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How will an increase of atmospheric temperature affect Gross Primary Production? A case study about lowland rivers in Austria

Master thesis

In partial fulfilment of the requirements

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Master of Science

submitted by:

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Abstract

Climate change got a growing challenge in our daily life and affects the aquatic ecosystem with extreme weather events and increases of temperature. Water temperature is one of the key parameters in stream ecology and determines the health of the aquatic ecosystem. This master thesis is part of a big project which assesses climatic and land use changes on water availability and water quality. In detail, the thesis investigates how a temperature increase of 1 °C affects gross primary production (GPP) and in a further step the trophic state of two Austrian rivers, the Raab and the Schwechat. Over decades it is known that the metabolic and biochemical rates increase exponentially with temperature, which also has an effect on the nutrient uptake. Therefore the aim of this master thesis was i) the identification of the relation between gross primary production and temperature, ii) the characterization of how nutrient uptake, especially phosphorus uptake is influenced by an increase of temperature and iii) the assessment of the potential limitations posed to the increase of gross primary production by nutrient availability under a modelled climate change scenario. The relation of temperature and GPP was calculated with the equation of the metabolic theory of ecology (MTE) and displayed with the Arrhenius plot for the years 2010 - 2012. For the calculations of GPP the excel based tool Rivermet and for the nutrient uptake the Redfield ratio were used. The results showed a strong and positive correlation of temperature and GPP for the whole years and different seasons as well as an increase of nutrient uptake with an increase of temperature. It could be also identified higher GPP values for the Schwechat than for the Raab. In the Raab, light availability is limited which impairs primary production. Another possible reasons are the different algae species that change with the seasons which lead to different biological characteristics and preferences. In total, the results do not serve as accurate predictions that give precise values as they are affected by a considerable degree of uncertainty, but rather show estimations about how GPP and phosphorus availability can be prospectively influenced by temperature increase and climate change.

Kurzfassung

Klimawandel wird heutzutage zu einer immer größer werdenden Herausforderung und beeinflusst das aquatische Ökosystem mit extremen Wetterereignissen und Temperaturanstiegen. Die Wassertemperatur ist einer der Hauptparameter in der Gewässerökologie und bestimmt das aquatische Ökosystem. Die vorliegende Masterarbeit ist Teil eines größeren Projekts, welches die Klima- und Landnutzungsänderungen hinsichtlich der Wasserverfügbarkeit und der Wasserqualität beurteilt. Im Detail untersucht die Arbeit wie sich der Temperaturanstieg von einem Grad Celsius auf die Bruttoprimärproduktion auswirkt und in einem weiteren Schritt auf den trophischen Zustand zweier österreichischer Flüsse, der Raab und der Schwechat. Seit Jahrzehnten ist bekannt, dass die metabolischen und biochemischen Raten exponentiell mit der Temperatur ansteigen, was sich auch auf die Nährstoffaufnahme auswirkt. Das Ziel der Masterarbeit war i) die Identifizierung des Zusammenhanges zwischen Bruttoprimärproduktion und Temperatur, ii) die Charakterisierung wie die Nährstoffaufnahme, vor allem Aufnahme von Phosphor, durch den Temperaturanstieg beeinflusst ist und iii) die Beurteilung der potentiellen Einschränkung des Zuwachses der Bruttoprimärproduktion durch die Nährstoffverfügbarkeit im Rahmen eines modellierten Klimawandelszenarios. Der Zusammenhang zwischen der Temperatur und der Bruttoprimärproduktion wurde mit Hilfe der Gleichung der metabolischen Theorie der Ökologie berechnet und mit dem Arrheniusgraphen dargestellt. Als Untersuchungszeitraum dienten die Jahre 2010 – 2012. Für die Berechnungen der Bruttoprimärproduktion wurde das auf Excel basierende Tool Rivermet und für die Nährstoffaufnahme das Redfield Verhältnis verwendet. Die Ergebnisse zeigten im Untersuchungszeitraum eine starke und positive Korrelation von Temperatur und Bruttoprimärproduktion. Genauso konnte eine Erhöhung der Nährstoffaufnahme durch einen Temperaturanstieg berechnet werden. In der Schwechat ergaben zudem die Berechnungen höhere Werte bezüglich Bruttoprimärproduktion als in der Raab. Ein Grund liegt in den limitierten Lichtverhältnissen der Raab, welche die Primärproduktion beeinträchtigen. Ein anderer möglicher Grund kann im Auftreten verschiedener Algenspezies liegen, die sich im Verlauf der Jahreszeiten ändern. Durch diese Diversität können hinsichtlich Temperatur und Nährstoffe unterschiedliche biologische Charakteristiken und Präferenzen auftreten. Da die Ergebnisse jedoch durch die Berechnungsmethoden bis zu einem gewissen Grad mit Unsicherheiten belastet sind, stellen sie keine präzisen Vorhersagen dar, sondern sind Schätzungen, wie die Bruttoprimärproduktion und die Phosphorverfügbarkeit zukünftig durch den Temperaturanstieg und den Klimawandel beeinflusst werden.

1. Introduction

This master thesis is part of the project *“Water resources under climatic stress. An integrated assessment of impacts on water availability and water quality under changing climate and land use“*, with short title “Aqua-stress”. The project deals with the assessment of impacts of socio-economic and climatic changes on agricultural production as well as the impacts of climate and land use changes on water quantity and quality (ANON, 2013). The topic of the current master thesis is the temperature dependence of primary production and the influence of increased temperature due to climate change.

Climate change got a growing challenge in our daily life and influences the Earth’s ecosystem and thus the livelihood and well-being of societies. Current modelling studies on climate change predict an increase in temperature of 3,7 °C till the end of the century (IPCC, 2013), extreme weather conditions and the alteration of the availability and distribution of rainfall, snowmelt, river flows and groundwater, and further deterioration of water quality (UN WATER, 2014).

1.1 General information about the aquatic ecosystem and gross primary production

1.1.1 Hydrological cycle

In the atmosphere water is moving in and out (see figure 1-1). Through evaporation and transpiration water gets transformed from liquid water into vapor which ascends into the atmosphere due to rising air currents. Cooler temperatures lead to condensation and the development of clouds which will be moved through strong winds around the world until the water falls as precipitation to replenish the earthbound parts of the water cycle (USGS, 2016).

After precipitation, water can be infiltrated and lead to groundwater flow and storage, flows as surface runoff to the oceans or serve flora and fauna as water source. Another possibility is also the storage as ice and snow on mountains and snowmelt. Thus, runoff through warmer temperatures will lead to a higher streamflow.

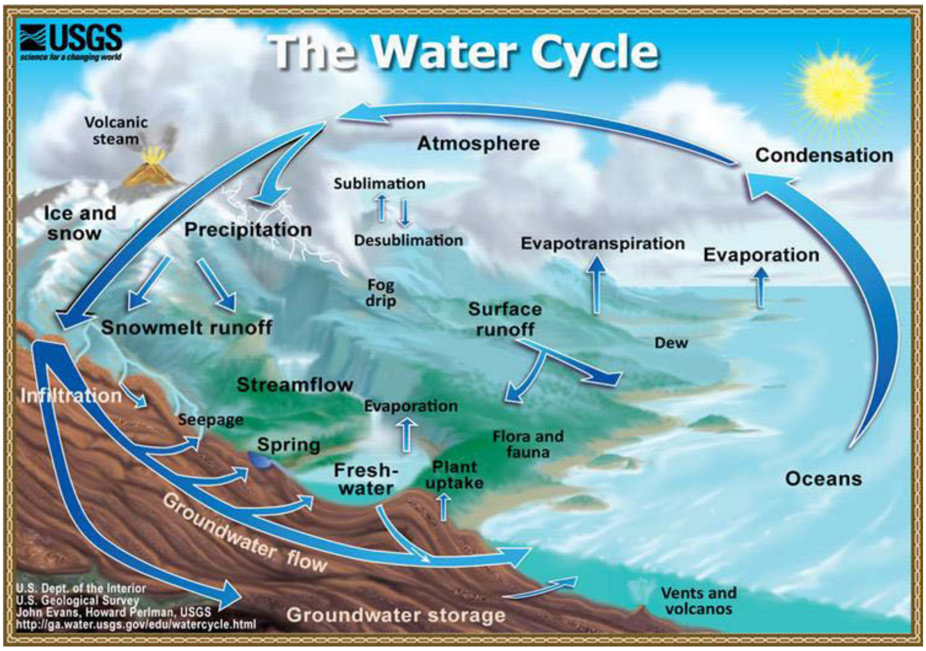

Figure 1-1*:* The Water Cycle (USGS, 2016)

Flowing waters are “open” ecosystems and are in strong relationship with their catchment area. They transport bedload and suspended particles as well as e. g. dissolved nutrients and organic material. Rivers consist of a longitudinal zonation and allochthonous components are dominant. From the beginning to the end there is a change of important basic conditions like flow velocity, substrate, oxygen content and temperature as wells as the fish habitat (see figure 1-2 and 1-3) (JUNGWIRTH, 2010).

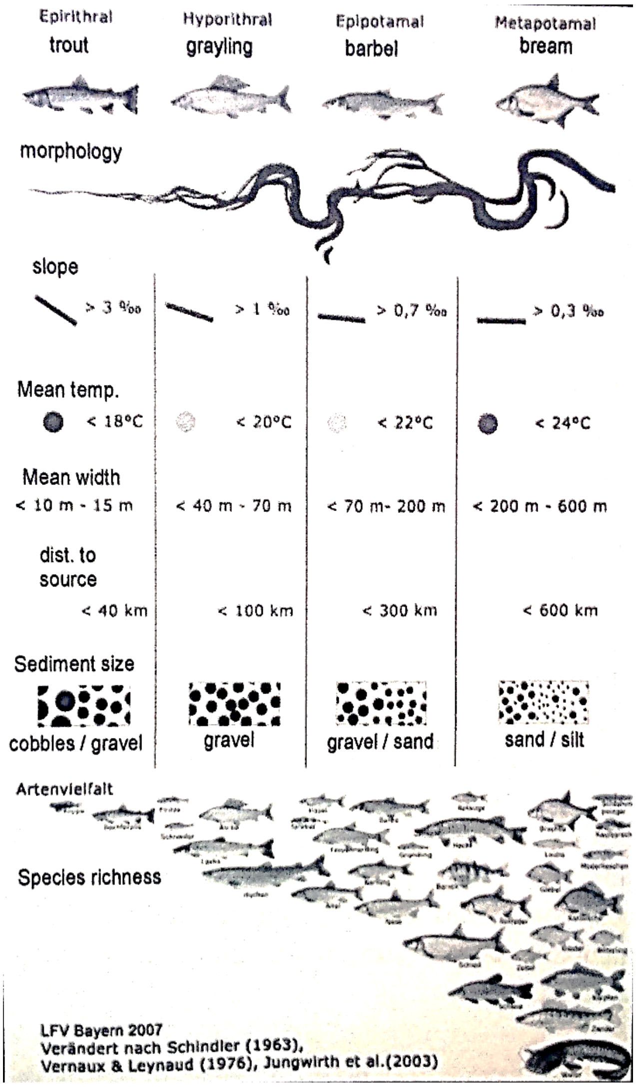

Figure 1-2: Longitudinal zonation of running waters (Jungwirth et al. 2003 cite JUNGWIRTH et al., 2014)

Figure 1-3 shows the transformation of the river course. At the beginning it consists of the rhithral, a constrained and braiding course. This section is especially characterised by the erosion and transportation of material. Afterwards the development of meanders, where transported material is deposited, is predominant. Finally, the river mouth is characterised by a widespread and in the sea growing delta. This section is called potamal.

Temperature regulation

Temperature regulation depends on the volume, distribution of the water mass, evaporation and condensation, absorbed radiation and heat exchange with the air and subsoil. Temperature increases from the source to the river mouth. Potamal water heats slowly due to the big water body but it is able to increase its temperature till 25-30 °C. Many brooks in the upper rhitral area are strongly influenced by their source and are shaded by riparian vegetation due to their small width. Therefore, they only can reach temperature around 12 °C in summer. In winter some rhithral sections stay comparatively warm because of the influence of the source but cool down till 0°C with a higher distance to the source.

Flow velocity, turbulence and O_2- content

Flow conditions in rivers are among the most important and most determinant parameters for river communities. Turbulent current in the rhithral is decisively responsible for balanced oxygen conditions (nearly 100% saturation). Here, the oxygen saturation is caused by superimposes biogenic processes (oxygen production during through assimilation during day and dissimilation, respiration and destruction processes during the night). There is also more oxygen oversaturation due to substantially primary production during the day. Strong diurne O_2 fluctuations with partly considerable O_2 deficits at night however are typical in quietly flowing potamal waters and / or in standing tributaries (JUNGWIRTH, 2010).

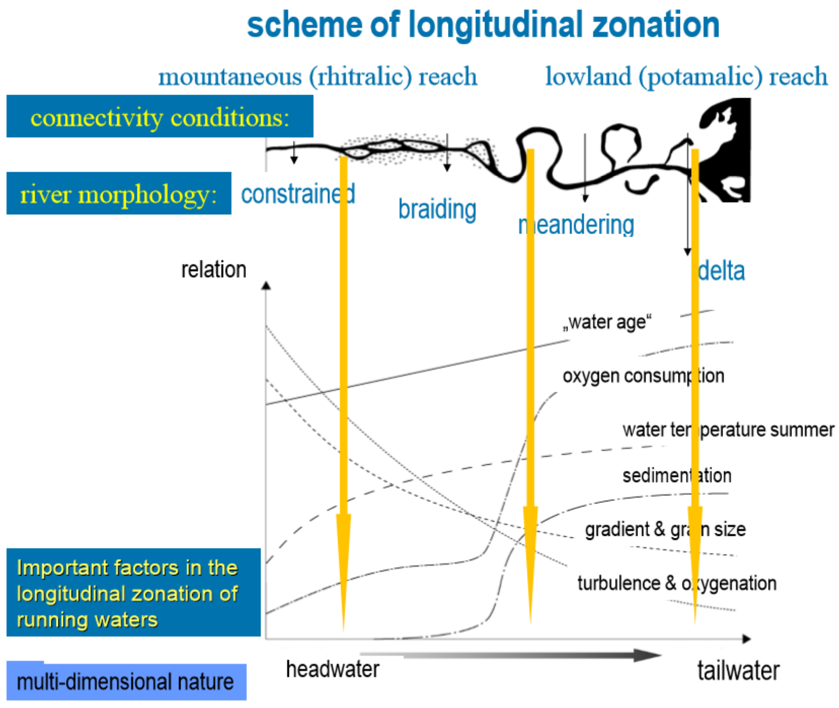

Figure 1-3: Important factors in the longitudinal zonation of flowing waters (Uhlmann, 1982 cite JUNGWIRTH, 2015)

1.1.2 Biological production

Biological productivity can be seen as an index of water quality and the production potential of organisms. It is composed of primary productivity, which in turn is divided into gross and net primary productivity and secondary productivity (KUMAR et al., 2016) and the production of biomass of heterotrophic organisms (SPEKTRUM, 2016). Primary production is defined as the rate at which energy is stored by photosynthetic activity of producer organisms in the form of organic substances which can be used as food substances (KUMAR et al., 2016).

1.1.2.1 Gross and Net primary production and respiration

Photosynthesis is the process of food production for primary producers. With the help of the sun, the use of carbon dioxide, water, nutrients and sometimes other chemicals they produce glucose, which is a type of sugar and an essential nutrient. Glucose is used to produce cell walls and to grow as it is the important energy source for plants (NATIONAL GEOGRAPHIC, 2017). A by-product of the photosynthesis process is oxygen which is used for the respiration (PFLANZENFORSCHUNG, 2017a). During night, the amount of oxygen decreases as photosynthesis ceases. More carbon dioxide is produced and released back to the atmosphere (PFLANZENFORSCHUNG, 2017b).

The total rate of photosynthesis is gross primary production (GPP) and includes organic matter consumed in respiration (ER) during the measurement period (KUMAR et al., 2016). Net primary production (NPP) is the result of GPP less ER and represents the total available energy in an ecosystem (figure 1-4) (HAKIM, 2012).

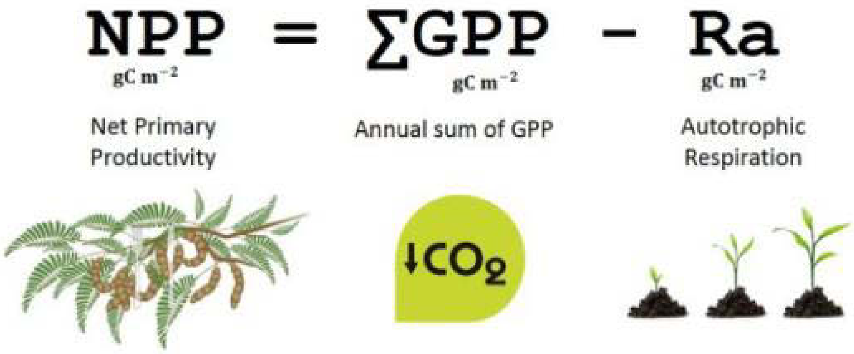

Figure 1-4: Equation of net primary production (HAKIM, 2012)

Respiration can be divided into autotrophic and heterotrophic respiration. Autotrophic respiration occurs during photosynthetic processes when one part of the assimilated CO_2 gets respired by the plant. As far as heterotrophic respiration is concerned, CO_2 is released into the atmosphere during the decomposition of organic matter and consumption of oxygen by heterotrophic organisms (WALD WISSEN, 2016).

Primary production and respiration are related by the net daily metabolism (NDM). Its equation is:

$$NDM = GPP - CR_{24}$$

CR_{24} is described as the community respiration (autotrophic and heterotrophic together) measured over a 24- hour period. Respiration can be analysed using a 24- hour curve (figure 1-5). The average night time respiration is extrapolated through the daylight hours to generate estimates of total daily respiration (CR_{24}) and light-dark period. The ratio of primary production and respiration provides an indication of metabolic processes. If GPP exceeds CR_{24} then this indicates a net addition of energy to the system. If GPP is smaller than CR_{24} more carbon is produced in the system than it is consumed (BOTT, 2006).

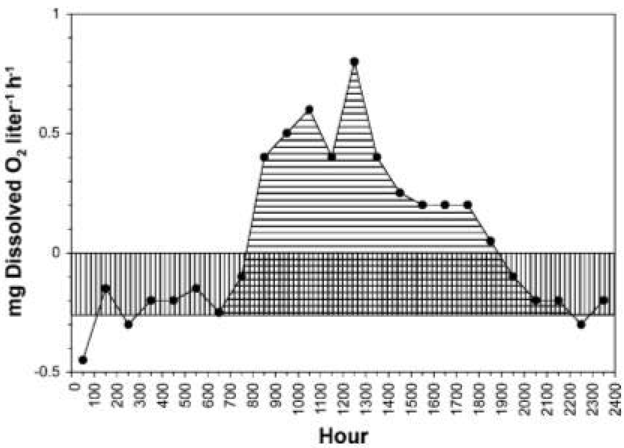

Figure 1-5: Dissolved oxygen diel curve (BOTT, 2006)

Primary production is mainly controlled and influenced by following factors:

Light: is one of the limiting factors and influences stream periphyton. Commonly the higher the light intensity the higher the primary production.

Temperature: can also affect primary productivity (KIFFNEY et al., 2004).

Flow disturbance: in lotic ecosystems flow disturbance can be seen as one of the most important drivers of community patterns (HOLOMUZKI and BIGGS, 2000). It is believed that during periods of flow stability the importance of biotic interactions increases (POWER et al., 1985).

Nutrients: limiting nutrients are phosphorous and nitrogen. An increase of nutrients leads to an increase of algae growth (MURDOCK et al., 2004).

1.1.2.2 Primary producers

Primary producers, are autotrophic organisms which produce their own food. Necessary to differentiate are autotrophs and heterotrophs. The difference is in the way they get their energy. Heterotrophs consume other organisms whereas autotrophs make their own energy. Autotrophs are the producers of energy for the rest of the organisms within the ecosystem. Heterotrophs are primary consumers and consume autotrophs or other heterotrophs for energy (MC BIOLOGY, 2008). The most common forms of autotrophs are plants, as well as many other organisms. Algae, or seaweed, the larger forms, for example are members of this group. Other autotrophs are a variety of bacteria and phytoplankton which are tiny organisms (NATIONAL GEOGRAPHIC, 2017).

Primary producers are situated at the bottom of the food chain (figure 1-6) and serve as food sources for other organisms including zooplankton and create biomass through photosynthesis. Zooplankton are heterotrophic organisms and are themselves food for larger planktivores (TEACH OCEAN SCIENCE, 2016).

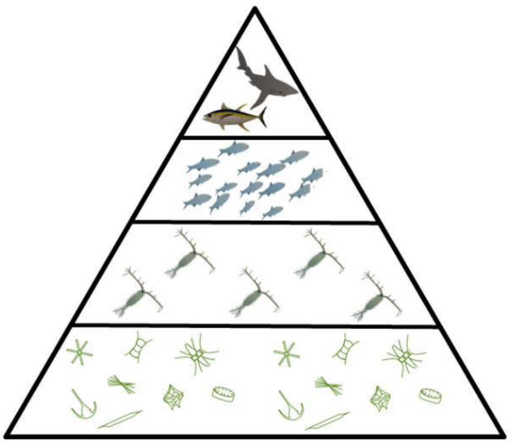

Figure 1-6: Aquatic trophic pyramid with phytoplankton and periphyton as primary producers, zooplankton as primary consumers and planktivorous and predatory fish as secondary and tertiary consumers (TEACH OCEAN SCIENCE, 2016)

Drivers of metabolic activity in streams are autochthonous productivity and the use of allochthonous inputs (RILEY and DODDS, 2013). The metabolic rate is the speed at which an organism uptakes energy and material resources, transforms them in useable forms and provides them to biochemical processes necessary for growth, survival and reproduction (Brown et al., 2004). Stream metabolism interacts with water quality via basic ecosystem properties, such as nutrient uptake rates, trophic status and C flux into the food web and indicates total biotic activity (RILEY and DODDS, 2013).

Just as individual primary producers, stream metabolism is also affected by many variables:

- Nutrients availability
- Composition and size of the heterotrophic community
- Light
- Availability of organic matter for respiration (ROMANI and SABATER, 1999)

Gross primary productivity and stream ecosystem respiration exert a significant control on organic carbon fluxes in fluvial networks (DEMARS et al., 2011) and several studies indicate that a major role in the global carbon cycle is played by fresh water (BATTIN et al., 2009).

For the carbon cycle plants convert atmospheric carbon dioxide into carbon- containing organic compounds such as sugars or fats. Plants pick up carbon dioxide through microscopic openings in their leaves, which are called stomata. When animals eat plants or other animals they incorporate the carbon in the sugars, fats and proteins derived from the ingested biomass into their bodies. During cellular respiration energy is extracted from the food inside their cells. This respiration requires oxygen and it produces carbon dioxide which is used in photosynthesis. Thus photosynthesis and cellular respiration are linked in the carbon cycle.

Photosynthesis needs atmospheric carbon whereas cellular respiration returns carbon to the atmosphere and vice-versa for oxygen. The global rates of respiration and photosynthesis influence the amount of carbon dioxide in the atmosphere. In summer, the high rate of photosynthesis consumes high amounts of carbon dioxide whereas in winter the amount of atmospheric carbon dioxide increases when the rate of photosynthesis is low. Carbon is also released into the atmosphere through the actions of decomposers, such as bacteria and fungi. They derive their nutrients by feeding on the remains of plants and animals. These decomposers use respiration to extract the energy contained in the chemical bonds of the decomposing organic matter and so release carbon dioxide into the atmosphere. Some ecosystems are typically characterized by fast decomposition like in tropical rainforests and carbon dioxide returns to the atmosphere at a relatively fast rate. On the other side, there are ecosystems like northern forests and tundra where decomposition proceeds more slowly. In some places such as bogs and deep ocean the organic matter of animals and plants can accumulate in deep sediments where decomposers cannot function well because of the lack of oxygen. These carbon rich materials are slowly converted into carbon- rich fossil fuels such as petroleum and natural gas over millions of years. In marine environments carbon- containing matter is also incorporated into the shells and other hard parts of aquatic organisms. When these organisms die the carbon- rich hard parts sink to the ocean bed. They get buried in sediment and eventually densify into rocks like limestone and dolomite (NET INDUSTRIES, 2016).

Figure 1-7 demonstrates the movement of the carbon cycle. It shows how plants use carbon dioxide from the atmosphere, use it for the photosynthesis and release it back to the atmosphere through respiration. The same happens for the aquatic ecosystem where water receives carbon dioxide through the atmosphere, photosynthesis happens and respiration releases carbon dioxide back to the atmosphere.

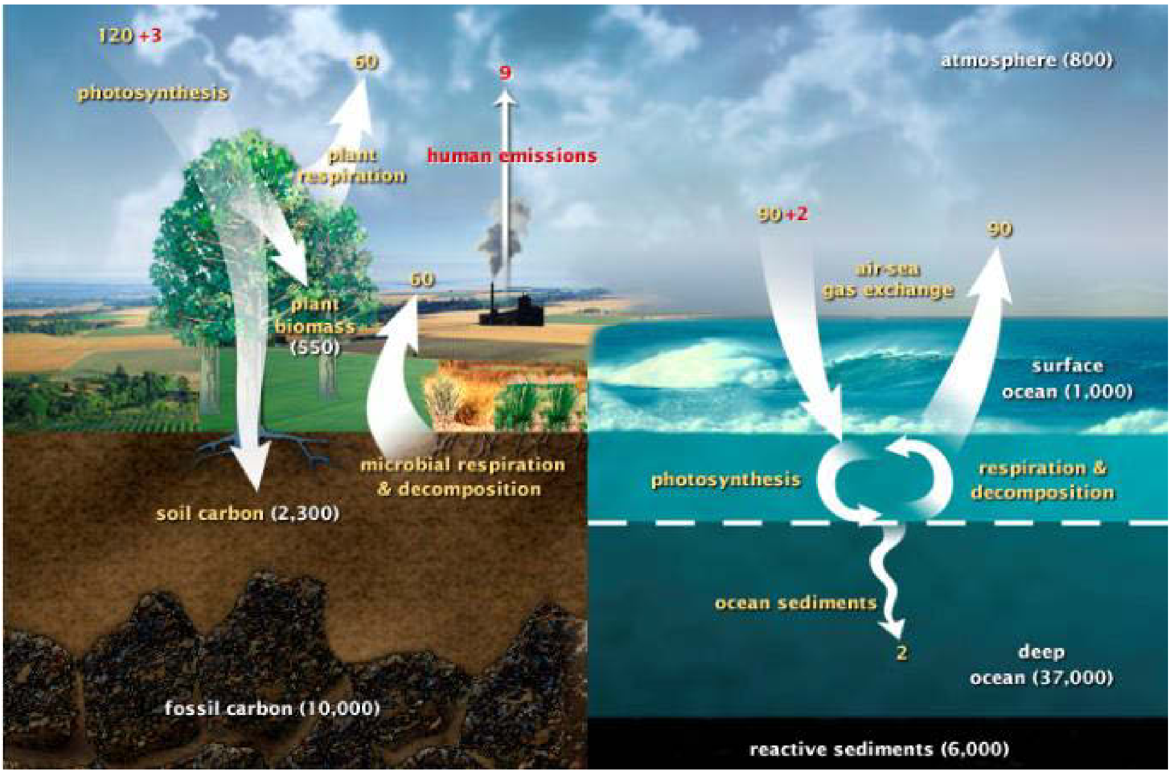

Figure 1-7: Movement of the carbon cycle between land, ocean and atmosphere (GENOMIC SCIENCE PROGRAM, 2015)

1.1.3 Nutrient uptake

As written before primary producers are macrophytes, phytoplankton as well as periphyton. To grow and to produce biomass they need phosphorus and nitrogen as macronutrients, in addition to micronutrients.

1.1.3.1 Phytoplankton and periphyton

The growth of algae depends on light and nutrients and the amount of these factors can be very different during the course of the year (figure 1-8). In winter there is too low light and temperature for growing and therefore the nutrients are also not needed. As a result there is also less algal growth in winter. In spring with more sunlight and higher temperature water bodies generally record an increase of phytoplankton and periphyton. At first diatoms start to grow. This species needs less light and starts growing at low temperatures. The process of growing can be very fast and dissolved nutrients are consumed. Phytoplankton and periphyton react to changed nutrient concentrations. If there are too many nutrients in the water column eutrophication happens and algal blooms can occur. Probably this is the reason of the shift of the species composition of algae. The amount of diatoms decrease while flagellates increase (ECOMARE, 2015).

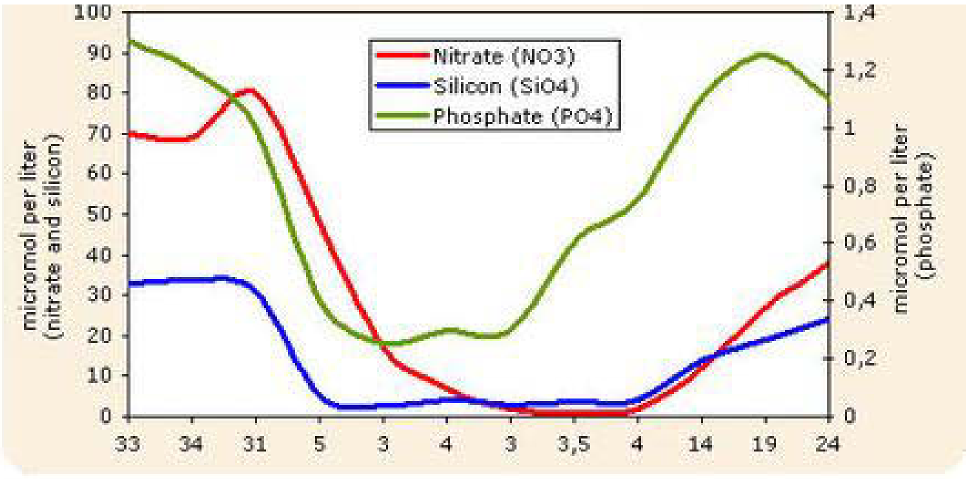

Figure 1-8: Decrease of nutrients in the spring due to the growth of phytoplankton and periophyton (ECOMARE, 2015)

1.1.3.2 Macrophytes

Macrophytes encompass all upper and lower plants which grow in the water and can be perceived with the eye. Flowering plants, ferns, moss and charophyceae number among macrophytes (GUTOWSKI et al., 2011). Macrophytes are classified into submerged anchored, submerged floating and emerged floating hydrophytes. Submerged anchored hydrophytes get nutrients through the floating leaves and through their rhizomes which are anchored in the soil. Submerged floating hydrophytes are rootles and get nutrients through their leaves. Emerged floating plants have roots and leaves on the water surface which serve for the nutrient uptake. Due to their reactions to changed environmental influences macrophytes are suitable for biological indication (BERNHARDT, 2016).

Too high contamination with nutrients in streams lead to eutrophication, i. e. the change of a stream with low nutrient and high oxygen content to a more stressed one (see 1.1.3.3). Streams with a high trophic degree e.g. through adjacent agricultural activities have the problem that they lose their good ecological status due to high plankton mass, low oxygen and in succession the death of fish.

1.1.3.3 Trophic degree

The trophic degree quantifies the nutrients content in a water body and is usually classified in the following four categories:

Trophic degree I: Due to the low plankton production only few fish have their habitat in these water bodies through the year. The water is clear with a viewing depth of over 4 m. Oxygen saturation lies at over 70% at the end of the summer stagnation period.

Trophic degree II: The low plankton production still grants viewing depths of more than 2 meters. Oxygen saturation lies at 30 to 70% at the end of the summer stagnation period.

Trophic degree III: The viewing depth still amounts to less than 2 metres due to the high plankton production. Massive accumulations of midge larvae and sludge tube worms in muddy bottoms show an already noticeable pollution of the water. The water body only contains 0 to 30% of oxygen at the end of the summer stagnation period.

Trophic degree IV: An excessive supply of nutrients allows only a viewing depth of less than 1 meter. During summer at day above the thermocline (in the see) there is an oxygen oversaturation due to the photosynthesis while there is no oxygen on the bottom which is covered with black sludge. Fish often die during night and early morning hours. Oxygen saturation lies at 0% at the end of the summer stagnation period (WASSER WISSEN, 2016).

1.1.4 Algal blooms and their behaviour in aquatic ecosystems

Algal blooms can be sometimes a natural phenomenon but generally occur due to nutrient pollution and are a rapid increase in the density of algae in an aquatic system. This enlargement of algal blooms turns the water noticeably green (figure 1-9). Algal blooms have different phenotypes. Species of algae can grow in clumps, covered in a gelatinous coating and are available to float. Other algal blooms occur as thick mats which float on or below the surface along the shoreline (figure 1-10) (ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, 2016).

Figure 1-9: Occurrence of algal blooms as thick mats floating on the shoreline (ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, 2016).

Figure 1-10: An overabundance of algal blooms that turn the water noticeably green (ST. JOHNS RIVER WATER MANAGAMEN DISTRICT, 2016).

Reasons for the growth of algal blooms are the overabundance of the essential plant nutrients nitrogen and phosphorus. These nutrients enter the aquatic ecosystem through point sources (e.g. industrial and wastewater treatment), nonpoint sources (e.g. stormwater runoff from farms or urban areas) and from nutrient enriched rainfall. If there is a too high concentration of nitrogen and phosphorus in a water body with the combination of temperature, sunlight and low flow this can trigger an algal bloom (ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, 2016).

1.1.4.1 Potential risks of algal blooms

The biggest issue of increased algae growth is eutrophication. The consequences are, besides the growth of blue-green algae blooms, polluted drinking water, the alteration of ecological structures and function of freshwater (DODDS et al., 2009).). Other problems are the limitation of light for deeper level which can lead to die-offs of plants in the littoral zone and predators are also affected as the need light to catch prey (LEHTINIEMI et al., 2005). Dissolved inorganic carbon can be depleted due to high rates of photosynthesis and raise pH to extreme levels during the day (TURNER and CHISLOCK, 2010). When these high amounts of algae die decomposer will decompose the organic matter under the consumption of high amounts of oxygen, creating a hypoxic or anoxic dead zone (CHISLOCK et al., 2013) which leads to fish death (THE FISH SITE, 2007).

Algae are typically not harmful for people but an increase and overabundance can lead to aesthetical unalluring and be harmful for the environment. The possibility of algal toxins is a serious concern. Native organisms, humans, pets who come in contact with the toxins can be affected. E. g. in the St. Johns River, in Florida, harmful algal blooms have occurred in the past years. The consequences were fish kill and numerous reports of skin rashes, accumulations of foam and shoreline scums and unappealing odors. The biggest problems which are associated with harmful algal blooms are environmental damage and the impacts on recreational activities (ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, 2016).

1.1.5 Climate change and extreme weather events

The last years extreme weather and climate events have changed, such as heat waves and droughts and the number and strength of some of these extreme events have already increased due to human induced climate change (GLOBAL CHANGE, 2014).

Heat waves and droughts

Heat waves, periods of abnormally hot weather lasting days to weeks, have been increasing in the recent years. Higher temperatures force higher rates of evaporation which includes more loss of moisture through plant leaves. In areas where precipitation does not decrease drying of soils is also increasing through the increasing of surface evaporation and loss of water from plants as long as the effects of higher temperatures are not offset by other changes (e.g. increased humidity or reduced wind speed). If soil dries out, a large portion of the incoming heat from the sun goes into heating the soil and adjacent air which leads to hotter summers under drier climatic conditions (GLOBAL CHANGE, 2014).

Heavy precipitation

Since the 1950s extreme precipitation events become more common and have produced more rain in many regions around the world. It is expected from scientists that these trends continue as the planet continues to warm. More water vapor can be better hold by warmer air and with each degree of warming the air’s capacity for water vapor increases by about seven percent. An atmosphere with more moisture tends to produce more intense precipitation events, which is exactly what has been observed over large areas of the Earth. But increases in heavy precipitation may not always lead to a total precipitation over the year. Some climate models recorded a decrease in moderate rainfall and an increase in the length of dry periods which leads to an offset of increased precipitation falling during heavy events (CENTER FOR CLIMATE AND ENERGY SOLUTIONS, 2017).

Freshwater quality affected by droughts

Temperature increases in streams and rivers during droughts have been recorded in many studies (DAVIES, 1978; ZIELINSKI et al., 2009; HRDINKA et al., 2012).). In some Polish streams temperature increased 1,3 °C (ZIELINSKI et al., 2009). A large temperature increase of 7 °C could be documented in the regulated lower Nakdong River in South Korea (HA et al., 1999) and temperature increases of 2 °C have been reported in the Meuse River (VAN VLIET and ZWOLSMAN, 2008) while during the same drought temperature in some Czech Republic streams went up to 1,7 °C (HRDINKA et al., 2012). Droughts also affect nutrient concentrations in river and streams. Total nutrient concentrations and lower dissolved concentrations could be observed in rivers and streams for phosphorus and nitrogen (BAURÈS et al., 2013; Caruso, 2002 cite MOSLEY, 2015). These high nutrient concentrations in rivers and streams have been derived from point sources (e.g. domestic, agricultural or industrial) and occurred during a lack of dilution (CARUSO, 2001).

1.2 GPP and climate change investigated in different literature reviews

1.2.1 Correlation of temperature and primary production

Several studies have focused on the investigation of climate change and the aquatic ecosystem including primary production. MCGOWAN et al. (2012) e.g. investigated climate and human as drivers of algal community change in Windermere, in Great Britain, where data reached back till

1850. They analysed historical archives, published data sets and lake sediments and found out that climate change influenced algal community on longer-term scales and affected the growth of the different species. Wet conditions in early spring for example were associated with lower abundances of siliceous algae. TALLING (2012) worked with algae and examined their occurrence. In his paper “Temperature increase – an uncertain stimulant of algal growth and primary production in fresh waters” he writes about the occurrence of the different algae types and their growth at specific temperatures. They have a broad temperature range where they can exist whereas the different types have specific temperature preferences. *Ceratium furcoides* e.g. have poor performance at temperature below 5 °C. But on the other the diatom *Asterionella formosa* where the growth cut off sharply above 25°C or the green algae *Chlorella* which has a high-temperature strain capable of exceptionally rapid growth at 39 °C. Figure 1-11 shows the temperature dependence of the growth rate and that with 10 more degrees the speed of the growth nearly doubles. Q_{10} is a parameter which describes how fast the velocity of a chemical reaction is at given temperature compared to the same reaction at a temperature 10 °C lower (OXFORD REFERENCE, 2016).

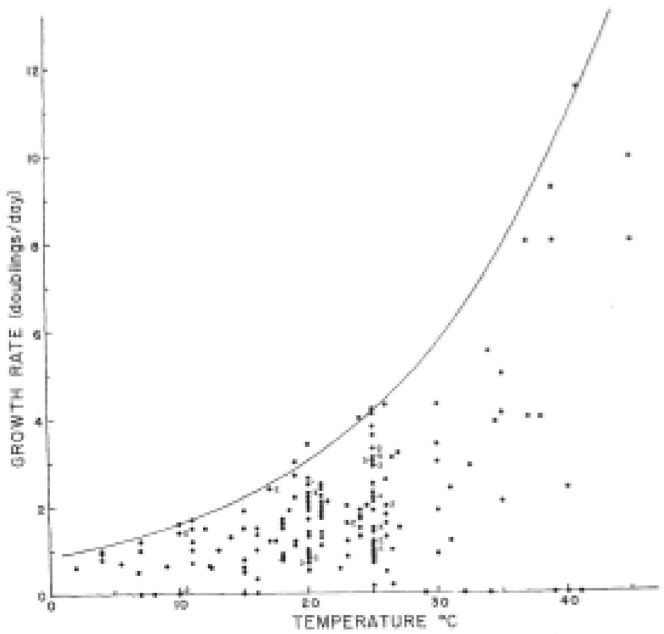

Figure 1-11: The maximum specific growth rates (as douplings per day) of a diversity of cultured freshwater and marine algae in relation to temperature and with an upper bounding envelope (Q_{10}=1,88) inserted (TALLING, 2012).

YVON-DUROCHER et al. (2010) used the MTE (metabolic theory of ecology) in their study about how the metabolic balance of ecosystems respond to warming. In their statistical analysis they show that primary production increased with temperature due to the temperature dependence of the activation energy which controls the photosynthetic reactions (LÓPEZ-URRUTIA et al., 2006) (figure 1-12).

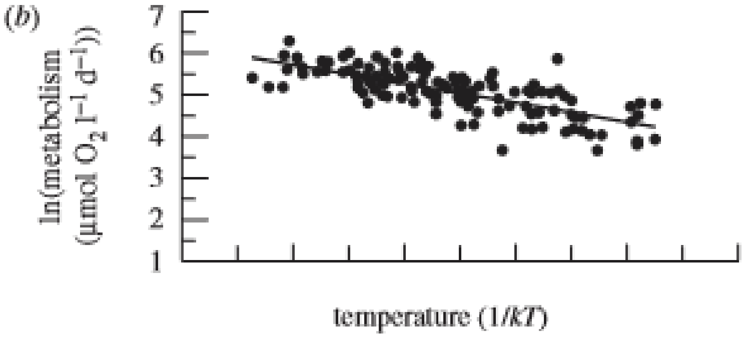

Figure 1-12: Temperature dependence of GPP. The slope of the temperature constitutes the activation energy (YVON-DUROCHER et al., 2010)

DEMARS et al. (2011) consider as well the temperature and the metabolic balance of streams. In their paper they determined that primary production also can have a positive feedback in the greenhouse effect. As ER is not only controlled by GPP in streams but also by allochthonous organic matter ER generally exceeds GPP during warmer summer periods with a maximum of light availability. Therefore ER should increase faster than GPP with increasing stream temperature because of the higher temperature dependence of respiration. In the end NEP will become more negative with warming and CO_2 will efflux from streams to the atmosphere and as a result leading to a potential positive feedback in the greenhouse effect. For their statistical analysis they also used the MTE and got the same results as YVON-DUROCHER et al. (2010), an increase of primary production due to an increase of temperature.

Beside the MTE there are also other methods to show the correlation of temperature and primary production as LASSEN et al. (2010) shows. They determined algae growth via chlorophyll content and could examine a temperature induced difference in the timing of algae growth due to changes in algae physiology. An earlier beginning of spring phytoplankton bloom in lakes of the temperate zone in warmer climates also studied PEETERS et al. (2007). Due to increasing air temperatures the spring stratification starts earlier. And it could be considered that the abrupt increase of temperature in spring and the steep increase in the mean chlorophyll a concentration occur simultaneously.

1.2.1.1 The danger of increased growth of algal blooms

A trial occupies with the question if harmful algal blooms (HAB) become the greatest inland water quality threat to public health and aquatic ecosystems. Their frequency, duration and magnitude increase on a global scale especially in coast and inland waters. They occur naturally and are induced by interacting factors that vary among algal species. But key factors for the development of HABs are climate change, droughts, nutrient enrichment and other modifications from anthropogenic activities like agricultural runoff and salinization. Not all of them are indigenous and occur as invasive species due to altered habitat conditions in developed regions. Due to the interactions of multiple factors, natural and anthropogenic, HABS are determined to occur in a specific water body and can affect the magnitude of toxin(s) production. For cyanobacterial HABs the interactions between nutrients and climate may tighten the potential impacts on the water quality (BROOKS et al., 2016).

Figure 1-13 by BROOKS et al. (2016) shows a distribution of cyanobacteria in the Lake Erie in 2011 which serves as source for drinking water for over 500000 residents. In 2014 impacts of cyanobacterial HABS were noticeable again.

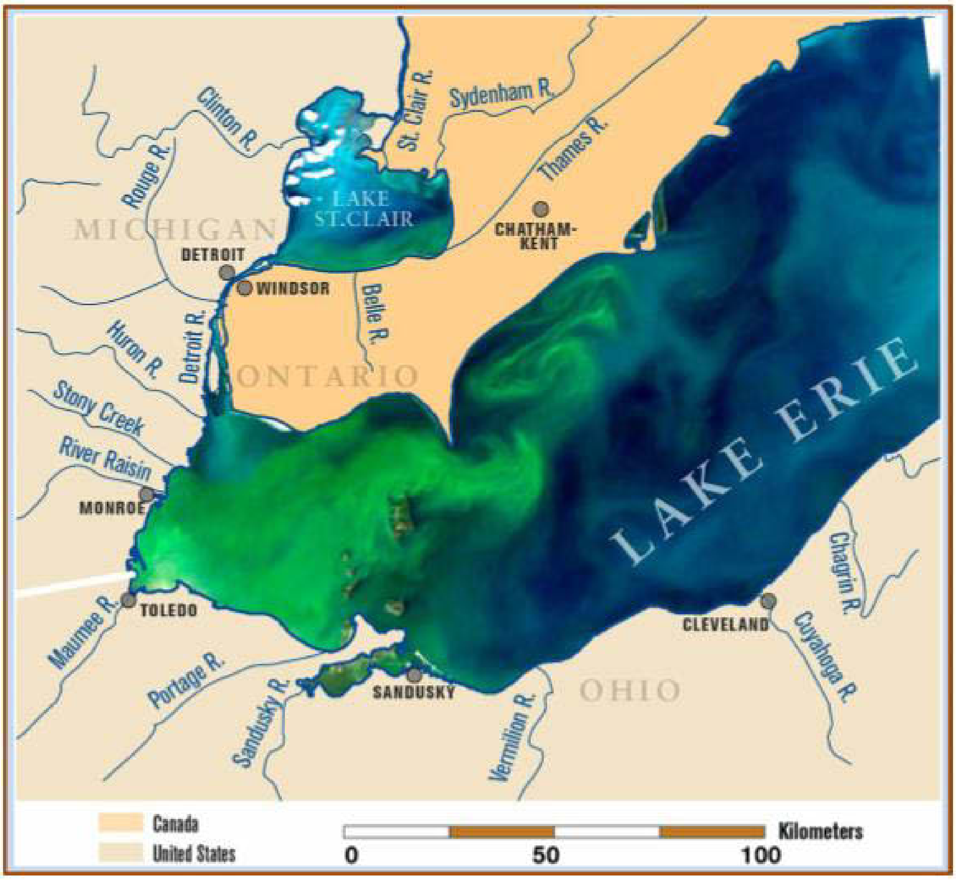

Figure 1-13: A moderate resolution imaging spectroradiometer (MODIS) satellite image indicating the extend and magnitude of a cyanobacterial harmful algal bloom (green area) in 2011 within Lake Erie, USA (modified from Michalak et al.), 3 years before the highly publicized cessation of drinking water intake for Toledo, Ohio, USA, from Lake Erie in 2014 (BROOKS et al., 2016).

ELLIOTT (2012) focuses his study on the behaviour of cyanobacteria in regard to climate change. He investigated different studies which are concentrated on different models to examine the impact of climate change on cyanobacterial growth like regional climate model (RCM) (ELLIOTT et al., 2005) or the cyanobacterial growth model, CLAMM, with data which were obtained from HADCM2 climate change model (HOWARD and EASTHOPE, 2002). His results show that increased temperature is a great impact of this algae and it is assumed that the biomass will increase with a warmer future climate.

An increase of HABs was also recorded in the North Sea in a study by PEPERZAK (2003). Due to climate change growth rates of potentially harmful dinoflagellates and raphidophytes will double. The risk of HABs by these species increases considerably. Climate change leads to higher temperatures and precipitation (IPCC, 2013). The climate situation promotes an optimum of water mass exchange in the North Sea and relative rapid dilution of anthropogenic pollution such as nutrients for phytoplankton (Backhaus, 1989 cite PEPERZAK, 2003). Flushing is reduced due to climate change which leads to increased nutrient concentrations and a suitable and beneficial situation for the development of HABs.

The different studies of the literature review showed that there is a common opinion concerning climate change and temperature dependence of primary production. During the next years, centuries or decades temperature as well as extreme weather conditions will increase and influence the aquatic ecosystem. It is known that temperature is a key driver for the growth of algal blooms and even now several negative effects of the distribution and the increase of algal blooms can be observed.

2. Research aim

The literature review showed that there are many studies about climate change and phytoplankton growth in lakes but only a few are written about the influences in river systems especially in Austria. Further, whereas existing studies have focused on the role of water bodies related to greenhouse gases exchange between the aquatic environment and the atmosphere, little has been investigated on the potentially increased risk of algal blooms induced by higher atmospheric temperatures. Therefore, the recent work will focus on the analysis of two typical Austrian rivers, Raab and Schwechat. The purpose is to investigate how Austrian rivers will be affected by climate change and with which impacts they will have to deal with, especially regarding the danger of eutrophication. The investigation is based on the predicted temperature increase of 1,5 °C till 2040 as well as the expected increase of 3,7 °C till the end of the century and a temperature increase of 10 °C in the worst case.

The overarching research question which should be examined reads as follows:

“How will expected increases in temperature due to climate change impact primary production in typical Austrian rivers?”

In particular, the following main goals are pursued:

i) The identification of the relation between gross primary production and temperature. It is expected that biomass production will rise with an increase of temperature as it is also discussed in the literature. This study will test this hypothesis in two case studies and will quantify the specific relationship in each of them.

ii) Characterization of how nutrient uptake is influenced by an increase of temperature. Nutrient uptake should accelerate with higher temperatures and the nutrient concentrations in the water column should decrease.

iii) Assessment of the potential limitations posed to the increase of gross primary production by nutrient availability under a modelled climate change scenario.

3. Material and methods

For the Aqua-stress project two ecological completely different rivers were chosen. The river Schwechat is a shallower stream with higher transparency and a higher oxygen content, whereas the river Raab is deeper, has higher flow velocities and a lower amount of oxygen.

3.1 Study sites and hydrological parameters

3.1.1 Schwechat

The Schwechat (figure 3-1) is a 62 km long river in the eastern part of lower Austria. It has its source on the Schöpfl in the Wienerwald of 893 m and flows in the east bound and near to the city Schwechat in the Danube. Its source creeks are the Großkrottenbach, Riesenbach, Lammeraubach, Kleinkrottenbach, Agsbach and Hainbach. All of them flow together at the Klausen- Leopoldsdorf and form the Schwechat. Through the Helenental it passes Baden where it is used for industrial processes and flows further to the Wiener Becken. The Mödlingsbach flows in the Schwechat in Achau and finally it comes together with the rivers Liesing, Triesting, Kalter Gang in the city Schwechat. In the eastern side of Mannswörth next to Schwechat it flows into the Danube (AUSTRIA-FORUM, 2012a). Human impacts are low (BRANDENBURGER et al., 2014) except for a few agricultural areas in the surroundings of the river (WISA, 2015). A strong natural meandering still exists and a high occurrence of wood and sediment transport during flood events is existent (BRANDENBURGER et al., 2014).

Figure 3-1: River Schwechat (GRUPPE WASSER, 2016)

During the investigation period from 2010 to 2012 the average temperature from April to September varied between 32,8 °C and 0 °C with a mean ±SD of 17,8 °C ± 4,3 °C (figure 3-2). Throughout the entire period the temperature curves followed a clear pattern with the highest temperatures in June, July and August. The average amount of discharge was between 61,3 m^3 s^{-1} and 2,6 m^3 s^{-1} with a mean ± SD of 7,3 m^3 s^{-1} ± 6,0 m^3 s^{-1}.

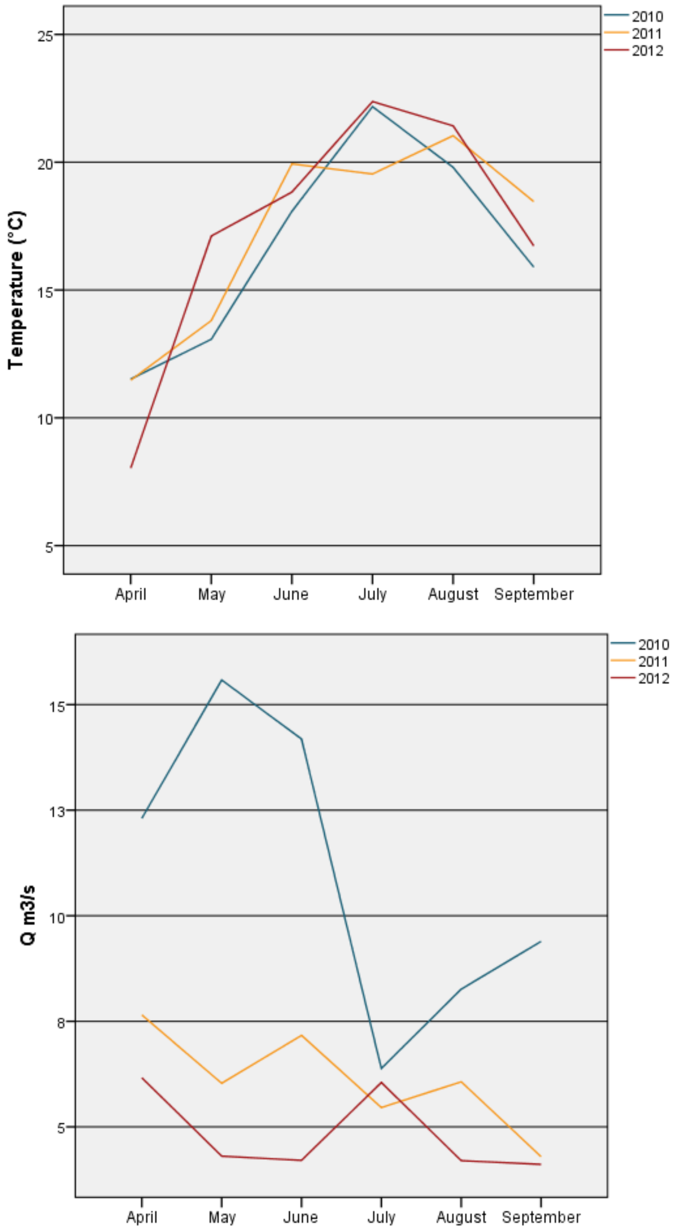

Figure 3-2: Mean temperature, oxygen content and discharge recorded from April to September in 2010, 2011 and 2012 for the river Schwechat.

3.1.2 Raab

The river Raab (figure 3-3) is an inflow of the Danube with an entire length of 250 km. It has its source in Styria, it passes Sárvár and flows in the Hungarian city Györ in the Moson- Danube a right tributary of the Danube. The Raab source is located at the foot of the Ossers. Between Passail and Oberdorf Raab flows through the Raabklamm, the longest gorge in Austria. Its tributaries include the Weizbach, Lafnitz, Pinka, Güns and Marcal (AUSTRIA-FORUM, 2012b).

The Raab is a polluted river in a both commercially and agricultural intensively used environment. Moreover it is affected by the use of hydropower. Beside the industrial pressure the water body is also influenced by several other factors. The utilization of the adjacent areas often reaches to the river bank has a large- scale loss of riparian forests and vegetation. The lack of shading leads to an unusual warming of the Raab as well as to an unusual high light availability which increases algae growth. The bacterial decomposition of the algae leads oxygen deficiency in the water body and the river bed. Due to the largely missing riparian vegetation the retention capacity of the nutrients is extremely reduced. Straightening of the river course results in a reduced retention and a reduced self- cleaning power. Transverse structures impede the migration of fish. The lack of lateral networking such as the loss of old branches also has negative effects for the functioning of the water ecosystem (WISA, 2014).

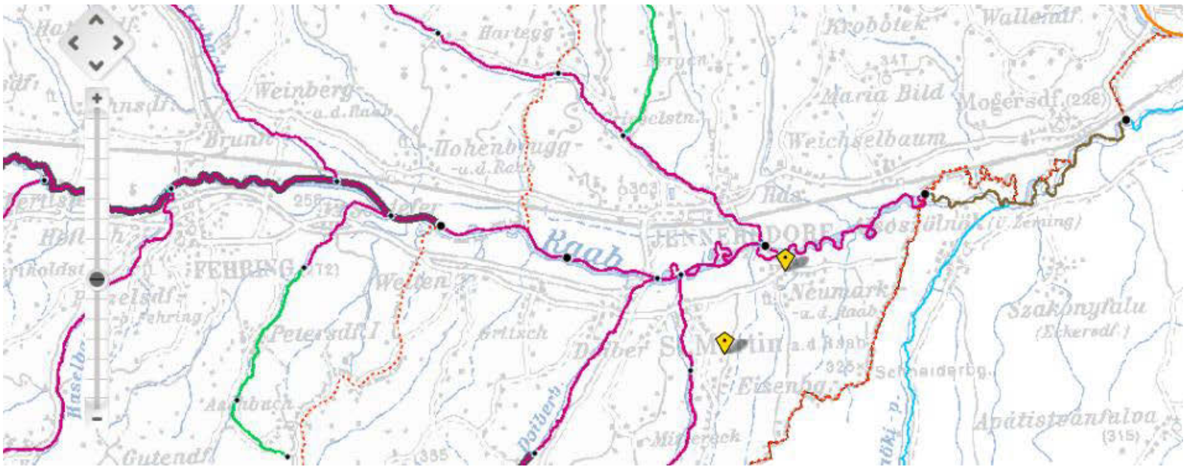

Figure 3-3: River Raab (WISA, 2016)

During the investigation period from 2010 to 2012 the average temperature from April to September varied between 27,2 °C and 3,5 °C with a mean ±SD of 17,4 °C ± 3,6 °C (figure 3-4). Throughout the entire period the temperature curves followed a clear pattern with the highest temperatures in June, July and August. The average amount of discharge was between 61,3 m^3 s^{-1} and 2,6 m^3 s^{-1} with a mean ± SD of 7,3 m^3 s^{-1} ± 6,0 m^3 s^{-1}.

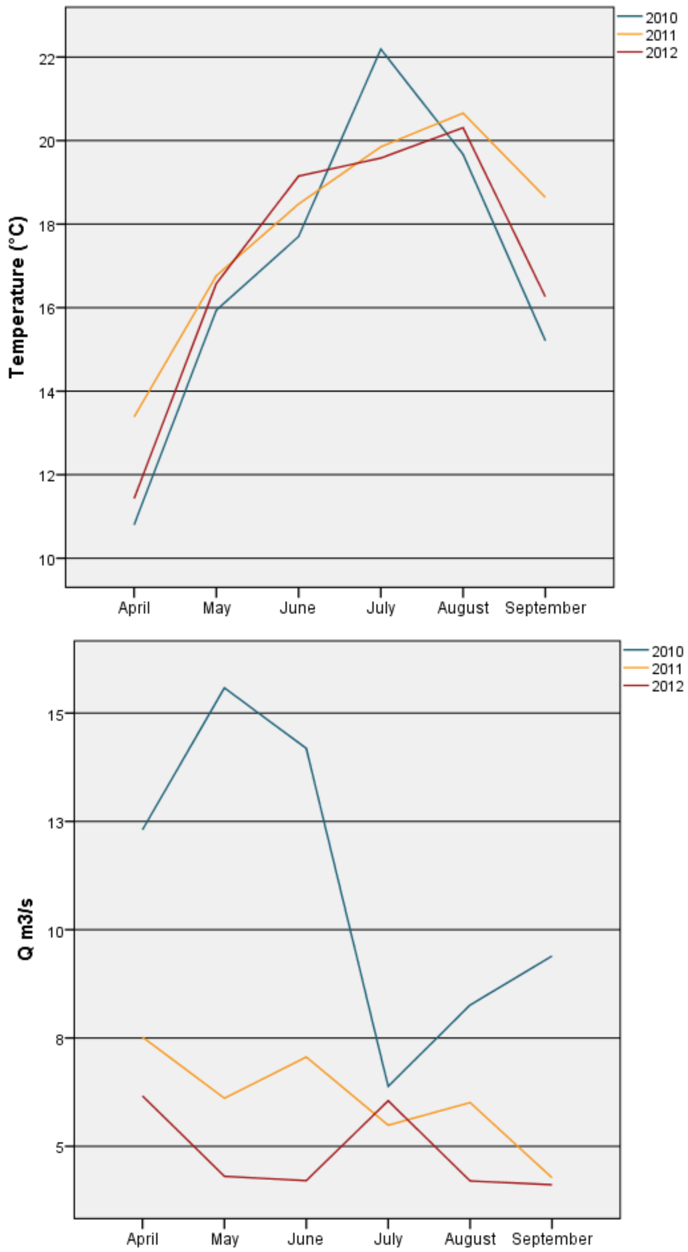

Figure 3-4: Mean temperature, oxygen content and discharge recorded from April to September in 2010, 2011 and 2012 for the river Raab.

3.2 Sampling

The used data was already available and collected by the Technical University in two stations with continuous measurement of several parameters. Necessary for the calculations were the water level (m) and the parameters O_2 (mg $l^{-1}d^{-1}$) and temperature (K). The samples were taken directly from the water column by probes every day at any hour for the River Schwechat and every 15 minutes for the river Raab. The original data from the river Raab was pre- processed to deliver hourly values. The water level was measured with pressure probes. The investigation period was from 2010 – 2012 although for the Raab the data was available for a much longer period of time where the project is actually still ongoing. However, the period 2010 – 2012 was chosen as for the Schwechat only that period is available.

The gaging station for the river Raab (figure 3-5) is situated near Neumarkt an der Raab in the lower part of the river. Figures 3-6 and 3-7show exemplary a measurement result of the diel O_2 curve and the temperature profile of the I[st] of April 2010.

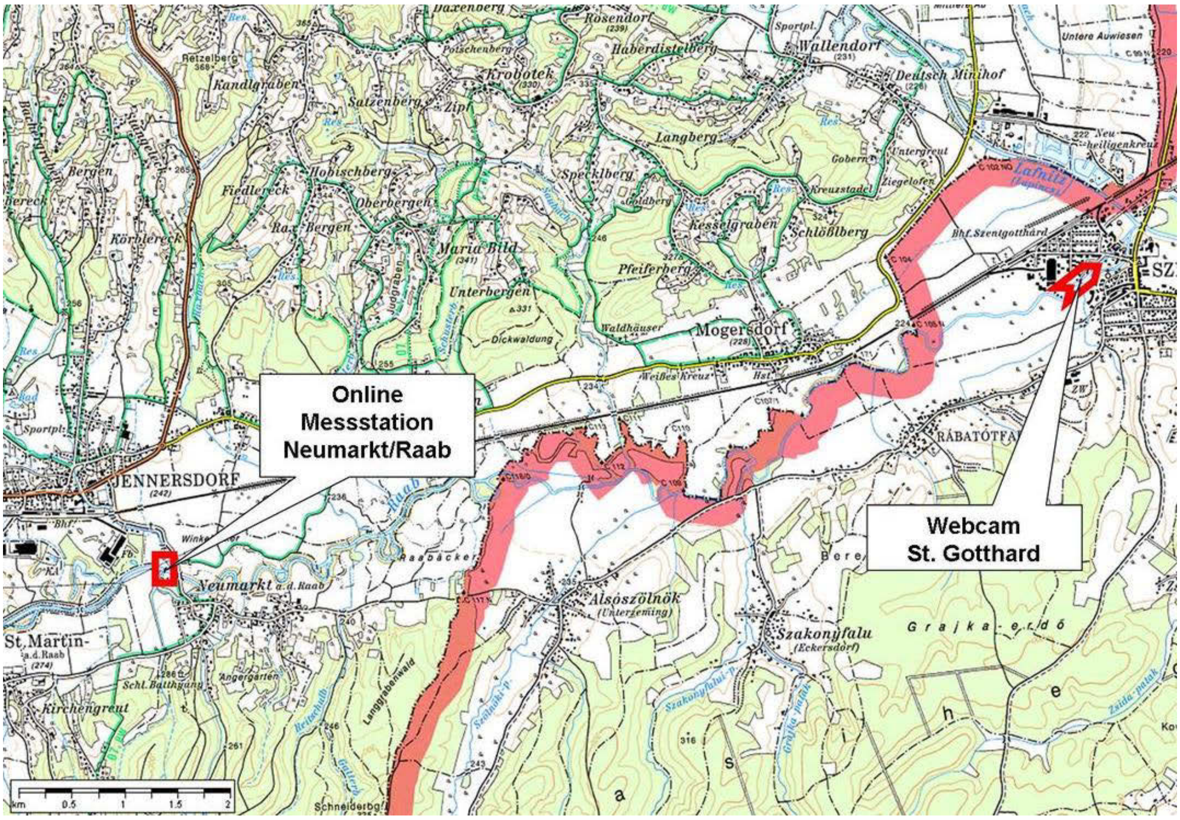

Figure 3-5: Gaging station river Raab (TU WIEN, 2017).

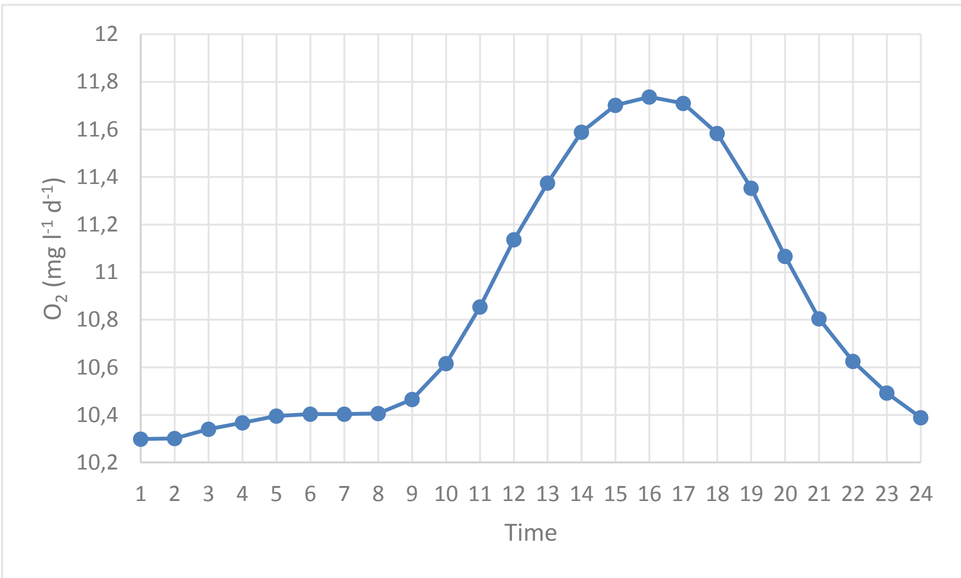

Figure 3-6: Diel O_2 (mg l^{-1} d^{-1}) curve of the I[st] of April 2010 in the Raab.

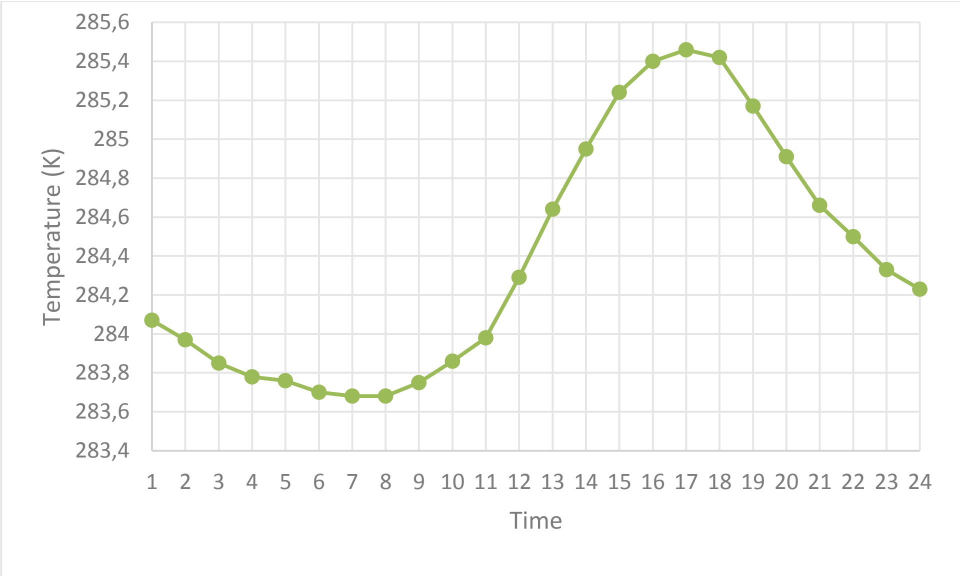

Figure 3-7: Diel temperature (in K) profile of the Ist of April 2010 measured for the Raab.

The gaging station of the river Schwechat (figure 3-6) is situated near to Guntramsdorf. Figure 3-9 shows again exemplary a measurement result of the diel O_2 curve and the temperature profile of the 5th of July 2010.

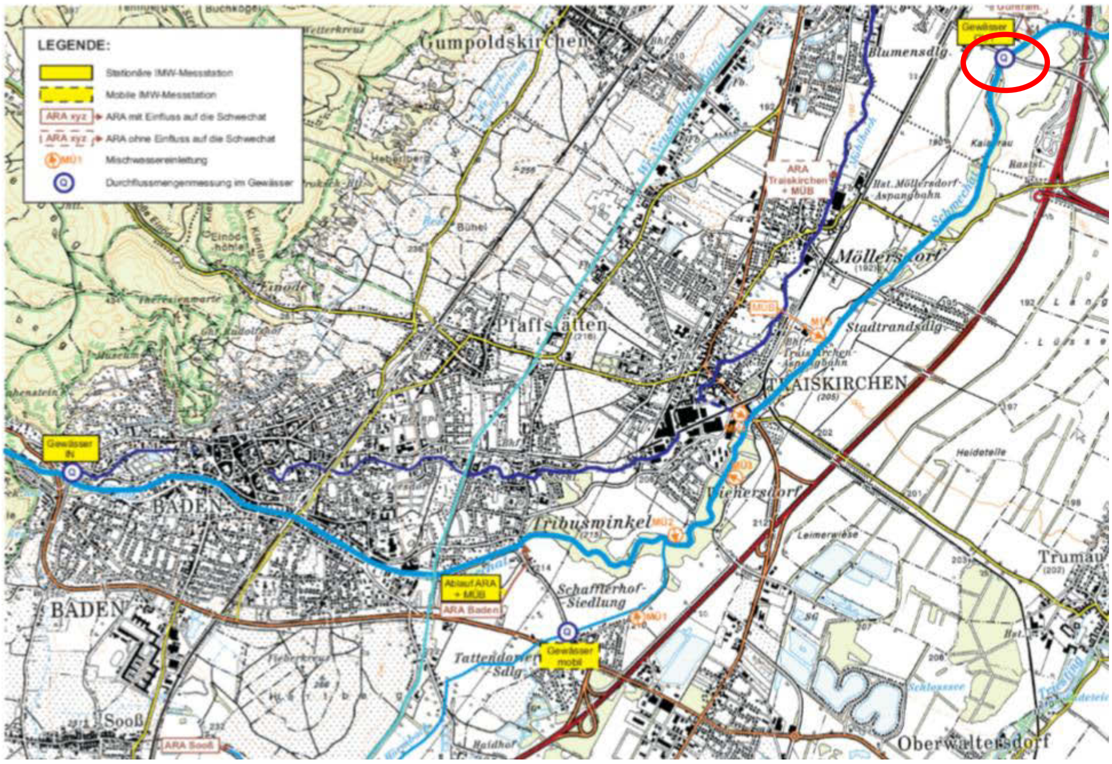

Figure 3-8: Gaging station river Schwechat (LEBENSMINISTERIUM, 2013).

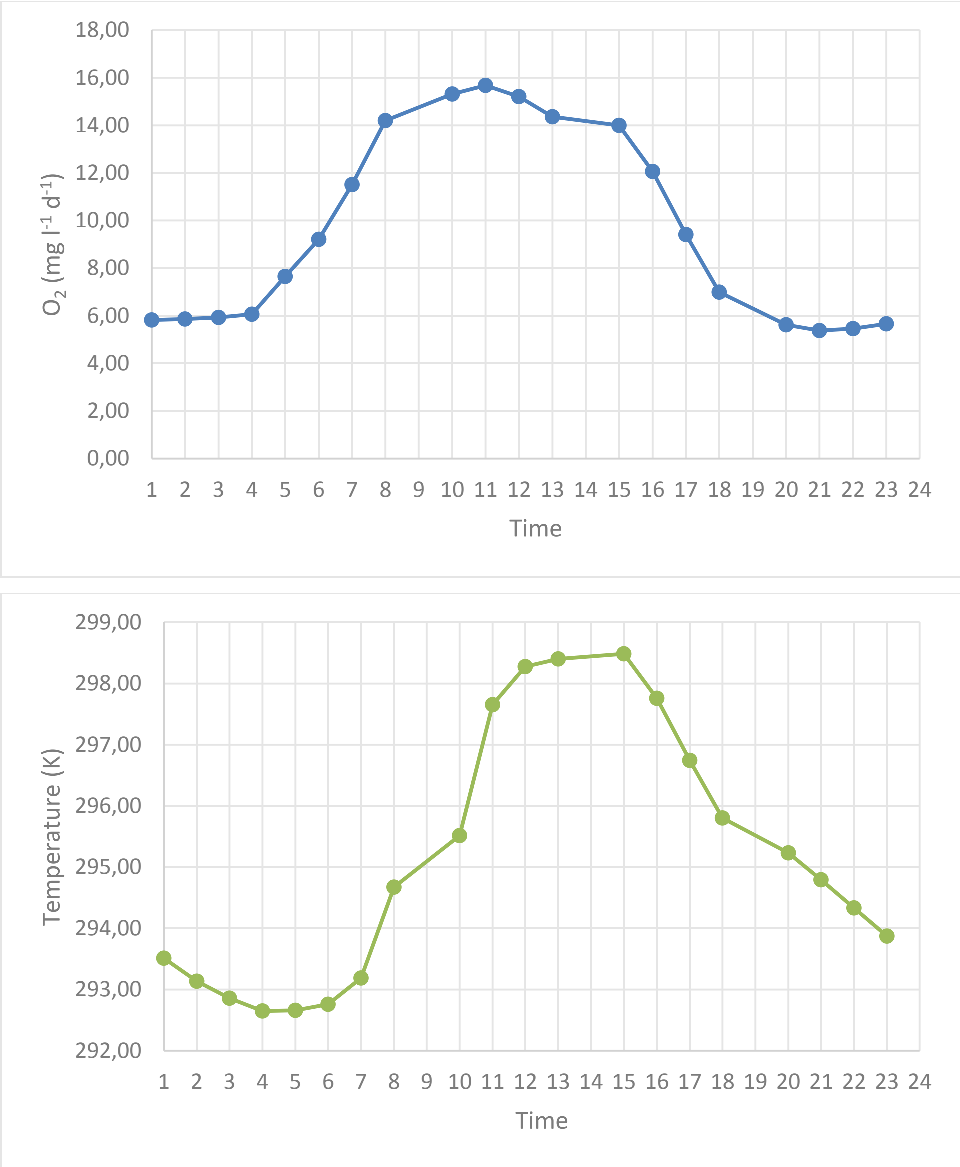

Figure 3-9: Diel O_2 (mg l^{-1} d^{-1}) curve and temperature (in K) profile of the 5th July 2010 measured for the Schwechat.

3.3 Data analysis

At the beginning of the master thesis there was the problem of the right calculation method. Firstly, the data was calculated with rivermet, an excel tool to calculate river metabolism, developed by the university of the basque country in Spain (IZAGIRRE et al., 2007). But the tool didn't create a sufficient regression analysis between temperature and GPP hence only the daily GPP was calculated with rivermet. Rivermet exists of formulas and cell references and works with macros. It can be downloaded as package from the internet. The original data has to be add in the tool and it automatically calculates GPP, NPP and ER. The formula for GPP is described below. For the correlation of temperature and GPP the MTE (Metabolic theory of ecology) was used and displayed with the Arrhenius plot. It was calculated in MS Excel® and plotted with the statistical software R. The equation is described in DEMARS et al., 2011. For the computation different time periods like the different seasons, the whole years and the period from April to September were used.

3.3.1 Rivermet©

Rivermet© is an Excel based tool to calculate river metabolism from diel oxygen concentrations. GPP is calculated through the rate of change of oxygen concentration (dC/dt), the reaeration coefficient (K), the saturating oxygen concentration (C_s), the oxygen concentration at a given time (C), the respiration (ER) and the accrual of groundwater (A) which is often neglected.

Its equation is:

$GPP(dt) = dC/dt – K(C_s – C) + ER + A$

With this equation it is possible to calculate river metabolism at any desired period of time (IZAGIRRE et al., 2007).

3.3.1.1 O_2 measurements and GPP calculation

The equations of rivermet were already used by former scientist who calculated the net metabolism of an aquatic ecosystem from a single diel oxygen curve, the mixing depth and the gas transfer velocity (Odum, 1956; DEMARS et al., 2015). Oxygen concentration changes at a single station between two subsequent measurements and can be stated as

$dC/dt = (C_t\text{-}C_{t\text{-}1})/\Delta t$ (1)

with C as oxygen concentration (mg O_2 L^{-1}) at time t and can be modelled as:

$dC/dT = [K_L(C_{SAT}\text{-}C_t)\text{+}GPP\text{-}ER]/z$ (2)

with K_L as gas transfer velocity (m h^{-1}), C_{SAT} as oxygen saturated concentration of O_2 as a function of water temperature and atmospheric pressure (mg O_2 L^{-1}), C_t as oxygen concentration at time t (mg O_2 L^{-1}), GPP as gross primary production (g O_2 m^{-2} h^{-1}), ER as ecosystem respiration (g O_2 m^{-2} h^{-1}) and z as mixing depth (m). Under these conditions GPP, ER and NEP were equally expressed as g O_2 m^{-2} and the gas transfer velocity K_L (m h^{-1}). The gas exchange coefficient was prescribed as a constant throughout the night-day cycle (range 0,1 – 5 h^{-1}). After substituting Eq. 1 in simplified Eq. 2 Δt=1 reads as:

$C_t\text{=}\ kC_{SAT}\text{+}NEP\text{+}C_{t\text{-}1}/(1\text{+}k)$ (3)

and the gas flux at the air-water interface F (mg O_2 L^{-1} h^{-1})

$F\text{=}k(C_{SAT}\text{-}C_t)$ (4)

from which estimated NEP and dC/dt were calculated from Eq.1 and rearranged Eq.2 (DEMARS et al., 2015).

Reaeration flux

The reaeration flux (mg O_2 m^{-2} min^{-1}) is the product of gas transfer velocity K_L (cm min^{-1}) and the specific surface are (area $volume^{-1}$ cm^{-1}) and is controlled by the oxygen deficit ($C_{SAT} – C_t$). Surface area and water depth estimates should have uncertainties which are attached to them because they can be tricky to estimate due to surface water turbulence and bed roughness. The best is to estimate depth from velocity, width and discharge (DEMARS et al., 2015). The reaeration flux is very sensitive regarding calculations as it is influenced by several parameters like depth, turbulence and varies therefore with river morphology and stage (IZAGIRRE et al., 2007). There are several methods calculating the reaeration flux like the night-time method developed by HORNBERGER et al. (1975). Photosynthesis stops from sunset to sunrise and respiration is therefore the main factor driving the night-time changes in oxygen concentration (IZAGIRRE et al., 2007). The rate of change of dissolved oxygen concentration with time is proportional to the difference between the actual oxygen concentration in the water and the saturated oxygen concentration (HORNBERGER et al., 1975). Oxygen concentration declines fast and as the saturation deficit increases also the oxygen diffusion from the atmosphere rises and therfore the night-time dynimacs depend on the reaeration coefficient and the respiration rate (IZAGIRRE et al., 2007).

3.3.2 MTE equation used on the Arrhenius plot

For the equation (figure 3-3) the natural log of a metabolic rate (GPP) and the reciprocal temperature 1/kT are needed, with k representing the Boltzmann's constant and T temperature (in K) (ENQUIST et al., 2003). The total metabolic rate was normalized to a standard temperature (GILLOOLY et al., 2001) which makes it biologically more meaningful (DEMARS et al., 2011).

$$\ln(B_e) = \ln(c) - E\frac{1}{k}\left(\frac{1}{T} - \frac{1}{T_c}\right)$$

Figure 3-3: MTE equation used on the Arrhenius plot (DEMARS et al., 2011)

B_e constitutes the total ecosystem metabolic flux per unit area (g O_2 m^{-2} $time^{-1}$). Ln (c) is the normalised absolute metabolic flux (g O_2 m^{-2} $time^{-1}$). Tc means the reference temperature and is given as 288 K which is equal to 15 °C. The temperature dependence is given by the slope E of the linear regression which describes the activation energy of the metabolic rate (eV). The activation energy is the minimum amount of energy necessary for a chemical reaction (DEMARS et al., 2011).

For the better understanding and to see the increase of GPP with the temperature the reciprocal temperature for the plot was neglected. Instead a plot with the correlation of GPP and temperature in °C was used.

3.4 Statistical analysis

3.4.1 Correlation of GPP and temperature

To show the dependence of temperature and GPP a regression analysis was computed in the statistical software R. The log transformed GPP was plotted against the reciprocal temperature. The dependence is given by the slope. The slope describes the activation energy E of the metabolic rate (figure 3-3) which is the minimum amount of energy necessary for a chemical reaction to occur. The intercept is ln (c) (DEMARS et al., 2011).

3.4.1.1 Regression analysis

Figure 3-4 shows a scatterplot with increasing regression line which is calculated with a regression analysis. A regression analysis exposes the dependence of two variables as for example height and weight.

Its equation is:

Y= a + bX

Y constitutes the dependent and X the independent variable which explains Y. a shows the intercept and b the slope of the line and therefore the dependence between X and Y.

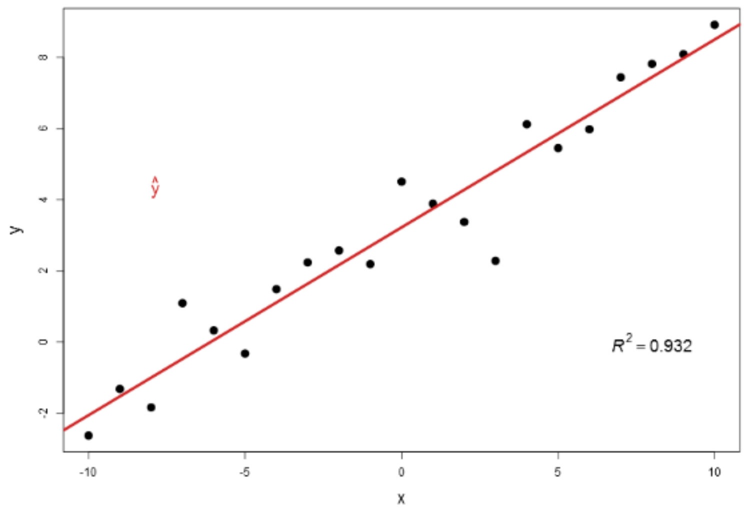

Figure 3-10: Well-fitting regression line (INWT STATISTICS, 2016)

A regression analysis also has r^2. R^2 is the coefficient of determination and represents how well the independent variables explain the dependent variables which can be seen on the regression line and the dispersal around this line. It reaches from 0 to 1 or from 0 to -1. The closer it is to 1 the better fits the model and has a positive or negative dependence.

3.4.2 Nutrient uptake

The extended Redfield ratio was used for the calculation of the nutrient uptake. That means that for 138 mol oxygen 1 mol phosphorus, 16 mol nitrogen and 106 mol carbon are needed (O_2:P:N:C). The ratio was developed by Alfred Redfield and is based on analyses of marine plankton (AMERICAN SOCIETY OF LIMNOLOGY AND OCEANOGRAPHY, 1983).

For the calculations and the graphs the MS Excel® was used. In a first step it was analysed how nutrient uptake would change due to an increase of temperature. For that the O_2 concentrations per m^3*d were calculated for different temperature scenarios. These scenarios reached from a temperature increase of only 1°C up to a worst case scenario of an increase of 10 °C. Afterwards it was calculated how much phosphorus, nitrogen and carbon were needed to get this amount of O_2. With the Redfield ratio it was also calculated how much biomass would emerge if temperature changes. The results were calculated for a river stretch of the main channel of 0,2 km^2 for the river Schwechat and 0,3 km^2 for the river Raab, both

3.5 Assessment of the nutrient availability by climate change scenarios

A novel integrated impact modelling framework (IIMF) by ZESSNER et al. (2017) deals with the assessment of climate and socio-economic drivers on land use and water quality and consists of loosely coupled models where state or flow variables from one model were added to other models. The framework links six independent models e.g. the crop rotation model CropRota (Schönhart et al., 2011) or the social-economic land use optimisation model PASMA[grid] (Kirchner et al., 2016). The IIMF also focuses on precipitation and runoff modelling, using the TUWmodel for the investigation of changing climatic conditions on the regional water balance flows. Runoff generation and water balance are stimulated on a daily time step by using air temperature, precipitation and potential evapotranspiration data. Another step is emissions modelling with the MONERIS which transfers land cover, changes of nutrient surplus and crop categories into nutrient emissions and in stream concentrations.

These models are linked as the TUWmodel transforms the climate signals into river flow and its runoff components which are used in the MONERIS for the emission modelling and calculations of river loads and nutrient concentrations. With this framework climate scenarios as dry scenarios were modelled with the assumption of an atmospheric temperature increase of 1,5 °C, which corresponds to a rise in water temperature by 1 °C. These results are combined with the results of the phosphorus uptake to see if the amount of phosphorus is available which will be needed for an uptake with one more degree. The modelled values for the Schwechat and Raab can be seen in table 3-1.

Table 3-1: Modelled phosphorus concentration for a temperature increase of 1 °C and Q_{90} for the Schwechat and Raab.

	Temperature increase 1 °C	Q_{90}
Schwechat	0,114 mg/l	1,47 m^3/s
Raab	0,033 mg/l	0,84 m^3/s

4. Results

4.1 Temperature dependence of GPP

Both log- transformed GPP were linearly related to the daily stream water temperature (figure 4-1 and 4-2). The observed activation energies of the Raab and the Schwechat were E_R= 0,51 for the river Raab and E_S= 0,65 for the river Schwechat. The calculated mean GPP, 9 (0 – 21) g O_2 m^{-2} day^{-1}, of the Raab was lower than the mean GPP of the Schwechat, 59 (1 – 167) g O_2 m^{-2} day^{-1}. Slightly higher temperatures were also measured for the river Schwechat. For both rivers similar response of GPP towards the temperature could be identified, with r^2 equal to 0,66 for the Schwechat and 0,63 for the Raab. However, with the lower activation energy the Raab is less temperature dependent than the Schwechat. Further calculations also exhibit that an increase of only 1 °C would lead to 7% higher GPP for the river Raab, 3,7 °C to 30% higher GPP and with 10 °C temperature GPP would increase more than 99%. The calculations for the Schwechat showed 9% more GPP with an increase of 1 °C, 37% GPP with an increase of 3,7 °C and 131% more GPP with a temperature increase of 10 °C.

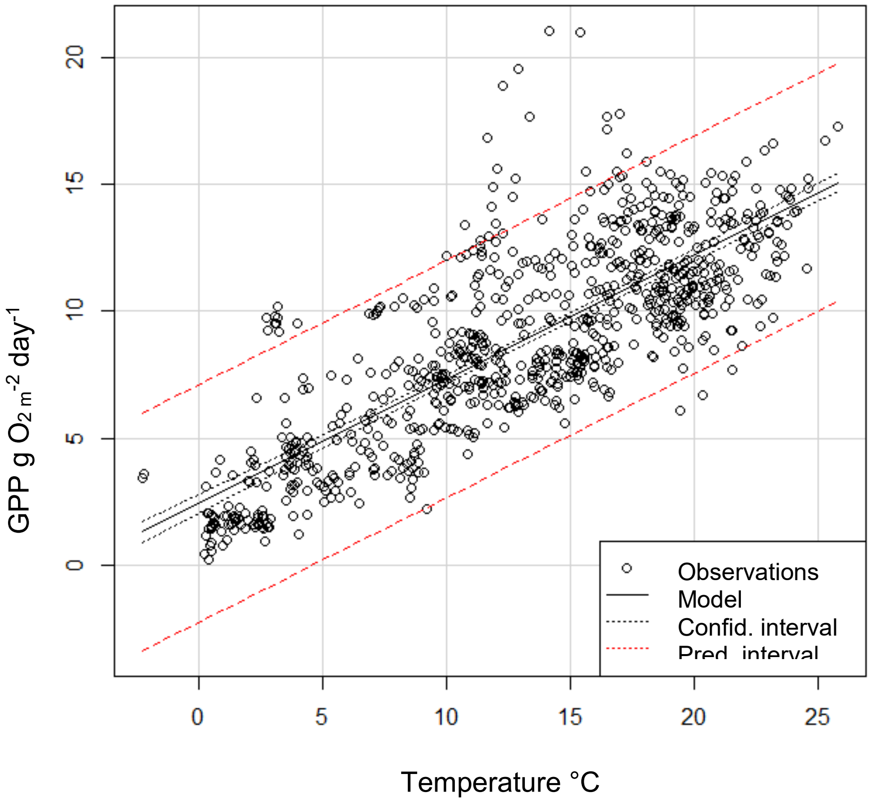

Figure 4-1: Increase of stream metabolism dependent on the stream temperature measured for the river Raab for the years 2010 – 2012.

4. Results

4.1 Temperature dependence of GPP

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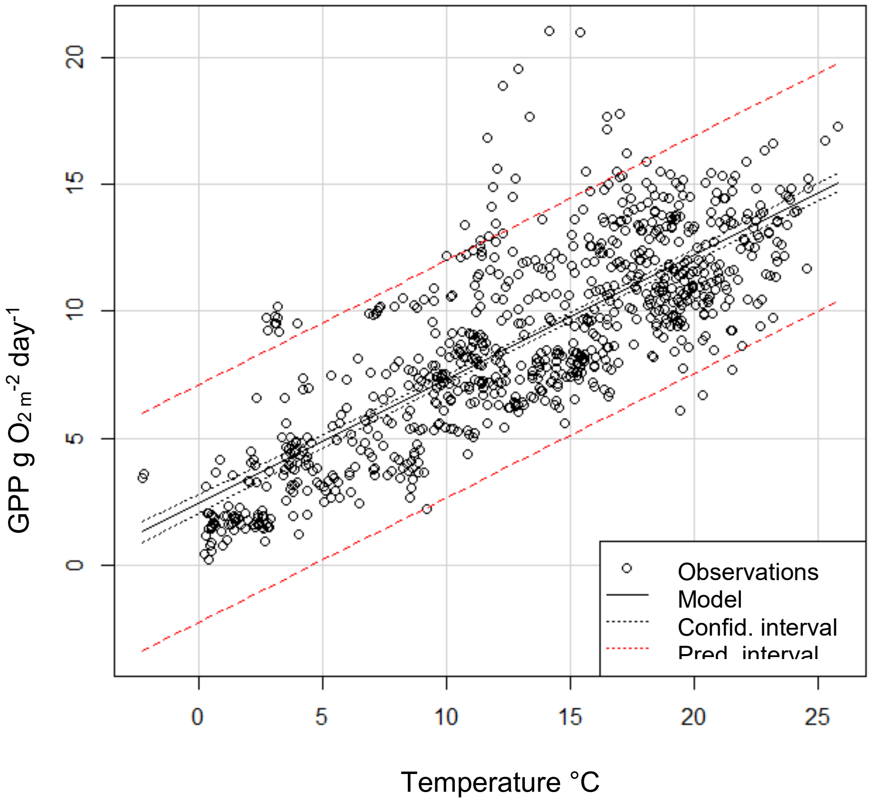

Figure 4-1: Increase of stream metabolism dependent on the stream temperature measured for the river Raab for the years 2010 – 2012.

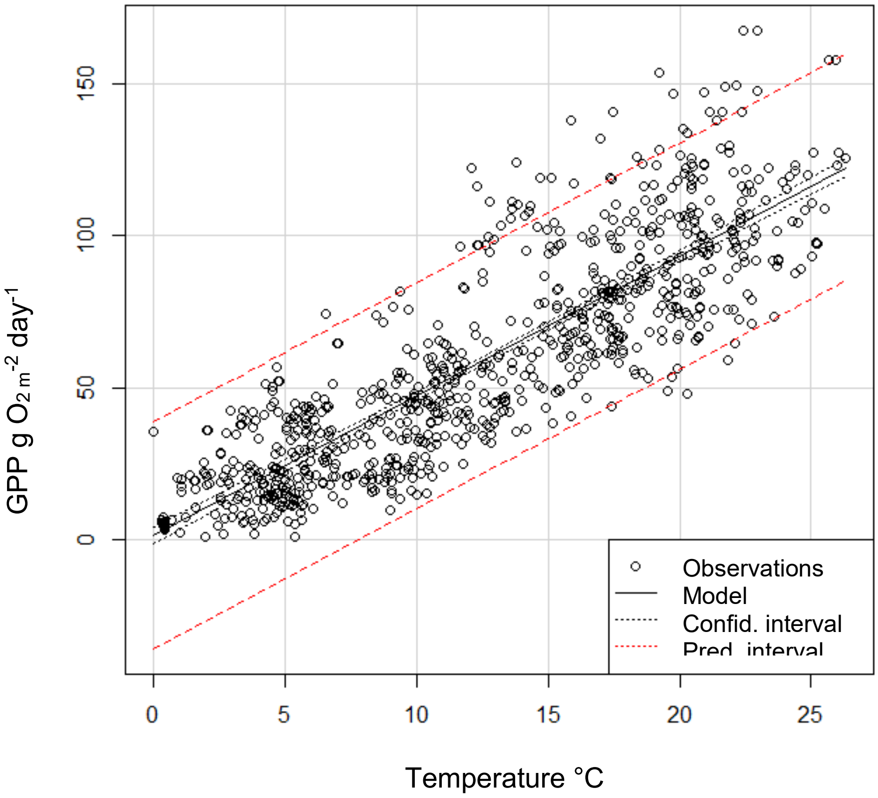

Figure 4-2: Increase of stream metabolism dependent on an increase of stream temperature measured for the river Schwechat for the years 2010 – 2012.

The months April to September from 2010 to 2012 also showed a positive correlation of temperature and GPP (figure 4-3 and 4-4) and a high significance towards the temperature dependence. For the river Raab the activation energy comes to E_r= 0,17 with a calculated mean GPP of 11 (6 – 21) g O_2 m^{-2} day^{-1} and the river Schwechat has an activation energy of E_s= 0,33 and a calculated mean GPP of 87 (19 – 167) g O_2 m^{-2} day^{-1}. Slightly lower activation energies than for the whole years but nevertheless, temperature affects the metabolic rate.

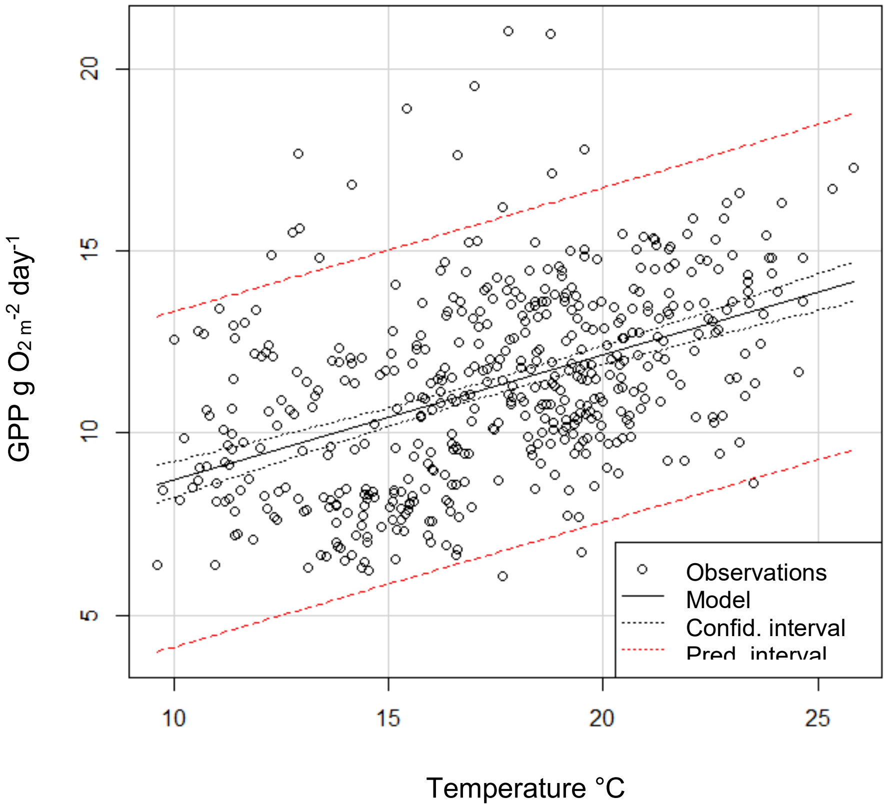

Figure 4-3: Increase of stream metabolism dependent on the stream temperature measured for the river Raab for the years 2010 – 2012 and from April to September.

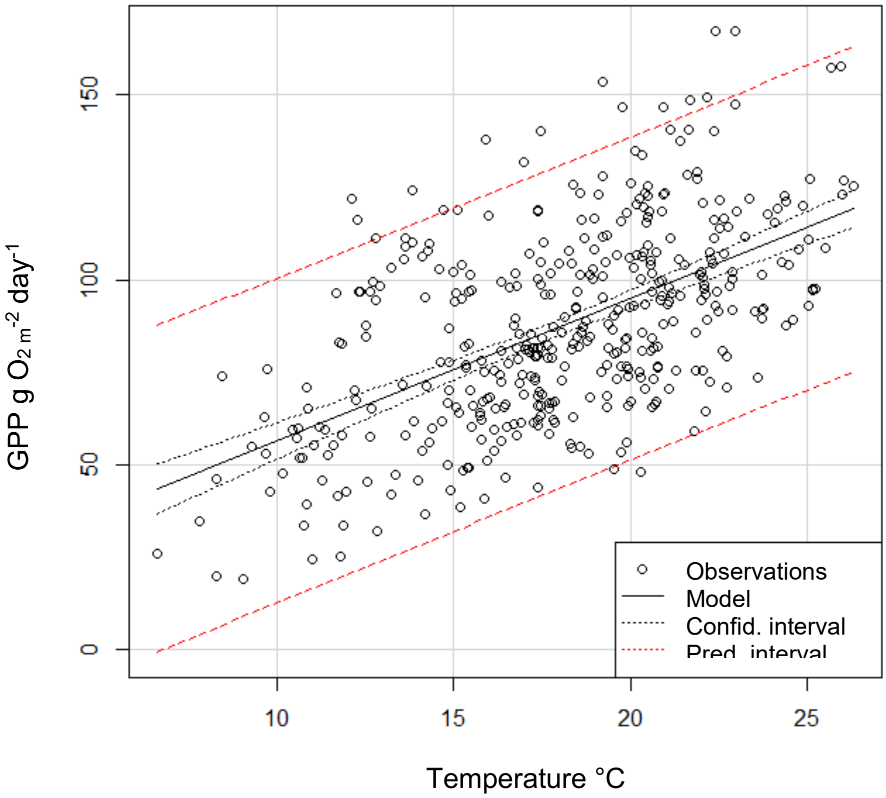

Figure 4-4:Increase of stream metabolism dependent on the stream temperature measured for the river Schwechat for the years 2010 – 2012 and from April to September.

Following calculations showed that for both rivers during winter the highest activation energies were measured (table 4-1). In contrast the Raab has its lowest activation energy in spring and the Schwechat in summer.

Table 4-1: Calculated activation energies (eV) for the different rivers and the seasons winter, spring, summer and autumn from 2010 – 2012.

Raab			Schwechat		
Season		Activation energy	Season		Activation energy
21st Dec – 20th Mar	Winter	1,43	21st Dec – 20th Mar	Winter	1,40
21st Mar – 20th Jun	Spring	0,11	21st Mar – 20th Jun	Spring	0,47
21st Jun – 20th Sept	Summer	0,27	21st Jun – 20th Sept	Summer	0,41
21th Sept – 20th Dec	Autumn	0,51	21th Sept – 20th Dec	Autumn	0,53

4.2 Nutrient uptake

4.2.1 Raab

The distribution of the nutrient uptake of the expected temperature increase of 1 °C as well as for an increase of 3,7 °C and 10 °C is constituted in figure 4-5. With higher temperatures nutrient uptake also starts to grow. The calculated values of 0,03 g m^{-3} for phosphorus, 0,21 g m^{-3} for nitrogen and 1,21 g m^{-3} for carbon in 2012 will increase to 0,031 g m^{-3} for phosphorus, 0,23 g m^{-3} for nitrogen and 1,30 g m^{-3} for carbon with one more degree. If temperature increases by 3,7 more degrees phosphorus will reach an uptake of 0,04 g m^{-3}, nitrogen 0,28 g m^{-3} and carbon 1,58 g m^{-3}. In the worst case, a temperature increase of 10 °C phosphorus uptake will increase to 0,06 g m^{-3}, nitrogen to 0,43 g m^{-3} and carbon to 2,45 g m^{-3}.

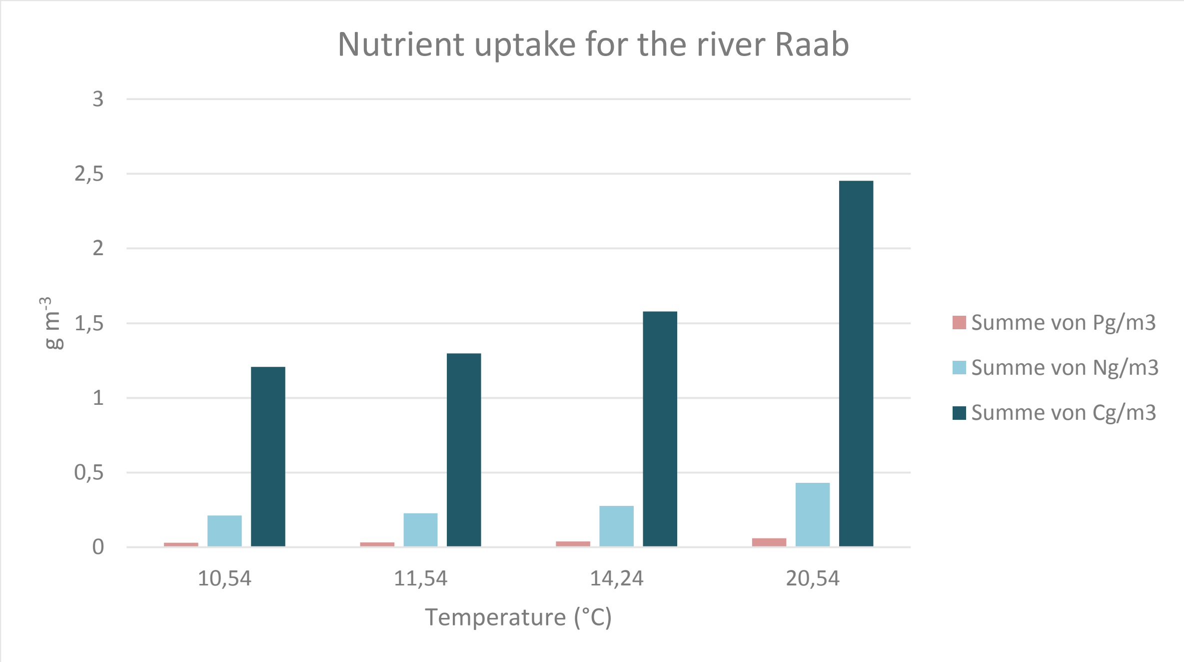

Figure 4-5: Uptake of phosphorus, nitrogen and carbon per m^3 related to a temperature increase of 1 °C, 3,7 °C and 10 °C for the river Raab from 2010 – 2012.

In detail, phosphorus uptake showed that the higher the activation energy is, the higher the phosphorus uptake will be (figure 4-6 and 4-7). A higher activation energy could be measured in winter (1,43 eV) than in spring (0,11 eV). Due to the higher activation energies metabolism proceeds faster and GPP production can increase more than 24% in winter and 2% in spring, calculated for one more degree. Consequently, phosphorus is uptaken in higher amounts. However, in total the primary productivity will be still lower in winter than in spring. In winter 2012 an amount of phosphorus of 0,024 g m^{-3} was uptaken. With one more degree the uptake will increase to 0,03 g m^{-3} and with 3,7 °C to 0,05 g m^{-3}. In spring 2012 a phosphorus uptake of 0,048 g m^{-3} was calculated. It increases to 0,049 g m^{-3} with one more degree and to 0,05 g m^{-3} with a temperature increase of 3,7 °C.

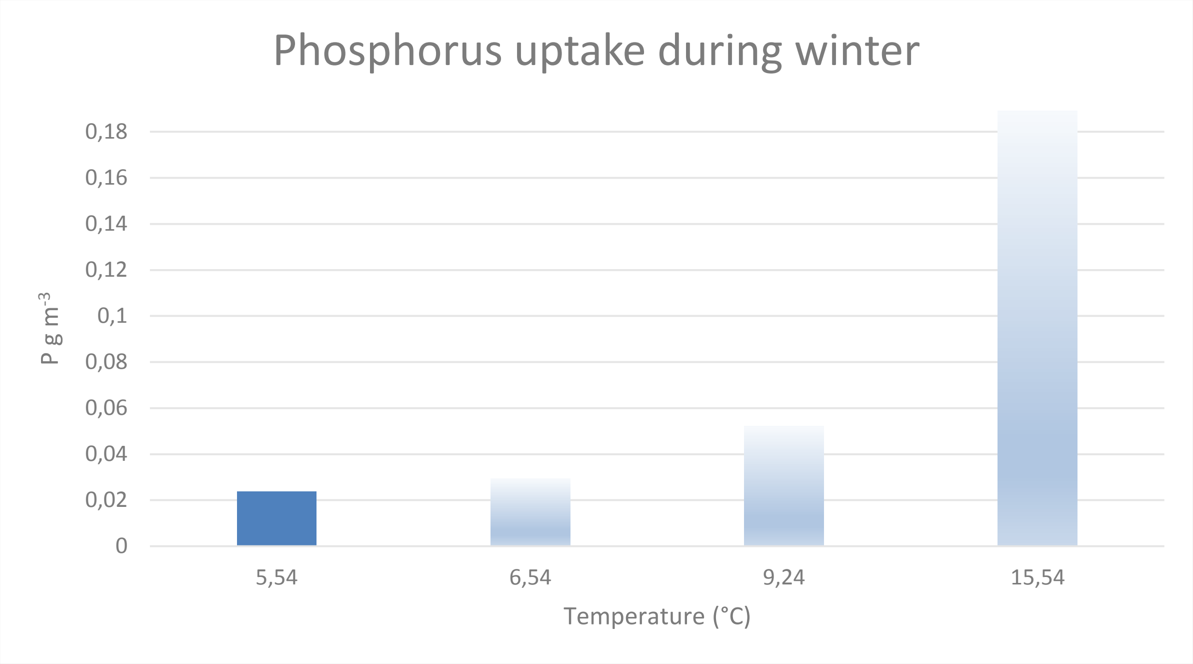

Figure 4-6: Phosphorus uptake per m³ during winter related to a temperature increase of 1 °C, 3,7 °C and 10 °C started from 2012.

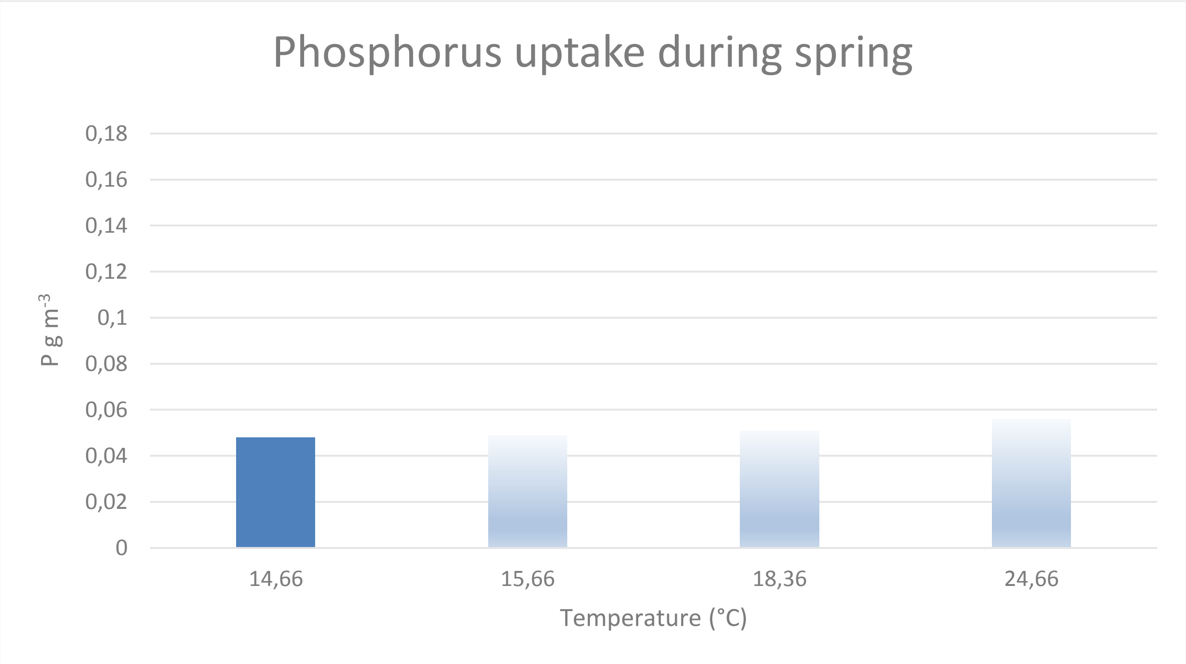

Figure 4-7: Phosphorus uptake per m³ during spring related to a temperature increase of 1 °C, 3,7 °C and 10 °C started from 2012.

4.2.2 Schwechat

The same as for the Raab, figure 4-5 shows the distribution of the nutrient uptake with a temperature increase of 1 °C as well as for an increase of 3,7 °C and 10 °C. In 2012 there was a nutrient uptake of 0,50 g m^{-3} of phosphorus, 3,62 g m^{-3} of nitrogen and 20,55 g m^{-3} of carbon. With a temperature increase of one more degree the values increase to 0,53 g m^{-3} for phosphorus, 3,88 g m^{-3} for nitrogen and 21,63 g m^{-3} for carbon. With an increase of 3,7 °C the values will increase to 0,60 g m^{-3} for phosphorus, 4,37 g m^{-3} for nitrogen and 24,79 g m^{-3} for carbon. Finally, 10 more degree mean an uptake of phosphorus of 0,82 g m^{-3}, 5,95 g m^{-3} for nitrogen and 33,77 g m^{-3} for carbon.

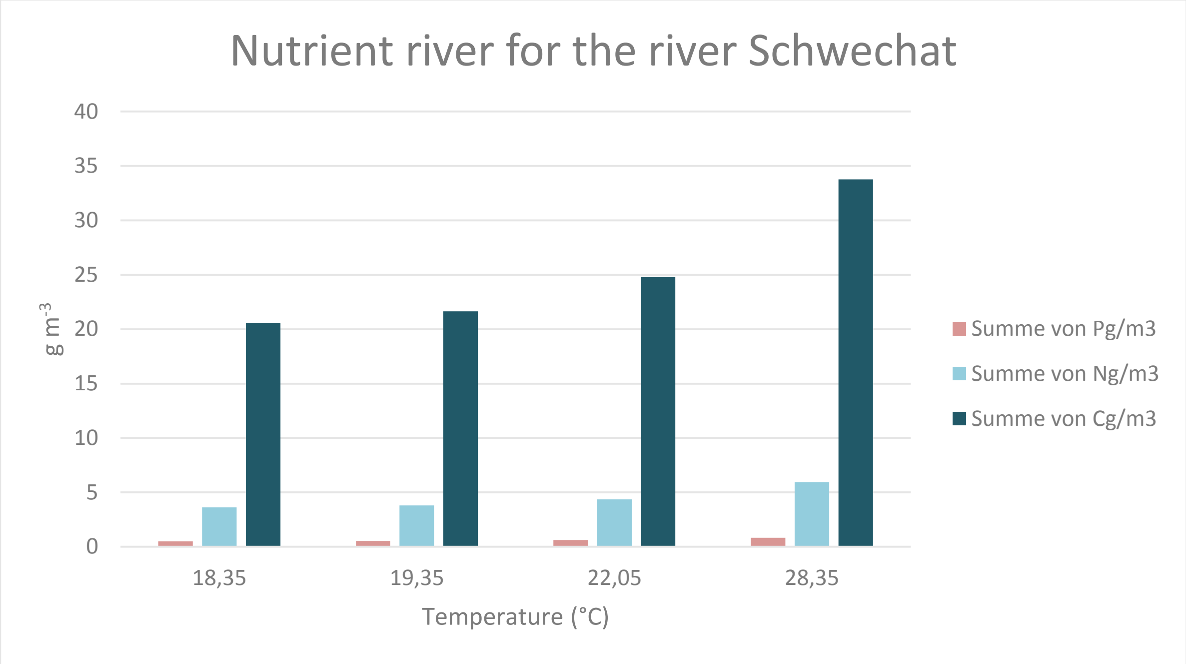

Figure 4-8: Uptake of phosphorus, nitrogen and carbon per m^3 related to a temperature increase of 1 °C, 3,7 °C and 10 °C for the river Schwechat from 2010 – 2012.

The same as for the Raab also the Schwechat showed higher phosphorus uptake rates due to higher activation energies (figure 4-9 and 4-10). For the Schwechat again a higher activation energy was calculated in winter (1,40 eV) than in summer (0,41 eV). Slightly higher are the increases of GPP for the Schwechat than the Raab. With one more degree 23% more GPP will be produced in winter. In summer 6% more GPP will occur. However, the total primary production will be still lower in winter than the biomass in summer. For the winter season 2012 a phosphor uptake of 0,12 g m^{-3} was calculated. It will increase to 0,15 g m^{-3} with one more degree and to 0,26 g m^{-3} with 3,7 more degree. In summer phosphorus uptake came to 0,45 g m^{-3} in 2012 and increases to 0,48 g m^{-3} and 0,56 g m^{-3} with a temperature increase of 1 and 3,7 °C.

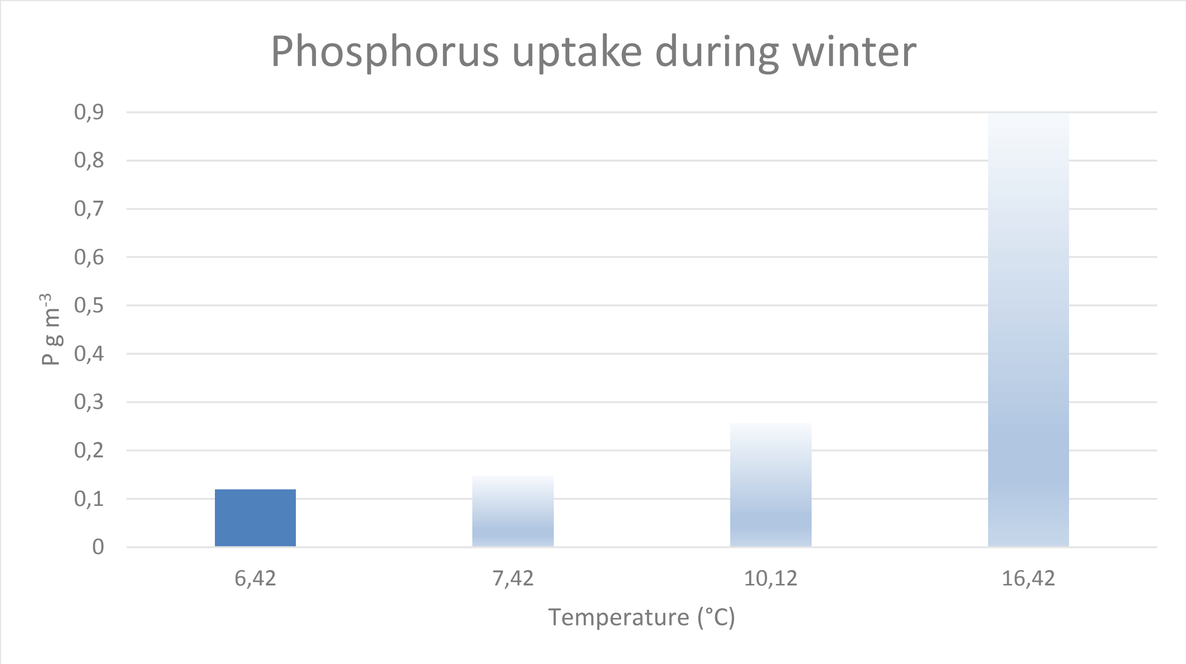

Figure 4-9: Phosphorus uptake per m^3 during winter related to a temperature increase of 1 °C, 3,7 °C and 10 °C started from 2012.

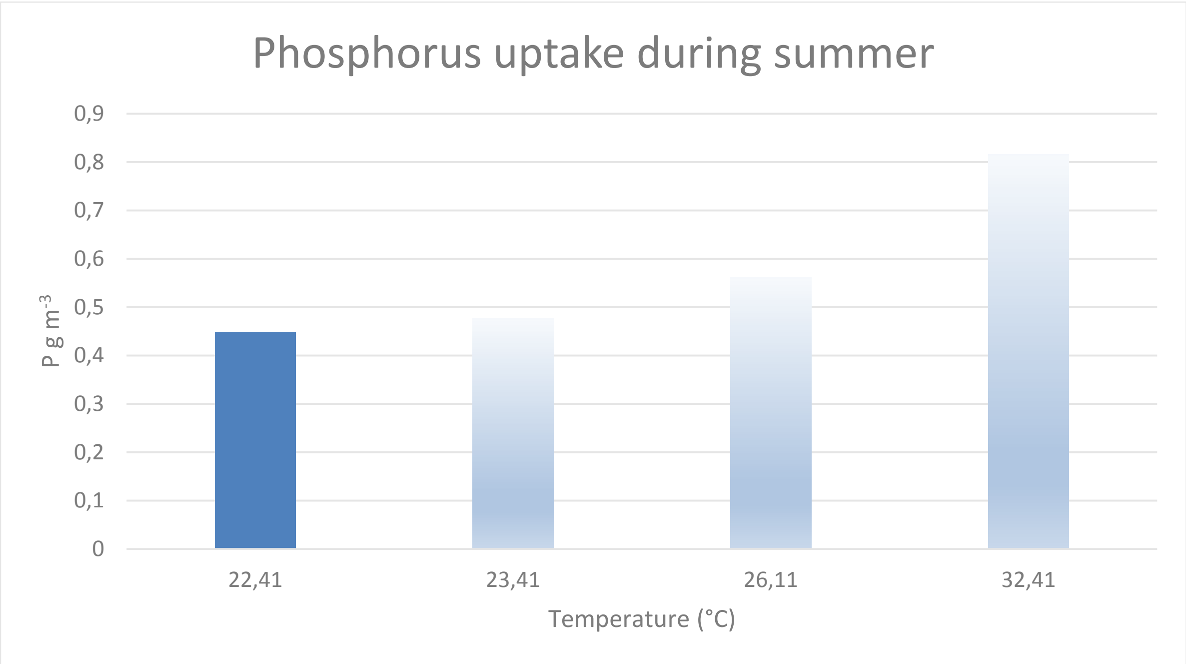

Figure 4-10: Phosphorus uptake per m^3 during summer related to a temperature increase of 1 °C, 3,7 °C and 10 °C started from 2012.

4.3 Phosphorus uptake and availability concerning a temperature increase of 1 °C

The evaluation of phosphorus uptake and the potential phosphorus availability showed that in case of higher algae growth enough nutrients will be available for both rivers. The availability for phosphorus is determined with 0,033 g m^{-3} for the Raab and the calculation for the uptake identified an additional uptake of 0,03 g m^{-3}. The same could be observed for the Schwechat. A phosphorus availability of 0,114 g m^{-3} could be calculated during the IIMF. This value meets the computed value of 0,09 g m^{-3} for the phosphorus uptake and enables additional algae growth.

5. Discussion

The aim of this master thesis was to achieve an extensive understanding of the impacts of climate change, especially the increase of temperature in Austrian rivers. Temperature dependence of GPP and different temperature scenarios were tested with the help of the MTE equation and the use of the Arrhenius plot, and the impacts concerning eutrophication were investigated. As the investigation showed, an increase of biomass production with an increase of temperature is possible and the hypothesis can be confirmed.

On the one hand temperature dependence of GPP has already been investigated in previous experiments. Consequently I wanted to compare the first results with the results from previous literature.

On the other hand the impacts of eutrophication in Austrian rivers and streams received little attention so far. As previous literature investigated climate change and GPP they focused in their studies on the impacts on the metabolism and consequences concerning greenhouse gas effects. However, the investigation of eutrophication is an important issue as it determines the health of the aquatic ecosystems and interesting findings could be done during this thesis.

What I find noteworthy to mention:

i) Both rivers showed a strong temperature dependence of GPP as previous literature already showed. An increase in temperature means also an increase in GPP. However, a slightly higher activation energy for the whole years could be recorded for the river Schwechat.

ii) During winter the highest activation energy and the highest increase of GPP could be measured whereas the total primary production is highest during spring and summer which have the lowest activation energies.

iii) Nutrient uptake showed a high correlation with temperature for both rivers. The higher the temperature the higher the nutrient uptake.

iv) The assessment of the nutrient uptake with the potential phosphorus availability showed that for both rivers phosphorus will be available in case of an increase of nutrient uptake.

5.1 GPP and the effect of increased temperature

First of all, it goes without saying that the temperature dependence of GPP is a circumstance as it is known for more than one century that metabolic rates and biochemical rates increase exponentially with temperature (BROWN et al., 2014). Moreover, the effects of temperature on the metabolism and consequently the increase of GPP are already investigated by several studies (GILLOOLY et al., 2001; ENQUIST et al., 2003; YVON-DUROCHER et al., 2010; DEMARS et al., 2011). All of these studies showed with the MTE equation and the Arrhenius plot a strong and positive correlation between temperature and GPP.

The question about why temperature strongly affects GPP can be answered with the in the MTE equation contained Boltzmann constant, as it has the ability to change the proportion of molecules with sufficient kinetic energy. Moreover, it can be also explained with the quarter-power allometric relation, the description of how biological rate processes scale with body size (BROWN et al., 2014). According to GILLOOLY et al. (2001), the activation energies of biochemical reactions of metabolism are about between 0,6 to 0,7 eV and fits to the results of the Schwechat with an activation energy of 0,65 eV and 0,51 eV for the Raab. Similar results were also computed by

DEMARS et al. (2011). An activation energy of 0,54 eV could be identified with a determination coefficient r^2 of 0,31, which is lower as the calculated values of 0,66 and 0,63 for the Schwechat and Raab. But there is also a strong and positive correlation between GPP and temperature (see figure 5-1).

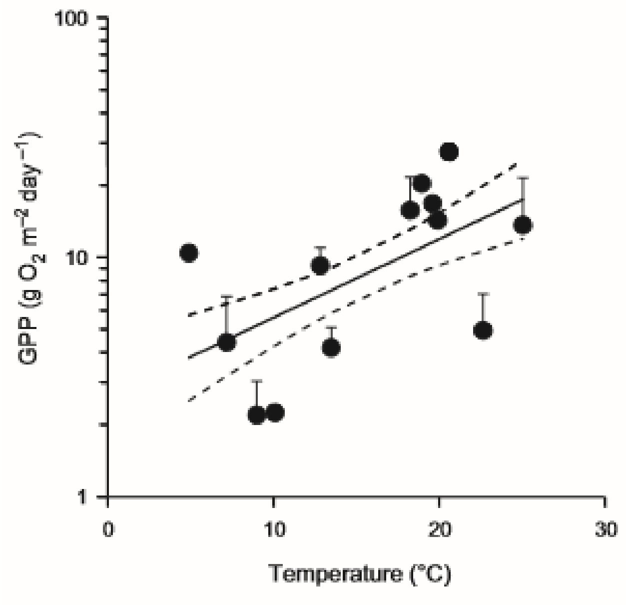

Figure 5-1: GPP correlated with temperature (DEMARS et al., 2011)

Compared to YVON-DUROCHER et al. (2010) the results have again only slight deviations, as they identified an activation energy of 0,45 eV for GPP.

The more interesting are the findings for the different seasons. For both investigated rivers, the lowest activation energies with the highest primary production occur in spring and summer. On the contrary, in winter primary production is at the lowest but has the highest activation energy. This goes along with the fact that primary production is driven by seasonally changes of light conditions (KOCUM et al., 2002; ECOMARE, 2015) and temperature, which are highest from April to September (see figure 5-2).

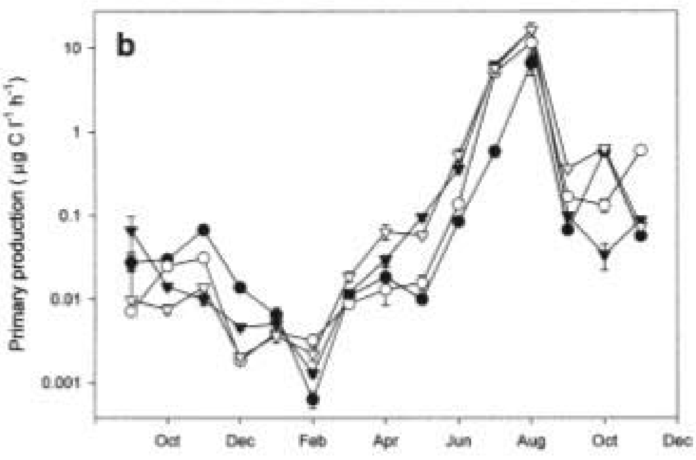

Figure 5-2: Seasonal changes in primary production at 4 sampling sites along the Colne Estuary between September 1994 and November 1995 (KOCUM et al., 2002).

Not only light and temperature are responsible for the fluctuations of primary production but rather the different algae species which occur during the different seasons. Due to this variety of algae species there are different biological characteristics and different responses to temperature change (WU et al., 2011). Where some algae species have their growing optimum at 35 °C, others decline significantly when e.g. 29 °C are reached (LÜRLING et al., 2013; WEISSE et al., 2016).

Temperature induce changes in the algae physiology and as a result, it also can cause impacts on the timing of bloom development. Especially an earlier onset of spring bloom could be already observed (PEETERS et al., 2007; LASSEN et al., 2012). In contrast, no significant influence of temperature on the timing of phytoplankton growth was found by HARDENBICKER et al. (1999). Their opinion is that the direct effects of temperature on phytoplankton are less important and the main focus should be set more on discharge conditions and light availability. This agrees with BIGGS and CLOSE (1989) and LANE et al. (2007). According to BIGGS and CLOSE (1989) the development of periphyton needs especially low and stable flow conditions for the nutrient uptake. Also LANE et al. (2007) observed that primary production is higher during period with low discharge than during seasons with high discharge. High riverine discharge causes reduced residence time, increases flushing of phytoplankton biomass and high turbidity, which leads to less chlorophyll concentrations. With a decrease of discharge, also turbidity declines and due to higher water residence time also more phytoplankton can develop (LANE et al., 2007).

Despite everything, the Schwechat and the Raab have both strong correlations of temperature and primary production. But on the contrast the Schwechat has higher values than the Raab, with higher activation energies and a higher primary production. It seems as temperature is not the determining factor for primary production in the Raab. More essential is the light availability which is higher in the Schwechat. The limited light availability affects therefore primary production in the Raab. Another possibility of the higher GPP of the Schwechat can be an ER dependence of GPP. According to DEMARS et al. (2011) during warming, higher rates of inorganic nutrient supply by ER are released back into the water column, which are taken up for primary production.

Nutrient uptake and GPP are closely linked as also nutrient uptake increases exponentially with higher temperature due to the temperature dependence of GPP. A higher amount of GPP goes along with a decrease of the nutrient concentration in the water column as for a more intensive primary production more nutrients has to be up taken. These findings also confirm YOUNG et al. (1999). During periods of algae growth, phosphorus concentration decreases and phosphorus peak values occur in late summer to autumn, after the phytoplankton maxima in summer. There are two possible reasons of the fluctuations of phosphorus concentration. Firstly, due to phytoplankton uptake phosphorus concentrations remain lower in the water column during the period of the peak of phytoplankton growth. However, after the death and the decomposition of algae phosphorus is released into solution and causes elevated river concentrations. Secondly, flow strongly influences phosphorus concentration. In early summer, higher flow conditions lead to low phosphorus levels. In late summer and with a decline of flow, phosphorus concentration increases correspondingly (YOUNG et al., 1999).

According to YOUNG et al. (1999), phosphorus do not always influence phytoplankton growth, as it is more dependent on flow conditions. This cannot be confirmed by WEISSE et al. (2016) as in their experiment algae only got higher amounts of biomass with the addition of nutrients. The same was observed by GUDMUNDSDOTTIR et al. (2011) and HARDENBICKER et al. (2014). GUDMUNDSDOTTIR et al. (2011) found a relation between nutrient enrichment and chlorophyll-a increase and states that eutrophication and temperature change will affect the species composition of primary producers considerably.

HARDENBICKER et al. (2014) investigated the river Elbe and the river Rhine. In these rivers the chlorophyll-a content followed a decline as nutrient especially phosphorus concentrations decreased in the water column. However, whereas they found a correlation of chlorophyll-a and nutrients, they do not see a central importance of nutrient concentrations for the regulation of phytoplankton compared to stratified lakes. In stratified lakes nutrient concentrations are necessary for the regulation of phytoplankton growth but rivers are constantly replenished from upstream regions and present nutrients in sufficient amounts. Here again as for the Schwechat and the Raab, also in the Rhine and the Elbe the difference of chlorophyll production was the light availability. In the Elbe light availability had not that high impact on the spring bloom development as in the Rhine but nevertheless exert a considerable influence on the river phytoplankton growth due to turbidity conditions (HARDENBICKER et al., 2014).

Compared to rivers, lakes are dependent on the spring and autumn stratification. In spring and autumn the upper layers of a lake are mixed with the lower layers by the help of the wind. It is a necessary ecological adaptation where during the winter season the produced CO_2 and due to decomposition the released nutrients achieve the upper layers and are used for primary production. Rivers are more influenced by point and diffusive sources (MAINSTONE and PARR, 2002) and this again has an impact on the trophic state of lakes or seas as rivers transport organic matter (STEPANAUSKAS et al., 2002). The effects of nutrients and primary production in lakes has been already extensively investigated. However, more detailed investigations of primary production especially about eutrophication and the species composition and community structure of phytoplankton in rivers lag behind (SMITH, 2003; WU et al., 2010).

5.2 Primary production under climate change especially droughts

Nowadays, it is commonly known that climate change is going on and has beside temperature increase also other impacts in extreme weather events like heavy precipitation and in a further step drought-flood events (IPCC, 2013; MOSLEY, 2015). The results especially the calculated phosphorus values of the IIMF by ZESSNER et al. (2017) showed that during droughts the additional phosphorus amount for a further uptake is available which leads to a higher production of biomass. This effect was also observed by WHITEHEAD et al. (2009; cite Whitehead and Williams, 1982). 1976 during a flood in Great Britain, high amounts of nitrate were flushed from the catchment into the river Thames. The Nitrate-N concentrations increased from 4 to 18 mg/l and forced eutrophication. Higher chlorophyll a concentrations were also found during droughts in 1976 and 2003 in an investigated site of the Meuse River (Netherlands) but in contrast in another investigated site with higher flow rates, no significant correlation of droughts and higher chlorophyll amount could be observed (VAN VLIET and ZWOLSMAN, 2008). An increase of benthic pelagic algae of 50 – 80% more bed cover during droughts was found in the Shag River and the Kakanui River (New Zealand) (CARUSO, 2001). According to DONNELLY et al. (1997), droughts also lead to a higher increase of cyanobacteria. In late 1991 hot conditions and low flow forced the development of large algal blooms in the Darling-Barwon River (Australia).

Referred to WHITHEAD et al. (2009 cite Whitehead et al., 2006b) the decrease of flow rates are problematic impacts. That leads to an increase of residence time of water and in a further step to an increase of the growth potential of algae, extent the settling rate of sediments and reduce water column sediment concentrations. This reduces turbidity that improve light penetration and extent algae growth. In the meantime, nutrients released from the agriculture could be less diluted due to the reduced flows. However, this disagrees with WILBERS et al. (2009) as they state that droughts have minor effects on water quality. During a drought they investigated the river Dommel and neither found any decrease of discharge nor higher nutrient concentrations which could affect the increase of the production of biomass. A drought that caused a decrease of phosphorus concentration was observed by BOAR et al. (1995). Causes for lower nutrient concentrations can be the decrease of discharge with a higher water retention time and assimilatory uptake by algae and higher plants (BOAR et al, 1995; ANDERSEN et al., 2004). In contrast, increasing nutrient concentrations occur where streams and rivers are influenced by point and diffusive sources (MAINSTONE and PARR, 2002) and a lack of dilution occurs (ZIELINSKI et al., 2009).

In total, the results showed the temperature dependence of GPP and a higher nutrient uptake, as well as the additional phosphorus availability during droughts. However, the estimations are affected by a considerable degree of uncertainty. First of all, the use of the open diel oxygen method is influenced by uncertainties, primarily due to the difficult determination of the reaeration coefficient, as it is very sensitive to calculate (IZAGIRRE et al., 2007; DEMARS et al., 2015). Secondly, the use of the Redfield ratio for the estimation of the phosphorus uptake is a general valid method but can show deviations in the different aquatic ecosystems, e.g. in the marine ecosystem compared to the freshwater ecosystem. Thirdly, the values of the additional phosphorus availability under low flow conditions calculated for dry climate change scenarios contain uncertainties as these values are the results of a modelling with multiple assumptions.

Therefore, these results do not serve as accurate predictions that give precise values about how climate change influence GPP, but rather show estimations how GPP can be prospectively influenced by temperature increase and phosphorus availability.

6. Summary

This master thesis was part of a big project which assesses climatic and land use changes on water availability and water quality. In detail the purpose of this thesis was to investigate how Austrian rivers will be affected by climate change and with which impacts they have to deal with especially regarding the danger of eutrophication. The investigation was based on the predicted air temperature increase of 1,5 °C till 2040 as well as the expected increase of 3,7 °C till the end of the century and a temperature increase of 10 °C in the worst case. The temperature dependence of GPP was already investigated by several literature, but these studies focused on the impacts of climate change on the metabolism and its feedback to the greenhouse gas effect and disregard the effects on a higher nutrient uptake.

At the beginning, three main goals were identified. First, the relation between gross primary production and temperature should be identified. Second, it should be characterised how nutrient uptake is influenced by an increase of temperature. Third, the potential limitations posed to the increase of gross primary production by nutrient availability under a modelled climate change scenario should be assessed.

For the calculations the MTE equation and the Arrhenius plot were used. With the Arrhenius plot the activation energies could be identified and the MTE equation showed how GPP changes with an increase of temperature. The Redfield ratio was used to see how many phosphorus has to be uptaken for the production of a special amount of oxygen and the additional phosphorus uptake for one more degree was compared with the phosphorus concentrations modelled by the climate change scenarios. For the calculations for both rivers the years 2010 – 2012 were selected and the results were computed for different time periods like the different seasons, the whole years and the period from April to September.

The results showed the following:

First, for both rivers a strong temperature dependence of GPP was identified as previous literature already showed. An increase of temperature means also an increase in GPP. However, a slightly higher activation energy for the whole years could be recorded for the river Schwechat.

Second, the highest activation energy and the highest increase of GPP could be measured during winter whereas the total primary production is highest during spring and summer which have the lowest activation energies.

Third, nutrient uptake showed a high correlation with temperature for both rivers. The higher the temperature the higher the nutrient uptake.

Last, the assessment of the nutrient uptake with the potential phosphorus availability showed that for both rivers phosphorus will be available in case of an increase of nutrient uptake.

Referred to the interpretation of the results the hypothesis can be confirmed. Due to an increase of temperature also biomass production increases. The research question can be answered with the fact that the Austrian rivers Raab and Schwechat will be faced with a faster metabolism rate and a higher uptake of nutrients due to the increase of temperature as several literature already showed which has impacts on the development of algal blooms.

Interesting findings are that during the cold seasons the highest activation energies occur with the lowest primary production. On the contrast, during warm seasons higher primary production exists with lower activation energies, as primary production is driven by seasonally changes of light conditions and temperature, which are highest from April to September. However, not in all studies a positive correlation between temperature and GPP was found and it was stated the main focus should be set more on discharge and light availability. But as algae species change during different seasons there are also different biological characteristics and preferences, which are a reason for the fluctuations of primary production and why GPP is not temperature dependent. Where some algae species have their growing optimum at 35 °C, others decline significantly when e.g. 29 °C are reached. For the nutrient uptake a common opinion was found

that with a higher nutrient amount also biomass increases. But here again, there are exceptions as not everywhere could be found a higher increase of biomass with nutrient enrichment but rather it is an interaction of flow and nutrients. The same was observed for the climate change scenarios of droughts. During droughts nutrient concentrations in the water column increases especially due to diffuse and point sources. With a decrease of discharge and an increase of water retention time the growth of algal blooms is forced.

To sum up, the results showed the expected temperature dependence of GPP, an increase of nutrient uptake as well as the additional phosphorus availability during droughts. But these values are also affected by a considerable degree of uncertainty. The use of the open diel oxygen method is influenced by uncertainties, as the reaeration coefficient is difficult to determine. The use of the Redfield ratio for the estimation of the phosphorus uptake is a general valid method, but can show deviations in the different aquatic ecosystems. The values of the additional phosphorus availability under low flow conditions calculated for dry climate change scenarios contain uncertainties, as these values are the results of a modelling with multiple assumptions.

Therefore, these results do not serve as accurate predictions that give precise values about how climate change influence GPP, but rather show estimations about how GPP can be prospectively influenced by temperature increase and phosphorus availability.

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8. List of figures

9. List of tables

10. Appendix

Table A-1: Mean GPP (g/m²*d) for each month from 2010 – 2012 for the river Schwechat

	GPP (g/m²*d)											
Year	January	February	March	April	May	June	July	August	September	October	November	December
2010		20,32	26,94	60,37	63,90	81,87	95,52	78,46	54,96	47,753	31,74	19,94
2011		18,44	49,19	80,21	112,92	104,48	106,74	84,14	78,854	50,27	38,04	39,11
2012	9,94	10,51	30,054	51,21	107,06	101,26	86,97	95,61	81,63	47,86	19,90	17,01

Table A-2: Mean GPP (g/m²*d) for each month from 2010 – 2012 for the river Raab

	GPP (g/m²*d)											
Year	January	February	March	April	May	June	July	August	September	October	November	December
2010	1,67	1,36	7,76	10,37	11,30	12,75	13,24	11,91	8,28	7,11	4,96	3,69
2011				10,45	11,85	11,58	12,51	11,55	9,79	8,41	5,40	3,68
2012	1,67	1,36	6,11	12,03	13,86	13,49	13,89	13,41	8,44	7,00	4,52	3,69

Table A-3: Mean Temperature (in K) for each month from 2010 – 2012 for the river Schwechat

						Temperature (K)						
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
2010		279,74	275,16	284,36	286,58	291,51	294,81	292,89	288,50	283,96	282,25	275,91
2011	273,15	275,53	279,95	286,32	289,67	293,18	293,02	293,18	291,42	283,49	279,95	278,21
2012	277,48	275,67	281,38	285,03	291,08	293,73	294,55	295,03	289,92	286,00	282,13	277,32

Table A-4: Mean temperature (in K) for each month from 2010 – 2012 for the river Raab

						Temperature (K)						
Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
2010			281,11	285,27	288,73	290,45	295,72	292,74	287,97	283,41		
2011			279,36	286,27	290,11	291,58	293,02	293,84	291,53	284,28	279,78	276,59
2012	275,01	274,09	281,68	285,33	289,44	292,35	292,62	293,43	289,18	285,02	281,32	276,41

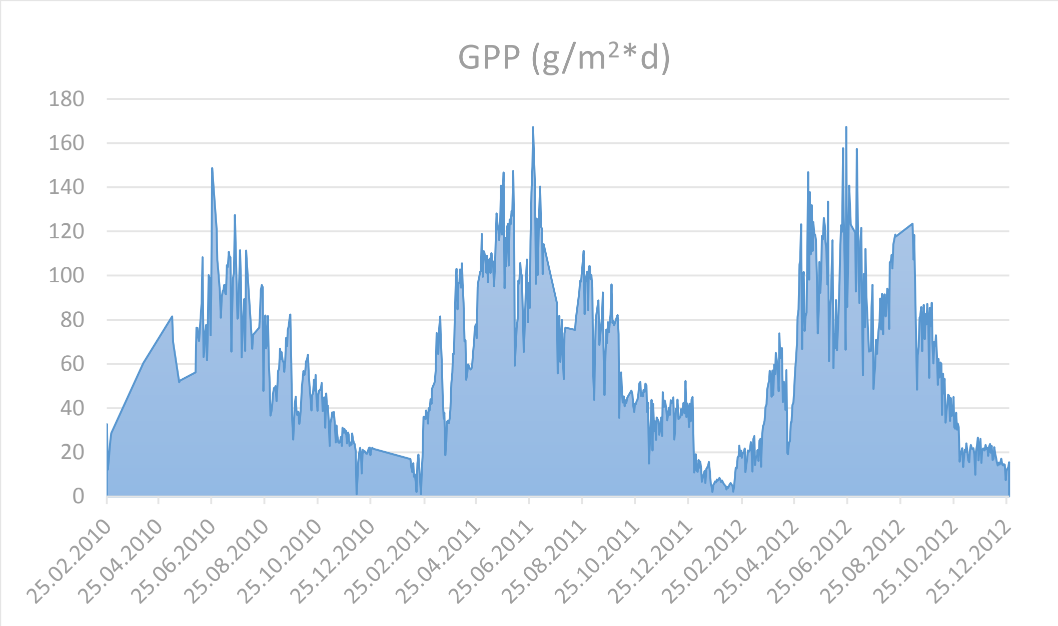

Figure A-1: GPP (g/ m²*d) distribution from 2010 – 2012 for the river Schwechat

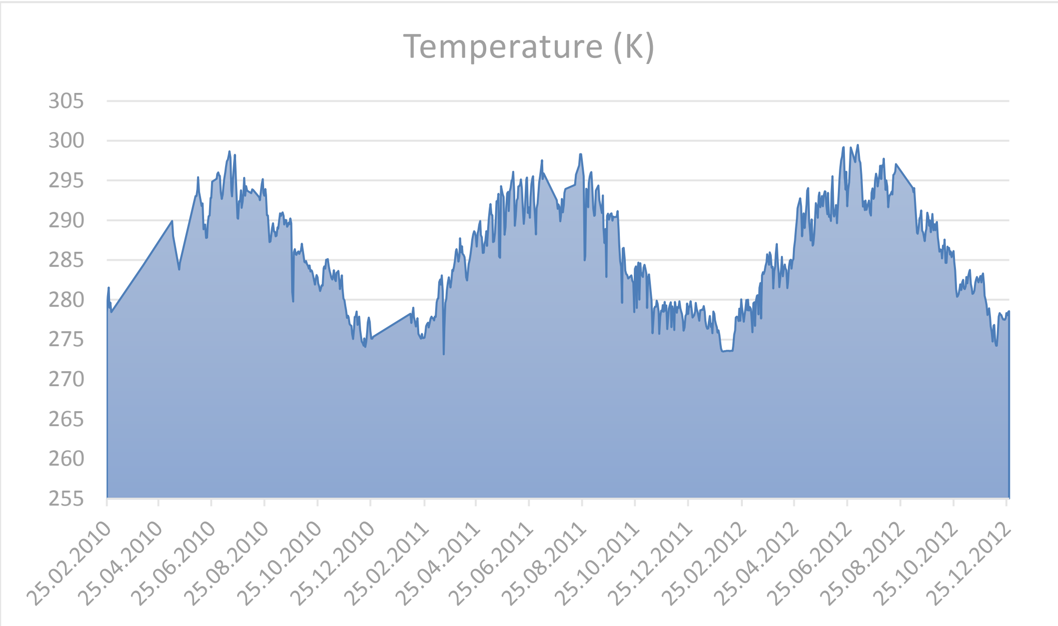

Figure A-2: Temperature (in K) distribution from 2010 – 2012 for the river Schwechat

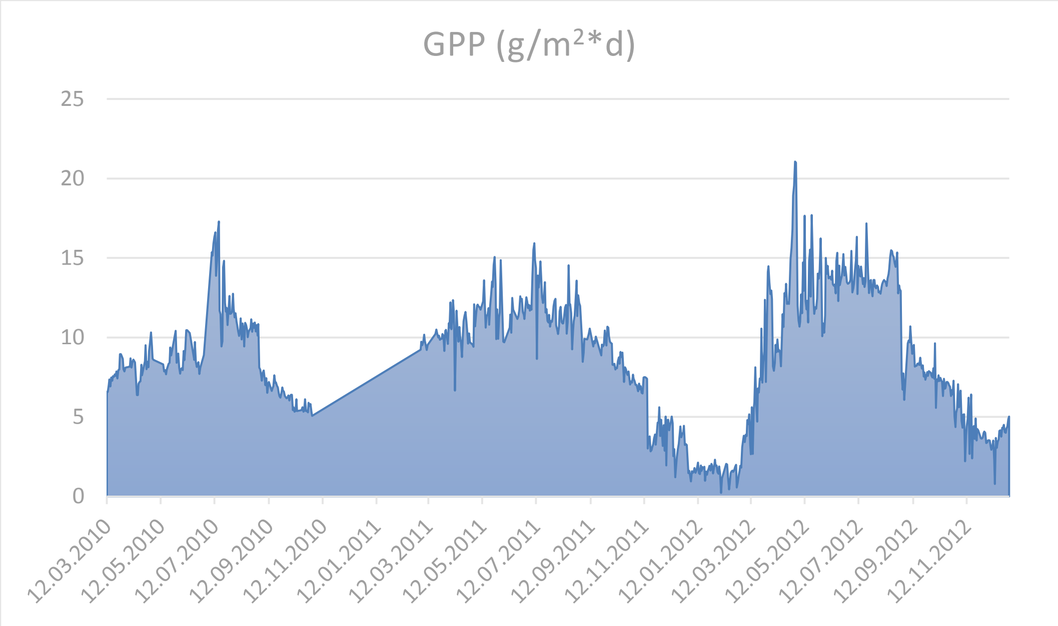

Figure A-3: GPP (g/ m^2*d) distribution from 2010 – 2012 for the river Raab

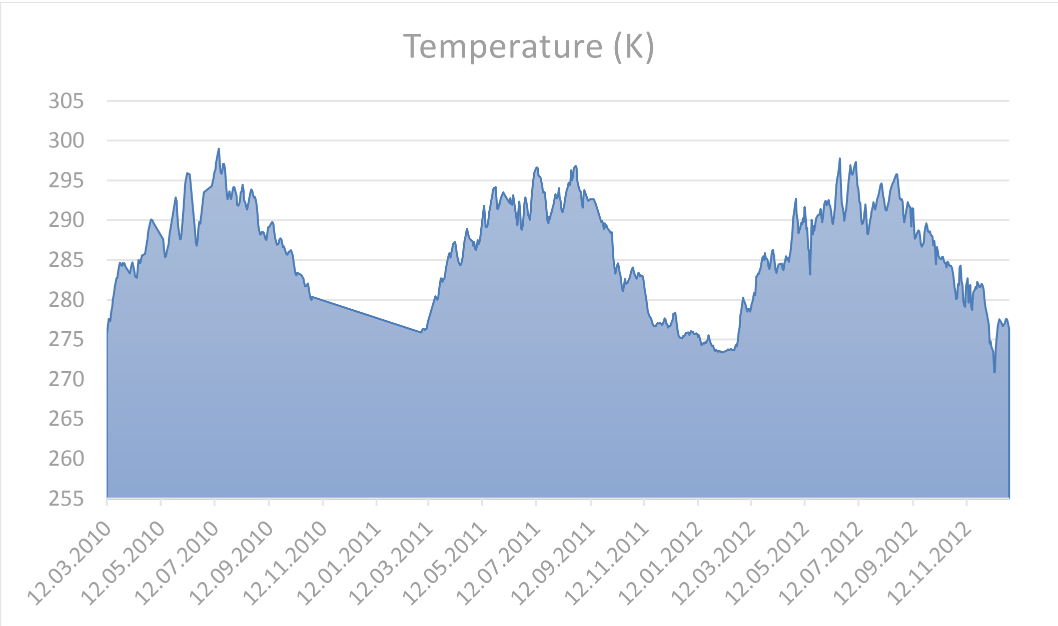

Figure A-4: Temperature (in K) distribution from 2010 – 2012 for the river Raab

11. Curriculum Vitae

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12. Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Place, date *name, surname* *signature*

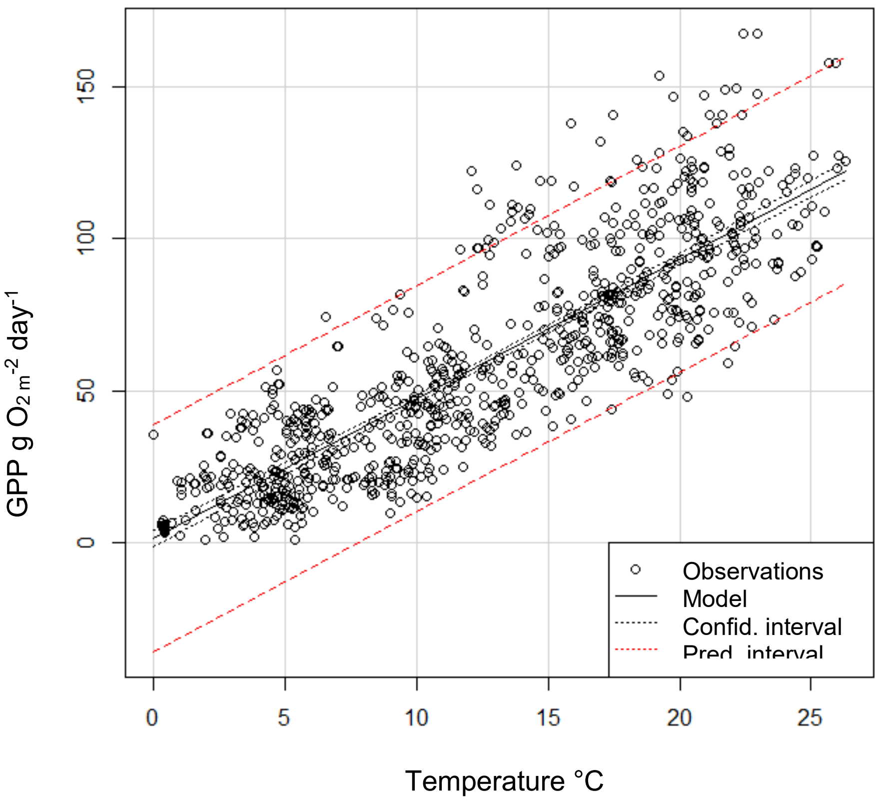

Figure 4-2: Increase of stream metabolism dependent on an increase of stream temperature measured for the river Schwechat for the years 2010 – 2012.

The months April to September from 2010 to 2012 also showed a positive correlation of temperature and GPP (figure 4-3 and 4-4) and a high significance towards the temperature dependence. For the river Raab the activation energy comes to E_r= 0,17 with a calculated mean GPP of 11 (6 – 21) g O_2 m^{-2} day^{-1} and the river Schwechat has an activation energy of E_s= 0,33 and a calculated mean GPP of 87 (19 – 167) g O_2 m^{-2} day^{-1}. Slightly lower activation energies than for the whole years but nevertheless, temperature affects the metabolic rate.

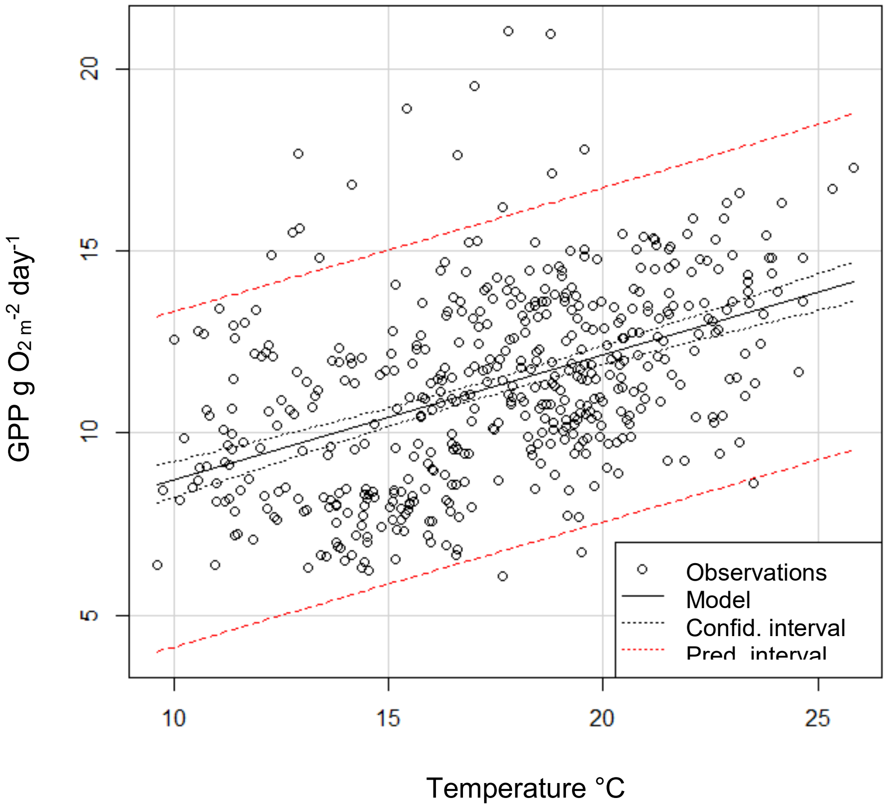

Figure 4-3: Increase of stream metabolism dependent on the stream temperature measured for the river Raab for the years 2010 – 2012 and from April to September.

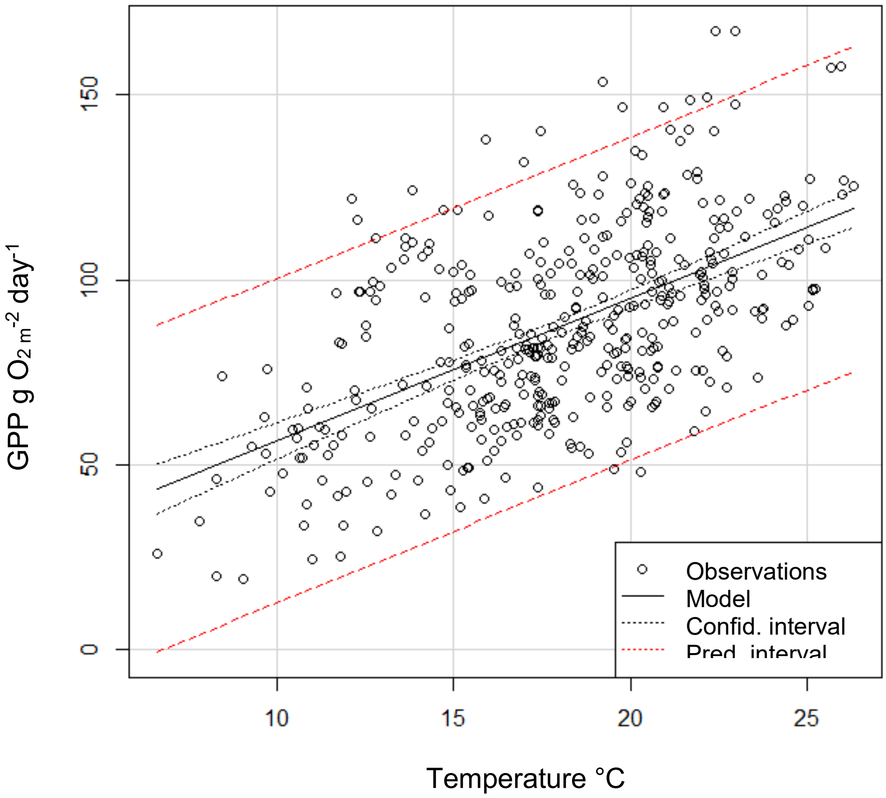

Figure 4-4:Increase of stream metabolism dependent on the stream temperature measured for the river Schwechat for the years 2010 – 2012 and from April to September.