along the *Mattig,* proves to carry significantly warmer water than the non-lake influenced rivers. For this reason that site was excluded from all further analysis.

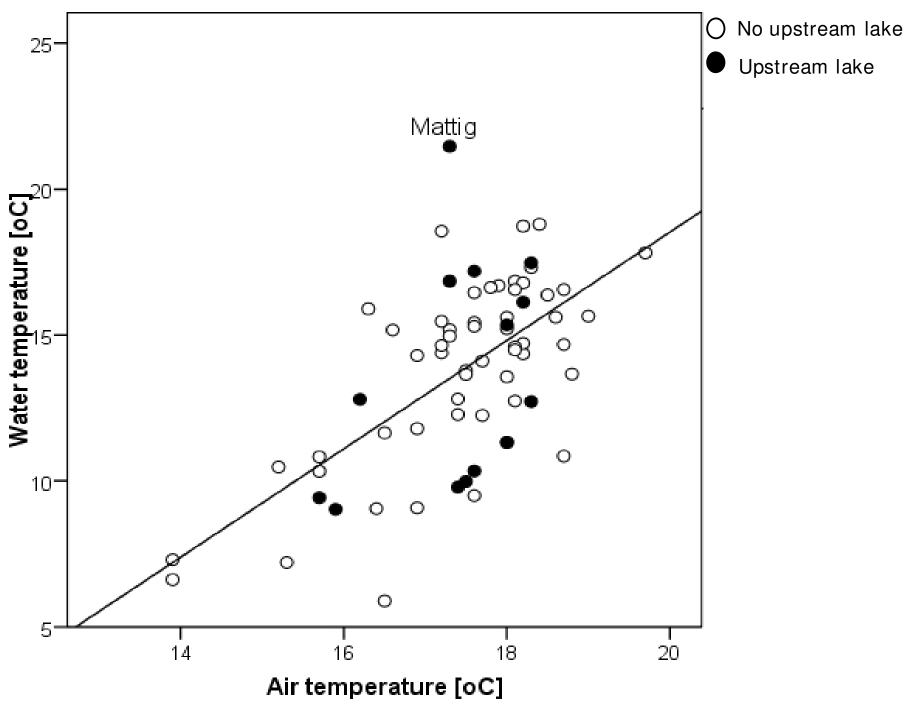


Figure 3.3: Identification of lake influence through the display of the mean air (WorldClim) and water temperature relationship in July. N=66 and R^2= 0.39.

3.1.4. GLACIAL INFLUENCE

In contrast to lake-influenced gauging stations indicating higher water temperatures, stations influenced by glaciers might show a cooled stream temperature regime, especially in spring and summer. The melt water increases the discharge and hence decreases the gradient of downstream temperature increase (CADBURY *et al.*, 2008). Three of the rivers included in the dataset carry melt water: the *Ötztaler Ache*, the *Schirmbach* and the *Isel*, all three of which are located in the western and southwestern part of Austria underneath the glaciated central Alps. As figure 3.4 shows, even though they are on the lower part of the graph, none of the three rivers can be regarded as outlier, and hence they were not excluded from the dataset.

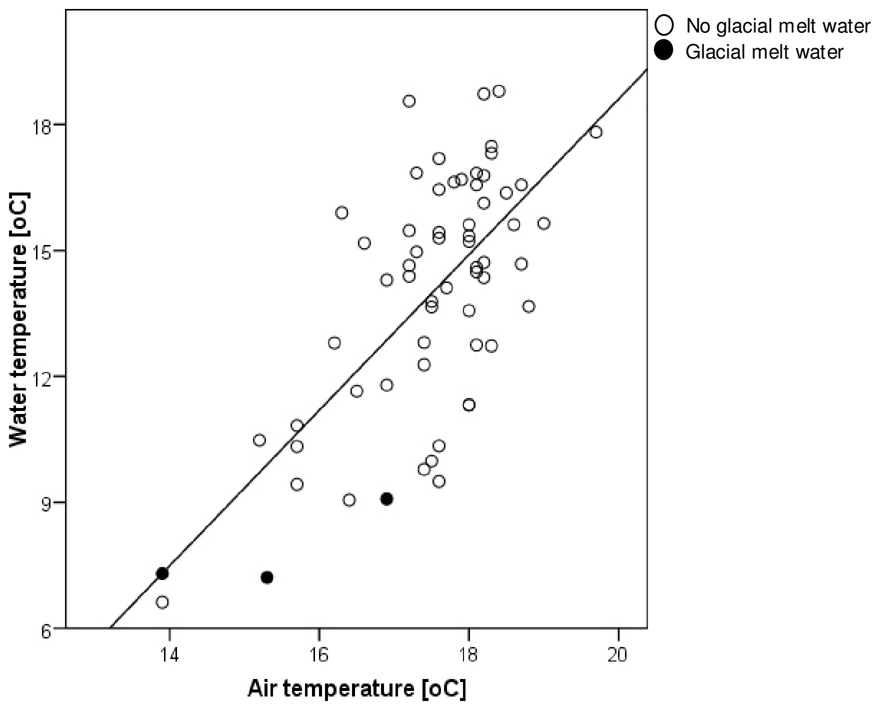


Figure 3.4: Identification of glacial influence through the mean air temperature (WorldClim) stream temperature relationship in July. N=65 and R^2=0.42

3.1.5. WATER TEMPERATURE

The water temperature observed at the different HZB sites between 1997 and 2008 throughout the year can be described by a sinus curve with the highest temperatures observed in July[3] and the lowest in January, 22.7℃ and -0.4℃ respectively.

However, when the yearly cycle of each HZB site is analyzed, then two river sections stand out through not exhibiting the expected shape. These are two stations which are located in

[3] Even though Figure 3.6 shows the highest temperature (24,1℃) to have been observed in August, this value represents an outlier and is therefore not considered when describing the general distribution of the data.

the headwaters of the *Fischa* and the *Steyr.* Their yearly temperature cycle is displayed in figure 3.5. The most likely reason for their almost nonexistent temperature variation throughout the year is their proximity to the source. Both sites are located within 2.5 km of the river's spring, and river temperature at the source is close to groundwater temperature which is constant throughout the year. Since both sites differ significantly from the rest of the dataset they were excluded from the analysis.

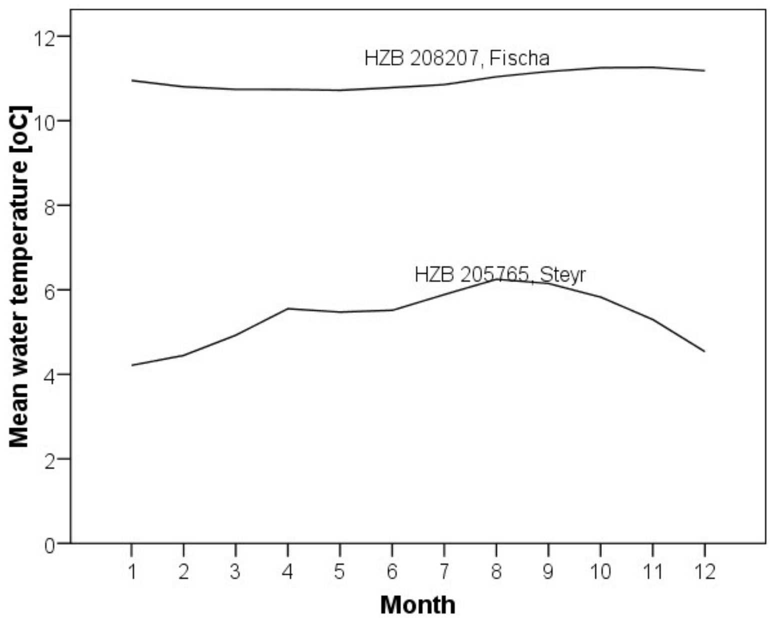


Figure 3.5: Yearly mean stream temperature (in degrees Celsius) cycle of two rivers under the influence of groundwater.

The remaining 63 sites exhibit the expected sinus shape when monthly stream temperature is plotted. As shown in figure 3.6, the standard deviation is greatest during summer and lowest during winter months. The outliers visible in the figure, most of which show warmer stream temperatures than expected, cannot be attributed to the same river but rather represent values from different HZB sites in different years, for which reason they were not excluded from the dataset.

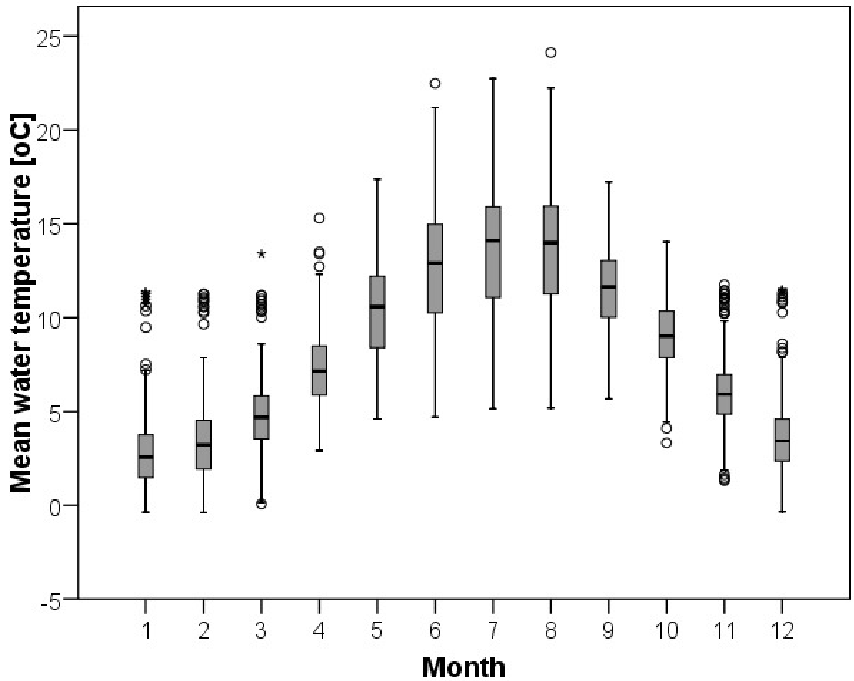


Figure 3.6: Box plot displaying the monthly water temperature in degrees Celsius of all remaining HZB-sites (N=63) between 1997 and 2008.

3.1.6. AIR TEMPERATURE

Two different sets of air temperature were available: (1) the ZAMG-data with mean values for every month between 1997 and 2008 for 34 HZB sites and (2) the WorldClim-data which consist of one long-term value per month and HZB-site (N=63), which represents the mean air temperature at that point between 1961 and 2000. As shown in figures 3.7 and 3.8, the air temperature course throughout the year is similar to the stream temperature course: the highest values in July and the lowest in January. However, a notable major difference between the two data sets is their standard deviation in each month: The ZAMG-dataset has a much broader spectrum of values displaying a broader variability. The reason for this is the fact that the data consist of daily observed temperatures, which were averaged for each month. Therefore, twelve values were available for each HZB-site and year (a total of 4896 values), whereas the WorldClim dataset consist of one monthly mean value per HZB-site (a total of 754 values). The WorldClim temperatures are therefore much more averaged than the ZAMG data, which shows a lower standard deviation.

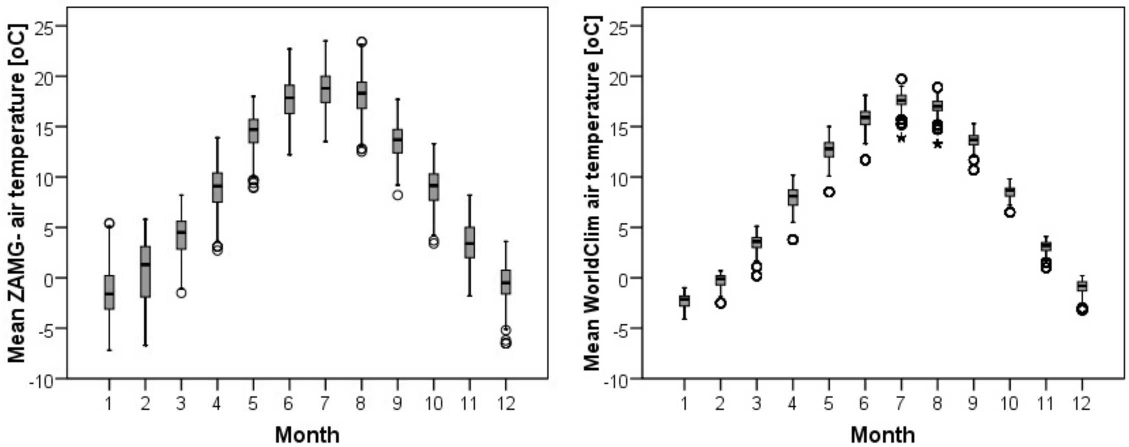


Figure 3.7 (left): Air temperature between 1997 and 2008 (ZAMG) (N=34), and Figure 3.8 (right): Mean air temperature between 1961 and 2000 (WorldClim) (N=63).

The maximum and minimum temperatures between the two datasets differ slightly in that the ZAMG measurements are spread about three degrees Celsius wider than the WorldClim measurements. This phenomenon can also be explained by the fact that the WorldClim dataset, unlike the ZAMG dataset, represents 40 years of monthly mean temperatures.

As regards the accuracy of the data, it must be kept in mind that the ZAMG-data does not always exactly spatially correspond to the HZB-sites, whereas the WorldClim data does. As mentioned in section 2.1, there is no ZAMG station for every HZB station, for this reason the nearest temperature measurement site within ten Kilometers was chosen. Even though measures were taken not to use stations with more than 50 meters of altitude difference, the data might not represent the exact conditions found at the point of stream temperature measurement.

3.1.7. Discharge

The monthly mean discharge at each HZB-station varies throughout the year, although not in the same way as stream and air temperature. As shown in figure 3.9, the highest values are observed in May and the lowest in January. The volume of discharge is dependent upon the amount of precipitation, evaporation and snow/ice melt rates (Solheim *et al.*, 2010). It can be argued, that snow melting combination with pluvial precipitation have a substantial impact in shaping the discharge regime, as their rates are highest in spring, and coincide with the maximum discharge rates.

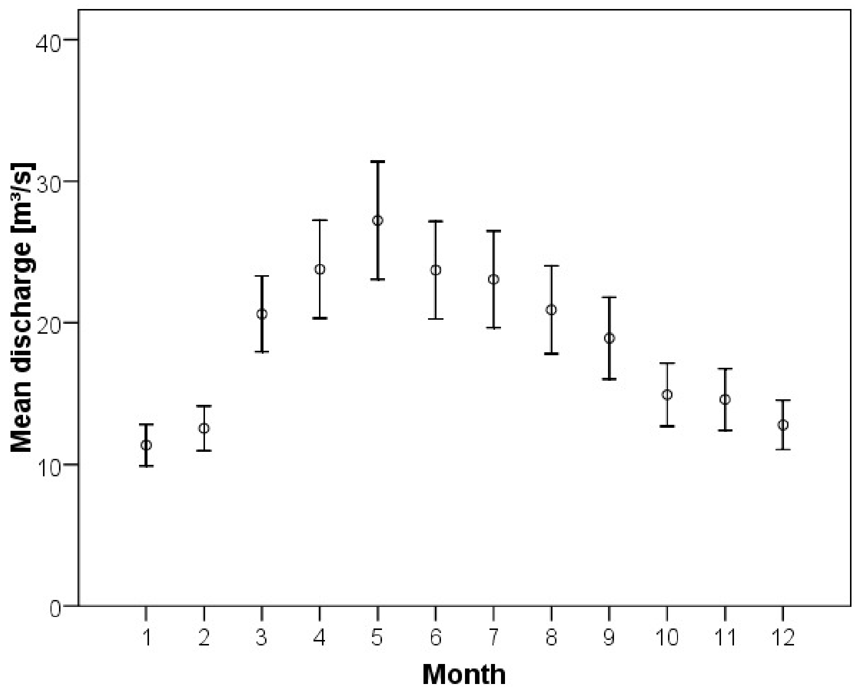
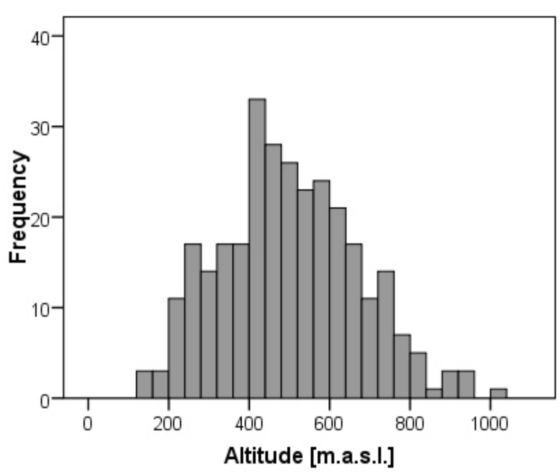


Figure 3.9: Monthly mean discharge for all remaining HZB sites (N=63)

3.1.8. River size and location of gauge

The geographic location and river size influence the thermal regime of rivers and therefore constitute a crucial background for the development of a stream temperature model. Figure 3.10 shows the altitude at which the HZB-sites are located. The lowest site lies 122 meters above sea level and the highest 1120 meters. The mean altitude is 419 meters above sea level and about 76% of all sites lie between 200 and 500 meters of altitude.



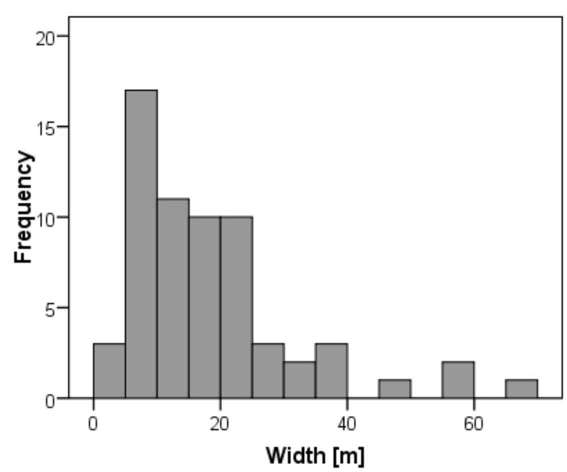
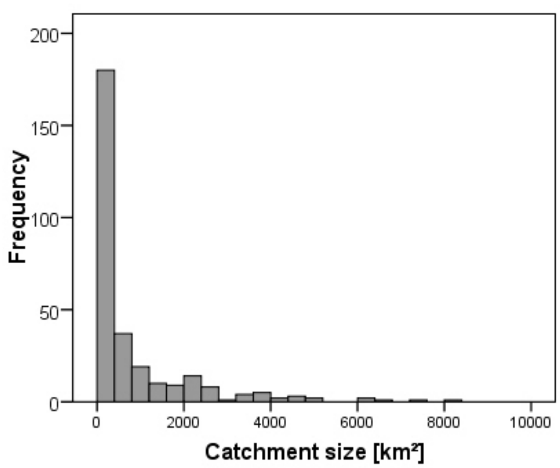


Figure 3.10 (left): Frequency of altitude of all remaining HZB sites (N=63), Figure 3.11 (right): of each river at the HZB-site (N=63).

The mean river width at the HZB-stations is 18.3 meters, the minimum 4.3 and the maximum 67.7 meters. As figure 3.11 shows, most streams have a width less than 20 meters. The few very broad rivers are two sites along the *Mur* and respectively one along the *Enns* and the *Traun*. These rivers are also those with the largest catchment sizes (see below) and highest discharge rates. However, they are not regarded as outliers and are hence not excluded from the dataset.

The mean catchment size is 419 km^2, the minimum and maximum 122 km^2 and 1120 km^2 respectively. 84% of the river sections at the corresponding HZB-sites have a catchment size below 500 km^2, as shown in figure 3.12. The four largest catchments correspond to the same four measurement sites along three rivers with the greatest river width: *Mur, Enns* and *Traun*. Generally, it can be said that all of the rivers with catchments above 700 km^2 are located in eastern or southern Austria at an altitude below 500 meters above sea level.

The lengths of the different rivers correspond somewhat to their width. Figure 3.13 shows the distribution of lengths and it can be noted that 67% of all rivers are shorter than 100 km. The mean length is 95 km and the minimum and maximum 9 km and 462 km respectively. The longest river is the *Mur*, along which two HZB-stations are located, followed by the *Thaya* and the *Raab*. The two shortest rivers in the analysis are the *Schirmbach* and the *Schalchener Brunnbach*.



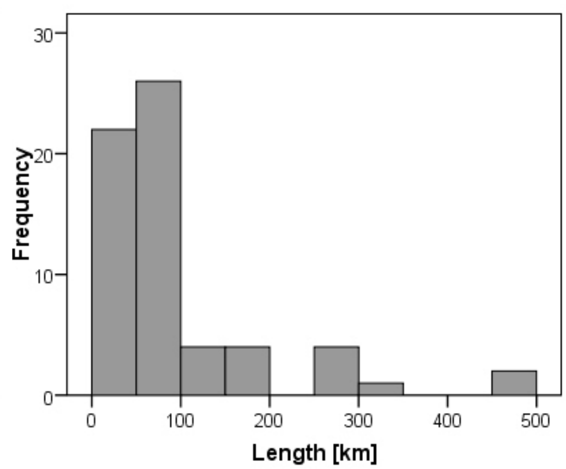


Figure 3.12 (left): Catchment size of the gauges (N=63). Figure 3.13 (right): Length of each river included in the analysis (N=63) in kilometers.

The distances to the mouth and from the source for the gauging stations correspond, shown in figures 3.14 and 3.15. The mean distance from the source is 54 km and the minimum and maximum 5.5 km and 336 km respectively. Similarly, the mean distance to the next confluence is 40 km, the minimum 0.04 km and the maximum 258 km. The two rivers with a

HZB-station furthest away from the source are again the *Mur* and the *Enns*, while the HZB-stations along the *Isar* and the *Raab* are furthest away from the next confluence.

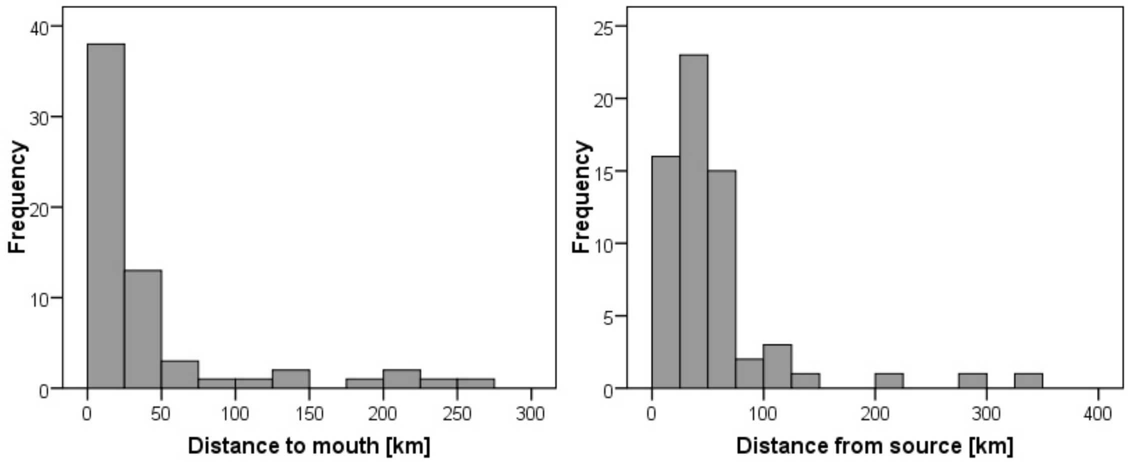


Figure 3.14 (left): Distance to the next confluence at each HZB-station (N=63) in kilometers and figure 3.15 (right) distance from the source in kilometers

3.1.9. ECOREGIONS

The Ecoregions correspond to the 25 regions initially described by ILLES (1978 in MOOG *et al.*, 2001), which have been classified according to bio-geographic and zoological aspects. Accordingly, Austria consists of four Ecoregions as shown in figure 3.16: the Alpine region, the Central Highlands, the Dinaric Western Balkan and the Hungarian Lowlands.

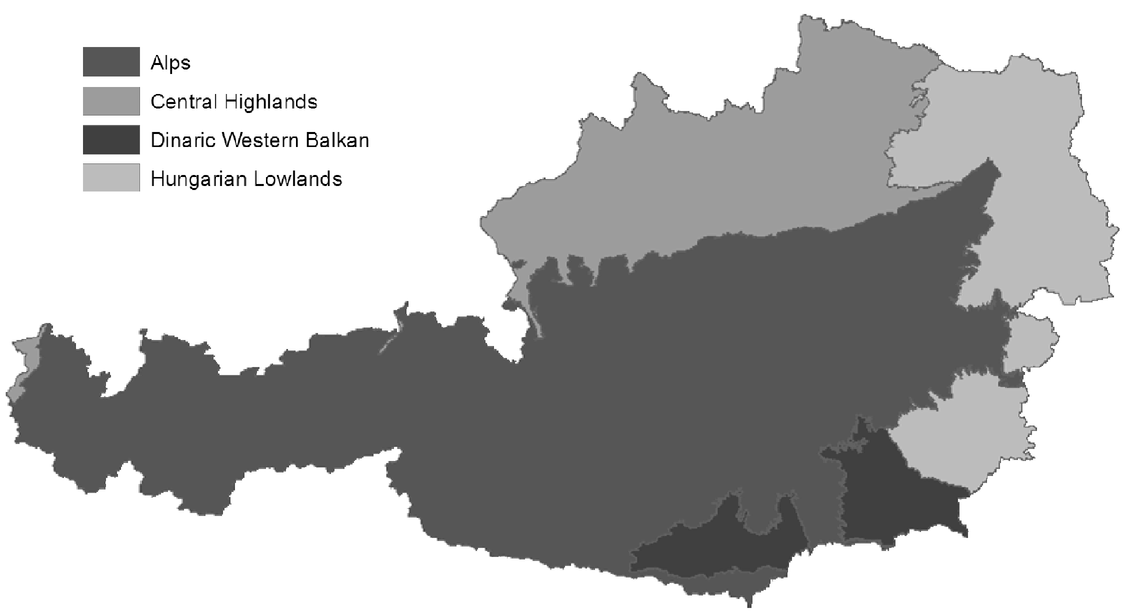


Figure 3.16: Ecoregions for Austria as defined in the EU Water Framework Directive

All four Ecoregions are represented in the dataset constructed from the 63 HZB-sites. As figure 3.17 shows, over half the stations are located in the Central Highlands, 22 in the Alpine region, and three and four in the Dinaric Western Balkan and Hungarian Lowlands respectively.

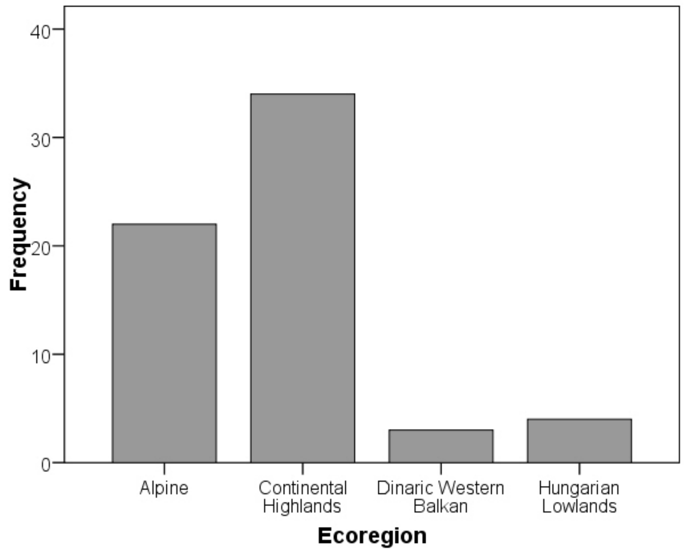


Figure 3.17: Distribution of the HZB-sites (N=63) across the Ecoregions

3.1.10. FISH REGIONS

Four of the biocoenotic fish regions introduced in section 1.3 are represented in the dataset. Figure 3.18 shows that 46% of the stations are located in the HR, the grayling region, and 25% along the MR, the lower trout region. 22% and 7% are in the EP and the ER respectively. No site is located in the MP or the fish-empty regions (Eucrenal and Hypocrenal). Figure 3.19 shows the observed summer (June-August) stream temperatures for each fish region. The mean water temperature in the ER is 8,8°C, 12,4°C in the MR, 13,8°C in the HR and 16,9°C in the EP.

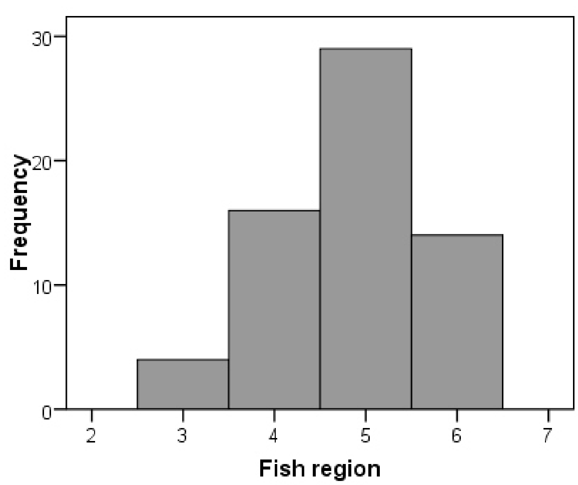


Figure 3.18: Distribution of the HZB-sites (N=63) across the fish regions (2=Hypocrenal, 3=Epirhithral, 4=Metarhithral, 5=Hyporhithral, 6=Epipotamal and 7=Metapotamal).

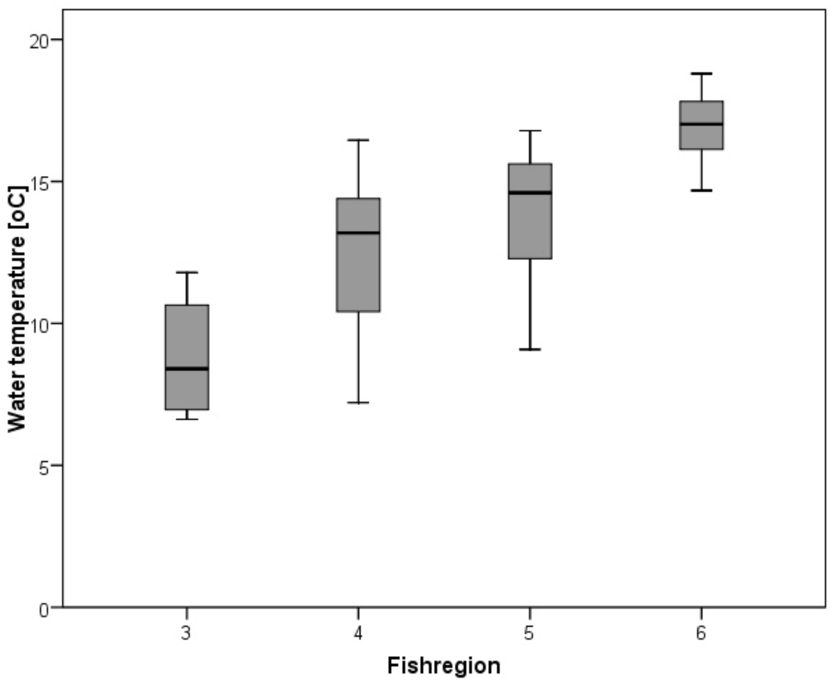


Figure 3.19: Observed mean summer (June-August) water temperatures for each fish region (N=189).

3.1.11. STREAM ORDER

In 1945, Horton developed a system to classify streams quantitatively, which was later adapted by STRAHLER in 1957 (WIMMER, 1992). This system is based on abiotic information, which can be extracted from topographic maps. The practical importance of the stream order concept relies on the hypothesis that "the stream orders are directly proportional to the catchment size, width and discharge" (WIMMER, 1992, p. 28) of each river. With increasing stream order the width, depth and bed load transport increase. Furthermore, the stream order determines the relative location of a stream section in a river system, since a mountain spring is allocated to stream order one. The number increases with each major confluence, and rivers with a stream order above six are considered as major or large rivers (e.g. in Austria the *Danube*, *Inn* or *Mur*). This system was also the basis for the later developed and much debated River Continuum Concept (for detail see: VANNOTE *et al.*, 1980), which assumes that the biological river components adapt to the constantly changing physical parameters in a downstream direction. WIMMER and MOOG (1994) assigned stream orders to every Austrian river. This classification was used to determine the stream orders for all river sections analyzed in this thesis.

Figure 3.20 shows that 47% of the stations measure the temperature and discharge of rivers with stream order 5, and 28% with stream order 4. nine river sections, which in total equate to 14%, are of stream order 6, three river sections, or 4%, of stream order 3, and two river sections of stream order 7 and one of stream order 2.

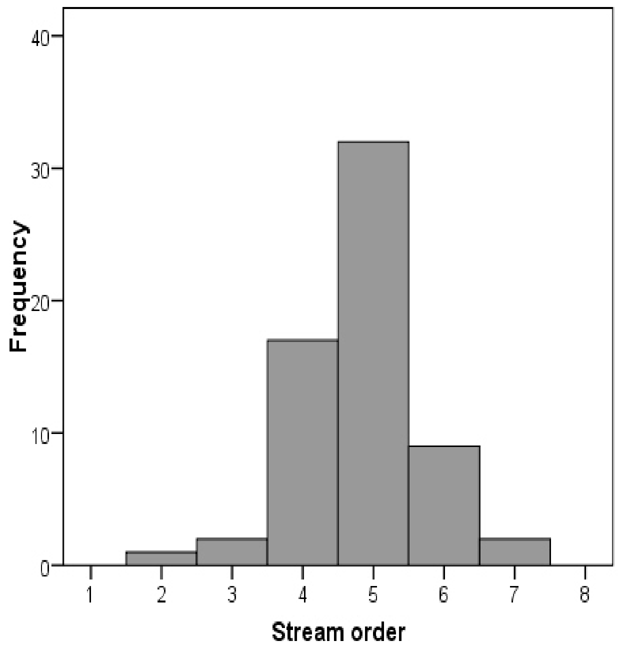


Figure 3.20: Stream order of the river sections at the different HZB-sites (N=63).

3.1.12. Summary

The progression and reasons for data exclusion are summarized in table 3.2. Additionally, figure 3.21 shows the geographic distribution of the sites throughout Austria. Figure 3.22 shows the stream-air-temperature relationship for the 63 HZB-sites which were used to develop the stream temperature model. A list of all HZB-sites included in the analysis and a corresponding map can be found in Annex III.

Table 3.2: Summary of data review and exclusion of HZB sites.

Step	Description	Number of sites excluded	Number of sites left over
1	Raw Data		117
2	*Werkskanal Fischa* (Channel)	1	116
3	*Warme Fischa* (Thermal baths discharge)	1	115
4	Lakes	9	106
5	No morning water temperature measurements between 1997 and 2008 available	14	92
6	No discharge measurements available	4	88
7	Hydro peaking	14	74
8	Impoundment	4	70
9	Water abstraction	4	66
10	Lake influence significant	1	65
11	Groundwater influence significant	2	**63**

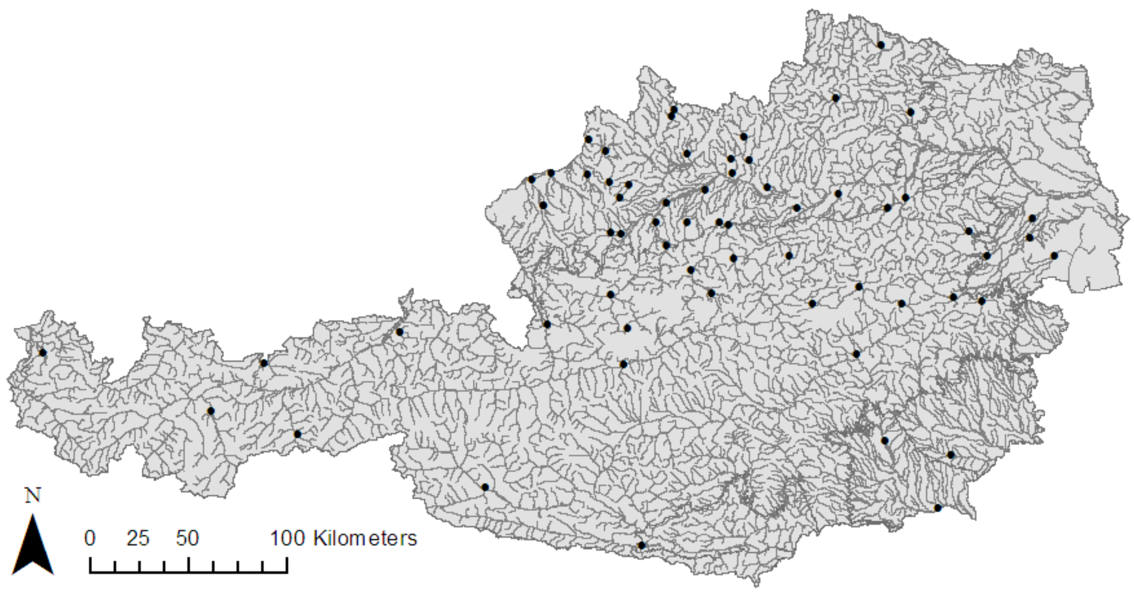


Figure 3.21: Distribution of the used HZB-sites in Austria. The dots represent the sites and the lines, rivers.

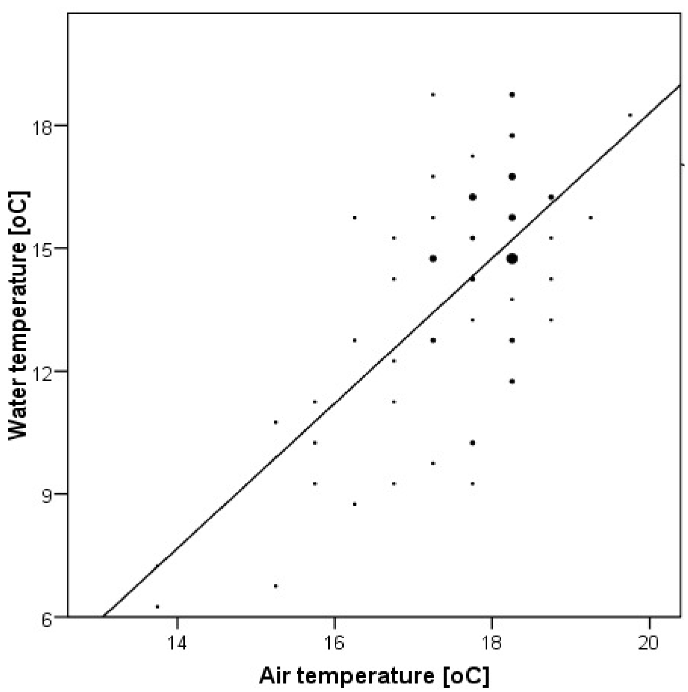


Figure 3.22: Stream-air-temperature relationship of the 63 HZB-sites used to develop the stream temperture model in July. The larger dots equal five values and the small ones one. R^2=0.46.

3.1.13. STREAM TEMPERATURE TRENDS

Stream temperature measurements were available from 1.1.1976 to 31.12.2008. During that time period, surface air temperatures were noted to have risen, as described in section 1.4. Due to the water-air-temperature relationship, stream temperatures are therefore expected to also have risen. Because of the diversity of measurement times within and between the different HZB-sites (compare section 2.2), only 22 sites[4] could be used to verify the expected change in stream temperature between 1976 and 2008.

Figure 3.23 shows the mean July temperatures from 1976 until 2008, where a general temperature increase can be noted. Furthermore, extremely warm years such as 1983, 1994 and 2003 can be detected as well as the colder years of 1980, 1984 and 1996. Figure 3.24 shows the mean July temperatures from 1997 to 2008. Both graphs show a temperature increase of approximately 1.4℃, with a long term mean temperature of 13.6℃. However, the gradient is steeper in the 12 years post 1997 (figure 3.24) than in the 21 years before (figure 3.23). Concerning the actual mean values, it must be kept in mind that figure 3.22 is based on daily mean measurements, whereas figure 3.24 is based on morning measurements, and hence the latter temperatures are generally lower than the daily mean values.

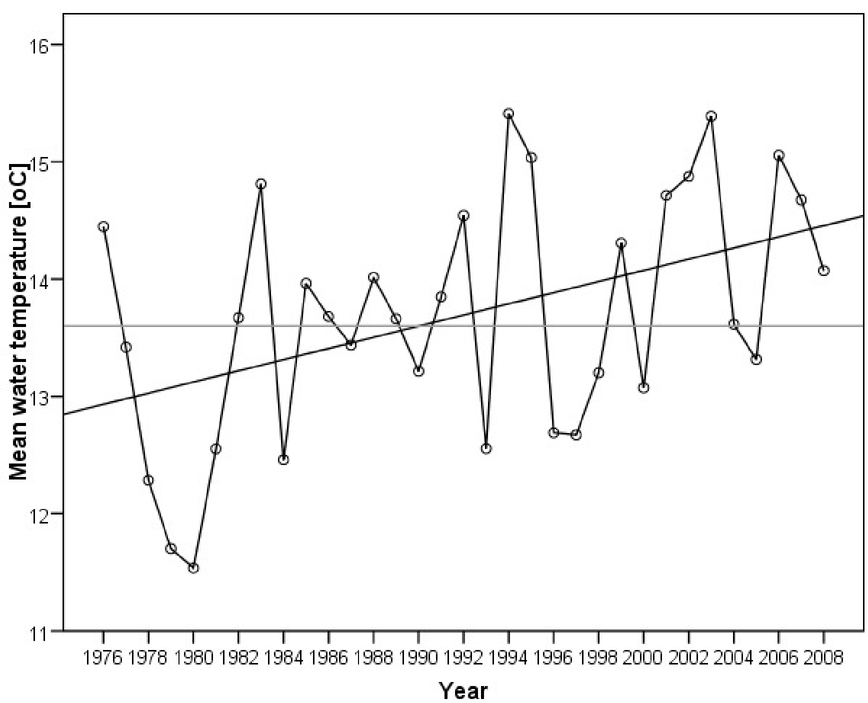


Figure 3.23: Mean stream temperature in July from 1976 to 2008 (N=22) with a long term mean (1976-2008) of 13.6℃ (light-grey line), R^2= 0.20 and linear equation for the trend: y= 0.0476x + 12.885 (black line).

---

[4] 22 sites for which daily mean temperature values were available for the period of 1976-2008

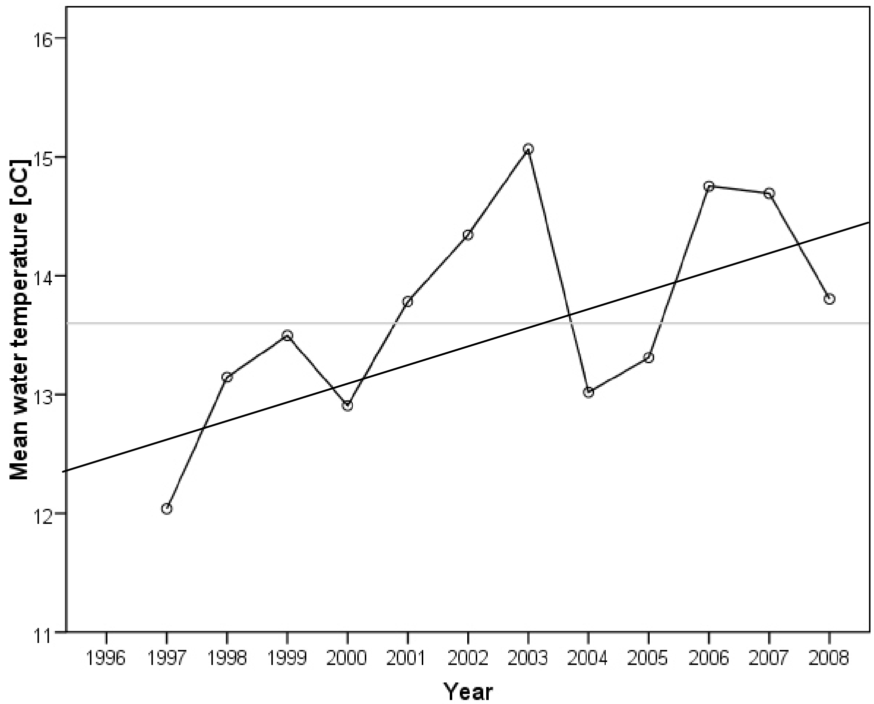


Figure 3.24: Mean morning water temperatures in July between 1997 and 2008 (N=63) with a long term mean of 13.6℃ (light-grey line), R^2= 0.36 and linear equation for the trend: y=0.14489x+ 12.728 (black line).

3.2. DATA REVIEW AND SELECTION: FISH SAMPLING SITES

The following section describes the selection process for the fish sampling sites and constitutes a review of the data, including the sites' geographic location. Biotic data from 1700 samplings at 1500 sites was available, consisting of the number of fish species and individuals sampled. Metadata consisting of the site ID, catchment ID, coordinates and sampling data was available as well as the following geographic/morphological data:

- Altitude of site
- River length
- Catchment size
- Distance from the source
- Distance to the mouth
- Lake influence
- Glacial influence
- Stream order
- Ecoregion

3.2.1. SITE SELECTION

Since the data included a number of redundancies and missing values, a review of the information as well as the elimination of sites was necessary. Firstly, the data was analyzed in regard of redundancies (i.e. sites with data from more than one sampling date), the latest catch-date chosen and the others excluded. Then all incomplete sites (i.e. where metadata, biotic- or morphological information was missing) were also eliminated. Sites within up to 5 km from the source and sites with upstream lakes or glaciers were also excluded to evade possible alterations of the temperature regime. In order to avoid spatial nestedness one site per primary catchment was chosen at random. This was done through the exclusion of repeated catchment-IDs which identify the primary catchments in the CCM2, and which were part of the metadata. Finally, all sites under the influence of residual water, hydropeaking or impoundment were also excluded, leaving 300 sites for further analysis. A summary of the reasons for the elimination of fish sampling sites can be viewed in table 3.3. Figure 3.25 shows the distribution of the remaining sites, used in the analysis.

Table 3.3: Summary of data review and exclusion.

Step	Description	Number of sites excluded	Number of sites left over
1	Raw data		1700
2	Redundant sites	200	1500
3	Incomplete sites	468	1032
4	Exclusion of potential groundwater influence	68	964
5	Exclusion of potential lake and glacier influence	141	823
6	Avoidance of spatial nestedness	358	465
7	Hydropeaking, impoundment, residual water	165	300

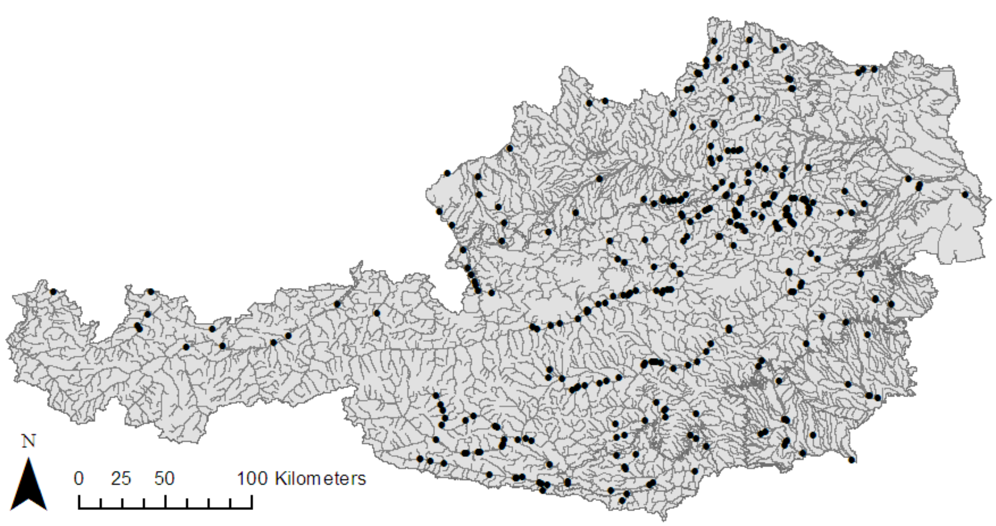
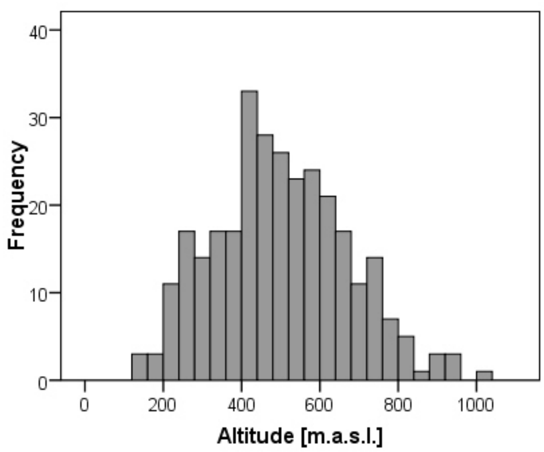


Figure 3.25: Selected IHG-fish-sampling sites in Austrian rivers used in the analysis (N=300).

3.2.2. GEOGRAPHIC LOCATION

The distribution of the fish sampling sites within Austria is uneven, as more sites are located in the central and eastern part of Austria, as shown in figure 3.25. The catchment size and distance from source as well as the altitude of the sites varies greatly. The maximum and minimum altitude of the sites is 1010 and 140 meters above sea level respectively, with a mean altitude at 500 meters above sea level. The frequency distribution is displayed in figure 3.26. The catchment size varies from 5.5 to 8169 km², with the mean at 826.4 km^2. Over two thirds of the sites has an upstream catchment <<500 km^2. The distance from the source varies between 5 and 298 km, with over half the sites located within 50 km of the spring. The river size described by the stream order is between 2 and 7, with most sites classified as stream order 3. Figures 3.27, 3.28 and 3.29 show the frequency distributions of the above mentioned attributes.



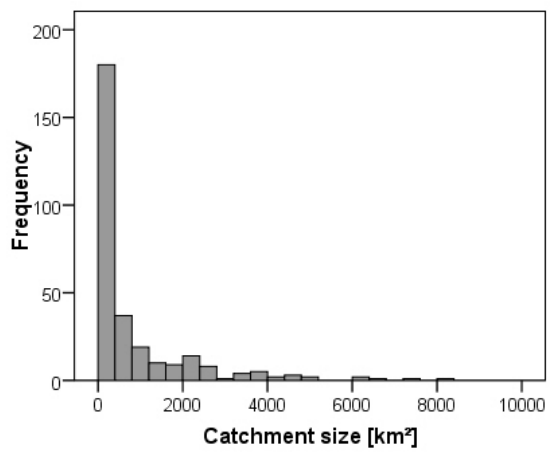
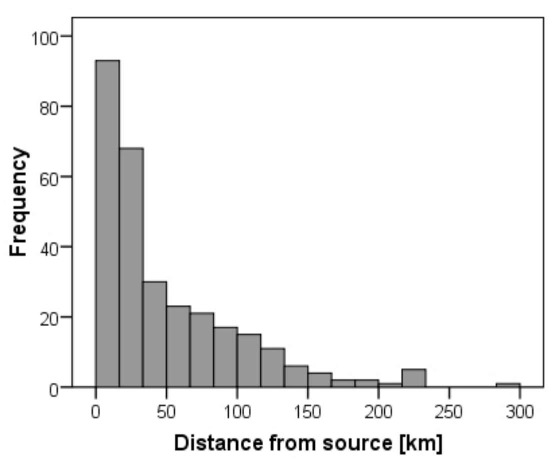


Figure 3.26 (left): Frequency distribution of the altitude of fish sampling sites (N=300). Figure 3.27 (right): Frequency distribution of the fish site's catchment size (N=300)



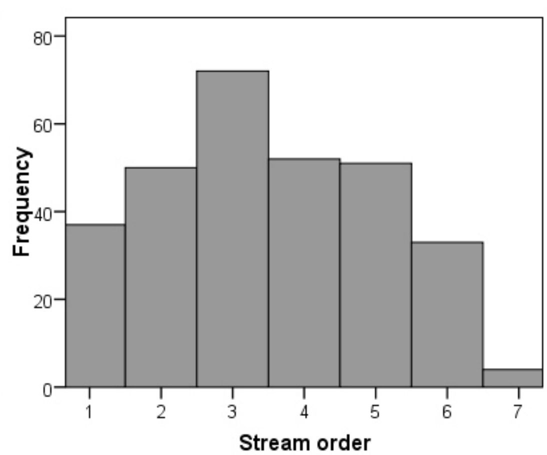


Figure 3.28 (left): Frequency distribution distance from the source (N=300). Figure 3.29 (right): Frequency distribution of the stream order at the fish sampling sites (N=300).

3.2.3. Fish distribution

Through the available fish data and the formulas mentioned in section 1.4, the calculation of the FiZI and the subsequent allocation to the fish regions was possible, with the boundaries for each region set as shown in table 3.4.

Table 3.4: Allocation of the FiZI values to the corresponding fish regions

FiZI	Fish region
<4,5	Metarhithral
4,5-5,5	Hyporhithral
5,5-6,5	Epipotamal
6,5-7,5	Metapotamal

The lowest FiZI is 3.74 and the highest 6.64. Out of the 300 fish sampling sites the majority are located in the trout region, as shown in Figure 3.30. 84% of the sites are located in the Rhithral and only 16% in the Potamal. Unlike the HZB-sites, these sites include streams in the MP.

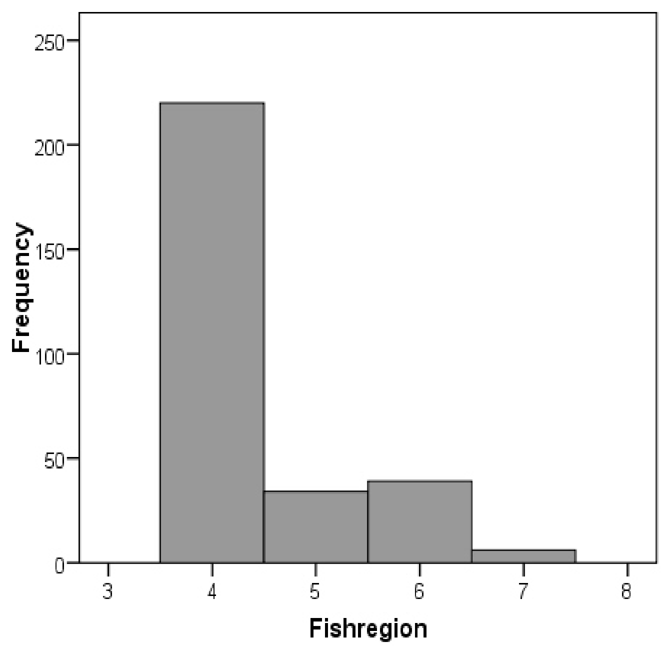


Figure 3.30: Frequency distribution of the 300 IHG-fish sampling sites across the fish regions.

Figures 3.31 and 3.32 show the relative proportion (percentage of total population) of Salmonidae and Cyprinidae found at the fish sampling sites. One third of the sites are dominated by Salmonids, and three percent of the sites are inhabited by Cyprinids only. On the other hand Cyprinidae do not occur at over two thirds of the sites while this holds for only six percent concerning Salmonidae. Overall it can be noticed that Salmonidae are represented much stronger than Cyprinidae. Figure 3.33 shows the SCI (relative proportion of each family in relation to the sum of Cyprinidae and Salmonidae at site- compare section 2.6) frequency distribution in comparison. The figure reveals that Salmonidae coexist with other species at half the sites, as the Salmonidae dominated sites double in frequency in figure 3.33 compared to 3.31. Cyprinidae on the other hand seem to solely inhabit their terrain, as the frequencies are constant between figure 3.32 and 3.33. Furthermore it shows that Salmonidae and Cyprinidae rarely coexist as the frequencies between SCI= 0.4 and 0.6 are very low. This supports the choice of these species representing the upper and lower river sections.

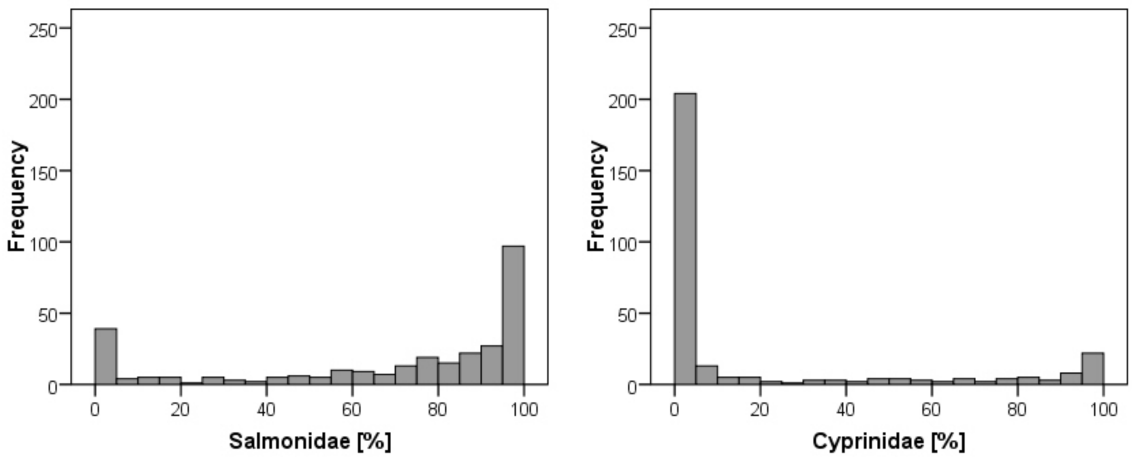


Figure 3.31 (left): Frequency distribution of the relative fraction of Salmonidae population at the 300 IHG-fish sites. Figure 3.32 (right): Frequency distribution of the relative fraction of Cyprinidae population at the sites.

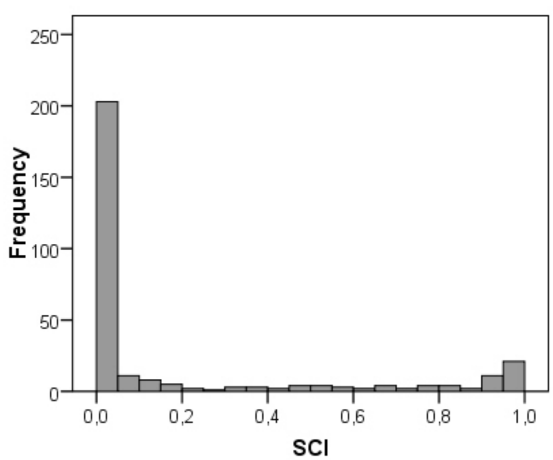


Figure 3.33: SCI frequency distribution at the 300 IHG-fish sampling sites; 0=100% Salmonidae, 1= 100% Cyprinidae.

The species to coexist with Salmonidae most frequently is the bullhead (*cottus gobio*), which is in line with the fishregion species allocation (compare Annex I), as it also mainly occurs in the headwaters. The northern pike (*esox lucius*), european perch (*perca fluviatilis*) and two zingel species were found to inhabit the transition area between Salmonidae and Cyprinidae at sites with an SCI above 0.4.

3.3. ABIOTIC FACTORS SIGNIFICANTLY INFLUENCING WATER TEMPERATURE

Different abiotic factors, such as air temperature, altitude or discharge are known to determine stream temperature. The correlation and factor analysis of the available variables concluded that the following variables are highly influential on water temperature: air temperature, mean air temperature in catchment and altitude. The discharge, the size of the catchment and the distance from the source has certain, but not significant, univariate effect on stream temperature. Table 3.5 displays Pearson's correlation coefficients of each factor with stream temperature in July as well as the significance level. The length of the river and the distance to the next confluence do not have an impact. No correlation could be found between the Bio- or Ecoregions and water temperature, or between stream order and stream temperature (data not shown).

*Table 3.5: Correlation coefficients and significance between abiotic factors and water temperature in July. ** =correlation significant on a level of 0.01 (two-sided). * = correlation significant on a level of 0.05 (two-sided)*

	Correlation	Significance
Air temperature at site	0.683**	0.000
Air temperature in catchment	0.734**	0.000
Altitude	-0.727**	0.000
Distance from source	0.205	0.053
Catchment size	0.130	0.154
Discharge	0.048	0.356
Width	0.008	0.476

It was noted that the univariate influence of abiotic factors varies with river size. Taking the catchment size as an example, table 3.6 shows the different correlation coefficients for four river categories. It can be seen that the air temperature's influence decreases slightly with increasing catchment size, but still highly influential, while the mean air temperature in the catchment increases. The altitude's influence is very similar to the air temperature. The influence of catchment size and the discharge varies strongly, while the influence of distance to the source decreases with increasing catchment size. Similar results were obtained when comparing different river width categories.

*Table 3.6: Correlation coefficients between abiotic factors and stream temperature in July for four categories of rivers according to their catchment size. ** =correlation significant on a level of 0.01 (two-sided). * = correlation significant on a level of 0.05 (two-sided)*

Catchment size	**<188 [km^2]**	**188-331 [km^2]**	**331-689 [km^2]**	**>689 [km^2]**
Air temperature at site	0.752**	0.801**	0.555*	0.663*
Air temperature in catchment	0.617*	0.851**	0.890**	0.893**
Altitude	-0.745**	-0.827**	-0.595**	-0.757**
Distance from source	0.543*	0.338	0.128	0.223
Catchment size	0.075	-0,043	-0.472*	0.157
Discharge	-0.285	-0.335	-0.740**	-0.105
Width	0.408	-0.301	-0.610**	0.096

The factor analysis using the entire dataset (corresponding to table 3.5), showed that two factors would be enough to explain over 80% of the variance. The factor plot (figure 3.34) shows the variables in the factor space, visualizing the relationship and loadings, where the axis represent the components. The plot visualizes two groups of variables: (1) water and air temperature, and (2) all variables related to river size. Altitude stands alone as the only strong negative factor, although from its location near the vertical axis it can be concluded that it behaves similarly to air and stream temperature, and therefore belongs to the first group. Similarly to the correlations varying if the data is split into groups depending on river width or catchment size, the factor plot strongly varies, as shown in figure 3.35, where the second catchment class (188-331 km^2; corresponding to table 3.6) is taken as an example. It can be noted that the two groups are not as defined as in figure 3.34, and that distance from the source is closely aligned to air and water temperature. The second group, consisting of catchment size, discharge and river width, is not closely aligned to the axis. This variation in variable location and, therefore, relationship suggests, that one single stream temperature model is unlikely to deliver satisfactory results.

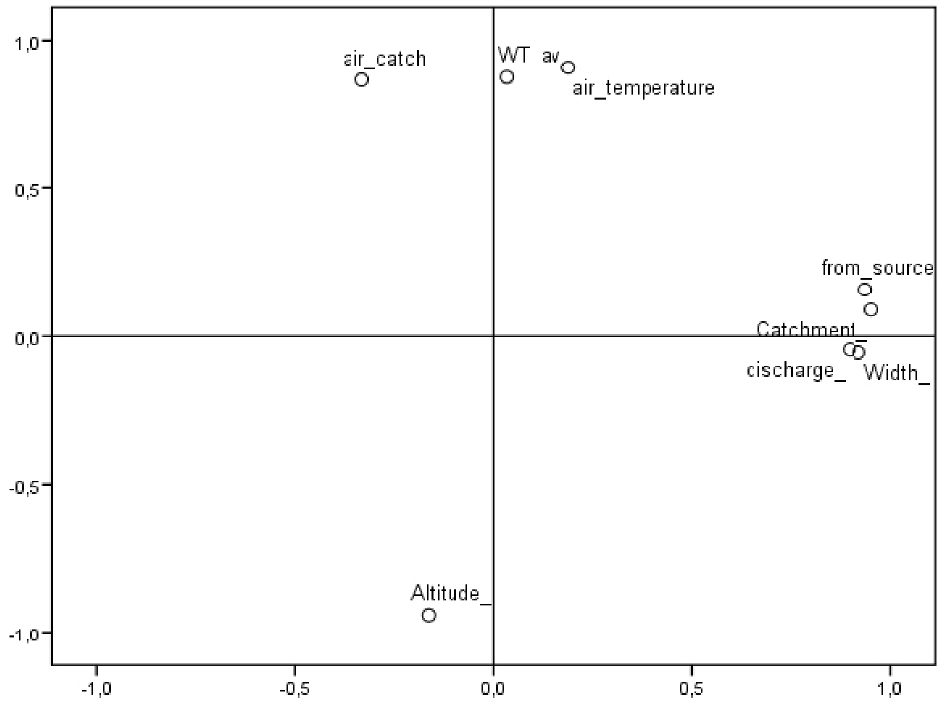


Figure 3.34: Factor plot in rotated factor space for the entire data set for July. (N=63) WT_av = Water temperature, from_source = distance from source and air_catch = mean air temperature in catchment.

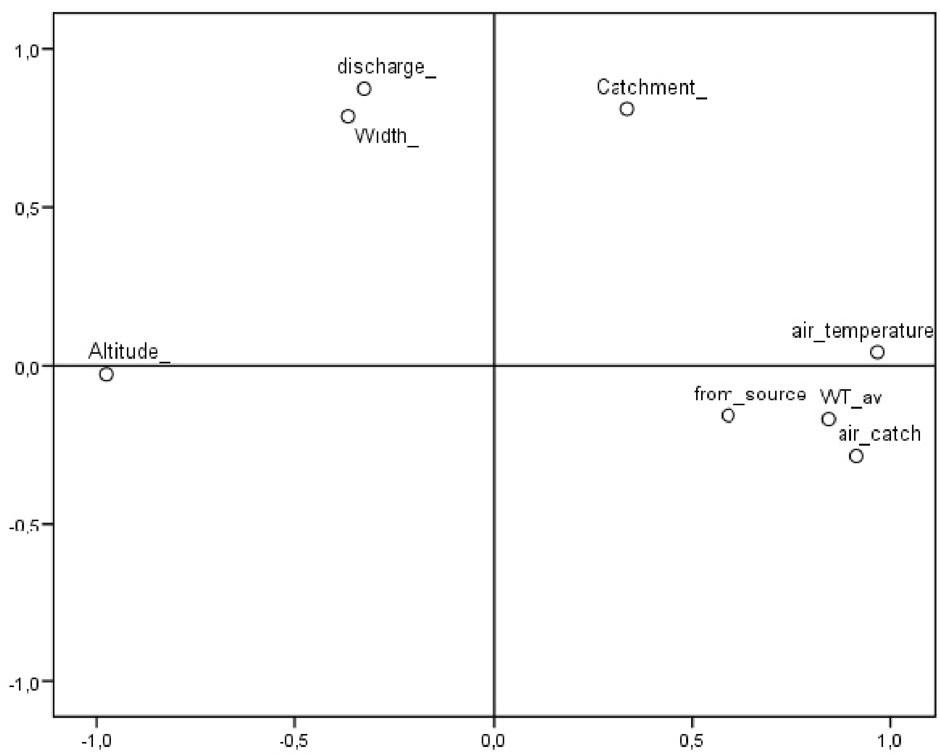


Figure 3.35: Factor plot in rotated factor space for sites for which the catchment is between 188 km^2 and 331 km^2 for July. (N=16). WT_av = Water temperature, from_source = distance from source and air_catch = mean air temperature in catchment.

3.4. CLIMATE CHANGE AND FUTURE SCENARIOS

3.4.1. ABIOTIC FACTORS INFLUENCED BY CLIMATE CHANGE

Climate change mainly affects air temperature and precipitation patterns. The IPCC (2007) concludes that in the past years cold nights and frosts have become less frequent, while the number of warm nights and hot days has increased, with it also likely that the frequency of heavy precipitation events has increased over most areas. The increase in temperature and a change in precipitation patterns further influence snow and glacial accumulation and melt patterns.

These predictetd climate change effects will have an influence on the riverine temperature regime as air temperature and precipitation, as well as snow melt, directly impact stream temperature (see section 1.2). Furthermore, precipitation and snow melt have an effect on the discharge volume, which in turn influences water temperature. Taking the scheme of factors influencing stream temperature (figure 1.1) developed by CAISSIE (2006) as a reference, it can be concluded that climate change directly alters all atmospheric conditions as well as indirectly the volume of discharge of influence to water temperature.

Applying this information to the findings reached through the analysis of available data, as outlined in section 3.2, the highest impact is to be attributed to air temperature and discharge. Since air and stream temperature always exhibit a high correlation, and discharge and water temperature in most cases, water temperature is expected to change with altering air temperature. Other factors described in section 3.3 are not influenced by climate change as they are constant in relation to river-typography and not influenced by the climate. The elevation above sea level will not change without a major natural catastrophe, respectively over geologic relevant periods (> 1 million years), nor will the width, length or distance from the source of the river. However, the classified bio-, eco- and fish regions might change as they themselves depend on air temperature and discharge, amongst other factors. Hence, in order to model future stream temperatures under the influence of climate change, expected future values of air temperature and or discharge (depending on the model) must be used.

3.4.2. CLIMATE CHANGE SCENARIOS

Since air and consequently stream temperature are influenced by climate change, an estimate of future climate change development and its effects is needed in order to predict future fish assemblages in Austrian rivers. This has been done by the IPCC (2011) in their Special Report on Emission Scenarios (SRES) on the future of the world's climate through the development of four scenarios:

- A1: assumes a rapid economic growth, a mid-century global population peak and rapid introduction of new technologies with the following energy sources:
    - A1FI: fossil intensive
    - A1T: non fossil energy sources
    - A1B: balance across all sources
- A2: describes a very heterogeneous world with high population growth, slow economic development and slow technological change.
- B1: adopts a convergent world with the same population as A1 but with more rapid changes in economic structures toward a service and information economy.
- B2: assumes a world with an intermediate population and economic growth, emphasizing local solutions to economic, social and environmental sustainability.

These scenarios do not take any environmental policy above current policies into account and are meant to show a variety of possible future developments (IPPC, 2007). According to the different assumptions described, expected climatic effects, such as temperature rise or changing precipitation patterns, shown in figure 3.36, have been calculated using high-resolution and variable resolution atmospheric GCMs.

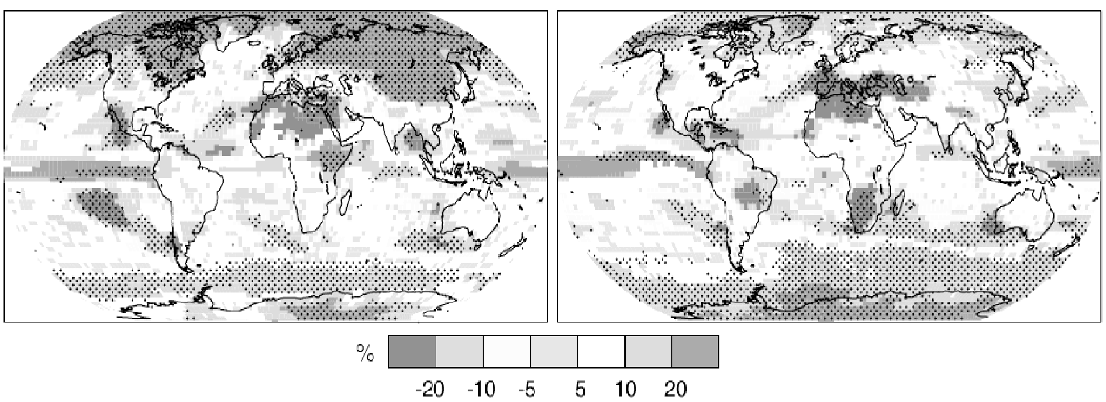


Figure 3.36: Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right) (IPPC, 2007, p. 47)

3.4.3. DOWNSCALING OF CLIMATE CHANGE SCENARIOS

The wide range of likely temperature changes within each scenario, for example 2,4°C in A1T (table 3.7), is not very useful when modeling stream temperatures for Austria, nor is the best estimate as these values propose global averages.

Table 3.7: Projected global average surface warming at the end of the 21st century (IPPC, 2007, p. 45)

Case	**Temperature change** (°C at 2090-2099 relative to 1980-1999)	
	Best estimate	Likely change
Constant year 2000 concentrations	0.6	0.3-0.9
A1B scenario	2.8	1.7-4.4
A1FI scenario	4.0	2.4-6.0
A1T scenario	2.4	1.4-3.8
A2 scenario	3.4	2.0-5.4
B1 scenario	1.8	1.1-2.9
B2 scenario	2.4	1.4-3.8

As described in section 1.4, the temperature change in the past 100 years in Austria was greater than the global average, and it may be therefore expected that any future change might also vary in relation to global change. For this reason, different methods have been developed which improve information on regional climate change: (1) high resolution GCMs, (2) Regional Climate Models (RCMs) and (3) statistical downscaling methods (SDMs). The first method requires either a very powerful computer or a short modeling time frame. Therefore, no such high resolution data is available for Austria. Regional Climate Models increase the resolution of a GCM in an area of interest by using the climatic data generated by GCMs along with detailed geographic information as inputs. The output is data with a resolution of 10 km^2 up to 50 km^2. The third method determines statistical relationships between observed small scale (e.g. station level) and larger scale (GCM) variables using regression analysis, analogue methods or neutral network methods (FRÜH *et al.*, 2010). Future values are then generated using the same relationship at resolutions down to 30 arc-seconds (~1km^2).

The statistically downscaled (delta method) dataset available from the International Centre for Tropical Agriculture (CIAT) offers a 30 arc-second (~1 km^2) resolution. It is based on the sum of interpolated anomalies to the same high resolution monthly climate surfaces from WorldClim (RAMIREZ-VILLEGAS & JARVIS, 2010), as used in this thesis, and available for three (A1b, A2a and B2a) emission scenarios. Between four and seven datasets based on different GCM outputs are available for each emission scenario.

The Alpine landscape is dominated by great climatic variability, and therefore high resolution is crucial when modeling temperatures on a small scale, i.e. stream temperature at certain points. For this reason and due to the fact that the model is based on the WorldClim data, which ensures comparability, the statistically downscaled delta method data was chosen as the source of future air temperatures. In order to ensure comparability between the scenarios, data based on the GCM HADCM3 was chosen, as it is the only GCM which has been used as the basis for all three scenarios. The HADCM3 is a coupled atmosphere-ocean GCM developed at the Hadley Centre in the United Kingdom and has been used by, among others, the IPCC.

3.4.4. *Future air temperature*

Future air temperatures have been predicted by a number of research institutes using three different methods, as described in section 3.3.3: (1) High resolution GCMs, (2) RCMs and (3) SDMs. However, MEARNS *et al.* (2007) found data obtained through statistical downscaling to exhibit a larger seasonal and daily temperature variability than data obtained from RCMs or GCMs.

The mean future air temperatures as modeled by the HADCM3 GCM and downscaled by the CIAT using the delta method at the HZB sites are displayed in table 3.8. The greatest increase is expected in scenario A1b, while the smallest increase is expected in scenario B2a. In any case, the temperature is predicted to rise by at least 2.27°C by 2050s and 3.77 °C by 2080s.

Table 3.8: Current and projected July air temperatures (RAMIREZ-VILLEGAS & JARVIS, 2010) for different scenarios and decades.

Scenario	Mean temperature (°C)	Temperature increase (°C)
1961-2000	17.46	
A1b 2050s	21.84	4.39
A1b 2080s	23.79	6.34
A2a 2050s	20.72	3.27
A2a 2080s	22.40	4.95
B2a 2050s	20.20	2.75
B2a 2080s	21.23	3.77

If the mean temperature increase is compared to current temperatures, as in figures 3.37 and 3.38, it can be seen that the temperature increase is predicted to be greater in areas with lower temperatures. It can also be noted that the temperature increase dependent on current air temperatures varies between the different scenarios, especially in the 2050s. While scenario A1b predicts an even increase, scenario B2a predicts a much stronger temperature increase for areas with relatively low temperatures. However, by the 2080s a parallel air temperature increase between the scenarios is expected. Furthermore, it can be concluded that the temperature increase for scenario B2a is expected to be greater in the coming years than between 2050s and 2080s, while the opposite is the case for scenario A2a.

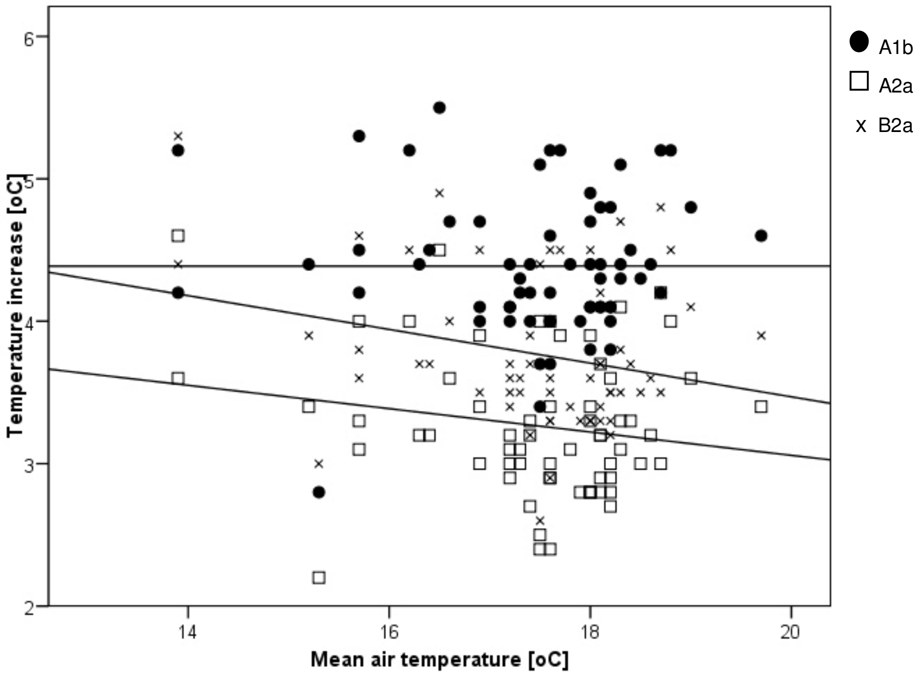


Figure 3.37: Modeled air temperature increase for July between the current climate and the 2050s for the SRES A1, A2 and B2.

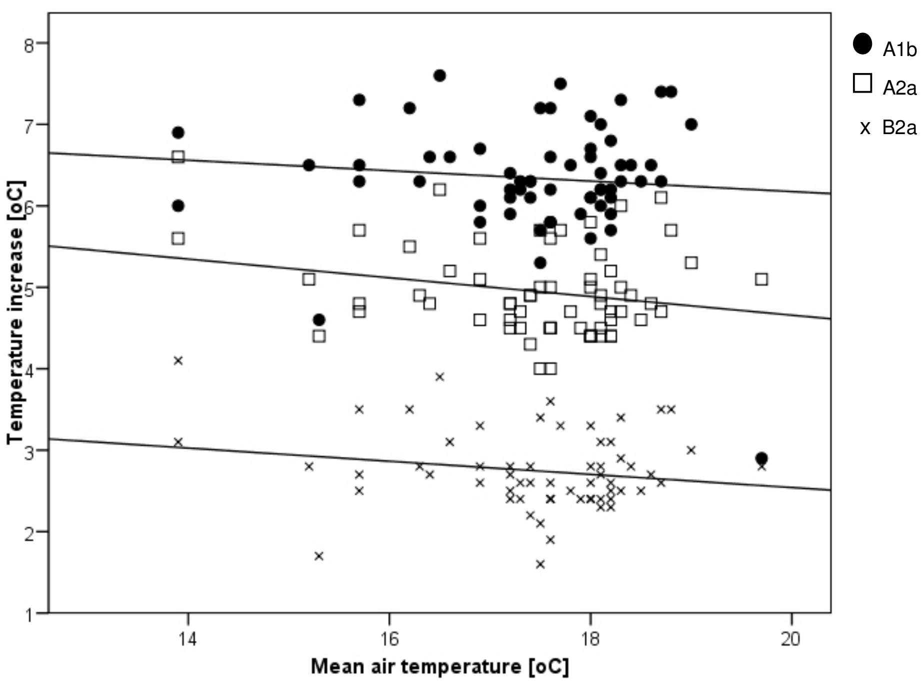


Figure 3.38: Modeled air temperature increase for July between the current climate and the 2080s for the SRES A1, A2 and B2.

3.5. STREAM TEMPERATURE MODEL

In this thesis, two different approaches were followed to develop the stream-temperature model: The first one being a well-established regression model, the second a less common, logic based crosstab model. The results of both are shown in the following sections.

3.5.1. REGRESSION MODEL

One of the main objectives of the stream temperature model is the accurate prediction of current and future stream temperatures. Therefore, air temperature and/or discharge had to be included as independent variables, as they are the only ones expected to vary under the influence of climate change in the future (see section 3.3). Since it should be possible to use the model at any given river site in Austria, including the discharge as an independent variable is not ideal, as reliable discharge measurements for an arbitrary river section are difficult to obtain and would therefore limit the applicability. Therefore, it was decided to take air temperature as the independent variable determining the effects of climate change. The model was further expected to deliver accurate and significant predictions and multiple equations were calculated as this could not be achieved with one equation. The basis for the differentiation was delivered through the classification and clustering methods described in section 2.3.3.

Two further aspects regarding accuracy had to be considered during the analysis: (1) the 40 year monthly mean air temperatures (WorldClim) cannot be used in the same way as monthly mean values (stream temperature). When these two variables were used to generate a regression model, this resulted in a very high, yet misleading, coefficient of determination (R^2) as the air temperate was no longer a variable but a constant. In order to avoid this problem, the twelve year (1997-2008) monthly mean stream temperature was calculated and then used in the analysis with the WorldClim data. (2) Similarly to the 40 year average air temperature acting as a constant, real constants distort the equation. However, as about half the influential factors on stream temperature are constants (e.g. altitude) they needed to be included in the model in order to deliver the most accurate result possible. Through the development of one regression equation for each month, using WorldClim values, and for each month per year[5], using ZAMG values, the constants acted as variables, ensuring validity. The development of monthly regressions also increased accuracy as the air-stream temperature relationship is stronger when the air temperature is above 0 °C (compare section 1.4) and therefore higher correlation coefficients were expected in the summer months.

[5] after HUBER (2008), 2001 was chosen as a “normal“ year

Due to the limited number of sites for which ZAMG-temperatures were available (N=34), WorldClim temperatures and hence monthly mean water temperatures for 1997 to 2008 were used for the final regression model. As mentioned earlier, the large abiotic inhomogeneity of the sites made clustering necessary and different combinations of classed catchment size, river width, distance from the source and altitude were attempted with the following independent variables included in the regression analysis:

- WorldClim air temperature at site
- WorldClim mean air temperature in upstream catchment
- Altitude
- Discharge
- River width
- Distance from the source
- Catchment size

Classification of the data according to the upstream catchment size proved to be the best clustering option, leading to the most accurate regression formula, defined as follows:

$$WT^*_{(s,m)} = a + AC_{sm} * b + C_s * c + S_s * d + A_s * e \quad [9]$$

WT* = estimated morning water temperature at site *s* in month *m* (°C)

$AC_{s,m}$ = mean air temperature for site *s*' catchment in month *m* (°C)

C_s = catchment size of site *s* (km^2)

S_s = distance from source at site *s* (km)

A_s = altitude of site *s* (m.a.s.l)

b, c, d, e = regression coefficients

a = constant

In July, for example, the four variables air temperature in catchment, catchment size, distance from the source and altitude explain the variability of the water temperature with an adjusted coefficient of determination of up to 0.83 and a significance level of 0.001 %. Table 3.9 shows the regression coefficients, constants and exact $adjR^2$ for each of the four catchment classes for July, a corresponding table for June and August can be found in Annex IV.

According to the Kolmogorov-Smirnov-Test, the residues, which represent the difference between the observed and estimated values, are distributed normally, with a mean in July around 0 and a standard deviation of 0.994, as shown in figure 3.39. If all four clusters are analyzed separately, similar results are obtained. If the observed and predicted stream temperatures are plotted against the mean air temperature in each catchment, then the lines of best fit differ by less than 0.3°C, as shown in figure 3.40.

Table 3.9: Constant (a), regression coefficients (b, c, d, e), R² and adjR² for each catchment class in July.

Catchment size	a	b	c	d	e	R^2	adjR²
<188,8 km²:	14.405	0.22	-0.005	0.34	-0.009	.754	.659
188,8-331,8 km²:	14.885	0.578	-0.016	-0.044	-0.010	.834	.793
331,8-689,4 km²:	-21.293	1.936	0.004	0.016	0.005	.843	.789
>689,4 km²:	-7.326	1.396	0.001	-0.005	0.004	.869	.831

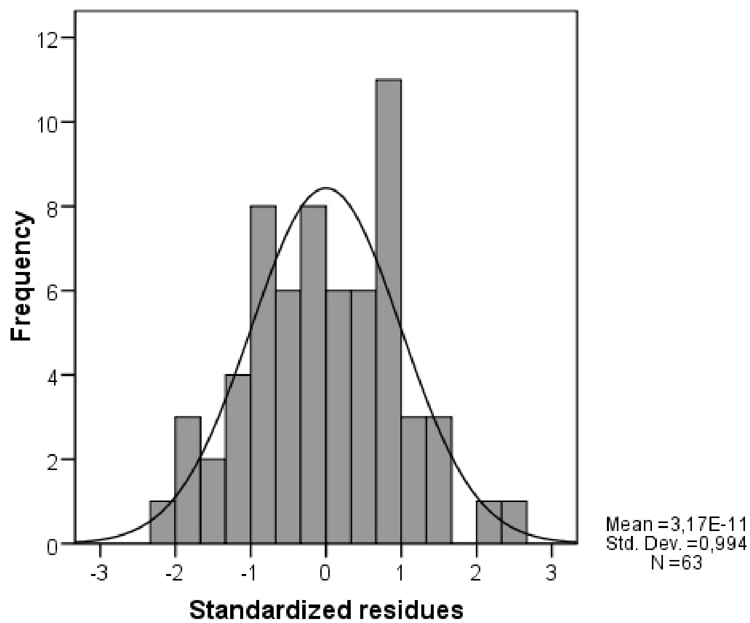


Figure 3.39: Distribution of the standardized residues of the regression model in July.

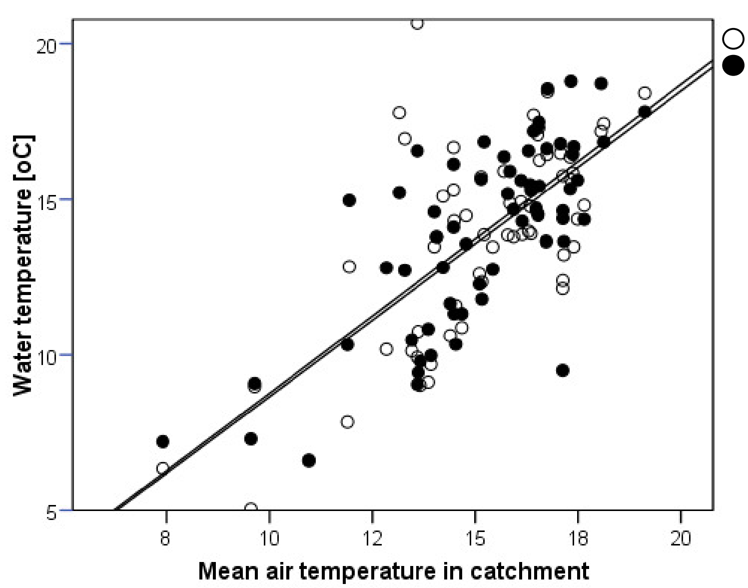


Figure 3.40: Observed and predicted stream temperature in relation to the mean air temperature in the catchment in July. (N=63).

3.5.2. CROSSTAB MODEL

The second approach in developing a stream temperature model was a crosstab method with standardized residues. As described earlier, if mega-variables are used it can function as a multiple regression model. Classified water temperature in 1℃ steps was used as the dependent variable and profiled clusters (i.e. mega variables) were used as the independent variable.

The major difference between this method and a regression model is that the cross tabulation does not give a defined value but a range for stream temperature. However, this range can be said to be very accurate since the divergence which also exists in the regression model is already included in the temperature range if confidence intervals are considered. Additionally, the cross tabulation matrix can be developed for more than one month at a time since constant values (e.g. catchment size) do not distort the model. The major drawback of this model is that if stream temperatures are to significantly increase in the future, as a result of increased air temperature or changed precipitation patterns, they cannot be estimated using the cross tabulation as it is based on observed frequencies and hence the current maximum temperatures are the model's upper limit.

The most accurate crosstab model consists of a mega variable generated through the aggregation of categorized WorldClim air temperature, river width and distance from the source, with the category boundaries set as displayed in table 3.10 and the formula [10] shown below. Figure 3.41 summarizes the development of the mega-variable used in the model and the list of each mega-variable with its corresponding classified profile variable can be seen in Annex V.

Table 3.10: Profiling categories

Category	Temperature (℃)	Width (m)	Distance from source (km)
1	<16.00	<8.00	<20.00
2	16.01-17.00	8.01-16.00	20.01-50.00
3	17.01-18.00	>16.01	>50.01
4	>18.01		

$$Profile_{tempwidthaltisource} = cat_{temp} * 100 + cat_{width} * 10 + cat_{source} \quad [10]$$

$Profile_{tempwidthaltisource}$ = the created profile

cat_{temp} = classified WorldClim-air temperature

cat_{width} = classified width

cat_{source} = classified distance from source

The alpha adjusted significance bound was calculated to be 3,2 through the following formula [11] and the corresponding table (3.11) from LAUTSCH and VON WEBER (1995, pp. 192-196):

$$\alpha^{*} = \frac{0{,}05}{(13 \times 6)} = 0.000641 \qquad [11]$$

Table 3.11: Extract from Table 1 "Standardnormvariables for sifginifcance levels" (LAUTSCH & VONWEBER, 1995, pp. 192-196)

α*	**u**
...	…
0.0006480	3.217
0.0006440	3.219
0.0006400	3.220

Table 3.12 shows the crosstab model for July with an exploratory value of 62%. The expected temperatures are obtained through entering the table with the classified profile variable on the top and then reading the corresponding highlighted water temperature range. Site 204925 in July 1997, for example, exhibits the features summarized in the mega-variable 212 which is clustered in the classified profile variable 5 and hence exhibits a stream temperature between 14 and 17℃. If, for example, the air temperature were to increase by 5℃ in future, the new profile variable would be 412 and the site would then be classed in the classified profile variable 6, with the future stream temperature estimated to be over 18℃.

Table 3.12: Crosstab model for July (α=3.2) (N=680)

Temperature (℃)		Classified Profiles					
		1	2	3	4	5	6
< 7.00	Count	11	0	1	0	5	2
	Residual	8.2	-1.5	-1.4	-1.7	-.1	-.8
7.01 – 8.00	Count	9	0	5	0	5	2
	Residual	6.1	-1.6	.4	-1.7	-.3	-1.0
8.01 – 9.00	Count	0	13	1	0	4	2
	Residual	-1.2	6.9	-1.5	-1.7	-.7	-.9
9.01 – 10.00	Count	0	29	3	0	8	0
	Residual	-1.7	11.2	-1.8	-2.4	-.9	-2.8
10.01 – 11.00	Count	0	27	20	1	2	2
	Residual	-1.9	8.4	3,0	-2.4	-3.3	-2.5
11.01 – 12.00	Count	3	7	22	1	4	7
	Residual	-.1	.8	4.4	-2.1	-2.3	-.5
12.01 – 13.00	Count	4	4	20	2	10	7
	Residual	.3	-.7	3.5	-1.8	-.8	-.6
13.01 – 14.00	Count	4	0	15	28	10	10
	Residual	-.4	-2.8	.4	5.9	-2.0	-.8
14.01 – 15.00	Count	4	0	11	28	46	10
	Residual	-1.2	-3.4	-2.0	3.6	3.6	-2.0
15.01 – 16.00	Count	8	0	9	15	47	20
	Residual	.3	-3.4	-2.4	,2	3.8	.3
16.01 – 17.00	Count	2	0	11	15	29	13
	Residual	-1.4	-2.9	-.8	1,5	3.2	1.3
17.01 – 18.00	Count	1	0	8	7	16	22
	Residual	-1.5	-2.5	-.9	-.3	.3	3.7
>18.01	Count	3	0	10	1	7	27
	Residual	-.2	-2.4	.1	-2.2	-1.7	5.9

Summary: Data clustering

The diagram below (figure 3.41) shows the process of data clustering that was ultimately used in order to find homogeneous groups of river-sites for which an accurate and valid stream temperature model could be developed.

1

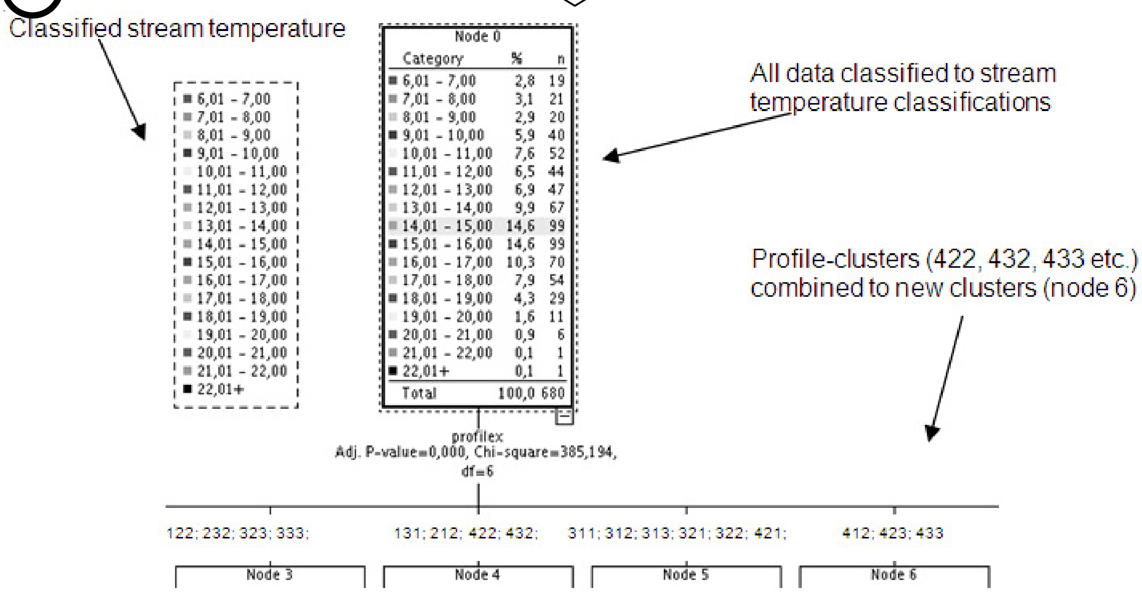
HZBID	Width	From source	WorldClim air	Water temp cat	airtemp cat	Width cat	From source cat
204925	6.30	24.57	16.9	10	**2**	**1**	**2**
205393	11.40	39.03	17.2	9	**3**	**2**	**3**
204933	24.00	50.01	16.6	9	**2**	**3**	**3**

2

$$Profile_{tempaltisource} = cat_{temp} * 100 + cat_{width} * 10 + cat_{source}$$

HZBID	Water temp cat	Temperature cat	Width cat	From source cat	Profile
204925	10	2	2	2	**212**
205393	9	3	2	3	**323**
204933	9	2	3	3	**233**

3



HZBID	Water temp cat	Temperature cat	Width cat	From source cat	Profile	Profile cat
204925	10	2	1	2	212	**4**
205393	9	3	2	3	323	**3**
204933	9	2	3	3	233	**5**

Figure 3.41: Diagram of the clustering method used: (1) categorization of metric variables, (2) calculation of profiles and (3) use of a classification tree to combine profiles to clusters.

3.6. STREAM TEMPERATURE AND FISH DISTRIBUTION

Finally, stream temperature for 300 fish sampling sites was modeled using the developed regression formula (see section 3.5.1). The selection of these sites was conducted in the same way as the HZB-sites were selected and a summary can be seen in table 3.3 in section 3.2.1.

The mean estimated current stream temperature at the IHG-sites varies between 9°C and 19°C, with a mean of 13.9°C in July. The mean temperatures for June and August are estimated as 12.8°C and 14.2°C respectively.

3.6.1. STREAM TEMPERATURE- FISH ZONE INDEX CORRELATION

The calculated FiZI at each fish sampling site was assigned to the different fish regions (boundaries see table 3.4), and the water temperature modeled for all sites. Figure 3.42 shows the predicted water temperatures for each fish region. The mean July temperature in the Trout region (MR) was estimated to be 13.1°C, 15.2°C in the Grayling region (HR), and 16.8°C and 18.3°C in the Barb region (EP) and Bream region (MP) respectively.

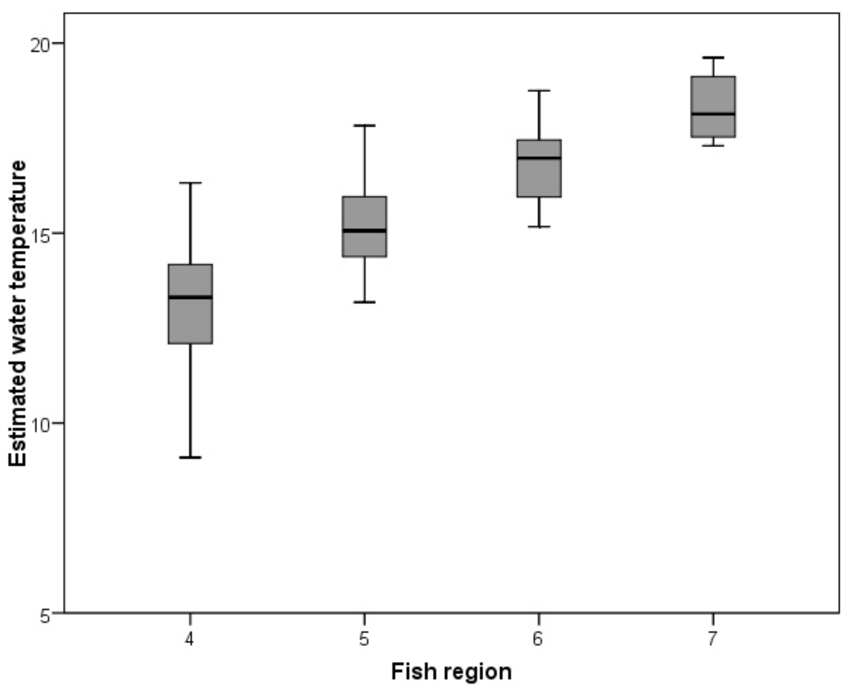


Figure 3.42: Predicted July water temperatures in degrees Celsius for the IHG-sites for each fish zone where 4=Metarhithral, 5=Hyporhithral, 6=Epipotamal and 7=Metapotamal. (N=300)

In order to verify the predicted water temperatures for each fish region, observed water temperatures from the HZB-sites, for which the fish region is known, were compared to the modeled mean water temperatures of each region. Figure 3.43 shows that the estimated mean stream temperatures for the MR, HR, and EP are almost identical to the observed mean values as only the estimated temperature for the Grayling region is slightly above the observed. No validation could be conducted for the MP as no HZB-site in this fish region were included in the analysis.

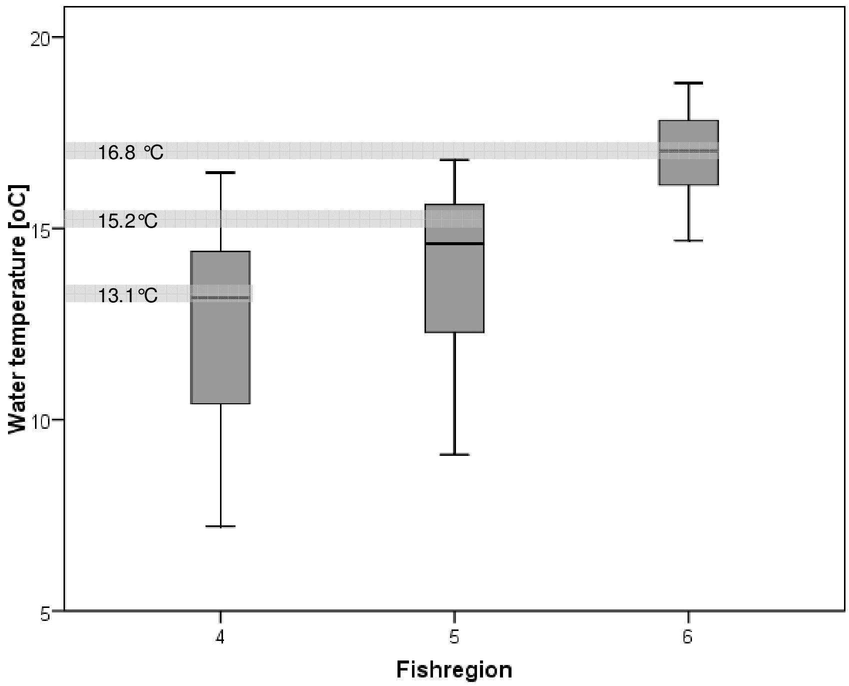


Figure 3.43: Estimated mean (light grey horizontal bars) and observed (box-plots) July water temperatures for each fish region where 4= Metarhithral, 5=Hyporhithral, and 6=Epipotamal.

There is a strong correlation (ρ= 0.77) between the estimated stream temperature in July and the Fish Zone Index, as shown in figure 3.44. The water temperature in the trout region (FizI~3.8) has the widest spread, with values ranging from 7° to 15° Celsius. An explanation for this might be the location of these sites. The trout region is located in the upper river section which is very cold if located in the Alps (i.e. altitude above 1000m) and warmer if located in the foothills.

The simple regression analysis confirms that there is a linear relationship between the two variables with an adjusted coefficient of determination of 0.6 and significance level of 0.001 in July. The resulting regression equation is as follows:

$$FiZI^*_{(s,m)} = a + b * WT_{(s,m)} \quad [12]$$

$FiZI^*_{(s,m)}$= estimated Fish Zone Index at site *s* in month *m*

$WT_{(s,m)}$= water temperature in °C at site *s* in month *m*

a= constant

b= coefficient

For July, the regression constant a= 0.015 and the coefficient b= 0.318. The regression coefficients for June and August as well as the coefficients of determination are listed in Annex IV. The Kolmogorov-Smirnov-Test as well as the Chi-Squared-Test showed the residues to be distributed normally.

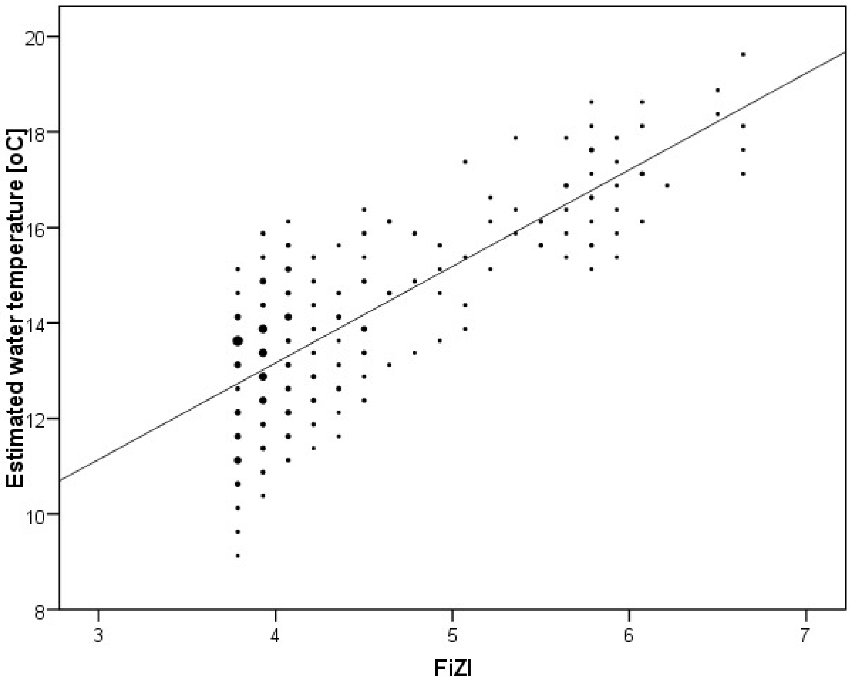


Figure 3.44: Correlation of estimated July water temperature and the Fish zone Index. Very large dots represent 14 values and very small ones one. N=300 and R^2=0.6

3.6.2. STREAM TEMPERATURE- SALMONIDAE/CYPRINIDAE PROPORTION

Salmonidae and Cyprinidae are used to represent the upper and lower parts of a river, and hence a significant difference in water temperatures between the habitats is expected. Figure 3.45 proves this as the temperature ranges for sites which are strongly dominated by one of the fish families are displayed and show a clear difference. In order to plot the temperatures, the SCI as well as the absolute percentages have been chosen. The first represents the relative presence of each family in relation to the sum of the two families at each site (see section 2.6), and the latter the presence of each family in relation to all fish at each site. The mean temperature for the darker box plots (i.e. SCI) was calculated for Salmonidae dominated sites with 13°C, and with 16.8°C for Cyprinidae dominated sites. The mean temperature of absolute percentages (light grey box plots) was found to be 12.9°C at sites where Salmonidae dominate, and 17.1°C for sites where Cyprinidae dominate. As it can be seen there is practically no difference in the temperature ranges between the two ways in which dominance was defined. And these almost identical mean temperatures prove that the SCI corresponds to the absolute percentages; hence Salmonidae and Cyprinidae rarely coexist, which is in line with the SCI frequency distribution (compare section 3.2.3). The temperature range at which Salmonidae dominate is much larger than for Cyprinidae, maybe due to the unequal number of sites in each category or due to the same reasons the temperature span in the trout region is the widest. It can further be observed that 15℃ is the temperature below and above which Salmonidae and Cyprinidae occur respectively, therefore defining the border between Rhithral and Potamal in the dataset.

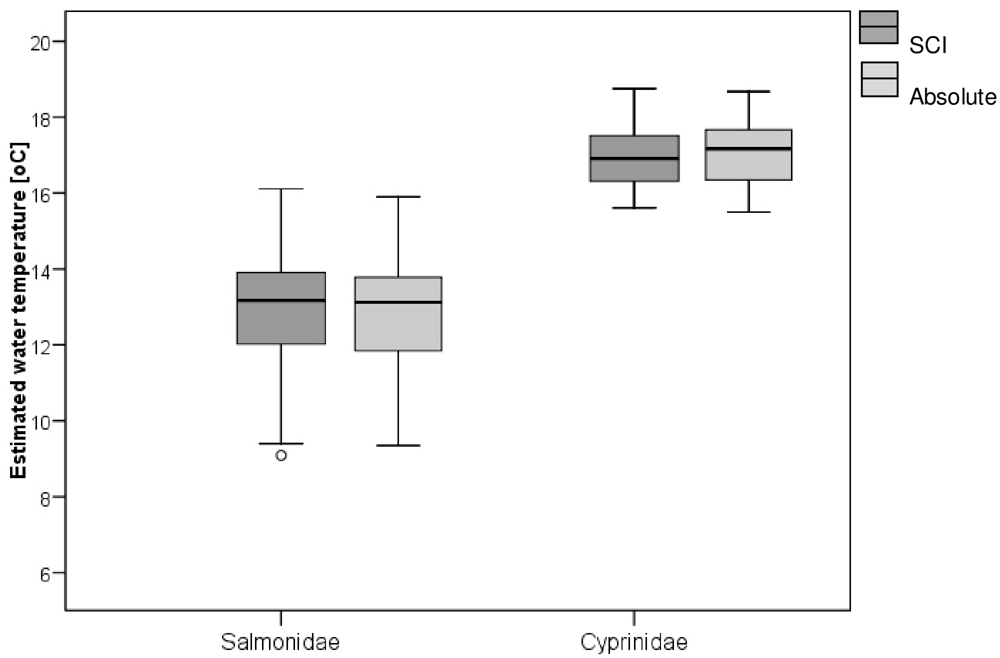


Figure 3.45: Box plots showing the estimated July temperature range of sites at which Salmonidae and Cyprinidae strongly dominate. SCI: SCI<0.02 = Salmonidae, N=192; SCI>0.98=Cyprinidae, N=22 and Absolute: Salmonidae> 98% N= 69; Cyprinidae> 98%, N= 10

Similarly to the stream temperature-FiZI relationship there is a correlation between the water temperature and the SCI, as shown in figure 3.46. The correlation after Pearson is 0.76 in July and a defined temperature range for both Salmonidae and Cyprinidae is visible. The regression formula for this relationship is as follows:

$$SCI^*_{(s,m)} = a + b * WT_{(s,m)} \qquad [13]$$

$SCI^*_{(s,m)}$= estimated Salmonidae/Cyprinidae Index at site *s* in month *m*

$WT_{(s,m)}$= Water temperature in ℃ at site *s* in month *m*

a= constant

b= coefficient

For July, the regression constant a= -1,556 and the coefficient b= 0.125, with an adjusted coefficient of determination of 0.53 for July. The values for June and August are listed in Annex IV.

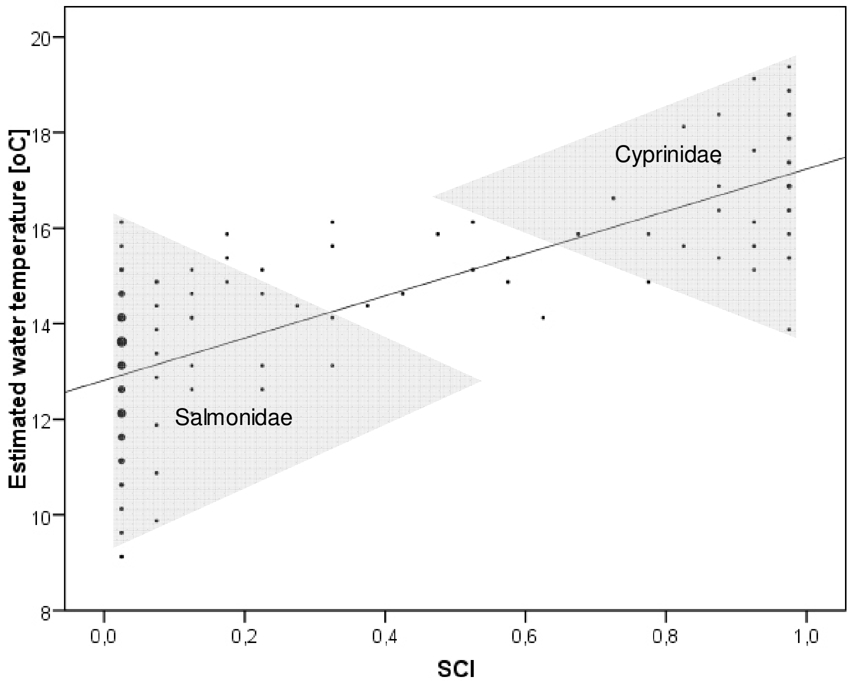


Figure 3.46: Correlation between estimated July water temperatures and the Salmonidae/Cyprinidae Index where 0= 100% Salmonidae and 1= 100% Cyprinidae; N=300, R^2= 0.53.

3.6.3. TROUT AND GRAYLING DISTRIBUTION

Brown trout (*Salmo trutta fario*) and grayling (*Thymallus thymallus*), being two of the most prominent species in Austrian rivers, prefer cold waters. Adult trout and grayling have an optimal water temperature range between 14-17℃ and 15-17℃ respectively (KÜTTEL *et al*., 2002). This is confirmed when the fish species distribution at the 300 fish sampling sites is analyzed. As figure 3.47 shows, most brown trout specimens are caught at sites with estimated temperatures below 14.5℃, and most grayling specimens at sites with temperatures below 15.5℃. The estimated mean temperature at which brown trout and grayling were caught is 13.7℃, however, the minimum temperature for brown trout is below the minimum temperature for grayling and the opposite is the case for the maximum temperatures.

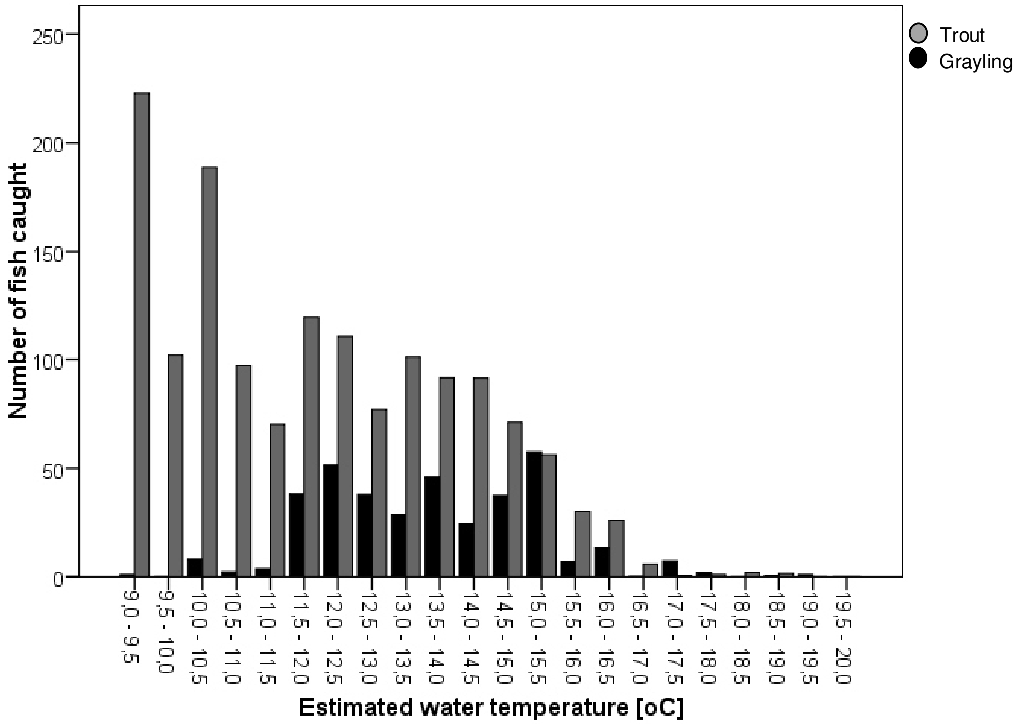


Figure 3.47: Number of trout and grayling specimen caught at the 300 IHG-sites with their corresponding modeled stream temperatures in July.

3.7. STREAM TEMPERATURE AND FISH DISTRIBUTION UNDER THE INFLUENCE OF CLIMATE CHANGE

In order to predict future stream temperatures and, consequently, future composition of stream fish assemblages, predicted future air temperatures were used in the regression model. Downscaled monthly mean catchment temperatures forecasted by the global hadcm3 model for the following three IPCC (2011) scenarios were used: A1b, A2a and B2a. It was noted, that although current air temperatures reach their maximum in July, the predicted temperatures reach their maximum in August. For this reason the following section will focus on that month.

3.7.1. STREAM TEMPERATURE

Stream temperature is estimated to rise by at least 3.1℃ by the 2050s and 4℃ by the 2080s. Table 3.13 shows the mean, maximum and minimum water temperatures for the different scenarios (A1b, A2 and B2) for the 2050s and 2080s, where the greatest increase is expected for scenario A1b and the lowest for scenario B2a. The mean water temperature at the selected fish sampling sites is currently 14.2℃, which is 7℃ below the estimated temperature in 2080s under the assumptions of scenario A1b.

Table 3.13: Mean, minimum and maximum estimated August water temperature in degrees Celsius for three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s (N=300/scenario)

Scenario		**2050s**			**2080s**	
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
A1b	12.5	18.8	29.2	12.6	21.2	30.9
A2a	11.3	17.2	31.0	13.5	20.0	33.1
B2a	11.78	17.3	30.2	12.0	18.2	31.3

However, the temperature increase is not linear across all rivers. As shown in figure 3.48, the greater the stream order, and hence the larger the river, the greater the temperature rise. The lowest increase is observed for stream order two rivers, and the biggest increase for stream order six and seven. The range of temperature increase is by far the greatest for large rivers (stream order 7) with up to 7.5℃, while all the other river sizes exhibit a margin of around 1℃.

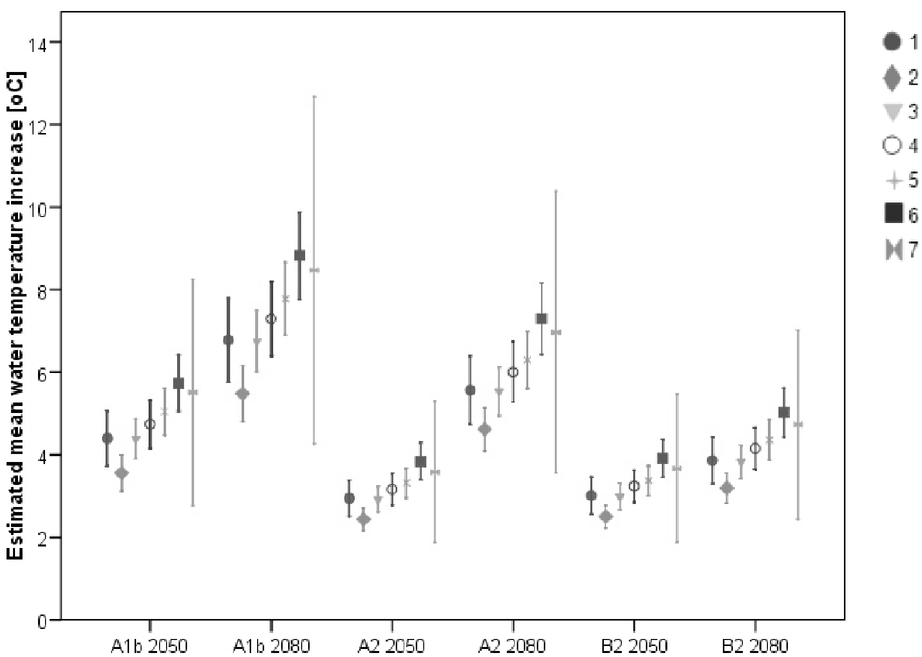


Figure 3.48: Mean estimated water temperature increase for different scenarios (A1b, A2a and B2a) and periods in regard to stream orders (1 to 7 after Wimmer & Moog (1994)) (N=300/scenario).

In the 2050s, scenarios A2a and B2a show very similar temperature increases, which is confirmed when water temperatures along the course of two Austrian rivers are displayed as shown in figure 3.49 and 3.50. However, beyond the 2050s the two scenarios develop differently as the temperature under scenario A2a increases about twice as much as under scenario B2a. Furthermore, it can be noted that the stream temperature increases with distance from the source, which is in line with the earlier observation that stream temperature increases with river size.

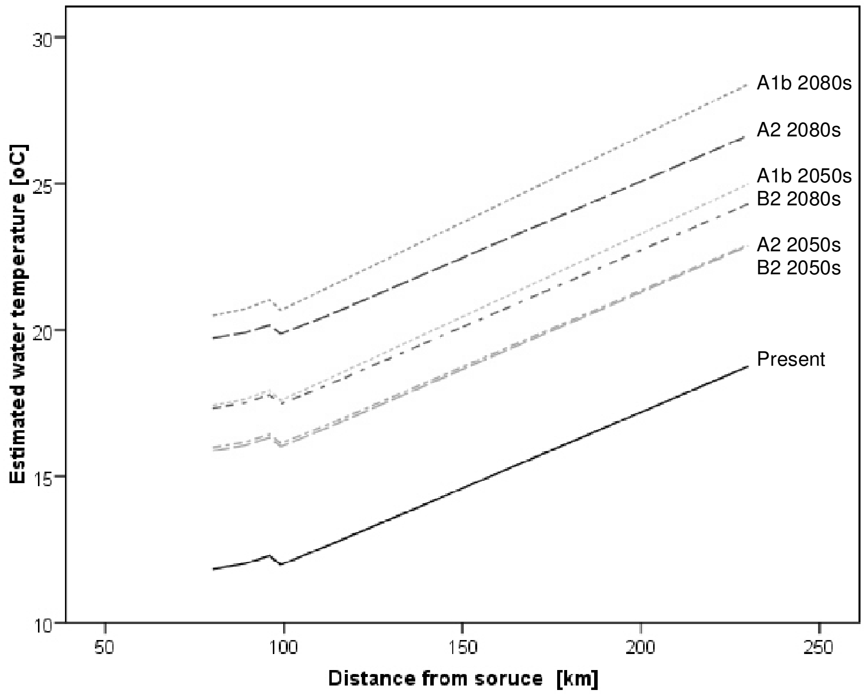


Figure 3.49: Estimated August water temperatures in degrees Celsius along the Drau for three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s.

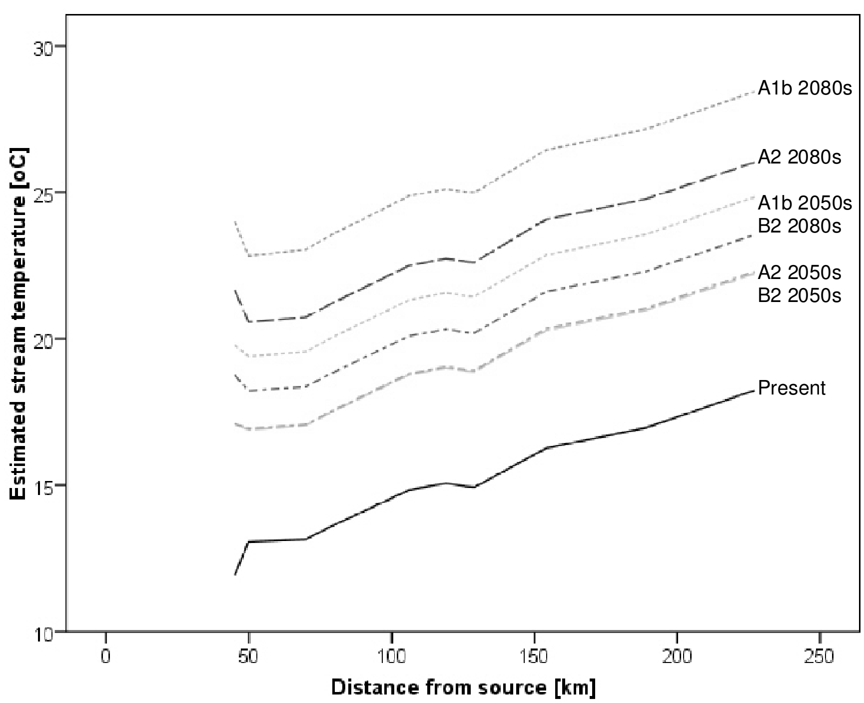


Figure 3.50: Estimated August water temperatures in degrees Celsius along the Enns for three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s.

3.7.2. FISH ASSEMBLAGE

Similarly to the expected water temperature increase, the fish community structure is expected to adjust to a warming climate. While some species might be able to adapt to rising stream temperatures, the majority are expected to migrate stream upward in search of colder realms (DAUFRESNE & BOET, 2007). Hence, species distribution in Austrian rivers is likely to change.

Fish Zone Index and fish regions

Stream temperature and the FiZI correlate strongly (see section 3.6.1), and for this reason the FiZI and fish region distribution throughout Austria are expected to adjust to rising temperatures. Table 3.14 lists the mean estimated Fish Zone Indices for the 2050s and 2080s under the different climate change scenarios at the investigated fish sampling sites. The mean FiZI of all sites is currently 4.4 and it is expected to increase to at least 5.39 (scenario B2) by the 2080s.

Table 3.14: Mean estimated FiZI for three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s (N=300/scenario)

	2050s		**2080s**	
Scenario	**mean**	**median**	**mean**	**median**
A1b	5.53	5.34	6.14	5.81
A2a	5.15	5.06	5.83	5.65
B2a	5.17	5.06	5.39	5.28

The frequency distribution of the potential fish zones is expected to change along with the FiZI. Figure 3.51 shows the frequency distributions according to the estimated fish regions of the fish sampling sites for the different scenarios. It can be noted that the proportion of sites in the MR is predicted to drastically decrease by the 2080s, particularly under scenario A1b and A2a. This is currently the fish region in which more than two thirds of the sites are located. Even though that is no longer expected to be the case under any of the climate change scenarios, the opposite is not likely to be the case either (i.e. that over two thirds are located in the MP region). All scenarios predict a major increase of sites in the HR, making this the region with the highest frequency of fish sampling sites by the 2080s. Only scenario A1b estimates an equal distribution of sites in the MP and HR. Even though the number of sites in the EP is expected to increase, this increase is predicted to be relatively small compared to the augmented number in the HR and MP. Comparing the frequency distribution within the distinct fish regions between the 2050s and 2080s, a gradual shift from the MR to the MP can be noted. While a number of sites remain in the upper fish regions (i.e. MR) by the 2050s, very few are expected to do so by the 2080s. The most sites by far are expected to be assigned to the HR by the 2050s and although this is still expected to be the most frequent fish region in the 2080s, the difference to the number of sites in the Potamal is significantly reduced.

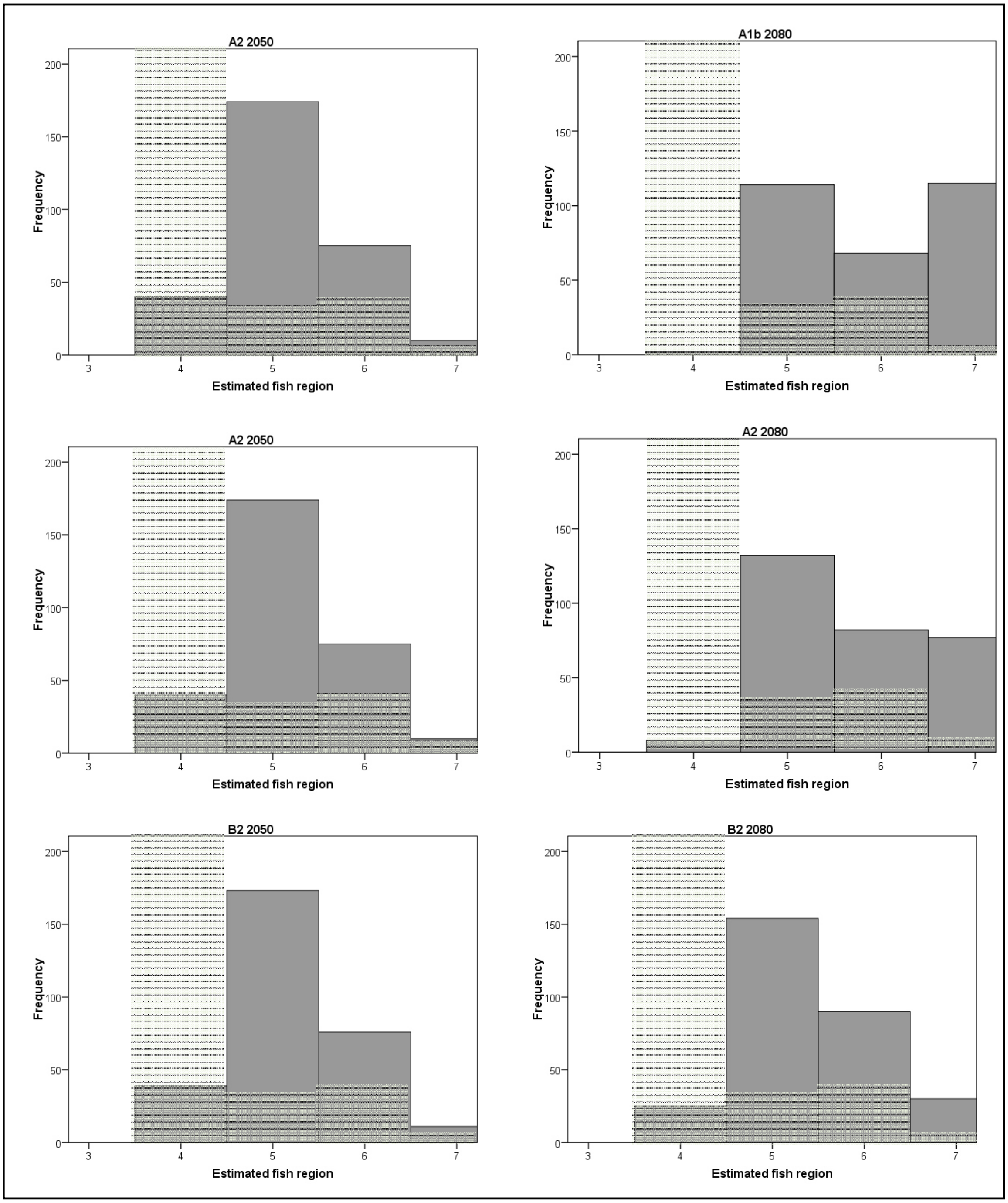


Figure 4.51: Estimated fish region frequencies (grey bars) for the different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s in comparison to the present ones (striped bars) where 4=Metarhithral, 5=Hyporhithral, 6=Epipotamal and 7=Metapotamal.

Currently the ratio of sites in the Rhithral to Potamal is 85:15. Under scenario A1b this ratio is expected to change to 38:62 in the 2080s and under scenario B2a to 59:41, where the former is the scenario which predicts the greatest temperature increase and the second the least. In any scenario, the proportion of sites in the Potamal is estimated to increase drastically, with a corresponding decrease in the number of sites in the Rhithral.

Salmonidae/Cyprinidae Index

Similarly to the Fish Zone Index increasing under the influence of climate change, the SCI is also expected to increase. Salmonidae, a family of fish that prefer cold water, are predicted to retreat upstream if possible, while Cyprinidae distribution is likely to increase. This is confirmed by the estimated Salmonidae/Cyprinidae Index under the influence of different climate change scenarios as listed in table 3.15. Currently, the mean Index is 0.19, which means that Salmonidae clearly dominate the majority of the investigated fish sampling sites. By the 2080s, Cyprinidae are expected to do so, as the mean Salmonidae/Cyprinidae Index is predicted to rise above 0.60.

Table 3.15: Mean estimated Salmonidae/Cyprinidae Index for three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s (N=300/scenario), where 0= 100% Salmonidae and 1= 100% Cyprinidae population.

Scenario	2050s	2080s
A1b	0.66	0.79
A2a	0.53	0.74
B2a	0.56	0.64

At present, Salmonidae comprise more than 95% of the total fish population at over two thirds of the selected fish sampling sites. However, as figure 4.52 shows, this is expected to change. Even though the populations are not predicted to invert (i.e. over two thirds being strongly dominated by Cyprinidae), a clear shift toward a stronger Cyprinidae proportion is visible. While today about 7% of the sites are populated solely by Cyprinidae, this is expected to be the case for 20% to 41% of the sites by the 2080s. Scenarios A1b and A2a predict that none of the fish sampling sites will be solely populated by Salmonidae by the 2080s, unlike scenario B2a where 5% are still expected to be dominated by Salmonidae. Currently, there are very few sites with a mixed Salmonidae Cyprinidae population and these sites are expected to increase in all scenarios, in particular up to the 2050s.

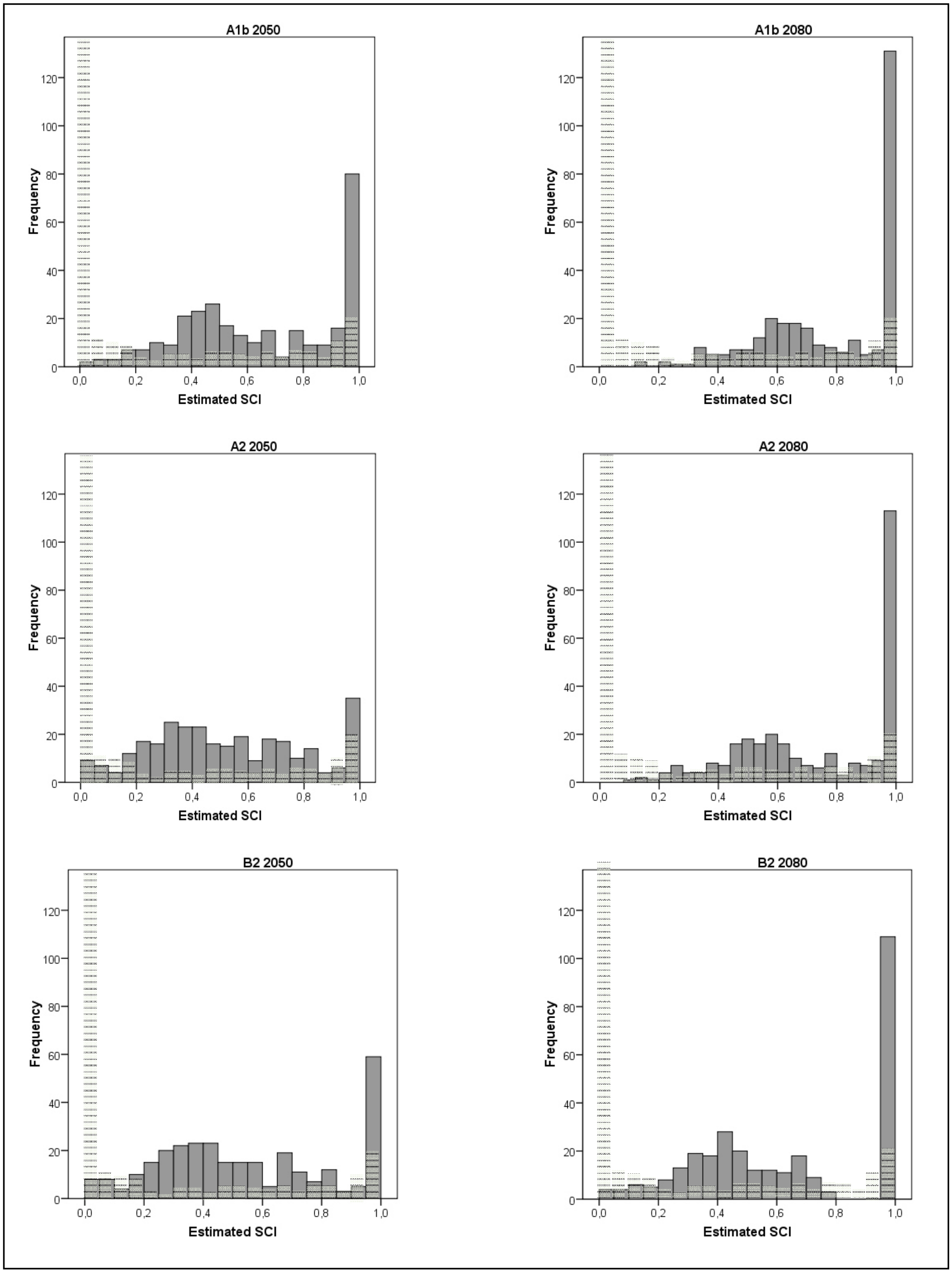


Figure 4.52: Estimated Salmonidae/Cyprinidae Index frequencies (grey bars) for the different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s compared to present frequencies (striped bars).

3.8. SUMMARY OF RESULTS

Based on water temperature data between 1997 and 2008 from 63 HZB-sites, the abiotic factors influential on water temperature were defined and two stream temperature models for Austrian rivers developed. The most significant factors were found to be air temperature at the site, mean air temperature in the catchment and altitude. The first model consists of four multiple regression equations according to river size with the mean catchment air temperature, the catchment size, distance from the source and altitude as independent variables and an average $adjR^2$ of 0.75 in June, 0.76 July and 0.73 in August. The second is a cross tabulation matrix with air temperature, distance from the source and river width as independent variables, and an exploratory value of 62%.

Water temperature for the months June to August was modeled for 300 fish sampling sites using the calibrated regression formula. Accordingly, the modeled water temperature was associated with occurring fish communities, represented by the FiZI, the corresponding fish regions and a Salmonidae/Cyprinidae Index. Mean July water temperatures were estimated to be 13.1°C for the MR, 15.2°C for the HR, and 16.8°C and 18.3°C for the EP and MP respectively. These mean temperatures were found to correspond to the observed temperatures at the HZB-sites for which the fish regions were known. Through a simple regression analysis, the modeled stream temperatures have shown to explain up to 60% and 52% of the variability of the FiZI and the Salmonidae/Cyprinidae Index respectively.

Through the use of predicted future air temperatures under three different climate change scenarios (A1b, A2a and B2a) for the 2050s and 2080s, future stream temperatures at the fish sampling sites were calculated, and an increase between 3.1°C and 4.7°C by the 2050s and between 4.0°C and 7.0°C in the 2080s was estimated. Using the simple regression analysis, the FiZI and Salmonidae/Cyprinidae Index were modeled under the predicted climate change scenarios, and a clear shift toward a higher FiZI and a more dominant Cyprinidae population was estimated.

4. DISCUSSION

The following section addresses issues concerning the data, methods and results in this thesis. Furthermore, the results and conclusions out of this study are linked to those of studies found in the literature. First, the dataset itself will be discussed, after which the different research questions will be considered as regards the approach used to tackle these questions and their outcome. Finally, this section will draw conclusions and offer an outlook.

4.1. DATASET

Abiotic and biotic data was used as the foundation of this thesis. None of the data was recorded exclusively as part of or specifically for this thesis, but was made available by a number of different institutions. However, without it the main research questions could not have been answered, as long term observations were necessary. The large quantities of information, over a long period of time, could easily compromise comparability and accuracy; hence data management and analysis of the metadata was crucial to ensure validity. The large-scale exclusion of stream temperature gauging sites as well as the different time scales over which stream and air temperature was averaged in order to develop the regression model are two drawbacks of the dataset which will be discussed below, along with the selection and distribution of fish sampling sites.

4.1.1. WATER TEMPERATURE DATA

Even though a large amount of water temperature data was available, only a fraction could be used to develop the stream temperature model, leading to an almost complete exclusion of western Austria.

For instance, all gauging stations along the *Inn*, *Salzach* and *Danube* were eliminated due to hydropower influence or inconsistent data. The *Danube*, being by far Austria's largest river with a number of hydropower sites and major areas of anthropogenic influence (HARTMANN *et al.*, 2007), stands apart from the other Austrian rivers. Therefore, it is legitimate to exclude it from the development of a general stream temperature model. However, the *Inn* and *Salzach* are two major rivers in the western part of the county, discharging most of the Austrian Alps' water. Both are very long, with large catchments. The amplitude frequency distribution of the rivers size used to develop the model is not normally dispersed, but shows a strong overrepresentation of smaller rivers. Through the inclusion of stations along the *Inn* and *Salzach,* this distribution might have been somewhat normalized. As regards the small rivers included in the model development, the majority are located in central Austria, since due to a limited number of gauges with long term measurements, only three sites in the west are included. Apart from that, the limited existence of gauges in small and very small rivers results in an underrepresentation of the upper trout region.

In conclusion, the actual effect on the model of including more and larger rivers in western Austria cannot be predicted. Nevertheless, in order to ensure applicability of the model throughout the country, an even distribution of sites used for its development is required. Given that either there are no gauges or the stations were excluded for some reason, the inclusion of these rivers would be difficult or would require additional information and analyses how the thermal regime of *Salzach* and *Inn* might differ from the natural state. Therefore, it cannot be guaranteed that the model developed is applicable throughout Austria, but is valid for the central and eastern parts of the country.

4.1.2. AIR TEMPERATURE

Air temperature, being one of the most influential factors on stream temperature, formed the basis for the development of the water temperature model for Austrian rivers. However, it was not possible to obtain observed values (ZAMG) for all sites where stream temperature values were available, so for this reason average temperatures between 1961 and 2000 (WorldClim) were used. Since mean water temperature data from 1997 to 2008 was used, along with the named average air temperatures, to develop the regression model, the time periods do not completely correspond. A drawback of this could be the observed air temperature increase of 1.8°C in the last 100 years (KROMP-KOLB, 2003), which is included in the averaged dataset. On the other hand, section 3.1.13 shows that the mean stream temperature in Austria's rivers rose by 1.4°C between 1967 and 2008, as well as between 1997 and 2008, with the latter time period showing the stronger increase. In line with these findings are the 0.2-2°C water temperature increases observed in European, North American and Asian rivers since the 1960s by the IPCC (BATES *et al.*, 2008) and a number of other studies (WEBB & NOBILIS, 1995; HARI & ZOBRIST, 2003; WEBB & NOBILIS, 2007; HUBER, 2008). Therefore, it can be concluded that although the time frames of the long term mean values do not correspond, both incorporate a temperature increase, legitimizing their use in the regression analysis.

4.1.3. FISH SAMPLING SITES

The IHG-database contains biotic data from 1700 fish samplings at 1500 sites. From these sites, 300 sites where selected with complete information and no human induced alteration of the water temperature regime. However, the histograms concerning the dimensions of the sampling sites as well as their geographic location in the country are not evenly or normally distributed.

The left-bound frequency distribution of river dimensions and fish regions indicates that most of the sites used to assess fish species composition are located along small rivers. This, however, can be explained by the fact that the majority of the country's rivers are Rhithral waters. Similarly to the HZB-gauges, the majority of the sites are located in central Austria, with a little less than 4% located in the west. One reason for this might be the increased occurrence of glaciers, lakes and reservoirs (SCHIMON *et al.*, 2011) in the western part of the country, which constitute three of the criteria used for the exclusion of sites. However, the fact that the distribution of the fish sampling sites corresponds to the distribution of the water temperature gauges supports the accuracy of the results, while keeping in mind the aforementioned limited applicability of the model in western Austria.

4.2. ABIOTIC FACTORS INFLUENTIAL ON WATER TEMPERATURE

WEBB and NOBILIS (1997), CAISSIE (2006) and others attribute air temperature as having the greatest effect on stream temperature. This was supported by the results obtained in this thesis, which show a significant correlation (ρ=0,683) between air and water temperature, and an even higher correlation with the mean catchment air temperature (ρ=0,734). Altitude was shown to be a third highly influential factor on water temperature (ρ=-0,727), which is again in line with results obtained by CAISSIE (2006). Other abiotic factors such as catchment size, discharge or distance from the source and water temperature were shown to have a certain degree of correlation, if not a significant one.

Furthermore, the influence of some abiotic factors varies with river size; in particular, the larger the river, the more important the mean catchment air temperature and the less influential the air temperature at site (see section 3.3). These results are supported by the fact that larger rivers are more stable in their water temperature regime as they respond less quickly to local environmental changes, i.e. air temperature at site or shading, due to their large water volume (CAISSIE, 2006; ALLAN & CASTILLO, 2007). Moreover, water temperature in large rivers is a product of processes which located in the upstream catchment.

4.3. ABIOTIC FACTORS INFLUENCED BY CLIMATE CHANGE AND FEASIBLE PREDICTIONS OF SUCH

Out of the factors which determine the water temperature, air temperature and discharge are those expected to alter under the influence of climate change. Even though vegetation and hence shading, amongst other factors, are also expected to alter under the effect of global warming (GUISAN, 2001), those factors do not significantly influence stream temperature and may therefore be disregarded. Due to the complexity of discharge modeling, very few studies estimating future stream run off for Austria are available, often related with a high uncertainty (STANZEL & NACHTNEBEL, 2010). For this reason discharge was legitimately excluded as a potential independent variable for the stream temperature model.

As regards the modeled future air temperatures used to estimate stream temperatures, two of three options were feasible, as the third option, data from high definition GCMs, is not available for Austria: (1) RCMs and (2) SDMs. RCMs are simpler than GCMs and a range of data for Europe is available. SDMs are based on statistical relationships, rely on accurate baseline information (UNFCCC, 2011) and data is available for the entire world - Europe in particular. Many studies that focus on the alpine region use data from RCMs, especially from the REMO-UBA and the CML model (JACOB *et al*., 2007; JACOB *et al*., 2010; STANZEL & NACHTNEBEL, 2010; ENDLER & MATZARAKIS, 2011). However, SUNYER, MADSEN and ANG (2006) found RCMs to overestimate mean and standard deviation and underestimate skewness while also underestimating the number of extreme events and overestimating their variance. Another major drawback of RCMs is a spatial resolution of no lower than approximately 10 km. As regards the large temperature variability within Austria, a grid of 10 x 10 km may reduce accuracy as river valleys often exhibit different temperatures than surrounding landscapes (SMORODINSKIJ & ZIESCHE, 2000). SDMs, however, have the advantage of a spatial resolution of approximately 1 km. MEARNS *et al*. (2007), though, found data obtained through statistical downscaling to exhibit a larger seasonal and daily temperature variability than data obtained from RCMs or GCMs. Furthermore, this study was not focused on extreme events, but on the general trend in temperature development. One dataset based on SDMs provided by the CIAT relies on the same baseline temperature data that was used to develop the stream temperature models (WorldClim). This, and the fact that a limited number of RCMs are freely available, constitutes the reason why this dataset was chosen as the source of future air temperatures. In order to ensure compatibility between the different scenarios, data based on the HADCM3 were selected. This GCM has been used by the IPCC and has been assessed to be an accurate model with its main deficiencies in tropical latitudes, as summarized by the German Climate Computing Center (Deutsches Klimarechenzentrum, DKRZ) (2003) and BARONTINI *et al.* (2009).

4.4. STREAM TEMPERATURE MODEL

Two different stream temperature modeling approaches were followed. The reasons for this are the known, and encountered, drawbacks associated with the regression model, as well as the capability of a simple logical model. The need to include static variables such as upstream catchment size or distance from the source in the regression model made it impossible for multiple months to be summarized by one equation (e.g. June-August). If repeated values (i.e. variables functioning as constants, such as catchment size) were used to generate the regression equation, a very high coefficient of determination was obtained. However, this coefficient was misleading as the validation of the model showed residues of up to 35°C. The fact that the used air temperatures (WorldClim) also functioned as constants, as the value for each month was the same for every year, meant that stream temperature needed to be averaged accordingly. This, however, resulted in only 63 available values from which the regression model was calibrated. Through the development of a second model, these barriers could be overcome since constants (i.e. repeating air temperatures and static variables) can be included in a cross tabulation matrix. In this way, more than 63 values could be used to develop the model (i.e. 680 for the July model[6]), thereby increasing significance. Another reason for the development of two models was the fact that a number of studies have predicted water temperature through regression models (CAISSIE *et al.*, 2001; HUBER, 2008; SAHOO *et al.*, 2009), but none through simple logical models, indicating the need of a comparison between these two methodogical approaches. The following section will elaborate the advantages and disadvantages of each model.

4.4.1. REGRESSION MODEL

The regression model developed resulted in exploratory values between 65 % and 83 % in June, 65 % and 83 % in July, and 62 % and 84 % in August. These results can be said to be satisfactory as comparable studies reached similar exploratory values (e.g. 74%, HUBER (2008)). Only WEBB and NOBILIS (1997) obtained exploratory values up to 95% with a simple regression analysis (air and water relationship). However, this study is only based on one catchment in northern Austria and is therefore not exactly comparable to models on a larger spatial scale, like a whole country.

The model delivers satisfactory results but the limited number of cases used to develop it can be considered as a drawback. Even though no sites in the MP were included in it the model calibration, the fundamental relationship between the model parameters and the water temperature seem to justify the model's applicability in that fish region. In total, only 63 values were available, from which a single satisfactory model could not be reached and so the dataset had to be split according to river size (i.e. catchment size). This categorization resulted in accurate models but each one is based only on 15 to 16 cases, greatly reducing significance and the power for extrapolation. Additionally, as mentioned above, very few rivers in western Austria are included, further reducing potential validity for that region. However, the validation, conducted by predicting stream temperatures at the fish sampling sites according to the different fish regions, showed the model to deliver accurate results.

Figure 4.1 shows that the observed (at HZB gauges) and estimated (for fish sampling sites) mean water temperatures correspond. Only the HR is estimated to be slightly warmer than it was observed to be. However, this comparison is also to be regarded with caution as the

[6] Number of sites x years = number of values – missing values = values used = 63x12=756-76=680

classification of the HZB sites into the different fish regions was not done in the course of this thesis, but by the Institute for Water Ecology, Fish Biology and Lake Studies (IGF: *Institut für Gewässerökologie, Fischereibiologie und Seenkunde*). The comparison of the estimated temperatures to those estimated in an earlier thesis by HUBER (2008) also shows a strong overlap. Even though the model developed by HUBER (2008) is based on a similar dataset as this thesis, there are a number of crucial differences: Firstly, the fact that the HZB-measurements were conducted at different times throughout the day was not known or disregarded, and for this reason the data was assumed to consist of homogenous daily mean values. Furthermore, the model was developed solely on the basis of one year, 2001, and the best coefficients of determination were found to be in August. Additionally, air temperature is not an independent variable in the model, but is based on altitude, discharge and distance from the source. However, the validation is based on a selection of fish sampling sites from the same database used in this thesis and the classification of the FiZI into the fish regions was conducted using the same boundary values.

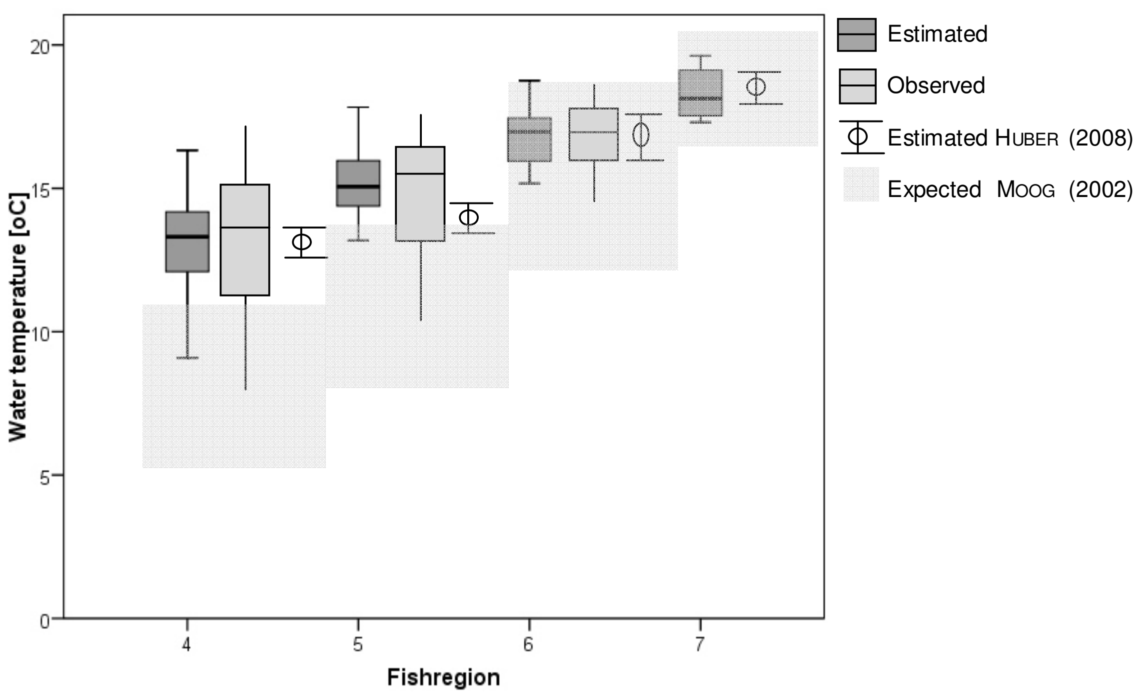


Figure 4.1: Estimated and observed water temperatures for the different fish regions (4=Metarhithral, 5=Hyporhithral, 6=Epipotamal and 7=Metapotamal). Estimated= mean July temperatures estimated by the model developed in this thesis. Observed= mean July temperatures measured at the HZB- sites ,Estimated HUBER (2008)= Mean August 2001 values and 95% confidence interval estimated by HUBER (2008) and Expected MOOG (2002)= mean summer temperatures expected by MOOG and WIMMER (1994 in: MOOG, 2002).

As shown in figure 4.1, the modeled temperatures for the lower fish regions correspond to those estimated by HUBER (2008) and observed at the HZB sites. However, the mean values for the MR and the HR are estimated to be around 1°C below those estimated in this thesis. A reason for this could be the fact that HUBER's (2008) estimates are for August while the others are for July. As shown in figure 3.6 earlier, the mean temperature in August is slightly below the mean water temperature in July. If the estimated temperatures are compared to temperatures expected by MOOG and WIMMER (1994 in: MOOG, 2002), the Potamal corresponds. However, the Rhithral is observed and estimated to be between 1°C and 2°C higher than the expected temperatures stated by MOOG and WIMMER (1994 in: MOOG, 2002). Taking into account that the modeled temperatures strongly correspond to the observed values, the expected ones may be underestimated. In any case, it can be concluded that the regression model developed, even though it has a number of drawbacks, estimates stream temperature to a satisfactory degree and the results are in line with observed and estimated values.

4.4.2. CROSS TABULATION MODEL

The second approach in developing a stream temperature model was a cross tabulation matrix. Through the use of mega-variables, as described by LAUTSCH and THÖLE (2003), and classified stream temperatures, the model functions in a similar manner to a graphical multiple regression analysis. The major drawback, however, is its limited applicability in predicting temperatures under the effect of global warming, while its major advantage is its simplicity.

The mega-variable developed consists of air temperature, river width and distance from the source. Although the regression model included catchment size, this parameter is less important in this model. With every variable that is added to the mega-variable, the number of created profiles increases exponentially[7]. Even though this improves the accuracy of the prediction, it decreases the probability of precise and practicable re-classification through the classification tree (see figure 3.41). Without the re-classification, however, the number of cases in each profile would be extremely low or correspond to only one site at a certain time, greatly reducing significance and validity by overfitting. Therefore, it was decided that the mega-variables should consist of only three individual variables. Air temperature had to be included as it is the only variable that changes due to global warming, while altitude and distance from the source proved to be the next two most practicable variables. The

[7] Example: If three variables are used, with each classified in three categories, the number of possible profiles equals 27. If four variables are added to one mega-variable with the same classification, the number of possible profiles equals 81.

classification of each variable was conducted according to frequency distribution as well as subject specific criteria, where the latter proved to be more applicable.

The resulting model exhibits an exploratory value of 62%, which is below the value obtained through the regression model. However, this model is based on one less independent variable and does not include mean catchment air temperature. With larger rivers in particular (i.e. catchment size above 689.4 km^2), the latter greatly improved accuracy. However, for the crosstab matrix, the focus was on applicability and simplicity, and mean catchment air temperature may not be obtainable in every case. Aside from the relatively low exploratory value, the potential to predict future stream temperatures is limited. Considering that the model is based solely on observations and does not extrapolate, the current warmest temperatures are its upper limit.

As regards climate change on a national scale this might not be very useful, although on a local scale it might. For example, if the model was to be based on measurements along the longitudinal course of a river, the exploratory value is likely to increase and predictions as to future stream temperature are likely to be possible. It has been shown that if only one river or catchment is used, exploratory values up to 95% can be achieved (WEBB & NOBILIS, 1997). Considering the stream temperature increase along the course of a river (CAISSIE, 2006), the temperature span from the Rhithral to the Potamal can be included and through the use of future air temperatures, the water temperature and hence fish region shift in an upstream direction may be modeled. In any case, the matrix is not likely to predict single temperatures but temperature ranges, however, these ranges are simply comparable to the error margins added and subtracted from the exact temperatures modeled by the regression analysis.

It is evident that the cross tabulation model has a number of significant drawbacks compared to the regression analysis and is less practicable, especially in relation to expenditure of time in order to obtain a large number of results, as well as concerning the applicability of the results themselves. However, it might be more practical in a political context than in a scientific one. There its simplicity and traceability, as well as the temperature ranges that are obtained, might be seen as a major advantage.

4.5. WATER TEMPERATURES AND FISH ASSEMBLAGES UNDER THE INFLUENCE OF CLIMATE CHANGE

The regression model has been used to model current and future water temperatures at the fish sampling sites. Additional regression models have then been developed as a method of predicting future fish assemblage structure in the face of changing stream temperatures. First, current fish assemblages and the developed FiZI and SCI models will be discussed, after which expected stream temperatures in comparison to present fish distributions and related implications will be elaborated.

4.5.1. Current fish assemblage and water temperature

The current temperature ranges for Salmonidae, Cyprinidae have been investigated, along with the temperatures in each fish region. Mean stream temperatures in each fish region have been discussed as part of the regression model validation (section 4.4.1) and were found to correspond to other studies.

The FiZI stream temperature correlation, with an exploratory value of 60%, is below the 74% achieved by HUBER (2008). The reason for this could be the increased number of fish sampling sites used to develop it, as HUBER (2008) only used 200 sites, while these were also distributed more evenly among the fish regions. However, the validation showed the residues to be distributed normally and the largest divergence to be less than one. Nevertheless, there is a drawback in the FiZI model: through its linearity it predicts indefinitely rising FiZIs with increasing temperatures. However, at the moment the highest observed FiZI in Austria is just under 7, and therefore any modeled value above 7 has to be regarded with caution as this indicates two possible scenarios: either there are no and never will be any values above 7, meaning that everything modeled above may be regarded as potential MP, or a new, currently not existent, fish region will be formed. Nonetheless, it can, be assumed that due to the large distance to the sea, the given species pool, high precipitation and the generally steep gradients in Austrian rivers, there will not be any rivers in Austria which can be classified as HP any time soon.

Salmonidae and Cyprinidae were chosen to characterize the headwaters and lower river sections. The temperature ranges at which they occur support this decision as a clear temperature difference between the families' niches could be observed. Salmonidae were found to dominate waters at around 13°C (range: 9-16°C) and Cyprinidae at 17°C (range: 16-19°C). These temperatures are in line with values from literature, BELL (1986 in: BJORNN & REISER, 1991) and JOBLING (1981), for example, state that Salmonids occur in rivers at a temperature range between 7°C and 15°C. KÜTTEL *et al.* (2002) states temperatures for Cyprinids above 14°C. Percidae were found to occur at the transition zone between Salmonidae and Cyprinidae, which is in line with their temperature preferences (KÜTTEL *et al.*, 2002).

The correlation between the SCI and stream temperature is significant, although limited by an exploratory value of 52%. The reason for this limited relationship can be explained by the wide temperature range at which Salmonidae occur and which will be discussed below. The validation showed normal distribution of the residues, slightly skewed to the left, expressing a slight underestimation. Nevertheless, the regression serves as a tool for the indication of future Rhithral and Potamal proportions in respect to water temperature conditions. Similarly to the FiZI model resulting in values above 7 under high temperatures, the SCI model predicts values above 1 which is not realistic. Accordingly, any value above 1 may are regarded as 1, indicating a habitat conditions appropriate for Cyprinidae dominance.

The temperatures at which brown trout and grayling were caught correspond to the temperature preferences for Salmonidae. The favored temperature range for adult brown trout is 14-17℃, while the upper limit is 25℃ (KÜTTEL *et al.*, 2002; HARI *et al.*, 2006). Therefore, the temperature range between 8℃ and 17℃, which was estimated for the fish sampling sites at which the majority of brown trout was caught, is feasible. A very small number of trout were caught above 18℃ which is in line with KÜTTEL *et al.* (2002) stating that temperatures above 19℃ constitute the upper critical limit for this species. The favored temperature range for adult grayling species is 15-17℃, with the critical temperature above 18℃ and the maximum 24℃ (KÜTTEL *et al.*, 2002). The observed temperatures at which the grayling occurs are between 9℃ and 17.5℃, with the majority populating waters with temperatures between 12℃ and 15℃ which is in line with the values mentioned in literature.

The wide temperature range estimated for the MR (see section 3.6.1) may be explained by Austria's morphology. Headwaters can be found on a broad range of altitude, including variability in air and water temperature. Furthermore, the trout region is characterized by steep gradients and highly oxygenated water (HUET, 1959; BJORNN & REISER, 1991), where the former occurs in most parts of Austria, due to a mountainous topography in the Alps and the foothills of the Alps. Accordingly river reaches classified as trout region occur in relatively warm regions too. This is supported by figure 4.2 as it shows the gradient altitude and stream temperature relationship for fish sampling sites in the trout region. It can be noted that even in lower areas (i.e. below 400 m.a.s.l.), gradients of over five percent are still observed. Similarly, it can be observed that warm temperatures (i.e. above 17℃) occur at lower gradients, but up to 650 m above sea level. Taking the figure below into account, the conclusion that the majority of the trout region's distribution is in line with literature (HUET, 1959; JOBLING, 1981; KÜTTEL *et al.*, 2002) seems reasonable.

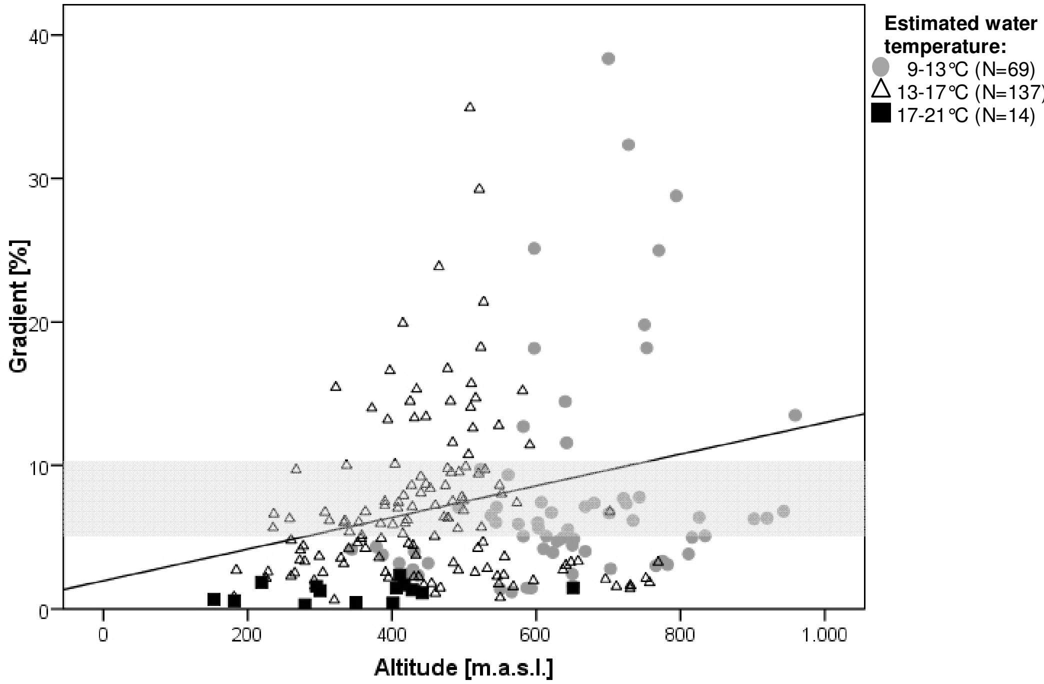


Figure 4.2: Slope-altitude-relationship (R2=0.04) at fish sampling sites in the trout region (N=229) classified by estimated water temperatures. The grey shaded area indicates the gradient most prominent in the trout region after Huet (1959).

4.5.2. Future stream temperature

Modeled air temperatures in regard to different SRES indicate a shift of the warmest month from July to August during the 21st century. Accordingly, the analysis concerning future stream temperature and fish assemblage are based on the latter month, due to highest relationships in the warmest months. Even though the stream temperature model is more accurate (i.e. higher exploratory value) in July, this was seen as a feasible measure for one of the major limiting factors in fish distribution, namely maximum temperature (Brett, 1956).

The highest mean temperature increase is expected for scenario A1b, while the highest absolute values are expected for A2a. In any case, stream temperatures are expected to rise by at least 3.1℃ in the 2050s and 4℃ in the 2080s. The highest mean temperatures that have been modeled for scenario A1b differ from the worldwide expected mean future temperatures (IPPC, 2007), which attribute the highest increase to scenario A2a. An explanation for this could be the varying downscaled air temperature increase in relation to current mean air temperature (compare section 3.4.4.). The increase for scenario A1b is constant across current temperatures, whereas for scenario A2a it decreases with increasing current temperatures. This uneven increase subsequently translates to water temperatures and leads to a higher mean water temperature for scenario A1b than A2a. The observation that stream temperature increase is stronger for larger rivers is seconded by the prominent influence other factors, such as the distance from the source or shading, have on smaller rivers (CAISSIE, 2006).

Fish distribution is not only dependent on temperature, but also on a number of other habitat parameters which may vary under the influence of climate change too but are more difficult to model and hence exhibit great uncertainty. In particular discharge is expected to decrease up to 25% in the alpine region and increase around 45% in the north east of the country (STANZEL & NACHTNEBEL, 2010). Sedimentation in turn is estimated to increase (SCHEURER *et al.*, 2009) along with nutrient concentrations due to a projected increase of rain as opposed to snow in winter and a consecutive shorter snow coverage in mountainous regions and an amplified intensity of flashfloods (SOLHEIM *et al.*, 2010). Furthermore, changes in stream temperature do not only affect fish but all aquatic organisms, which may in turn have an effect on fish species' nutrient uptake and hence distribution and health. Therefore the predictions reached and points discussed in the next section are only to be regarded as indicatory, as the factors named above were not considered.

4.5.3. FUTURE FISH ASSEMBLAGE

Future fish assemblage has been modeled through FiZI-water temperature and SCI-water temperature regression analysis, with conclusions drawn in relation to estimated stream temperatures. A shift in dominance from Salmonidae to Cyprinidae can be expected, which is in line with conclusions from the Euro-limpacs project (HERING, 2011). First, the actual results will be discussed, then implications for distinct species, after which general implications of these results will be elaborated.

Estimated FiZI and SCI distributions

The mean FiZI is currently 4,4 and it is expected to increase to at least 5,4 by the 2080s. Up to the 2050s, a strong shift from the MR to the HR is estimated, followed by a further shift to fish regions of downstream reaches until the 2080s, leading to very few sites adequate for the trout region, and resulting in the grayling region becoming the most frequent. These results are in line with those from studies conducted in the United States (EATON & SCHELLER, 1996) and France (DAUFRESNE *et al.*, 2003; BUISSON *et al.*, 2008).

Similarly to the FiZI, the SCI is expected to shift from an average of 0.2 to over 0.6, indicating a country-wide dominance of Cyprinid-adequate habitats. The expected SCI frequency distribution for all future scenarios shows an increase of sites with SCIs between 0.4 and 0.7. This change promotes the assumption that the coexistence of Cyprinidae and Salmonidae species will be further established in future. However, currently this is the case for only very few sites and also supported by literature (KÜTTEL *et al.*, 2002) since other families such as Esocidae and Percidae dominate the transition area. But a certain degree of adaption to changing habitat parameters has been observed for some species (HOKANSON, 1977; HYATT *et al*., 2003; JENSEN *et al*., 2008), even more so for invasive ones (RAHEL & OLDEN, 2008), which could theoretically lead to a coexistence of Salmonidae and Cyprinidae. Especially reaches which exhibit a low gradient may be co-inhabited by Cyprinidae while this is not likely to be the case for sections with very steep gradients since a certain degree of rheophilly would be required. However, in order to prove the model's results of increased Salmonidae Cyprinidae coexistence additional information would be necessary since more factors than just the relation between these two families define the species composition. In any case, they are characteristic for the upper and lower river reaches and the outer boundaries of the results (i.e. <0.3 and >0.7) can therefore definitely be regarded as valid. Furthermore, general information supplied by this approach can be considered as reasonable as the results indicating a stronger shift toward Cyprinidae dominance are in line with the outcome of the FiZI model.

Implications for specific species

The fact that the HR is expected to be the most frequent fish region does not mean that grayling will be the dominant species in Austrian waters. Figure 4.3 shows the current frequency distribution of sites across the fish regions at which grayling was caught. As shown, most grayling specimens have been sampled in the trout region, while relatively few have been caught in the actual grayling region. This supports the suspicion that fish regions are not static but flow into one another and a clear definition of borders is impossible, which is one of the main criticisms on the fish zone concept. As visualized by SPINDLER (1997) in a table (Annex I), none of the species occur in only one fish region. Accordingly, an increase in potential HR river reaches does therefore not imply a consecutive increase of grayling occurrence. Grayling is a niche species inhabiting intermediate streams with cold waters and already threaded by extinction (SPINDLER, 1997). BUISSON *et al.* (2008) found it to be among the three species most influenced by rising stream temperatures and MATULLA *et al*. (2007) predict this species to face additional pressure, especially from more temperature tolerant species such as rainbow trout *(oncorhynchus mykiss)*. HARI *et al.* (2006), on the other hand, suggests that grayling may take over some of the brown trout's habitats. Even if this is to be the case, the stagnating growth in waters over 21°C, mortality at slightly higher temperatures (MALLET *et al*., 1999) and the limited possibilities of retreat due to weirs fragmenting European rivers (MATULLA *et al*., 2007) support the proposition that grayling are amongst the species most endangered by rising temperatures, with the estimated frequency of the Hyporhithral therefore being potentially misleading.

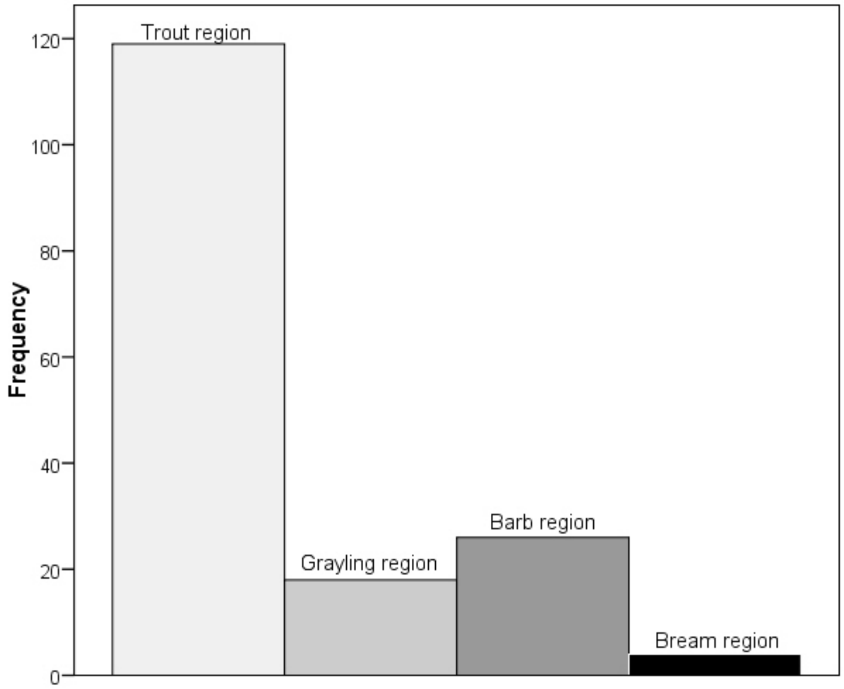


Figure 4.3: Frequency distribution of the fish regions where grayling was caught (N=300).

Apart from the grayling, another Salmonid, the brown trout, is among the species likely to be severely affected by climate change in Austria, as suggested by the decrease in the number of sampling sites located in the MR and with a low SCI. Investigations associated with the Rocky Mountains (RAHEL *et al.*, 1996) and models related to Switzerland have found that an air temperature increase of 1°C would require the fish to retreat 100-200 m further upstream in order for them to stay in their natural habitat (MEILI *et al.*, 2004). However the river fragmentation from weirs and dams is most likely to hinder this (MATULLA *et al.*, 2007), further pressuring the species.

Rising temperatures generally reduce habitats adequate for Salmonidae as the species' spawn is especially vulnerable to high temperatures (MACCRIMMON & MARSHALL, 1968). A reduction of Salmonid distribution is also expected to have an effect on the aquatic food-web, putting additional pressure on the species of the upper fish regions (MEILI *et al.*, 2004). This, in addition to their general, relatively low temperature tolerance and high susceptibility to diseases at higher temperatures (MEILI *et al.*, 2004; HARI *et al.*, 2006), further supports the estimated reduction of Salmonid abundance in Austria.

Cyprinidae, on the other hand, are estimated to profit from climate change in Austria. Their current limited distribution is expected to greatly increase, making them the dominant fish family in the country's waters (mean SCI>0.6). This is particularly encouraging for their status considering that the majority are threatened with extinction or potentially threatened with extinction (SPINDLER, 1997). A limiting factor however is the general increase in current towards the headwaters. Certain Cyprinidae species, such as the tench (*tinca tinca*) or the crucian carp (*carassius carassius*), are stagnophil species less probable to inhabit steep river reaches. But the likely upstream migration of other species such as the common nase (*chondrostoma nasus*), which preferably inhabit deep, fast running waters might result in a profitable situation due to reduced competition for both: the Cyprinidae likely to move further upstream and the ones not likely to do so.

Further implications

Further implications relate to, among others, ecological and economic consequences as well as challenges for the WFD. As such, fishing can illustrate economic and ecological consequences of a changing species composition.

Even though implications for professional fishing are negligible considering it's limitation to lakes, with the Danube in Upper Austria as an exception (SPINDLER, 1997), recreational fishing, being a prominent and well organized sport with an economic value in Austria, may be severely impacted. Over 1000t of fish are extracted each year and about the same amount is restocked in the same timeframe (BUTZ, 1996 in: SPINDLER, 1997). The restocked fish are mainly Salmonids and Carps either raised in farms with genetic material from very few mother fish, reducing genetic variability, or imported from the Czech Republic, Germany and South Africa, leading to the introduction of foreign variations (SPINDLER, 1997). Through decreasing Salmonidae populations as a result of climate change and a yearly increase in recreational fishing (SPINDLER, 1997), pressure on the species can be expected to increase further and the consequent restocking with genetically homogenized or foreign Salmonidae may additionally limit the species' distribution. Furthermore, considering that Cyprinidae fishing differs completely from Salmonidae fishing, it could be feasible that if nothing can be caught fly-fishing (method used to catch Salmonids) anymore, the technique may become less interesting. This however will in turn have economic implications as fishing beats in the lower fish regions cannot be sold as expensive as beats with high Salmonidae populations. Therefore, recreational fishing may well impact the ecology of riverine ecosystems while having economic benefits for hatcheries or fish farms on one hand, and deficits for land owners, fishing associations and governments on the other hand.

Within the WFD, Austria, along with a number of other countries, uses fish population as an indicator for biological quality elements of a river, in particular in relation to habitats and morphology, indicating an ecological integrity of the river (EUROPEAN COMMISSION, 2003). With changing fish distribution, an adaption of the WFD's indicator system will be necessary in order for any observed fish population alteration not to be attributed to other impacts. In 2009, the WFD published a white paper which presents the framework for adaption to climate change in general and in relation to water resources on a pan-European level (EUROPEAN COMMISSION, 2009). The paper is kept rather general and a tangible adaption of the indicators, etc. is only expected by late 2012. However, the cyclical structure of the WFD offers scope for adjustment to and incorporation of new information. One way of doing so would be to integrate the relation between water temperature and biocoenotic regions in riverine ecosystems. Furthermore, individual consideration of species should be emphasized, as parameters such as the FiZI can misrepresent the actual fish composition or certain species, especially invasive ones, are not covered by it. Through these measures, eventual adaption of specific species or increased presence of invasive species would be noted. Furthermore, the rehabilitation and management measures need to be adapted accordingly.

4.6. CONCLUSION AND OUTLOOK

In the course of this thesis, water temperature was shown to be dependent on the abiotic factors air temperature at site, mean air temperature in the catchment, altitude, and distance from the source as well as catchment size. These factors were shown to explain up to 83% of the variance of stream temperature through the development of regression and cross tabulation models. Furthermore, correlations between the water temperature and the FiZI and SCI could be proven, making it possible to assign specific temperatures to the different fish regions as well as fish families' habitats. Modeled future air temperatures for the different IPCC scenarios were used to predict future stream temperatures and consequent fish assemblages, indicating a defined shift from a Salmonidae to a Cyprinidae dominance in Austria's rivers. The limited possibilities for retreat are likely to lead to a drastic decimation and possible elimination of sensible niche species such as the grayling and a general distribution decrease of Salmonidae, while leading to an expansion of Cyprinidae habitats and a subsequent, partial relief of the species' current endangerment status.

The implication of warming stream waters (at least 4°C by the 2080s) and the resulting altered fish species composition, pose challenges for future renaturation and management actions. As such, it would be advisable for the WFD to incorporate the stream temperature fish region relationship into its scope and emphasize adaption measures such as the removal of barriers to allow upstream Salmonidae migration or the limitation of restocking with foreign or genetically homogenized fish.

Literature

ALLAN, J. D., & CASTILLO, M. M. (2007). Stream Ecology (2nd ed.). Dordrecht: Springer.

BARONTINI, S., GROSSI, G., KOUWEN, N., MARAN, S., SCARONI, P., & RANZI, R. (Producer). (2009, 14.01.2011). Impacts of climate change scenarios on the runoff regimes in the southern Alps. Hydrology and Earth Systems Sciences Discussions. [Presentation] Retrieved from http://www.hydrol-earth-syst-sci-discuss.net/6/3089/2009/hessd-6-3089-2009.pdf

BATES, B. C., KUNDZEWICZ, Z. W., WU, S., & PALUTIKOF, J. P. (Eds.). (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPPC Secreteriat.

BENYAHYA, L., CAISSIE, D., ST.HILAIRE, A., OUARDA, T., & BOBEE, B. (2007). A review of statistical water temperature models. *Canadian Water Resources Journal, 32*(3).

BJORNN, T. C., & REISER, D. W. (1991). Habitat requirements of salmonids in streams. In MEEHAN (Ed.), *Influence of forests and rangeland management on salmonid fishes and their habitat*. Bethesda: American Fisheries Society.

BÖHM, U., KÜCKEN, M., AHRENS, W., BLOCK, A., HAUFFE, D., KEULER, K., ROCKEL, B., & WILL, A. (2006). CLM- The climate version of LM: Brief description and long-term applications. *COSMO Newsletter, 6*, 225-235.

BRETT, J. R. (1956). Some Principles in the Thermal Requirements of Fishes. *The Quarterly Review of Biology, 31*(2), 75-87.

BUISSON, L., & GRENOUILLET, G. (2009). Contrasted impacts of climate change on strem fish assemblages along an environmental gradient. *Diversity and Distributions, 15*, 613-626.

BUISSON, L., THUILLER, W., LEK, S., LIM, P. U. Y., & GRENOUILLET, G. (2008). Climate change hastens the turnover of stream fish assemblages. *Global Change Biology, 14*(10), 2232-2248. doi: 10.1111/j.1365-2486.2008.01657.x

BURKHARDT-HOLM, P. (2009). Klimawadel und Bachforellenrückgang- gibt es einen Zusammenhang? Resultate aus der Schweiz. *Umweltwiss Schadst Forsch, 21*, 177-185. doi: 10-107/s12302-009-0043-7

CADBURY, S. L., HANNAH, D. M., MILNER, A. M., PEARSON, C. P., & BROWN, L. E. (2008). Stream temperature dynamics within a New Zealand glacierized river basin. *River Research and Applications, 24*(1), 68-89. doi: 10.1002/rra.1048

CAISSIE, D. (2006). The thermal regime of rivers: a review. *Freshwater Biology, 51*, 1389-1406. doi: 10.111/j.1365-2327.2006.01597.x

CAISSIE, D., EL-JABI, N., & SATISH, M. G. (2001). Modelling of maximum daily water temperatures in a small stream using air temperatures. *Journal of Hydrology, 251*(1-2), 14-28. doi: 10.1016/s0022-1694(01)00427-9

CHARBONNEAU, R., FORTIN, J.-P., & MORIN, G. (1977). The CEQUEAU model: Description and examples of its use in problems related to water resource management. *Hydrological Sciences - Bulletin- des Sciences Hydrologiques, XXII*(3).

COUTANT, C. C. (1990). Temperature-Oxygen Habitat for Freshwater and Coastal Striped Bass in a Changing Climate. *Transactions of the American Fisheries Society, 119*(2), 240-253. doi: 10.1577/1548-8659(1990)119<0240:thffac>2.3.co;2

DAIGLE, A., ST-HILAIRE, A., PETERS, D., & BAIRD, D. (2010). Multivariate Modelling of Water Temperature in the Okanagan Watershed. *Canadian Water Resources Journal, 35*(3), 1-22.

DAUFRESNE, M., & BOET, P. (2007). Climate change impacts on structure and diversity of fish communities in rivers. *Global Change Biology, 13*, 2467-2478. doi: 10.1111/j.1365-2486.2007.01449.x

DAUFRESNE, M., ROGER, M., CAPRA, H., & LAMOUROUX, N. (2003). Long-term changes within the invertebrate and fish communities of the Upper Rhone River: effects of climatic factors. *Global Change Biology, 10*, 124-140. doi: 10.1046/j.1529-8817.2003.00720.x

DECOSTER, J. (1998). Overview of Factor Analysis Retrieved 18.11., 2011, from http://www.stat-help.com/factor.pdf

DEUTSCHES KLIMARECHENZENTRUM. (2003). The IPPC Data Distribution Center: HadCM3 Description Retrieved 14.01, 2011, from http://cera-www.dkrz.de/IPCC_DDC/IS92a/HadleyCM3/Readme.hadcm3

EATON, J. G., & SCHELLER, R. M. (1996). Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology Oceanography, 41*(5), 1109-1115.

ENDLER, C., & MATZARAKIS, A. (2011). Analysis of high-resolution simulations for the Black Forest region from a point of view of tourism climatology – a comparison between two regional climate models (REMO and CLM). *Theoretical and Applied Climatology*(103), 427-440. doi: DOI 10.1007/s00704-010-0311-x

ESRI. (2008). ArcMap (Version 9.3).

EUROPEAN COMMISSION. (2000). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. Brussels: European Parliament.

EUROPEAN COMMISSION. (2003). *Guidance document n.o 7: Monitoring under the Water Framework Directive*. Luxenbourg: European Communities.

EUROPEAN COMMISSION. (2009). *White paper- Adapting to climate change: towards a European framework for action*. Brussels: European Parliament.

FICKE, A. D., MYRICK, C. A., & HANSEN, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries, 17*(4), 581-581-613. doi: 10.1007/s11160-007-9059-5

FINK, M. H., MOOG, O., & WIMMER, R. (2000). Fließgeässer- Naturräume Österreichs. Wien: Umweltbundesamt GmbH (Federal Environment Agency Ltd)

FRÜH, B., FELDMANN, H., PANITZ, H.-J., SCHÄDLER, G., JACOB, D., LORENZ, P., & KEULER, K. (2010). Determination of Precipitation Return Values in Complex Terrain and Their Evaluation. *Journal of Climate, 23*(9), 2257-2274. doi: 10.1029/ 2002jd002287.

GUISAN, A. (2001). Potential impact of climate change on vegetation in the European Alps: A review. *Climatic Change, 50*(1-2), 77-109. doi: 10.1023/a:1010632015572

HARI, R., LIVINGSTONE, D., SIBER, R., BURKHARDT-HOLM, P., & GÜTTINGER, H. (2006). Consequences of climatic change for water temperature and brown trout populations in Alpine rivers and streams. *Global Change Biology, 12*(1), 10-26. doi: 10.1111/j.1365-2486.2005.001051.x

HARI, R., & ZOBRIST, J. (2003). Trendanalyse der NADUF-Messresultate 1974-1998. *Schriftreihe der EAWAG*(17).

HARTMANN, J., JANSEN, N., KEMPE, S., & DÜRR, H. H. (2007). Geochemistry of the river Rhine and the upper Danube: Recent trends and lithological influence on baselines. *Journal of Environmental Science for Sustainable Society, 1*, 39-46.

HERING, D. (2011). Climate Change and Freshwater Retrieved 15.01, 2012, from http://www.climate-and-freshwater.info

HIJMANS, R., CAMERON, S., PARRA, J., PETER, J., & JARVIS, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology, 25*, 1965-1978. doi: 10.1002/joc.1276

HOKANSON, K. E. F. (1977). Temperature Requirements of Some Percids and Adaptations to the Seasonal Temperature Cycle. *Journal of the Fisheries Research Board of Canada, 34*(10), 1524-1550. doi: 10.1139/f77-217

HUBER, J. (2008). *Entwicklung von empirischen Modellen zur Prognose der Wassertemperatur und von Fischbiozönosen in Österreichischen Gewässern.* DI, Universität für Bodenkultur, Wien.

HUET, M. (1959). Profiles and Biology of Western European Streams as Related to Fish Management. *Transactions of the American Fisheries Society, 88*(3), 155-163.

HYATT, K. D., STOCKWELL, M. M., & RANKIN, D. P. (2003). Impact and Adaptation Responses of Okanagan River Sockeye Salmon (Oncorhynchus nerka) to Climate Variation and Change Effects During Freshwater Migration: Stock Restoration and Fisheries Management Implications. *Canadian Water Resources Journal, 28*(4), 689-713. doi: 10.4296/cwrj2804689

ILLIES, J. (1961). Versuch einer allgemeinen biozönotischen Gliederung der Fließgewässer. *Internationale Revue der gesamten Hydrobiologie und Hydrographie, 46*(2), 205-213. doi: 10.1002/iroh.19610460205

IPPC. (2007). Synthesis Report: Contibution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In PACHAURI, R. K. & REISINGER, A. (Eds.). Geneva: IPCC.

JACOB, D. (2001). A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. *Meteorology and Atmospheric Physics, 77*(1), 61-73. doi: 10.1007/s007030170017

JACOB, D., BÄRRING, L., CHRISTENSEN, O. B., CHRISTENSEN, J. H., CASTRO, M. D., DÉQUÉ, M., GIORGI, F., HAGEMANN, S., HIRSCHI, M., JONES, R., KJELLSTRÖM, E., LENDERINK, G., ROCKEL, B., SÁNCHEZ, E., SCHÄR, C., SENEVIRATNE, S. I., SOMOT, S., ULDEN, A. V., & HURK, B. V. D. (2007). An inter-comparison of regional climate models for Europe: Model performance in Present-Day Climate. *Climatic Change, Special Issue: PRUDENCE*.

JACOB, D., MIKOLAJEWICZ, U., & KOTOVA, L. (2010). Assessment report on climate evolution scenarios relevant for the selected regions: CLIMATE FOR CULTURE.

JENSEN, L. F., HANSEN, M. M., PERTOLDI, C., HOLDENSGRAAD, G., MENSBERG, K.-L., & LOESCHCKE, V. (2008). Local adaption in brown trout early life-history traits: implications for climate change adaptability. *Proceedings of the Royal Society Bilogical Sciences, 275*(1653), 2859-2868. doi: 10.1098/rspb.2008.0870

JOBLING, M. (1981). Temperature tolerance and the final preferendum- rapid methods for the assessment of optimum growth temperatures. *Journal of Fish Biology*(19), 439-455.

JUNGWIRTH, M. (2003). Angewandte Fischökologie an Fließgewässern (1st ed.). Stuttgart: UTB.

KROMP-KOLB, H. (2003). Auswirkungen von Klimaänderungen auf die Tierwelt- Derzeitiger Wissenstand, fukussiert auf den Alpenraum Österreich. . Wien: Universität für Bodenkultur im Auftrag des Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

KÜTTEL, PETER, J., & WÜEST. (2002). Temperaturpräferenzen und -limiten von Fischarten Schweizerischer Fließgewässer *Rhône Revitalisierung* (Vol. 1).

LAUTSCH, E., & THÖLE, U. (2003). Classification and explanation of life conceptions using the case of the 14th Shell Youth Study 2002. *Psychology Science, 45*(2), 263-279.

LAUTSCH, E., & VONWEBER, S. (1995). Methoden und Anwendungen der Konfigurationsfrequenzanalyse (KFA). Weinheim: Beltz, Psychologie Verlags Union.

MACCRIMMON, H. R., & MARSHALL, T. L. (1968). World Distribution of Brown Trout, Salmo trutta. *Journal of the Fisheries Research Board of Canada, 25*(12), 2527-2548. doi: 10.1139/f68-225

MALLET, J. P., CHARLES, S., PERSAT, H., & AUGER, P. (1999). Growth modelling in accordance with daily water temperature in European grayling (Thymallus thymallus L.). *Canadian Journal of Fisheries and Aquatic Sciences, 56*(6), 994-1000.

MATULLA, C., SCHMUTZ, S., MELCHER, A., GERERSDORFER, T., & HAAS, P. (2007). Assessing the impact of a downscaled climate change simulation on the fish fauna in an Inner-Alpine River. *International Journal Biometeorol, 52*, 127-137. doi: 10.1007/s00484-007-0107-6

MEILI, M., SCHEURER, K., SCHIPPER, O., & HOLM, P. (2004). Dem Fischrückgang auf der Spur. Schlussbericht des Projektes Netzwerk Fischrückgang Schweiz - "Fischnetz". Trägerschaft des Projekts «Fischnetz».

MICROSOFT. (2007a). Office Access (Version 12.0.6606.1000).

MICROSOFT. (2007b). Office Excel (Version 12.0.6611.1000) [SP3 MSO].

MOHSENI, & STEFAN. (1999). Stream temperature/air temperature relationship: a physical interpretation. *Journal of Hydrology*(218), 128-141.

MOOG, O. (Ed.). (2002). Fauna Aquatica Austriaca (2 ed.). Wien: Federal Ministry of Agriculture, Forestry, Environment and Water Management.

MOOG, O., SCHMIDT-KLOIBER, A., OFENBÖCK, T., & GERRITSEN, J. (2001). Aquatische Ökoregionen und Fließgewässer-Bioregionen Österreichs- eine Gliederung nach geoökologischen Milieufaktoren und Makrozoobenthos-Zönosen. Wien: Bundesministerium für Land - und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wasserwirtschaftskataster.

MORRILL, J. C., BALES, R. C., & CONKLIN, M. H. (2005). Estimating Stream Temperature from Air Temperature: Implications for Future Water Quality. *Journal of Environmental Engineering, 131*(1), 139-146. doi: 10.1061/(ASCE)0733-9372(2005)131:1(139)

PETZ-GLECHER, R., & PETZ, W. (2005). Fischökologische Charakterisierung von Seeausrinnen österreichischer und bayrischer Seen unter Berücksichtigung der Vergleichbarkeit mit Ager und Attersee.

PRATS, J., VAL, R., ARMENGOL, J., & DOLZ, J. (2010). Temporal variability in the thermal regime of the lower Ebro River (Spain) and alteration due to anthropogenic factors. *Journal of Hydrology, 387*(1-2), 105-118. doi: 10.1016/j.jhydrol.2010.04.002

RAHEL, F. J., KELEHER, C. J., & ANDERSON, J. L. (1996). Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: Response to climate change. *Limnology Oceanography, 41*(5), 1116-1123.

RAHEL, F. J., & OLDEN, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. *Conservation Biology, 22*(3), 521-533. doi: 10.1111/j.1523-1739.2008.00950.x

RAMIREZ-VILLEGAS, J., & JARVIS, A. (2010). Downscaling Global Circulation Model Outputs: The Delta Method. Decision and Policy Analysis Working Paper No. 1: International Center of Tropical Agriculture.

ROBERTS, J. K., & HENSON, R. K. (2002). Correction for Bias in Estimating Effect Sizes. *Educational and Psychological Measurement, 62*(2), 241-253. doi: 10.1177/0013164402062002003

RUTHERFORD, J. C., MARSH, N. A., DAVIES, P. M., & BUNN, S. E. (2004). Effects of patchy shade on stream water temperature. how quickly do small streams heat and cool? *Marine and Freshwater Research, 55*(8), 737-.748. doi: 10.1071/MF04120

SAHOO, G. B., SCHLADOW, S. G., & REUTER, J. E. (2009). Forecasting stream water temperature using regression analysis, artificial neural network, and chaotic non-linear dynamic models. *Journal of Hydrology, 378*(3–4), 325-342. doi: 10.1016/j.jhydrol.2009.09.037

SCHEURER, K., ALEWELL, C., BÄNNINGER, D., & BURKHARDT-HOLM, P. (2009). Climate and land-use changes affecting river sediment and brown trout in alpine countries—a review. *Environmental Science and Pollution Research, 16*(2), 232-242. doi: 10.1007/s11356-008-0075-3

SCHIMON, W., SCHÖNER, W., BÖHM, R., HASLINGER, K., BLÖSCHL, G., KROIß H., MERZ R., BLASCHKE A.P., VIGLIONE A., PARAJKA J., SALINAS J.L., DRABEK U., LAAHA G., & N., K. (2011). Anpassungsstrategien an den Klimawandel für Österreichs Wasserwirtschaft. Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

SCHMIDT-NIELSEN, K. (1997). Animal physiology: adaption and environment (5th ed.). Cambridge: Cambridge University Press.

SCHMUTZ, S., KAUFMANN, M., & JUNGWIRTH, M. (2000a). Methodische Grundlagen zur Bewertung der fischökologischen Funktionsfähigkeit von Fließgewässern. (1st ed.). Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserrwirtschaft, Wasserwirtschaftskataster.

SCHMUTZ, S., KAUFMANN, M., VOGEL, B., JUNGWIRTH, M., & MUHAR, S. (2000b). A multi-level concept for fish-based, river-type-specific assessment of ecological integrity. *Hydrobiologia, 422-423*(0), 279-289. doi: 10.1023/a:1017038820390

SMORODINSKIJ, J. A., & ZIESCHE, P. (2000). Was ist Temperatur (1st ed.): Harri Deutsch.

SOLHEIM, A. L., AUSTNES, K., ERIKSEN, T. E., SEIFERT, I., & HOLEN, S. (2010). *Climate change impacts on water quality and biodiversity*. (1/2010). European Environment Agency.

SPINDLER, T. (1997). Fischfauna in Österreich (Vol. 87). Wien: Bundesministerium für Umwelt, Jugend und Familie.

SPSS. (2006). SPSS 15.0 for Windows (Version 15.0.1 (22.11.2006)).

STANZEL, P., & NACHTNEBEL, H. P. (2010). Mögliche Auswirkungen des Klimawandels auf den Wasserhaushalt und die Wasserkraftnutzung in Österreich. *Österreichische Wasser- und Abfallwirtschaft*(10), 180-187.

UNFCCC. (2011). Statistical Downscaling Retrieved 17.11.2011, from http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/statistical_downscaling.pdf

VANNOTE, R. L., MINSHALL, G. W., CUMMINS, K. W., SEDELL, J. R., & CUSHING, C. E. (1980). The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences, 37*(1), 130-137.

VOGT, J. (2010, 19.08.). Catchment Characterisation and Modelling (CCM). Joint Research Centere- Institue for Environment and Sustainability Retrieved 11.01, 2012, from http://ccm.jrc.ec.europa.eu/

VOGT, J., SOILLE, P., DEJAGER, A., RIMAVICIUTE, E., MEHL, W., FOISNEAU, S., BODIS, K., DUSART, J., PRACCHINI, L. M., HAARSTRUP, P., & BAMPS, C. (2007). A pan-European River and Catchment Database (pp. 120). Luxembourg: EC-JRC.

VONEYE, A. (2002). Configural Frequency Analysis- Methods, Models and Applications. London: Lawrence Erlbaum Associates.

WEBB, B. W., & NOBILIS, F. (1995). Long term water temperature trends in Austrian rivers. *Hydrological Science- Journal, 40*(1).

WEBB, B. W., & NOBILIS, F. (1997). Long term perspective on the nature of the air-water temperature relationship: a case study. *Hydrological Processes, 11*(2), 137-147. doi: 10.1002/(sici)1099-1085(199702)11:2<137::aid-hyp405>3.0.co;2-2

WEBB, B. W., & NOBILIS, F. (2007). Long-term changes in river temperature and the influence of climatic and hydrological factors. *Hydrological Sciences Journal, 52*(1), 74-85. doi: 10.1623/hysj.52.1.74

WIMMER, R. (1992). Flussordnungszahlen, Gewässersystemanalyse und Abflussregime der Traun *Kataloge des OÖ Landesmuseums* (Vol. 54, pp. 27-38).

WIMMER, R., & MOOG, O. (1994). Flussordnungszahlen Österreichischer Fließgewässer. Wien: Bundesministerium für Umwelt.

ANNEX I

Allocation of Austrian fish species to the fish regions; after SPINDLER (1997, P. 33).

Fish species	Epi- and Metarhithral Upper and lower trout region	Hyporhithral Grayling region	Metapotamal Barb region	Hypopotamal Bream region
Brown Trout (*Salmo trutta*)				
Bullhead (*Cottus gobio*)				
Stone Loach (*Barbatula barbatula*)				
Grayling (*Thymallus thymallus*)				
Minnow (*Phoxinus phoxinus*)				
Danube Salmon (*Hucho hucho*)				
European Chub (*Squalius cephalus*)				
Schneider (*Alburnoides bipunctatus*)				
Souffia (*Telestes souffia*)				
Burbot (*Lota lota*)				
Gudgeon (*Gobio gobio*)				
Barbus barbus				
Northern Pike (*Esox lucius*)				
Common Dace (*Leuciscus leuciscus*)				
Common Nase (*Chondrostoma nasus*)				
European Perch (*Perca fluviatilis*)				
Vimba Bream (*Vimba vimba*)				
Common Roach (*Rutilus rutilus*)				
Streber (*Zingel streber*)				
Danube Gudgeon (*Romanogobio uranoscopus*)				
White-finned Gudgeon (*Gobio albipinnatus*)				
Sterlet (*Acipenser ruthenus*)				
Danube Roach (*Rutilus pigus*)				
White-Eye Bream (Ballarus sapa)				
Bream (*Abramis brama*)				

Fish species	Epi- and Metarhithral Upper and lower trout region	Hyporhithral Grayling region	Metapotamal Barb region	Hypopotamal Bream region
Common Bleak (*Alburnus alburnus)*				
Asp (*Aspius aspius)*				
Kessler's Gudgeon, (*Romanogobio kessleri)*				
Zingel *(Zingel zinge)*				
Ide, Orfe (*Leuciscus idus)*				
Zander (*Sander lucioperca)*				
Schraetzer, Striped Ruffe (*Gymnocephalus schraetzer*)				
Balon's Ruffe (*Gymnocephalus baloni*)				
Silver Bream (*Blicca bjoerkna*)				
Zope *(Cyprinus ballerus)*				
Spined Loach (*Cobitis taenia*)				
Golden Spined Loach *(Sabanejewia balcanica)*				
Ziege, Sabre Carp (*Pelecus cultratus)*				
Common Carp (*Cyprinus carpio*)				
Marbled Sleeper *(Oxyeleotris marmorata*)				
Volga Pikeperch *(Sander volgensis)*				
Eurasian Ruffe (*Gymnocephalus cernuus*)				
Wels Catfish (*Silurus glanis)*				
Tench, Doctor fish (*Tinca tinca*)				
European Weatherfish *(Misgurnis fossilis)*				
European Bitterling (*Rhodeus amarus)*				
Moderlieschen or Belica (*Leucaspius delineatus*)				
Common Rudd (*Scardinius erythropthalmus)*				
Crucian Carp (*Carassius carassius*)				
European Mudminnow (*Umbra krameri*)				

ANNEX II

Data source: List of all abiotic variables used in the course of this thesis. For each variable a description, categorization and example is given as well as the source.

Variable Name	Description	Categorization	Example	Source
ID	Measuring point ID	6-digit number	200204	HZB
River	River name	Name	Dornbinerache	HZB
Discharge	Discharge	Yes/no (1/0)	1	HZB
WT	Water Temperature	Yes/no (1/0)	1	HZB
Altitude	Altitude (m.a.s.l.)	Number	467,06	HZB
Catch	Catchment size (km^2)	Number	51,1	HZB
LENGISKM	Length of River (km)	Number	33,51	HZB
FROM SOURCE	Distance from source (km)	Number	16,49	HZB
MEAS	Distance to confluence (km)	Number	17,00	HZB
DMORPH	Morphological risk assessment	Number (0-5)	3	NGP
IMPOUNDMENT	Impoundment	Yes/no (1/0)	0	NGP
HYDROPEAK	Hydropeak	Yes/no (1/0)	0	NGP
WAT_ABSTR	Water abstraction	Yes/no (1/0)	0	NGP
FLOZ	Strahler number	Number (1-6)	6	WIMMER & MOOG, 1994
ECOREGION_BEZ	Ecoregion identifier	Number (1-11)	1	Wasserwirtschafts-katatster
ECOREGION	Ecoregion name	Name	Alpine	Wasserwirtschafts-katatster
BIOREGION_BEZ	Bioregion identifier	Number (1-15)	9	Wasserwirtschafts-katatster
BIOREGION	Bioregion identifier	Name	Alpine Molasse	Wasserwirtschafts-katatster
LAKE_INFL	Lake influence	Yes/no (1/0)	0	eHYD
LAKE_DIST	Lake distance (km)	Number	0	eHYD
LAKE	Lake name	Name	Wolfgangsee	eHYD, CCM2
LAKE_SIZE	Lake area	Number (m^2)	380000	CCM2
GLACIAL INFLUENCE	Glacial Influence	Yes/no (1/0)	0	Wasserwirtschafts-katatster
Y_ROUT_MGI	Y-coordinate	Number	394836,410875	HZB

Variable Name	Description	Categorization	Example	Source
X_ROUT_MGI	X-coordinate	Number	130619,656148	HZB
WIDTH	River width at measuring point	Number (m)	1.9	Google Earth
X_MEAN_WT	Mean Water temperature in month X	Number (°C)	1.6	HZB
YEARLY_MEAN_WT	Mean Water temperature since start of measurement	Number (°C)	7.7	HZB
X_MEAN_AT	Mean Air temperature in month X	Number (°C)	-1.0	Worldclim.org
YEARLY_MEAN_AT	Mean air temperature 1961-2000	Number (°C)	8.3	Worldclim.org
X_MEAN_CATCH_AT	Mean air temperature 1961-2000 in catchment in month x	Number (°C)	12.7	Worldclim.org
FISH_REGION_BEZ	Fishregion identifier	Number (1-8)	5	IGF Scharfling
FISH_REGION	Fishregion name	Name	Hyporhithral	IGF Scharfling
TEMP_AVE	Mean observed temperature	Number (°C)	15.2	ZAMG
TEMP_MAX	Maximum observed temperature	Number (°C)	17.9	ZAMG
TEMP_MIN	Minimum observed temperature	Number (°C)	10.3	ZAMG

ANNEX III

HZB sites, corresponding rivers and important abiotic information used for the development of the stream temperature model:

ID	Name	River	Altitude (m.a.s.l)	Catchment size (km^2)	Distance from source (km)	River width (m)
200204	Enz	Dornbirnerach	467,06	51,10	16,78	19,02
201095	Scharnitz (Weidach)	Isar	956,95	203,60	19,93	17,7
201434	Tumpen	Oetztaler Ache	931,10	785,50	53,33	29,3
201558	St. Jodok am Brenner	Schmirnbach	1120,98	108,80	9,85	4,7
201897	Kaiserwerk	Weissache	556,01	94,00	18,30	5,0
203307	Obergäu	Lammer	470,77	394,50	41,23	26,3
204677	Jahrsdorf	Mattig	349,82	446,90	53,21	12,9
204719	Mamling	Ach	328,45	314,90	35,76	12,4
204750	Haging	Antiesen	378,67	164,90	27,04	10,8
204867	Pramerdorf	Pram	308,48	340,90	50,09	15,9
204925	Hartmannsdorf	Steinerne Muehl	499,59	137,80	24,57	6,3
204933	Teufelmühle	Grosse Muehl	478,82	452,20	50,01	24,0
204974	Strötting	Trattnach	379,04	52,00	16,87	8,7
205088	Rottenegg	Grosse Rodl	271,83	227,40	35,64	7,8
205104	Obertraun	Traun	526,20	317,40	24,99	26,6
205187	Bad Ischl	Ischl	469,64	250,90	14,94	11,9
205393	Timelkam	Voeckla	441,65	331,80	39,03	11,4
205427	Schalchham	Ager	411,19	949,90	62,03	18,3
205500	Friedlmühle	Alm	442,11	326,10	33,49	17,3
205518	Penningersteg	Alm	357,71	436,80	51,66	24,6
205641	Kremsmünster (Ort)	Krems	338,84	147,20	30,74	11,4
205658	Kremsdorf	Krems	270,35	365,30	53,90	8,5
205740	Reichraming	Reichramingbach	347,78	168,60	26,98	5,2
205823	Teichlbrücke	Teichl	571,17	148,60	13,54	6,9
205864	Klaus an der Pyhrnbahn	Steyr	420,29	542,40	27,44	33,4
205914	Pergern	Steyr	301,81	898,10	62,55	21,4
205922	Steyr (Ortskai)	Enns	283,97	5915,40	222,35	55,9
205971	Pfahnlmühle	Waldaist	322,36	266,10	56,99	4,3
206029	Haid	Naarn	233,54	303,10	38,99	8,5
206078	Furth (Bundesstraße)	Schwemmbach	428,73	188,80	33,32	4,7
206086	Furth (Ort)	Schalchener Brunnbach	426,40	31,20	6,68	6,2
206102	Pram	Pram	427,11	41,20	7,51	6,4
206326	Winertsham (Steg)	Pram	335,94	128,10	34,18	10,02
206375	St. Georgen an der Gusen	Gusen	246,67	257,70	32,24	7,16
206391	Wels-Lichtenegg	Traun	309,00	3387,10	122,71	48,1
206565	HWR-Becken Leithen	Trattnach	467,44	19,50	5,41	5,1
206573	Engerwitzdorf	Grosse Gusen	313,19	107,10	18,46	8,3
206581	Kefermarkt	Feldaist	462,04	189,20	34,46	6,6

ID	Name	River	Altitude (m.a.s.l)	Catchment size (km2)	Distance from source (km)	River width (m)
207654	Opponitz (Mirenau)	Ybbs	391,29	506,70	73,01	23,4
207688	Greimpersdorf	Ybbs	261,73	1116,60	113,43	35,1
207803	Niederndorf	Erlauf	225,37	604,90	70,84	36,3
207852	Hofstetten (Bad)	Pielach	311,15	289,50	37,28	24,8
207910	Windpassing	Traisen	294,15	733,30	46,10	33,2
207944	Zwettl (Bahnbrücke)	Kamp	506,57	621,80	52,29	17,5
207993	Stiefern	Kamp	217	1493,30	131,06	17,3
208116	Fahrafeld	Triesting	338,23	186,00	21,96	10,8
208280	Wöllersdorf (Hydro)	Piesting	307,06	284,10	42,75	11,3
208413	Marienthal (Bahnbrücke)	Fischa	176,61	417,30	25,96	8,9
208629	Raabs an der Thaya	Thaya	395,44	1405,80	96,98	17,5
208710	Gloggnitz (Adlerbrücke)	Schwarza	435,38	472,20	37,97	18,5
208835	Warth	Pitten	372,71	277,00	8,80	8,7
208991	Deutsch Brodersdorf	Leitha	193,04	1598,90	35,18	20,5
210096	Schützen am Gebirge	Wulka	122,17	383,70	42,14	5,6
210641	Schladming	Enns	724,85	648,80	43,59	24,1
210864	Gußwerk	Salza	735,50	280,00	26,90	10,9
210898	Wildalpen	Salza	583,06	592,30	63,80	21,3
210989	Feldbach	Raab	275,45	689,40	50,43	23,7
211227	Neuberg an der Mürz	Muerz	715,30	231,50	22,50	17,5
211268	Kapfenberg-Diemlach	Muerz	485,94	1364,50	80,25	10,7
211326	Graz	Mur	328,67	6988,90	279,97	57,7
211490	Mureck (Schreibpegel)	Mur	224,23	9769,90	336,76	67,7
212167	Lienz	Isel	667,20	1198,70	56,02	21,2
212787	Federaun	Gail	498,54	1304,90	113,32	37,3

ANNEX IV

Regression coefficients and coefficients of determination for the stream temperature model:

Catchment size	a	b	c	d	e	R^2	$adjR^2$
June							
<188,8 km²:	0.914	0.688	-0.019	0.208	0.000	.785	.599
188,8-331,8 km²:	11.596	0.736	-0.017	-0.033	-0.007	.876	.832
331,8-689,4 km²:	-20.086	2.007	0.005	0.009	0.005	.869	.822
>689,4 km²:	-8.124	1.446	0.001	-0.002	0.006	.840	.782
July							
<188,8 km²:	14.405	0.220	-0.005	0,34	-0.009	.702	.659
188,8-331,8 km²:	14.885	0.578	-0.016	-0,044	-0.010	.834	.773
331,8-689,4 km²:	-21.293	1.936	0.004	0,016	0.005	.843	.781
>689,4 km²:	-7.326	1.396	0.001	-0,005	0.004	.869	.821
August							
<188,8 km²:	2.597	0.630	-0.019	0.208	-0.001	.730	.622
188,8-331,8 km²:	15.025	0.562	-0.015	-0.047	-0.009	.808	.739
331,8-689,4 km²:	-15.821	1.709	0.003	0.016	0.004	.816	.749
>689,4 km²:	-7.286	1.369	0.001	0.000	0.005	.883	.841

Regression coefficients and coefficients of determination necessary to estimate the FiZI:

Month	a	b	R2	adjR2
June	1.353	0.136	0.536	.535
July	0.355	0.289	0.602	.600
August	0.901	0.246	0.532	.531

Regression coefficients and coefficients of determination necessary to estimate the Salmonidae/Cyprinidae index:

Month	a	b	R^2	$adjR^2$
June	-1.311	0.095	0.464	.462
July	-1.556	0.096	0.529	.527
August	-1.446	0.115	0.470	.468

ANNEX V

Profile classification:

Profile	Classified Profile
111	3
112*	3
113*	3
121*	3
122	3
123*	4
131	4
132	2
133	2
211	2
212	4
213*	5
221*	3
222*	3
223*	4
231	1
232	3
233	5
311	5
312	5
313	5
321	5
322	5
323	3
331	1
332	2
333	3
411	1
412	6
413*	6
421	5
422	4
423	6
431	1
432	4
433	6