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# The role of fish-eating predators and socio-economic trends in recreational fishing

# Role rybožravých predátorů a socio-ekonomických trendů ve sportovním rybaření

Disertační práce

Vedoucí práce: doc. RNDr. Martin Čech, Ph. D.

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Role rybožravých predátorů a socio-ekonomických trendů ve sportovním rybaření

Doctoral thesis

Supervisor: doc. RNDr. Martin Čech, Ph. D.

Prague, 2018

Declaration

I declare that I have written this thesis and cited all references therein. This thesis (or its part) has not been used to obtain an additional title.

In Prague, 29 May 2018

Roman Lyach

**Table of content**

# 1. Acknowledgements

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# 2. Abstract

Recreational fishing is a very important leisure activity and one of the most important ways how humans influence freshwater habitats and wild fish populations. Both fish-eating predators and socio-economic trends play a major role in recreational fishing.

This thesis found that the Eurasian otter feeds mainly of small (5-10 g) and very abundant fish species of low angling value. In this case, gudgeon *Gobio gobio* dominated in the otter diet. The overlap between catches of otters and anglers was very low, and commercially important salmonids made up only 10 % of the otter diet by biomass. Cormorants also prey mostly on smaller (10-100 g) a very abundant fish species. In this case, roach *Rutilus rutilus* dominated in the cormorant diet. The overlap between catches of cormorants and anglers was also quite low. Commercially important fish species made up less than 10 % of the cormorant diet. Even though cormorants consume mostly smaller fish, they are potentially removing fish that serve as prey for piscivores, and they are also removing smaller fish that would grow into angling size.

The Atlantic salmon *Salmo salar* reintroduction programme has not yet been successful. However, cormorant predation is not the main reason for its low success. The main problem is somewhere on the lower River Elbe in Germany. If this programme is to be a success, the main reasons of high salmon mortality need to be found.

Recreational fishing seems to be on the rise. The numbers of anglers and angling visits are increasing, anglers visit more fishing grounds, and they are less loyal to their favourite fishing grounds. The amount of angling guard controls in the field is increasing as well. On the other hand, catch and yield of fish is steadily decreasing, and it is mostly because the catch-and-release fishing strategy is gaining popularity. Fishing grounds in urban and natural (rural) areas showed different patterns in recreational fishing. While the visit rates were similar on both types of fishing grounds, urban fishing grounds showed higher catch and yield. Inversely, natural fishing grounds showed higher amount of angling guard controls. Smaller and larger fishing grounds also showed different patterns in recreational fishing. Most importantly, large fishing grounds did not show the highest catch and the most visit rates. Instead, mid-sized fishing grounds showed the highest catch and the most visit rates. The fisheries management should reflect on the fact that fishing is gaining popularity and that different types of fishing grounds should be managed differently.

The large-scale regulation of angling size of grayling *Thymallus thymallus* did not affect the overall catch and yield of grayling in the study area. However, it affected the distribution of catches between fishing grounds, and also the average body weight of caught fish. Anglers displayed high solidarity with grayling, and they are strongly supporting grayling conservation, mostly because they are aware of its poor population status. While fishing regulations may be sometimes effective, it is mainly the actual opinion and behaviour of anglers in the field that matters the most.

## 2. Abstrakt

Sportovní rybaření je jednou z nejvýznamnějších rekreačních aktivit a zároveň jedním s nejvýraznějších způsobů jak člověk ovlivňuje vodní ekosystémy a rybí populace. Socio-ekonomické trendy i rybožraví predátoři přitom hrají ve sportovním rybaření důležitou roli.

Jedním z poznatků práce byl fakt, že se vydra říční živí převážně malými rybami (5-10 g), a to u druhů, které jsou velice početné, a mají malý význam pro rybáře. V tomto případě dominoval v potravě vydry hrouzek obecný. Překryv mezi úlovky vyder a rybářů byl velice malý. Rybářsky významné druhy lososovitých ryb tvořily pouze malý podíl potravy vydry (10 % podle biomasy). Kormoráni se také živí především malými rybami (10-100 g), a to u druhů, které jsou taktéž velice početné. V tomto případě dominovala v potravě kormoránů plotice obecná. Rybářsky významné druhy ryb představovaly pouze 10 % v potravě kormoránů. Kormoráni sice odstraňují především početné druhy a malé ryby, nicméně tyto ryby slouží jako potrava pro dravce. Malé ryby by zároveň mohly v budoucnu dorůst do lovitelné velikosti.

Záchranný program lososa obecného nebyl prozatím příliš úspěšný. Predace kormoránů na lososech není ovšem důvodem jeho neúspěchu. Největší problém je na dolním Labi na území Německa, kde dochází k vysoké mortalitě migrujících lososů. Pokud má být tento program úspěšný, bude potřeba zjistit, jaký je hlavní důvod mortality lososů právě na dolním Labi.

Sportovní rybaření je na vzestupu. Počty rybářů i rybářských návštěv na revírech se zvyšují, rybáři navštěvují více různých revírů a jsou méně fixováni na své oblíbené revíry. Počet kontrol rybářské stráže se také zvyšuje. Na druhou stranu, úlovek ryb se snižuje, a to především proto, že roste popularity strategie chyť-a-pusť. Revíry v městských a přírodních lokalitách se většinou odlišují ve svém využívání. Počty návštěv jsou podobné, ale rybáři si odnášení více ryb z městských revírů. Na druhou stranu, přírodní revíry vykazují více kontrol rybářské stráže. Rybaření vypadá také výrazně jinak na malých a velkých rybářských revírech. Největší revíry nevykazují nejvíce návštěv ani nejvíce úlovků – toto prvenství patří středně velkým revírům. Rybářský management by měl při rozhodování vzít v potaz fakt, že se rozdílné typy revírů chovají rybářsky jinak.

Velkoplošná regulace úlovků lipana podhorního pomocí zvýšení minimální lovné míry z 30 na 40 cm neměla žádný vliv na celkový počet úlovků lipana ve studované lokalitě. Tato regulace ale výrazně ovlivnila rozložení úlovků mezi jednotlivými rybářskými revíry, a také ovlivnila průměrnou hmotnost ulovených lipanů. Rybáři vykázali vysoko míru solidarity s lipanem, a ukázalo se, že výrazně podporují ochranu lipana obecně, a to především proto, že jsou si vědomi špatného stavu populací lipana. Regulace lovu mohou být někdy prospěšné a užitečné, nicméně ve výsledku záleží především na názoru rybářů a jejich chování na samotných revírech.

## 3. List of Publications

**1. Lyach R.** and Čech M., 2017. Do otters target the same fish species and sizes as anglers? A case study from a lowland trout stream (Czech Republic). Aquatic Living Resources 30, 11.

**2. Lyach R.** and Čech M., 2017. The effect of cormorant predation on newly established Atlantic salmon population. Folia Zoologica 66: 167-174.

**3. Lyach R.** and Čech M., 2018. A new trend in Central European recreational fishing: More fishing visits but lower yield and catch. Fisheries Research 201: 131-137.

**4. Lyach R.** and Čech M., 2018. Great cormorants (Phalacrocorax carbo) feed on larger fish in late winter. Bird Study (accepted)

**5. Lyach R.** and Čech M. Differences in catch, yield, fishing visits, and angling guard controls on differently sized fishing grounds. Fisheries Management and Ecology (under review)

**6. Lyach R.** and Čech M. The differences in catch, yield, fishing visits, and angling guard controls on natural and urban fishing grounds. Urban Ecosystems (under review)

**7. Lyach R.** and Čech M. Do cormorants and recreational anglers take fish of the same species and sizes as anglers? Ardea (under review)

**8. Lyach R.** and Čech M. Solidarity of anglers is more important than any fishing regulation: a case study of grayling *Thymallus thymallus* in the Czech Republic. Fisheries Research (under review)

**9. Lyach R.** and Čech M. A tale of two trout: the intensively stocked, non-native rainbow trout *Oncorhynchus mykiss* is not replacing the native brown trout *Salmo trutta* in catches of recreational anglers. Fisheries Management and Ecology (under review)

**10. Lyach R.** Public attitudes towards and trends in recreational fisheries across the world: Central Europe: the Czech Republic. In: Arlinghaus R. (ed.). Global participation in and public attitudes towards recreational fishing: international perspectives and developments (in preparation)

## 4. Author´s contributions

**Manuscript 1** I have analysed samples, obtained supplementary data, performed statistical analyses, written the manuscript, and o managed the whole review and publication process.

**Manuscript 2** I have partially (50 %) collected samples, fully analysed samples, obtained supplementary data, performed statistical analyses, written the manuscript, and managed the whole review and publication process.

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**Manuscript 9** I have obtained data, analysed samples, performed statistical analyses, written the manuscript, and managed the whole review and publication process.

**Manuscript 10** I have co-written (together with one other author) the book chapter.

Mgr. Roman Lyach

# 5. Introduction

## 5.1 Recreational fishing

Recreational fishing is defined as fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic, or black markets (FAO 2012). Cooke and Cowx (2004, 2006) roughly estimated that all anglers around the world might catch up to 47 billion fish annually. Further, they claimed that the overall catch in recreational fishing is about 12 % of catch in commercial fishing. While commercial fishing still remains the main source of fish removal by man, it is clear that recreational fishing has been catching up lately. By studying fishing in European inland freshwater ecosystems, previous researchers claimed that recreational fishing has become more important and impactful than commercial fishing (Wolter et al. 2000, Arlinghauset al. 2002, Arlinghaus and Cooke 2005, FAO 2010). Commercial fishing has lost its importance in inland waters mainly due to the increasing importance of hatcheries and aquaculture. Basically, fishing at sea is dominated by commercial fishing, while fishing in inland waters is dominated by recreational fishing. In addition to that, recreational fishing has been recognized as one of the main factors that influence populations of commercially valuable fish species in inland freshwater ecosystems (Cooke and Cowx 2004, Westphal et al. 2008, Elmer et al. 2017). Fish species with lower commercial value are influenced by recreational fishing as well, mostly because large-scale targeted removal of piscivorous fish species has a significant effect on all fish populations. Arlinghaus et al. (2015) claimed that approximately 10.5 % of population in developed countries practice angling. Recreational fishing has been on the rise in many countries and can be counted among the most popular outside leisure activities (Marta et al. 2001, Rasmussen and Geertz-Hansen 2001, Freudenberg and Arlinghaus 2010, Freire et al. 2012, Gupta et al 2015). Recreational fishing is probably the most important way in which people influence freshwater ecosystems.

People still seek fishing experience and tranquil natural surroundings despite having access to variety of tempting ways to spend leisure time in the world of electronic gadgets and virtual reality (Manfredo 1994, Schramm et al. 2003, 2008, Morales-Nin et al. 2015). Angling is a major recreational activity in many countries because it holds many socio-economic benefits like recreation, socialization, and escape from reality (Schramm and Dennis 1993, Schramm and Edwards 1994, Arlinghaus and Cooke, 2009, Tufts et al. 2015). People seem to be more interested in natural and outside activities, and recreational fishing is definitely one of them. However, anglers throughout the world keep complaining that “fishing is not what it used to be” but scientific proof of this statement is lacking (Post et al. 2002, Pulford et al. 2017). Anglers often claim that there is a shortage of fish in the ecosystem, and they also claim that this problem has been increasing in significance in the last decade.

Several authors suggested that recreational fishing has been overlooked and understudied even though it has significant effect on fish stocks (Arlinghaus et al. 2002, Cooke and Cowx

2004, Altieri et al. 2012, Westphal et al. 2016, Elmer et al. 2017). While the importance of commercial fishing has been known and thoroughly studied, the importance of recreational fishing is a bit of an unknown. Despite the importance of recreational fishing in inland freshwaters, social aspects of angling are still significantly understudied (Arlinghaus et al. 2002, Lewin et al. 2006, Beardmore et al. 2015, Ward et al. 2016). However, it is anglers themselves who affect fish stocks the most. Their behaviour in the field is crucial, and the importance of studies on the behaviour of anglers cannot be overstated. Humans are a crucial part of freshwater ecosystems and their behaviour should receive more attention because all inland waters are greatly influenced by human activities (Rasmussen and Geertz-Hansen 2001, Post et al. 2002, Cooke and Cowx 2004, Martin et al. 2017). Several researchers suggested that social aspects of recreational fishing are poorly understood and studies regarding social aspects in fishing are urgently needed (Arlinghaus et al. 2002, Lewin et al. 2006, Beardmore et al. 2015, Ward et al. 2016). It has been stated that social aspects play a very important role in sustainable management of recreational fishing and monitoring of trends in recreational fishing should definitely receive more attention (Arlinghaus et al. 2002, 2008, 2014). Most importantly, neglecting the effects of angling behaviour on fish stocks could definitely come back to fisheries managers in a negative way. For example, suboptimal management of fishing grounds could have a negative effect on fish populations and also on satisfaction of anglers (Arlinghaus et al. 2002, Arlinghaus et al. 2004, Lang et al. 2008, Arlinghaus et al. 2009). It is anglers who pay for fishing permits, and money from selling of fishing permits is the main financial source for the Czech Fishing Union.

The Czech Fishing Union is collecting fisheries data with high precision (Humpl et al. 2009, Jankovský et al. 2011, Boukal et al. 2012). We believe that this dataset has not yet been utilized enough.

## 5.2 Fish-eating predators

### 5.2.1 The Eurasian otter

The Eurasian otter *Lutra lutra* is one of the most important fish-eating mammals in European freshwater ecosystems (Mason and Macdonald 1986, Kruuk and Moorhouse 1990, Kruuk 1995, Kruuk 2006, Krawczyk et al. 2016). Otters are highly adaptable piscivorous predators that can easily utilize new sources of prey. That goes especially for naïve hatchery-reared stocked fish. Otter populations in Europe declined dramatically during the 20th century, mainly due to water pollution, poaching, increased road traffic, and habitat loss (Kranz 2000), yet have begun to recover in the last 20-30 years (Kranz 2000, Conroy and Chanin 2002). After being driven close to extinction, numbers of otters in the wild have begun to stabilize. Recently, otters have been returning to the wild, and numbers of wild otters have been increasing throughout the whole European range. With rising numbers of otters in the wild, their effect on fish stocks is being heatedly debated between anglers and fishermen on one side and environmentalists and the society itself on the other (Kruuk et al. 1991, Kruuk et al. 1993, Kranz 2000, Adámek et al. 2003, Jacobsen 2005, Václavíková et al. 2011). The main problem is that otters are usually hunting on smaller streams with very limited fish stocks and small fish populations. In some cases, the high density of otters can lead to significant loss on fish stocks, and this is especially problematic in areas where financially expensive fish stocking and reintroductions take place. Together with poor water sources management in general, the addition of predation pressure form otters can lead to declines of fish populations. Salmonids were reported to be especially vulnerable to otter predation.

Although otters live in a large variety of watery habitats (Mason and Macdonald 1986, 1987, Kožená et al. 1992, Conroy and Chanin 2002), smaller streams are especially important as migratory routes. They provide them with steady, sufficient, and reliable source of fish prey (Jurajda et al. 1996, Ludwig et al. 2002, Lanszki et al. 2009), especially in cold winters when water bodies freeze over (Lanszki et al. 2009, Sittenthaler et al. 2015). Otter predation on such streams during winter is especially problematic because salmonids usually reproduce during winter.

5.2.2 The great cormorant

The Great Cormorant *Phalacrocorax carbo* is one of the most important fish-eating avian predators and a widespread water bird. It is an opportunistic predator that feeds almost entirely on fish (Cramp and Simmons 1977, Johnsgard 1993). Cormorants are able to move great distances and utilise new sources of prey, especially stocked fish. Cormorants were driven close to extinction during the second half of the 20th century, mainly due to poaching, hunting, and contamination of freshwater ecosystems with DDT (Debout et al. 1995, Suter 1995a, Marion 2003, European Commission 2013). However, cormorant populations have been increasing since 1970 in the European range mainly due to legal protection, availability of prey, intensive fish farming, and eutrophication of freshwater habitats (Debout et al. 1995, Van Eerden and Gregersen 1995, Russell et al. 1996, Marion 2003, European Commision 2013). In particular, numbers of the continental subspecies *Phalacrocorax carbo sinensis* have increased greatly, and Cormorants have moved to previously unoccupied areas (Carss and Marzano 2005). In the last decades, cormorants went from endangered species to one of the most important issues of the fisheries industry. Conflicts between environmentalists and ornithologists on one side and fisheries and anglers on the other have been reported in many countries (Russel et al. 1996, Cowx 2003, Čech and Vejřík 2011). In Central Europe, migrating and overwintering Cormorants cause conflicts with fisheries, mostly because the Czech Republic is one of the most important migration corridors for European cormorant population. The numbers of Cormorants in freshwater ecosystems in Central Europe significantly increase during winter due to migration, and Cormorants consume more fish during winter than during the rest of the year (Čech and Vejřík 2011). While the nesting cormorant population in the Czech Republic is relatively small (200-600 pairs), the numbers of wintering migrants reach 7-14 000 birds per year. Since wintering cormorants have become one of the most important (and the most debated) piscivores in European freshwater ecosystems (Čech and Vejřík 2011), it is becoming more important to assess their diet preferences at different overwintering areas. Only analyses of cormorant diet can provide data on their actual diet and therefore point out the magnitude of the conflict between cormorants and man.

The Cormorant-based conflict between fisheries and environmental protection has been escalating in Central Europe for decades (Suter 1995 a, b, Suter 1997), yet diet composition of Cormorants has never been studied at the upper Elbe River before. Cormorants play a very important role in fisheries research and management (Čech and Vejřík 2011). Fisheries managers claim that fish stocking is often being conducted with respect to cormorant numbers in the area. Due to climate change and river fragmentation, large rivers in Central Europe usually do not freeze over during winter (Čech and Vejřík 2011). That allows migrating Cormorants to overwinter in Central Europe. Rivers and streams without ice cover offer an excellent feeding opportunity for overwintering cormorants. Therefore, it is very important to assess diet of overwintering Cormorants in this geographical area.

5.4 Reintroduction of the Atlantic salmon

The Atlantic salmon, *Salmo salar* L. 1758, is a native European anadromous fish species. It used to be one of the most important fish species in recreational and commercial fisheries in Europe (Frič 1893, Crisp 1995, Dieperink et al. 2001). In the past, hundreds of salmon used to migrate through the Elbe River every year. Anglers used to catch and kill salmon using specialised salmon traps. Salmon used to be abundant across Northern, Western, and Central Europe, migrating into majority of European rivers in significant numbers. During the $20^{th}$ century, salmon populations have declined in the whole Europe. The population in the Elbe River basin perished completely. The last salmon in the Elbe River was caught in the 1950s. The main reason why salmon vanished from the Elbe River was river fragmentation (Chanseau et al. 1999). Migrating adult salmon were not able to overcome the newly constructed river dams, and therefore were not able to reach their spawning sites, not being able to reproduce. However, other factors such as presence of diseases and parasites, predation, climatic change, water pollution, overfishing, and losses of spawning habitats were also important factors in the extirpation of salmon populations (Frič 1893, Jonsson et al. 1991, Christensen 1996, Blackwell et al. 1997, Parrish et al. 1998, Carss and Marquiss 1999, Carss and Ekins 2002, Jonsson and Jonsson 2004, Bostrom et al. 2009, Descroix et al. 2009, Emmrich and Duetmann 2011, Wolter 2015).

After realising the effects of river damming on populations of migratory fish, many obstacles were built on fish passes that should allow salmon and other fish species to move upstream even through the obstacle. Recently, salmon reintroduction has become one of the main goals in environmental protection and fisheries management in Europe (see European Habitats Directive). Water management realised that salmon belongs to European waters and started acting to make the return of salmon possible (Adam et al. 2012).  The salmon reintroduction has already been somewhat successful in several European countries where new salmon populations have been established (Eklov et al. 1998, Aarestrup et al. 1999, Aarestrup and Koed 2003, Breve et al. 2014, Wolter 2015). Although it is a long way from a few returning salmon to reestablishment of the original salmon populations, some projects definitely showed a promising start. Genetically speaking, Czech populations of salmon perished about 60 years ago and salmon is now listed as critically endangered species. For that reason, in the year 1998, a new salmon reintroduction programme named "Salmon 2000" was founded (Kortan et al. 2010). The goal of this programme is to establish a thriving salmon population in the upper Elbe River basin (Benda and Šmíd 2002, Wolter 2015). This reintroduction programme has bene supported by the European Union, the Czech Fishing Union, and by numerous people from the public.

## 6. Aims, questions, and hypotheses

### 6.1 Aims of the study

To assess the differences in fish catches between an important piscivorous mammal, the Eurasian otter *Lutra lutra*, and recreational anglers.

To assess the effect of predation of an important piscivorous bird, great cormorant *Phalacrocorax carbo*, on newly established populations of migratory fish species, the Atlantic salmon *Salmo salar*.

To assess trends in basic variables in recreational fishing (catch, yield, fishing visits, angling guard controls) over the course of time.

To assess the changes in body size of fish in the diet of overwintering cormorants on the River Elbe.

To assess the differences in recreational fishing on smaller and larger fishing grounds.

To assess the differences in recreational fishing on urban and natural fishing grounds.

To assess the differences in fish catches between the great cormorant and recreational anglers.

To assess the effect of a large-scale angling regulation on catches of endangered and commercially important fish species, grayling *Thymallus thymallus*.

To assess the long-term trends in catch and yield of rainbow trout and brown trout.

6.2 Research questions and hypotheses

Manuscript 1

Q: Do otters catch fish of the same species and sizes as recreational anglers?

H: We hypothesized that otters catch different fish species and different fish sizes than anglers. Otters usually feed on the most common and available species in the ecosystem and those are usually small species of low angling interest.  Inversely, anglers usually target rare large-growing stocked fish species.

Q: Do small fish dominate in otter diet?

H: We hypothesised that small fish would dominate in otter diet in this study area. Previous authors discovered that otters preferably target small fish. In addition, small fish are the most common and available prey item for otters, especially in smaller streams like the one in this study.

Q: Do otters feed on non-fish prey as well?

H: We hypothesised that we wound also find remains of non-fish prey in the otter diet. Otters are known to feed on non-fish prey, especially amphibians, crayfish, birds, small mammals, and even cadavers of larger animals.

Q: Do otters mostly consume fish of high commercial value?

H: We hypothesised that otter would mostly consume fish of lower commercial value. The most common fish species in the study are was the gudgeon *Gobio Gobio*, a fish species with no commercial value. Salmonids made up only about 10 % of the fish biomass in the stream, and so we expected that otter diet would reflect this distribution.

Manuscript 2

Q: Do cormorants feed on the newly stocked salmon parr and migrating salmon smolts?

H: We hypothesized that a few remains of salmon would be found in the diet of cormorants. Cormorants usually feed on the most common and available prey, which is not salmon, but rather cyprinids.

Q: Do newly stocked salmon grown and survive in nursery streams?

H: We hypothesized that salmon would survive and grow in nursery streams because the streams were carefully chosen for the reintroduction of salmon in the Czech Republic, and the streams should be able to support salmon populations.

Q: Do salmon adults return to spawning habitats?

H: We hypothesised that adult salmon would be returning to nursery streams because the downstream barriers that prevented salmon reintroduction have been equipped with fish passes. Also, since salmon fry is stocked to the nursery streams in tens of thousands of individuals, a few salmon adults should return.

Manuscript 3

Q: Is the number of angling visits recently increasing?

H: We hypothesised that more anglers should be visiting fishing grounds because recreational fishing seems to be on the rise.

Q: Is the overall catch and yield of fish recently increasing?

H: We hypothesised that catch and yield should be decreasing because the catch-and-release fishing strategy is gaining popularity.

Q: is the amount of angling guard controls in the field increasing?

H: We hypothesised that the amount of angling guard controls should be increasing because recreational fishing is gaining popularity.

Manuscript 4

Q: Is the average body size of fish in cormorant diet changing over the course of winter?

H: We hypothesised that the size of fish in cormorant diet would be fluctuating during winter but we did not expect to find any significant trend.

Q: Are shoaling fish species dominating in cormorant diet?

H: We hypothesised that shoaling fish species, especially cyprinids, would dominate in cormorant diet in this study area. As other authors found, cormorants are known to prefer shoaling fish species. Cyprinids dominate in the study area, and we expected that cormorants found feed predominantly on cyprinids.

Manuscript 5

Q: In general, do smaller fishing grounds have lower catch, yield, number of fishing visits, and amount of angling guard controls than larger fishing grounds?

H: We hypothesised that smaller fishing grounds would show lower catch, yield, number of fishing visits, and amount of angling guard controls in general. We did not know how those variables would change when standardized to one hectare of fishing grounds.

Q: How do the variables such as catch, yield, number of fishing visits, and number of angling guard controls per hectare change when standardised to one hectare of fishing grounds?

H: We did not know how those variables would change when standardized to one hectare of fishing grounds.

Manuscript 6

Q: Is there a difference in angling visit rates between urban and natural fishing grounds?

H: We hypothesised that natural fishing grounds would show higher rates of angling visits because they are located in natural areas. Anglers are known to prefer natural areas.

Q: Is there a difference in angling catch and yield between urban and natural fishing grounds?

H: We hypothesised that natural fishing grounds would show higher catch and yield because they are located in natural areas with better environment for fish growth and reproduction.

Q: Is there a difference in angling guard controls between urban and natural fishing grounds?

H: We hypothesised that urban fishing grounds would display higher amount of angling guard controls because they are located in highly populated areas with close proximity to public transportation.

Manuscript 7

Q: Do cormorants catch fish of the same species and sizes as recreational anglers?

H: We hypothesised that cormorants catch different fish species of different sizes than anglers. Cormorants prefer common and available fish prey. Inversely, anglers usually target rare large-sized stocked fish species of high commercial value.

Manuscript 8

Q: Does the large-scale increase in minimum angling size of grayling have any effect on the overall catch and yield of grayling?

H: We hypothesised that the increase in angling size would lead to decrease in the overall catch and yield of grayling. The increase from 30 to 40 cm is significant, and fish over 40 cm in size are quite rare in the conditions of Central Europe.

Q: How do anglers view conservation of grayling?

H: We hypothesised that anglers would be supporting conservation of grayling, mainly because grayling is and endangered and vanishing species with high angling value. Anglers are aware of the poor state of grayling populations.

Manuscript 9

Q: What is the long-term trend of catches of rainbow trout and brown trout by recreational anglers?

H: We hypothesised that catch of rainbow trout is increasing. We also hypothesised that catch of brown trout is decreasing.

# 7. Materials and Methods

## 7.1 Study areas

The Eurasian otter study was conducted on the Chotýšanka stream in Central Bohemia. The cormorant studies were conducted on the upper Elbe River in Northern Bohemia. The Atlantic salmon study was conducted on the upper Elbe River, on the Kamenice stream, the Liboc stream, and the Ještědský stream, located in Northern and Western Bohemia. The studies regarding trends in recreational fishing were conducted in Prague, Central Bohemia, and Eastern Bohemia.

## 7.2 Dietary analyses

The diet of otters and cormorants was analysed via analyses of spraints and pellets, respectively. Samples were collected and diagnostic bones and other identifiable remains were extracted. Those bones and remains were then analysed under stereo microscope. Identified bones and remains were identified to species, measured, and used for analyses of estimated original fish weights and lengths. Non-fish prey was listed only as an occurrence.

## 7.3 Fisheries data analyses

Data regarding fishing visits, fish catches, and angling guard controls were obtained from the annual summaries provided by the Czech Fishing Union. Data regarding electrofishing surveys and salmon observations were provided by the Czech Fishing Union and the Office of the National Park Bohemian Switzerland.

## 8. Major findings

**1. Lyach R.** and Čech M., 2017. Do otters target the same fish species and sizes as anglers? A case study from a lowland trout stream (Czech Republic). Aquatic Living Resources 30, 11.

The aim of this study was to assess the differences in fish catches between Eurasian otter and recreational anglers. We discovered that otters catch and feed on very different fish species of different sizes than anglers. The diet of otter was dominated by small fish but non-fish prey (mainly crayfish and amphibians) was also found in the diet. Otters mainly preyed upon gudgeon Gobio gobio, a small and very common fish species in the study area. Inversely, anglers mostly caught rainbow trout *Oncorhynchus mykiss* and European chub *Squalius cephalus*. Otters mostly caught very small fish (5-10 g) but anglers mostly caught large fish (100-200 g). Stocked salmonids made up only a small amount of otter diet (13 %). That is quite a low number of salmonids in otter diet. Usually, otters prefer salmonids as prey, and especially brown trout *Salmo trutta* and rainbow trout make up significantly more in otter diet than in this case. Otters mostly consumed fish of lower or no commercial value. The overlap between catches of otters and anglers was very low but that does not exclude competition – on estimate, otters still caught tens of stocked rainbow trout over the course of winter. While it is clear that preferences of otters and anglers are different, the competition between animals and fisheries exists even when the overlap in catches is low. On the other hand, the anglers´ claim that otters feed mainly on commercially valuable salmonids was not proved. Note that this competition for fish between otters and anglers could be higher in different areas. For example, in the Třeboň biosphere area, otters that visit carp ponds and feed on resident common carps *Cyprinus carpio* could be causing more potential loss on commercially valuable fish species than otter living in natural areas with high abundances of commercially unimportant fish species.

**2. Lyach R.** and Čech M., 2017. The effect of cormorant predation on newly established Atlantic salmon population. Folia Zoologica 66: 167-174.

This study aimed to estimate predation pressure of cormorants on the newly established population of Atlantic salmon in the Czech Republic. We discovered that stocked salmon fry and parr in nursery streams are able to survive, grow, and smoltify in order to undergo migration. While the conditions in nursery streams are suitable for salmon, very few adult salmon return to nursery streams for reproduction. It is clear that there is some kind of problem downstream of the nursery streams, probably in the lower Elbe River area. Cormorants were not important predators of salmon fry, parr, smolts or adults – no signs of salmon remains were found in the diet of cormorants. The reason why cormorants did not consume any salmon was the low amount of salmon in the study area. When compared to the amount of cyprinids in the study area (about 100-200 kg per hectare), the amount of stocked and migrating salmon is insignificant. Cormorants are known to prefer feeding on shoaling fish species like roach *Rutilus rutilus* or bream *Abramis brama*. Also, salmon smolts usually migrate during night, while cormorants are strictly diurnal predators. In addition, the main salmon smolt run occurs during April and May, and by then, majority of the wintering cormorants is already gone. The Salmon 2000 programme is producing good amount of smolts but the migration path in the Elbe River is still too problematic to support salmon migration. If the salmon reintroduction programme is to be successful, movement of salmon should be monitored, and the main cause of salmon mortality needs to be addressed. In the future, if the programme is a success, and salmon start returning and spawning in greater numbers, we expect that cormorant predation could become more significant.

**3. Lyach R.** and Čech M., 2018. A new trend in Central European recreational fishing: More fishing visits but lower yield and catch. Fisheries Research 201: 131-137.

This study aimed to evaluate long-term changes in the most important variables in recreational fishing – mainly catch, yield, fishing visits, and angling guard controls. We discovered that more anglers are visiting fishing grounds each year. In addition, the number of all fishing visits is increasing as well. Inversely, we found that the overall catch (individual fish) and yield (kg of fish) is decreasing in time. The amount of angling guard controls is increasing in time, making it harder for anglers to break fishing rules. Anglers are getting more mobile and they keep switching fishing grounds more often than they used to. Anglers also return to their favourite fishing grounds less frequently than they used to. It is linked to the increased mobility of anglers. The higher visitation rate is linked to increasing popularity of recreational fishing and also to improved economic situation and increasing well-being of people in general. The decreasing catch and yield is linked to the increasing popularity of the catch-and-release fishing strategy. It seems that recreational fishing is not just about catching and killing a fish anymore, but rather about the fishing experience itself. This trend is also linked to improved economic situation. In conclusion, recreational fishing in the Czech Republic is gaining popularity but the catch is decreasing due to the catch-and-release strategy.

**4. Lyach R.** and Čech M., 2018. Great cormorants (Phalacrocorax carbo) feed on larger fish in late winter. Bird Study

This study aimed to assess diet of overwintering cormorants over the course of one winter. We discovered that the size of fish in cormorant diet is increasing throughout the course of winter. Cormorants feed on mostly small fish in early winter but the size keeps on increasing in time. Cormorants feed on the largest fish in late winter. This was true for majority of the most important fish species in the diet. There are two possible explanations for this phenomenon – firstly, cormorants actively select larger fish during late winter. Ectothermic fish are significantly weakened over the course of long winter. That makes fish more susceptible to bird predation. Larger fish have more developed anti-predation behaviour, and significantly faster and therefore harder to catch. Cormorants are also limited by the gap size of their beak, making it harder to swallow a lager fish. Secondly, cormorants simply prey upon the most common fish in the ecosystem, and smaller fish are less abundant in the study are in late winter. Small fish are more vulnerable to starvation and mortality during winter, and that explains why there is lower abundance of small fish in late winter. Cormorants could also be switching feeding sites, mostly because different areas could be available for birds during different parts pf winter. Roach dominated the diet of cormorants (50 % by biomass). We suggest that the fisheries management should reflect on the fact that cormorants compete with anglers for large fish mostly in late winter. The conflict between cormorants and fisheries is the highest in late winter and early spring. For that reason, we suggest that stocking of potentially vulnerable fish should be put off to mid spring when all overwintering birds are gone.

**5. Lyach R.** and Čech M. Differences in catch, yield, fishing visits, and angling guard controls on differently sized fishing grounds. Fisheries Management and Ecology

This paper aimed to compare the most important variables in recreational fishing – catch, yield, fishing visits, and amount of angling guard controls – on smaller and larger fishing grounds. We discovered that the relationship between the size of a fishing ground and the variable is not always linear. It was not true that the largest fishing grounds would show the highest visit rates and the highest catch, yield, and amount of angling guard controls. Most important and surprising discovery was that mid-sized fishing grounds showed the highest rates of fishing visits, catch, yield, and amount of angling guard controls. Larger fishing grounds showed significantly lower numbers, and smaller fishing grounds showed the smallest numbers. When standardized to one hectare, smaller fishing grounds showed the highest rates of fishing visits, catch, yield, and amount of angling guard controls. Largest fishing grounds showed the lowest numbers. In conclusion, the most important variables in recreational fishing respond to the size of a fishing ground, but not always in a linear way. The fisheries management should reflect on the fact that fishing grounds of different sizes are very different in basic variables in recreational fishing. The smallest fishing grounds are under the highest pressure per one hectare, and fisheries management should adjust the management of smaller fishing grounds to partially remove the fishing pressure.

**6. Lyach R.** and Čech M. The differences in catch, yield, fishing visits, and angling guard controls on natural and urban fishing grounds. Urban Ecosystems

This study aimed to assess the differences in the most important variables in recreational fishing – catch, yield, fishing visits, and amount of angling guard controls – between urban and natural fishing grounds. Urban and natural fishing grounds showed similar visit rates. Urban fishing grounds showed higher catch and yield and also higher amount of anglers who took home at least one fish. Inversely, natural fishing grounds showed higher amount of angling guard controls. Common carp dominated in catches of anglers on both types of fishing grounds. Urban fishing grounds showed higher catch of intensively stocked fish species while natural fishing grounds showed higher catch of bream *Abramis brama* and large-growing piscivorous fish species. Anglers caught on average larger fish on natural fishing grounds, mostly because natural areas offer better environmental conditions for fish populations. We suggest that fisheries management should take those differences into consideration, for example by advising angling guards to visit urban fishing grounds more frequently. For example, urban fishing grounds could be subjected to revitalisations in order to make the habitat more attractive for piscivorous fish species.

**7. Lyach R.** and Čech M. Do cormorants and recreational anglers take fish of the same species and sizes as anglers? Ardea

This study aimed to assess the differences in fish catches of cormorants and recreational anglers in a study area where the conflict between environmentalists and fisheries has been escalating for years. We discovered that cormorants mostly preyed upon smaller fish (50-100 g) of lower or medium angling value. Inversely, recreational anglers caught large fish (1000-2000 g) of medium and high angling value. Cormorants mostly preyed upon cyprinids such as roach, bream, ide, and European chub, and in addition to that also perch. Inversely, anglers mostly caught cyprinids like common carp, bream, and in addition to that also piscivorous species like pike *Esox lucius*, zander *Zander lucioperca*, and European catfish *Silurus glanis*. Cormorants mostly consumed fish that were undersized for angling purposes. The overlap of catches between cormorants and anglers was overall quite low. On the other hand, this low overlap of catches does not exclude competition between cormorants and fisheries. Firstly, cormorants were still consuming small fish that would grow into legal catchable size for anglers, and therefore cormorants were causing indirect financial loss on those fish. Secondly, cormorants were consuming cyprinids that serve as prey for highly valued piscivores. This way, cormorants are competing for catches with piscivorous fish species, potentially preventing them from growing to angling sizes.

**8. Lyach R.** and Čech M. Solidarity of anglers is more important than any fishing regulation: a case study of grayling *Thymallus thymallus* in the Czech Republic

The aim of this study was to evaluate the effect of a large-scale fishing regulation (increase in angling size of grayling from 30 to 40 cm) on the overall catch and yield of grayling. We discovered that the restriction in minimum angling size of grayling had no effect on the overall catch and yield of grayling. However, the change had an effect on the distribution of catches of grayling among fishing grounds. The percentage of fishing grounds with any catches of grayling decreased after the restriction took place. In addition, the restriction had an effect on the average body weight of grayling in catches of anglers – the body weight increased due to the restriction. We also searched discussion forum regarding fisheries to find out the opinion of anglers on conservation of grayling. Those discussion forums revealed that anglers place high priority on conservation of grayling. Anglers support protection of grayling, they release all caught grayling back to the water, and they are actively trying to improve environmental conditions in grayling streams at their own expenses. We conclude that the large-scale restriction had no effect on the overall catch and yield of grayling, mostly because anglers were already releasing all caught grayling back to water before the restriction took place. The reason for this behaviour was that anglers are aware of the poor population status of grayling in the Central Europe. While fisheries regulations are usually an effective measurement that helps to prevent overfishing, in this case, it was not needed. Solidarity of anglers with an endangered species was more important than the actual fishing regulation.

**9. Lyach R.** and Čech M. A tale of two trout: the intensively stocked, non-native rainbow trout *Oncorhynchus mykiss* is not replacing the native brown trout *Salmo trutta* in catches of recreational anglers. Fisheries Management and Ecology

The aim of this study was to evaluate long-term trends in catch, yield, average body weight of caught rainbow trout and brown trout. We discovered that catch and yield of both trout species has been increasing over time. While anglers are catching rainbow trout of similar size every year, the size of caught brown trout is increasing. The number of fishing grounds with trout catches has been stable. The idea that the number fishing grounds where trout can be seen and caught has been decreasing was not supported by results of this study. There was also a positive correlation between body size of caught rainbow trout and brown trout on individual fishing grounds. Similarly, there was a positive correlation in yield between both trout species on individual fishing grounds. The competition between the native and non-native trout species is not apparent from angling statistics. Rainbow trout is perceived as a weak competitor, stocked trout have high post-stocking mortality, and anglers usually remove stocked trout very quickly. Therefore, the time that stocked trout spend in the ecosystem is very limited. That is the main reason why native brown trout is usually not threatened by intensively stocked rainbow trout. However, more research should be done to actually analyse the competition more thoroughly.

**10. Lyach R.** Public attitudes towards and trends in recreational fisheries across the world: Central Europe: the Czech Republic. In: Arlinghaus R. (ed.). Global participation in and public attitudes towards recreational fishing: international perspectives and developments (in preparation)

The aim of this chapter was to bring more information on the perception of anglers and angling activities by the public, mainly by people who do not fish. While the data on similar studies that assess public opinion on recreational fishing are basically non-existent in the Czech Republic, the results of three studies that were presented by the Czech Fishing Union showed interesting ideas. Recreational fishing is a very important hobby in the Czech Republic – about 3 % of the Czech population practice recreational fishing. Anglers have mostly medium or low economic status. Most anglers are older (in age group 40-49 years) and seniors (60 plus) form 30 % of all anglers. About 50 % of all anglers practice the catch-and-release fishing strategy. Anglers are mostly perceived positively, although some aspects of angling and fisheries management and seen negatively by the public. Mainly, intensive stocking of non-native fish species (common carp, rainbow trout) is perceived negatively. Fishing competitions are also often perceived as cruel and unnecessary.

## 9. Conclusions

In conclusion, this thesis was addressing the main issues of fisheries.  Especially, it was aiming at explaining the main drivers of recreational fishing, feeding ecology of the most important piscivorous birds and mammals, and also the issue of reintroductions of fish species of high commercial and angling value.

While the losses of fish that are caused by the Eurasian otter and the great cormorant are significant, the conflict between environmentalists and fisheries is perhaps not as intense. Piscivorous predators mainly feed on the most common and available fish species. Otters usually prey upon small and very abundant fish species of low angling value. Similarly, cormorants usually prey upon very abundant shoaling fish species of low and moderate angling value. The results did not support the statement that otters or cormorants select large-growing fish species of high commercial value. On the other hand, it is true that some percentage of prey consists of highly valuable salmonids and piscivorous fish species. Especially overwintering cormorants consume lots of fish over the course of winter, and even if the commercially valuable species made up fewer than 10 % of the diet, it is still a significant financial loss.

Recreational fishing has changed significantly over the course of the last decade. We observe the increase in visit rates but also the decrease in the catch and yield. Angling guards are getting more active every year, meaning that anglers should not get away with breaking the law that easily. Fishing grounds of different types also show different results, and sometimes not in a way that the fisheries management would expect. Fishing grounds in natural areas and in cities display different results, and so do smaller and larger fishing grounds. Most importantly, larger fishing grounds do not show the highest visitation rates and the highest catch and yield – the mid-sized fishing grounds are visited at much higher rates. The catch and yield is also the highest at mid-sized fishing grounds. In addition, urban fishing grounds showed higher catch and yield but lower rates of angling guard controls. It is clear that the fisheries management should take those differences into consideration, mostly because they are not visible at first, and they are sometimes quite counter-intuitive.

The salmon reintroduction programme is certainly a good idea, and the Czech Republic is cooperating with other countries (mainly Sweden and Germany) in exchange of knowledge regarding salmon stocking. However, more research needs to be done on this topic. If we want to make the salmon reintroduction successful, this international cooperation is crucial, especially when both sides are trying to find the reason why, even after 20 years, the results are not what they should be.

Fishing restrictions are usually a god idea and certainly the easiest way to prevent streams and rivers from being overfished. However, the main result of similar restriction is mostly dependant on the actual opinion and education of anglers. It is clear that anglers need to be in agreement with such restriction, mostly because there is no real way to enforce it in the field. Angling guards are certainly playing a crucial role in those cases, yet even angling guards are very limited in what they can actually do. Recreational fishing is about people as much as it is about fish, and attitude of anglers is the most important factor in fisheries.

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Research Article

# Do otters target the same fish species and sizes as anglers? A case study from a lowland trout stream (Czech Republic)

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**Abstract** – Stocking of hatchery-reared fish into streams is a common practice in fisheries industry as it provides catches for recreational anglers and support for native fish populations. The Eurasian otter *Lutra lutra* is one of the most important freshwater piscivorous predators in Europe. Impact of otters on stocked fish is a source of conflict between fisheries industry and environmental protection. This study aimed to describe differences between otter diet and catches of anglers on a lowland trout stream with salmonid stocking. Otter diet was studied during winter, using spraint analysis. Fish dominated otter diet (85% of biomass). Gudgeon *Gobio gobio* was the most important otter prey (38% of biomass). Catches of otters and catches of anglers on the stream were significantly different. Otters mostly preyed upon small-growing fish species of medium or no angling value while anglers took large-growing fish species of medium and high angling value. Otters took fish with average weight of 10 g while anglers took fish with average weight of 290 g. Stocked salmonids made up 13% of estimated biomass in otter diet. Otters targeted significantly different fish species of different sizes than anglers did.

**Keywords:** Brown trout *Salmo trutta* m. *fario* / Fish losses / Fish predation / Hatchery-reared fish / Pharyngeal bones / Rainbow trout *Oncorhynchus mykiss*

## 1 Introduction

The Eurasian otter *Lutra lutra* is one of the most important fish-eating mammals in European freshwater ecosystems (Mason and Macdonald, 1986; Kruuk, 1995, 2006). Otter populations in Europe declined dramatically during the 20th century, mainly due to water pollution, poaching, increased road traffic, and habitat loss (Kranz, 2000), yet have begun to recover in the last 20–30 years (Kranz, 2000; Conroy and Chanin, 2002). With rising numbers of otters in the wild, their effect on fish stocks is being heatedly debated between anglers and fishermen on one side and environmentalists and the society itself on the other (Kruuk et al., 1991, 1993; Kranz, 2000; Adámek et al., 2003; Jacobsen, 2005; Václavíková et al., 2011). Fishermen claim that otters are significantly responsible for losses on farmed and stocked fish (Kloskowski, 2000; Adámek et al., 2003; Kortan et al., 2007), while environmentalists consider otters to be flagship species of aquatic ecosystems (Juhász et al., 2013), and the society considers otters to be highly charismatic and popular animals.

Although otters live in a large variety of watery habitats (Mason and Macdonald, 1986; Conroy and Chanin, 2002), smaller streams are especially important as migratory routes. They provide them with steady, sufficient, and reliable source of fish prey (Jurajda et al., 1996; Ludwig et al., 2002; Lanszki et al., 2009), especially in cold winters when water bodies freeze over (Lanszki et al., 2009; Sittenthaler et al., 2015). Otters are (to a certain extent) fish-eating specialists (Erlinge, 1969; Taastrom and Jacobsen, 1999; Copp and Roche, 2003), but within this category, they are opportunistic predators (Carss et al., 1990; Taastrom and Jacobsen, 1999; Lanszki et al., 2001; Geidezis, 2002). They usually take the most abundant and available fish prey (Jurajda et al., 1996; Chanin, 2003; Kortan et al., 2007), although they can be selective as well, for example by preferring younger age classes of large-growing pond fish (Kloskowski, 2000) or partially rejecting non-native species (Blanco-Garrido et al., 2008; Miranda et al., 2008). In freshwater ecosystems in moderate climate, otters usually prey upon smaller fish of no commercial value, with larger fish being taken only occasionally (Jurajda et al., 1996; Lanszki and Sallai, 2006; Lanszki and Széles, 2006, Lanszki et al., 2015).

Salmonid stocking is a common practice in fisheries management of trout streams (Larsen, 1972; Baer et al., 2007). The main goal is to increase the numbers of commercially attractive fish in the streams in order to increase the yield of recreational anglers. Large legal or almost-legal sized salmonids (17–30 cm, 150–400 g) are usually being stocked for this purpose (Rasmussen and Geertz-Hansen, 1998). Another goal is to support native wild fish populations and to re-establish extirpated fish populations by stocking smaller salmonids (10–15 cm, 10–30 g), mostly because fish stocked at

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older life have higher mortality than stocked fry (Naslund, 1992). Although otters show preference for slow-moving cyprinids during warmer months, they prey on salmonids as well (Mason and Macdonald, 1986; Taastrom and Jacobsen, 1999), especially during winter when the endothermic predator has higher advantage over its ectothermic prey (Ludwig et al., 2002), and when non-fish prey becomes less available (Kortan et al., 2007). Stocked salmonids have poorly developed anti-predation behaviour (Maynard et al., 1995; Jacobsen, 2005) and reduced ability to capture prey and defend their feeding grounds (Bachman, 1984); therefore they are particularly vulnerable to predation (Aarestrup et al., 2005).

The goal of this study was to analyze otter diet in one winter season on a secondary trout lowland stream that is being stocked with salmonids, used by anglers, and being polluted from a cascade of upstream ponds. The stream is being used by one to three otters (based on tracking in snow). We hypothesized that otter catches would differ from catches of anglers since anglers select specific fish species and sizes while otters usually take the most abundant and available prey.

## 2 Materials and methods

### 2.1 Study area

The study was carried out on Chotýšanka stream (Fig. 1), a small lowland stream (45 km south-east from Prague, fishery no. 413 006, Chotýšanka 1, in the list of fisheries of the Czech Anglers Union) in Central Bohemia, Czech Republic, during winter 2005/2006. It is a left-hand tributary to the Blanice River on the 8th kilometre (Vltava River basin). It is 11.7 km long, meandering coefficient 1.15, average width 4.44 m, average annual flow of 0.68 $m^3 s^{-1}$ at the mouth, 690 mm annual rainfall by long-term measurement. Average air temperature in December 2005 was −1.3 °C; in January 2006 it was −6 °C in this area (Czech Hydrometeorological Institute, unpubl. data). The area has a temperate climate and an altitude of 320 m above sea level. It is located between pond Smikov (49°43′32.2″ N, 14°49′53.0″ E) and the Blanice River (49°45′34.0″ N, 14°54′52.6″ E), and covers an area of 5 ha. The stream is surrounded by meadows and forest, and is situated in a region with active soil erosions. The stream has two smaller tributaries on kilometre 5.5 and 7.

The stream is listed as trout water and is alpha/beta mesosaprobic. Discharge of warm and eutrophic water from the pond surface occurs frequently in the summer, increasing the water temperature under the pond. Dredging during autumnal (middle to late October 2005) fish harvest caused release of large portions of muddy water, polluted with organic compounds, that swept fish stocks downstream, making them migrate back upstream in order to recolonise the area. Since there is no other source of water pollution on the stream, the own flow gets cleaner downstream as it dilutes and thereby rids itself of the organic, muddy, and thermal pollution. Irregular summer discharges are causing occasional droughts (Poupě, unpubl. data). Those are especially relevant in the upstream section (Fig. 1) since there is no additional tributary or other consistent water source and fewer pools present in this stream section (own observation).

Salmonid stocking was conducted from September to November 2005 (Table 1). Fish were stocked on several spots where the stream was accessible from the bank (Fig. 1). Stocked salmonids were reared in a hatchery on pellet food and had no prior experience with a natural habitat or a predator of any kind. All fish seemed to be in a good shape before stocking (Czech Anglers Union, unpubl. data). Statistics regarding catches of anglers are collected by Czech Anglers Union every year; it is mandatory for anglers to report all fish they remove from the stream.

In years 2005–2006, altogether 180 visits of 42 individual anglers occurred on the stream. Anglers caught and took away from the stream altogether 107 individual rainbow trout *Oncorhynchus mykiss* with total biomass of 31.6 kg (average fish weight 0.3 kg), 9 individual brown trout *Salmo trutta* m. *fario* with total biomass of 2.3 kg (average fish weight 0.3 kg), 283 individual European chub *Squalius cephalus* with total biomass of 49.3 kg (average fish weight 0.17 kg), 2 individual

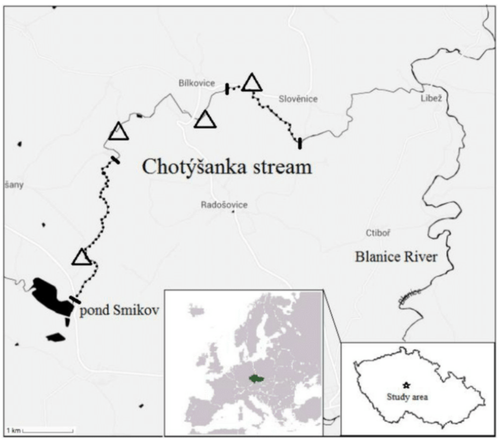


**Fig. 1.** Map of the study area: Chotýšanka stream (Central Bohemia, Czech Republic); the dotted line represents the stretches where spraints of Eurasian otter *Lutra lutra* were found and collected in winter 2005/2006 (km 3.0–5.5 and 7.5–11.7 from the confluence with the Blanice River); the full line represents section limits; the triangles represent spots where fish stocking occurred in September–November 2005.

**Table 1.** Fish stocking on Chotýšanka stream (Chotýšanka 1, fishery no. 413 006) in September–November 2005: species, fish species stocked; number, total number of stocked fish; biomass, total biomass of stocked fish [kg]; length, individual fish length [cm]; weight, individual fish weight [g].

| Species | Number | Biomass | Length | Weight |
|---|---|---|---|---|
| Brown trout *Salmo trutta* m. *fario* | 5000 | 100 | 8–15 | 10–30 |
| Rainbow trout *Oncorhynchus mykiss* | 480 | 120 | 25–35 | 200–400 |

**Table 2.** The number of spraints of Eurasian otter *Lutra lutra* collected on Chotýšanka stream (Chotýšanka 1, fishery no. 413 006) in winter 2005/2006: date, date of spraint collection; spraints, number of spraints collected; *n*, number of food items identified in spraints; *b*, estimated biomass of all food items identified in spraints [kg], Sec1, Section 1 (km 7.5–11.7); Sec2, Section 2 (km 3.0–5.5) (Fig. 1).

| Date | Spraints | | *n* | | *b* | |
|---|---|---|---|---|---|---|
| | Sec1 | Sec2 | Sec1 | Sec2 | Sec1 | Sec2 |
| 11 Dec 2005 | 92 | 61 | 547 | 319 | 6.12 | 4.13 |
| 14 Jan 2006 | 82 | 44 | 430 | 299 | 5.20 | 3.25 |
| Total | 174 | 105 | 977 | 618 | 11.32 | 7.38 |

brook trout *Salvelinus fontinalis* with total biomass of 0.5 kg (average fish weight 0.25 kg), one individual common carp *Cyprinus carpio* (weight 2.1 kg), 3 individual European perch *Perca fluviatilis* with total biomass of 0.5 kg (average fish weight 0.17 kg), and 4 individual pike *Esox lucius* with total biomass of 3.4 kg (average fish weight 0.85 kg) (Czech Anglers Union, unpubl. data).

### 2.2 Sample collection and diet analysis

The diet of Eurasian otter was investigated from spraints (otter faeces). Those spraints were collected on 11 December 2005, and 14 January 2006. The whole stream (11.7 km) was searched by the same two experienced surveyors both times, carefully "zigzagging" along the banks while also searching mid-channel features (rocks, boulders, tree roots, and fallen branches). Only fresh or almost fresh new spraints with wet and soft consistency (Mason and Macdonald, 1987) were collected individually into plastic bags, sealed, labelled, and stored in a freezer (−18 °C). After being thawed, each spraint was soaked in a mixture of water and soapy detergent until the lumps lost their compactness. Remaining hard parts were washed through sieve (mesh size 0.5 mm) several times to remove any remaining contaminants or detergent, then dried at room temperature. All recognizable remains (fish diagnostic bones, fish scales, non-fish parts) were separated and analysed under a stereo microscope (magnification 8–16×). Fish species were identified to the lowest possible taxonomic level based on morphological differences of diagnostic bones (*os pharyngeum*, *maxillare*, *dentale*, *intermaxillare*, *operculare*, *praeoperculare*, *praevomer*). The diagnostic bones were measured to the nearest 0.1 mm and paired whenever possible. The number of individuals represented in a spraint was determined by the highest total of any identifiable parts present after pairing. Our own collection of diagnostic bones was used to determine original size of damaged bones. Estimated original fish length ($L_T$, *longitudo totalis* in cm) was calculated from the length of diagnostic bones using length–length equations from the work of Čech et al. (2008), Čech and Vejřík (2011), Čech and Čech (2013). Estimated original fish weight was calculated from the ($L_T$) using length–weight equations from the same sources. Amphibians were identified by examination of skeletal parts (*maxillare* and *tibiofibula*). Remains of chitinous external skeletons were used to identify crayfish. The number of amphibian and crayfish individuals in a spraint was determined by the highest number of identifiable parts present after pairing. Total weight of amphibians and crayfish was estimated using average weight of individuals previously caught on Chotýšanka stream (43 g for frog *Rana* spp. and 51 g for crayfish *Astacus fluviatilis*). For frequency of occurrence calculation, each identified prey item was, after pairing, considered as one occurrence. Otter diet was expressed as % Frequency of Occurrence (%FO) following this method: % FO = the number of spraints with occurrence of certain prey item, divided by the total number of spraints examined, multiplied by 100.

### 2.3 Statistical analysis

A statistical programme R (R version 3.2.5, R Development Core Team, 2016) was used for statistical analyses. Shapiro–Wilk test was used to test the distribution of estimated fish lengths and weights in otter diet. Pearson's chi-square test was used to test the difference in proportion of fish species in the diet (contingency table 1 × 12), and to test the difference in proportion of fish species in catches of anglers and in the diet of otters (contingency table 2 × 12), using relative frequency of fish species. A 95% confidence interval for frequency and estimated biomass of each individual species in otter diet was calculated using bootstrap analysis (based on content of individual spraints), comparing 1000 bootstrap samples, generated by R programme. Overlap between otter diet and catches of anglers was calculated using Pianka's index (range 0–1; Pianka and Pianka, 1976, Cupples et al., 2011), comparing relative frequency and estimated biomass of fish species in otter diet to relative frequency and estimated biomass of fish species in overall catches of anglers, respectively. Minimum probability level of $p < 0.05$ was accepted for all the statistics, and all *p*-values are two-tailed.

## 3 Results

During winter 2005/2006, 279 otter spraints were found exclusively on kilometres (3.0–5.5) and (7.5–11.7) of the stream (Fig. 1, Table 2). Those spraints included 2731 diagnostic elements which gave 1532 individual fish, 54 frogs, and 9 crayfish after pairing.

Fish dominated otter diet in this area (85% of estimated biomass). The overall fish diet of otter was composed of 12 fish species belonging to 5 families (Table 3). Gudgeon *Gobio*

**Table 3.** Overall diet of Eurasian otter *Lutra lutra* on Chotýšanka stream (Chotýšanka 1, fishery no. 413 006) in winter 2005/2006: *n*, total number of individuals identified in the spraints; %*n*, percentage of frequency; 95% CI (%*n*), 95% confidence interval on percentage by frequency; *b* [g], estimated biomass identified in the spraints [g]; %*b*, percentage of estimated biomass; 95% CI (%*b*), 95% confidence interval on percentage by estimated biomass; %FO, frequency of prey occurrence; *L* mean, mean fish length [cm]; *L* min–max, minimum–maximum fish length [cm]; *W* mean, mean fish weight [g]; *W* min–max, minimum–maximum fish weight [g]; N/A, data not available.

| Species | *n* | %*n* | 95% CI (%*n*) | *b* [g] | %*b* | 95% CI (%*b*) | %FO | *L* mean | *L* min–max | *W* mean | *W* min–max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cyprinidae** | | | | | | | | | | | |
| Bleak (*Alburnus alburnus*) | 4 | 0.3 | 0.0–0.5 | 2 | 0.0 | 0.0–0.2 | 1.4 | 5.1 | 4.0–6 | 0.6 | 0.2–0.9 |
| Common carp (*Cyprinus carpio*) | 14 | 0.9 | 0.7–1.1 | 2926 | 15.7 | 5.1–26.7 | 5.0 | 16.9 | 5.5–45 | 209.0 | 2.4–1736 |
| Common dace (*Leuciscus leuciscus*) | 2 | 0.1 | 0.0–0.1 | 10 | 0.1 | 0.0–0.1 | 0.7 | 8.6 | 8.4–9 | 4.9 | 4.5–5.4 |
| European chub (*Squalius cephalus*) | 95 | 6.0 | 4.8–7.4 | 2508 | 13.4 | 12.3–14.5 | 23.8 | 10.9 | 2.9–30 | 26.4 | 0.2–250 |
| Gudgeon (*Gobio gobio*) | 1331 | 83.4 | 79.2–86.7 | 7041 | 37.7 | 34.9–41.3 | 100.0 | 7.8 | 3.1–16 | 5.3 | 0.2–35 |
| Roach (*Rutilus rutilus*) | 12 | 0.8 | 0.5–0.9 | 378 | 2.0 | 1.8–2.6 | 4.3 | 12.5 | 7.1–28 | 31.5 | 3.3–210 |
| Stone moroko (*Pseudorasbora parva*) | 14 | 0.9 | 0.4–1.3 | 22 | 0.1 | 0.1–0.1 | 5.0 | 6.2 | 5.0–8 | 1.6 | 0.8–2.3 |
| **Salmonidae** | | | | | | | | | | | |
| Brown trout (*Salmo trutta* m. *fario*) | 27 | 1.7 | 1.3–2.1 | 415 | 2.2 | 1.7–2.8 | 9.7 | 12.2 | 8.6–18 | 15.4 | 4.6–45.7 |
| Rainbow trout (*Oncorhynchus mykiss*) | 7 | 0.4 | 0.2–0.7 | 2082 | 11.1 | 4.8–17.5 | 2.5 | 33.1 | 32–34 | 297.0 | 250–323 |
| **Percidae** | | | | | | | | | | | |
| European perch (*Perca fluviatilis*) | 14 | 0.9 | 0.5–1.4 | 473 | 2.5 | 2.0–2.9 | 5.0 | 13.4 | 8–18 | 33.8 | 5.5–69 |
| **Balitoridae** | | | | | | | | | | | |
| Stone loach (*Barbatula barbatula*) | 9 | 0.6 | 0.2–0.9 | 42 | 0.2 | 0.1–0.3 | 3.2 | 8.2 | 6–10 | 4.7 | 1.7–7.6 |
| **Cottidae** | | | | | | | | | | | |
| Bullhead (*Cottus gobio*) | 3 | 0.2 | 0.0–0.4 | 15 | 0.1 | 0.0–0.2 | 1.1 | 7.4 | 6.9–8 | 4.9 | 3.8–6.5 |
| **Non-fish** | | | | | | | | | | | |
| Frogs (*Rana* spp.) | 54 | 3.4 | 2.8–4.1 | 2322 | 9.6 | 8.0–11.0 | 14.9 | N/A | N/A | 43.0 | N/A |
| Crayfish (*Astacus fluviatilis*) | 9 | 0.6 | 0.2–1.0 | 459 | 2.5 | 0.1–4.3 | 3.2 | N/A | N/A | 51.0 | N/A |
| Total | 1595 | 100.0 | – | 18695 | 100.0 | – | – | 8.4 | 2.9–45 | 10.4 | 0.2–1736 |

*gobio* was the most commonly consumed species. The most important fish families were cyprinids (Cyprinidae), followed by salmonids (Salmonidae) and percids (Percidae). Majority of fish eaten were smaller than 10 cm and lighter than 10 g (78.5% and 79.4%, respectively; Figs. 2 and 3). Fish of medium or high angling value made up 10% in overall otter diet by frequency of fish species and 45% by estimated biomass of fish species (Table 4). Otters consumed fish with average length of 8.4 cm (95% confidence interval: 8.2–8.6) and average weight of 10.4 g (95% confidence interval: 7.7–13.1).

Non-fish prey consisted of native frogs *Rana* spp. and native crayfish *A. fluviatilis*.

Shapiro–Wilk test showed that neither the length nor the weight of fish consumed by otters have normal distribution; for length ($W = 0.80$, $p < 0.001$) and for weight ($W = 0.11$, $p < 0.001$). Gudgeon was consumed at disproportionally higher rate than other species by frequency (chi-squared = 1915.3, d.f. = 11, $p < 0.001$).

Anglers took different fish species in years 2005–2006 than otters did during winter 2005/2006 by frequency (chi-squared = 191.31, d.f. = 11, $p < 0.001$). Anglers took fish with average weight of 290 g; otters took fish with average weight of 10.4 g. In otter diet, brown trout *S. trutta* m. *fario* made up 1.7% by frequency (95% confidence interval: 1.3–2.1%) and 2.2% by estimated biomass (95% confidence interval: 1.7–2.8%), and rainbow trout *O. mykiss* made up 0.4% by frequency (95% confidence interval: 0.2–0.7%) and 11.1% by estimated biomass (95% confidence interval 4.8–17.5%). Dietary overlap between otter diet and catches of anglers was low ($I = 0.07$) for frequency of fish species and moderate ($I = 0.30$) for estimated biomass of fish species.

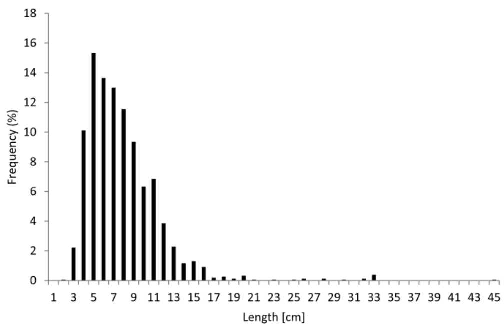


**Fig. 2.** Frequency distribution of estimated length ($L_T$) of all fish ($n = 1532$) consumed by Eurasian otter *Lutra lutra* on Chotýšanka stream in winter 2005/2006.

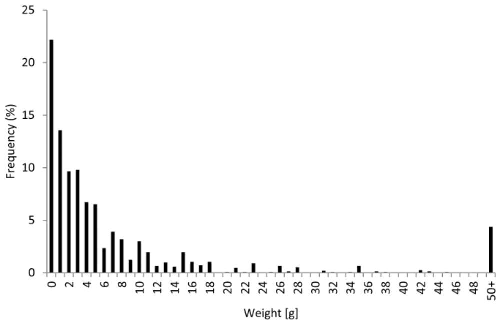


**Fig. 3.** Frequency distribution of estimated weight of all fish ($n = 1532$) consumed by Eurasian otter *Lutra lutra* on Chotýšanka stream in winter 2005/2006. *X*-axis: the value 0 represents fish with weight under 0.5 g; the value 50+ represents fish with weight 50 g and more.

**Table 4.** Overall fish diet of Eurasian otter *Lutra lutra* on Chotýšanka stream (Chotýšanka 1, fishery no. 413 006) in winter 2005/2006: value, the value of fish species to anglers (high – salmonids, common carp *Cyprinus carpio*; medium – European chub *Squalius cephalus*, European perch *Perca fluviatilis*; none – other fish species included in Table 3); %*n*, percentage of frequency; %*b*, percentage of estimated biomass.

| Value | %*n* | %*b* |
|---|---|---|
| High | 3 | 29 |
| Medium | 7 | 16 |
| None | 86 | 40 |

## 4 Discussion

Winter diet of otter on Chotýšanka stream was dominated by fish. That is common for otters, regardless of habitat type (Erlinge, 1969; Kruuk and Moorhouse, 1990; Carss, 1995; Jedrzejewska et al., 2001; Kruuk, 2006; Lanszki and Sallai, 2006; Krawczyk et al., 2016). Amphibians and crayfish are the most important non-fish prey in temperate areas (Jedrzejewska et al., 2001; Chanin, 2003). Lower number of fish species in otter diet is common for smaller rivers and streams, especially in comparison to coastal areas or areas with combination of ponds and/or rivers and/or streams (Harna, 1993; Gourvelou et al., 2000; Marques et al., 2007; Kortan et al., 2010). It is mainly caused by lower species diversity in the environment (Jedrzejewska et al., 2001). On Chotýšanka, the upstream pond was fenced and guarded by German Shepherd dogs, which disallows otters to diversify their diet by hunting pond fish (Britton et al., 2005), although some cyprinids and percids could penetrate into the stream from the pond through its outlet.

Gudgeon *G. gobio* was the dominant prey item in otter diet in this area. Otters somewhat prefer smaller fish that they can consume directly in the water (Roche et al., 1995; Jurajda et al., 1996; Lanszki et al., 2015), which makes gudgeon an optimal prey, as it is both small-growing and very abundant in this area (Czech Anglers Union, unpubl. data). Majority of fish consumed by otters are small (Kruuk et al., 1993), especially on small streams with a lack of larger fish (Lanszki et al., 2009; Kortan et al., 2010; Almeida et al., 2012). Exceptions for this rule do exist (Carss et al., 1990), especially within pond complexes stocked with larger fish (Adámek et al., 2003; Britton et al., 2005; Kortan et al., 2007; Almeida et al., 2012).

One large carp (1736 g, identified from large scales) was found in otter diet. With average daily food intake being 0.75–1.5 kg per adult otter (Kruuk, 1995), otters sometimes catch larger fish that they cannot consume completely (Adámek et al., 2003; Kortan et al., 2007; Lanszki et al., 2015). Unlike fish-eating birds (e.g. the Great cormorant *Phalacrocorax carbo*), otters do not have to swallow their prey whole. They can use teeth and claws to tear the prey to smaller pieces and bite out only the soft tissue, allowing them to prey upon larger fish. Head parts of larger fish are sometimes not consumed, so diagnostic bones of those fish can be missing in the spraint, leading to underestimation of larger fish in the diet. This is mainly true for fish with higher weight than the daily food intake of otter; those are mostly being exploited at times of food shortage (Kortan et al., 2007). Stocked rainbow trout consumed by otters weighted 200–400 g, which is less than the daily food intake of otter, so those should be consumed whole.

Otters consumed less salmonid than what is expected on trout streams, especially considering the fish stocking (Carss et al., 1990; Kožená et al., 1992; Harna, 1993; Ludwig et al., 2002; Jacobsen, 2005; Kortan et al., 2010). On Chotýšanka stream, the goal of brown trout *S. trutta* m. *fario* stocking is to establish a prospering population in the stream (Czech Anglers Union, pers. comm.). Rainbow trout *O. mykiss* is being stocked for angling purposes only, being the main target for anglers. Only brown trout with size 9–18 cm and rainbow trout with size 32–34 cm were identified in otter diet, which corresponds well with the size of stocked trout. Otters did not catch any trout outside of the stocked size. Otters could be prioritizing stocked trout in winter (Ludwig et al., 2002; Jacobsen, 2005), mostly because fish stocking usually occurs in autumn, lower water temperature favours endothermic predator over its ectothermic prey, and anti-predator behaviour is poorly developed in hatchery-reared fish (Maynard et al., 1995). In warmer months, otters could be partially ignoring salmonids, mostly because those are faster swimmers than cyprinids (Erlinge, 1968). Salmonids are being taken from fish farms more than from trout streams (Ludwig et al., 2002). Stocked salmonids are being preferably taken on streams with existing salmonid populations (Jacobsen, 2005). For otters, availability of salmonids may be more important than salmonid abundance. Otters frequently prey upon adult migrating Atlantic salmon *Salmo salar* (Carss et al., 1990; Kortan et al., 2010) and juvenile salmon and trout (Kruuk et al., 1993). Mink *Mustela vison* was found responsible for increased mortality of salmon and trout parr in small Norwegian streams (Heggenes and Borgstrom, 1988).

Otters took different fish species of different sizes than anglers did. While otters were mostly interested in small-growing fish species with medium or no angling value, anglers were mainly interested in salmonids, European chub *S. cephalus*, and other large-growing species. The dietary overlap index was significantly different when calculated and compared for frequency of fish species and for estimated biomass of fish species. Dietary overlap was low for frequency, but moderate for estimated biomass. Otters took very different fish species than anglers by frequency, but the difference was lower for estimated biomass. Similarly, otters seemed to feed mostly on fish of no angling value by frequency, but the amount of fish of medium and high angling value was higher for estimated biomass. Anglers took bigger fish than otters did, mostly because only salmonids bigger than 25 cm $L_T$ can be legally taken. European chub can be taken at all sizes on trout streams, but anglers took mostly larger individuals. Accidental catches of undersized fish are not recorded by anglers; those fish are returned to the stream after being caught. All rainbow trout consumed by otters were of catchable size for anglers (>25 cm $L_T$); all brown trout consumed by otters were undersized for anglers (<25 cm $L_T$). On streams and rivers, otters were observed to prey upon economically unimportant fish species (Lanszki and Sallai, 2006). The differences in catches of fish between fishermen and otters are usually lower within pond systems with high concentration of stocked fish like common carp *C. carpio* or other large-growing species with high commercial value (Adámek et al., 2003; Kortan et al., 2007; Marques et al., 2007). Fish in small water basins with no hideouts are especially vulnerable to otter predation (e.g. Kortan et al., 2007), but even in these conditions, otters still avoid fish heavier than 1 kg (Lanszki et al., 2001).

## 5 Conclusion

Otters took different fish species of different sizes than anglers did. Otters preyed mostly upon small-growing species of medium or no value to anglers, although stocked and highly valued salmonids were consumed as well. Anglers took a low variety of large-growing fish species of medium or high angling value. Therefore, the difference in catches of fish between otters and anglers was high. We studied the difference in catches of fish during one winter season on one lowland stream with salmonid stocking and a limited number of otters inhabiting the area (one to three otters). In order to better understand the differences in catches of fish between anglers and otters on a larger scale, more studies need to be performed on streams, rivers, and lakes where fish stocking is a common practice. We suggest that a study should be carried out, comparing more different freshwater habitats with stocking of different fish species from different families (e.g. salmonids, cyprinids, esocids, and percids) in different geographical areas for a longer time period.

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# The effect of cormorant predation on newly established Atlantic salmon population

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**Abstract.** This study aimed to describe the effect of cormorant predation on newly established Atlantic salmon, *Salmo salar*, population in three nursery streams in the upper Elbe River basin (Czech Republic). Salmon have been annually stocked into the nursery streams since 1998 as part of a salmon reintroduction programme. Salmon parr density in nursery streams was 3-81 fish per 100 $m^2$. Only thirteen adult salmon were observed in the study area during two years of research. Altogether 912 cormorant pellets were collected, 5482 diagnostic bones were analysed, and 3915 fish were identified in the diet. Cormorant diet was composed of 24 fish species from six families but no salmon were consumed. The salmon stocking programme produces a reasonable amount of smolts but return rates of adults are very low. The cause of low return rates is not cormorant predation on nursery streams but, most likely, a low survival rate on the passage downstream. We suggest that more studies should focus on monitoring of survival and return rates of salmon in the upper River Elbe to ensure that, in the future, the salmon reintroduction programme will be really successful.

**Key words:** fish reintroduction, hatchery-reared fish, pharyngeal bones, *Salmo salar*, Salmon 2000, the upper Elbe River basin

## Introduction

The Atlantic salmon, *Salmo salar* L. 1758, is a native European anadromous fish species. It used to be one of the most important fish species in recreational and commercial fisheries in Europe (Frič 1893). Salmon used to be abundant across Northern, Western, and Central Europe. During the 20th century, salmon populations have declined in the whole Europe. The population in the Elbe River basin perished completely. The main reason was river fragmentation but other factors such as presence of diseases and parasites, predation, climate change, water pollution, overfishing, and losses of spawning habitats were also important (Frič 1893, Parrish et al. 1998, Jonsson & Jonsson 2004, Wolter 2015). Recently, salmon reintroduction has become one of the main goals in environmental protection and fisheries management in Europe (see European Habitats Directive). Salmon reintroduction has already been somewhat successful in several European countries where new salmon populations have been established (Wolter 2015). Czech populations perished about 60 years ago and salmon is now listed as critically endangered species. In year 1998, a new salmon reintroduction programme named "Salmon 2000" was founded (Kortan et al. 2010). The goal of this programme is to establish a thriving salmon population in the upper Elbe River basin (Benda & Šmíd 2002, Wolter 2015).

The great cormorant, *Phalacrocorax carbo* L. 1758, is one of the most important piscivorous predators in European freshwater ecosystems (Keller 1995, Suter 1997, Čech et al. 2008). Cormorants are opportunistic predators and are able to quickly adapt to new sources of prey (Keller 1995, Suter 1997, Leopold et al. 1998, Emmrich & Duttmann 2011). It has been stated that bird predation can be a significant source of salmon mortality (Jepsen et al. 1998, Mather 1998, Koed et al. 2002, 2006, Ibbotson et al. 2011). Previous research suggested that stocked fish are especially vulnerable to bird predation (Jonsson et al. 1991, Maynard et al. 1994, Christensen 1996, Eklov & Greenberg 1998, Dieperink et al. 2001). Stocked salmon could therefore serve as easy prey for cormorants (Jackson & Brown 2011, Salvanes 2017). The effect of cormorant predation on newly established salmon population in the area of the upper River Elbe has not been studied yet. It is important to assess any obstacles that could prevent the reintroduction programme from being successful.

This study had three aims: firstly, to assess lengths and density of salmon parr in nursery streams; secondly, to assess numbers and lengths of adult salmon in nursery

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streams; thirdly, to discover the effect of cormorant predation on salmon parr in nursery streams. We expected that stocked salmon juveniles survive and grow in nursery streams. We also expected that a significant number of adult salmon would be observed in nursery streams. Lastly, we expected to find remains of a few salmon in cormorant pellets.

## Material and Methods

*Study area*

Cormorant pellets were collected during winters 2014/2015 and 2015/2016 from cormorant roosting places at the upper River Elbe (Velké Březno, North Bohemia, Czech Republic, 100 km north of Prague, 50°40′34.2″ N, 14°07′28.5″ E) (Fig. 1). Cormorants roosted in this area from October to April. About 100 cormorants roosted in the area in October. The numbers increased to approximately 500 birds in November and remained constant till February. Then the numbers dropped to approximately 100 birds in March and April. All birds were gone by May (Agency of Nature and Landscape Protection, unpublished data).

Salmon stocking was conducted on three nursery streams: the River Kamenice (angling ground no. 443 015, 50°50′15.1″ N, 14°21′16.9″ E), the Ještědský stream (angling ground no. 443 501, 50°42′30.5″ N, 14°47′58.0″ E), and the Liboc stream (angling ground no. 443 062, 50°17′02.8″ N, 13°15′47.6″ E). All three nursery streams are located in the Elbe River basin (Fig. 1).

Groups of 10-30 cormorants were observed hunting on the River Kamenice in both winters 2014/2015 and 2015/2016 (Czech Fishing Union, unpublished data). The River Kamenice enters the River Elbe 24 km downstream from the roosting colony (air distance). In contrast, no cormorants were observed on the Ještědský stream or on the Liboc stream (Czech Fishing Union, unpublished data). The Ještědský stream is situated 47 km from the colony where it enters the River Ploučnice (in Stráž pod Ralskem). The River Ploučnice then enters the River Elbe 13 km downstream from the colony (in Děčín). The Liboc stream is situated 58 km from the colony where it enters the River Ohře (in Žatec). The River Ohře then enters the River Elbe 16 km upstream from the colony (in Litoměřice). According to the work of Platteeuw & van Eerden (1995), Grémillet & Argentin (1998), and Carss & Ekins (2002) most of the River Kamenice, lower River Ploučnice, and lower River Ohře are well in the reach of the roosting colony of cormorants in Velké Březno (Fig. 1). The studied colony was the largest cormorant colony in the North Bohemia. No other permanent colonies were identified in the study area (Agency of Nature and Landscape Protection, unpublished data).

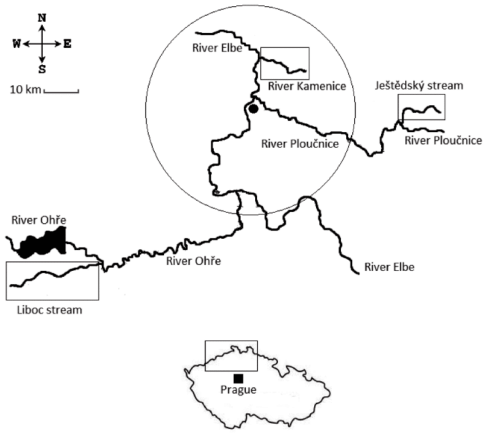


**Fig. 1.** Map of the study area with location of the cormorant colony (full black circle), estimated reach of cormorants roosting in the study area (wide black circle), the River Kamenice, the Ještědský stream, and the Liboc stream (black rectangles).

**Table 1.** The numbers of Atlantic salmon stocked into nursery streams (the River Kamenice, the Ještědský stream, and the Liboc stream) in the Czech Republic during years 2014 and 2015. Note: fry (n), the number of stocked salmon fry (standard length 20-30 mm); parr (n), the number of stocked salmon parr (standard length 80-100 mm). Numbers (n) are in thousands of fish.

| Location | Date | fry (n) | parr (n) |
|---|---|---|---|
| River Kamenice | 14 April 2014 | 120 | 0 |
| River Kamenice | 15 Nov 2014 | 0 | 10 |
| Ještědský stream | 14 April 2014 | 40 | 0 |
| Liboc stream | 14 April 2014 | 40 | 0 |
| River Kamenice | 17 April 2015 | 140 | 0 |
| River Kamenice | 16 Nov 2015 | 0 | 5 |
| Ještědský stream | 17 April 2015 | 20 | 0 |
| Liboc stream | 17 April 2015 | 20 | 0 |
| Total | | 380 | 15 |

*Cormorant diet analysis*

Cormorant pellets were used for diet analysis. Pellets were collected monthly during November-April in winters 2014/2015 and 2015/2016. At least 50 pellets were collected during each visit. Pellets were collected individually into plastic bags and frozen (–18 °C). After defrosting in the laboratory, each individual pellet was soaked in a solution of hot water (300 ml, 50 °C) and Na(OH) (15 g, 1 M, 97-99 %). Remaining hard parts were washed through a sieve (0.5 mm mesh size) and separated under a stereo microscope (8-16 × magnification). Fish species were identified based on morphological differences of the following fish parts: *os maxillare*, *intermaxillare*, *dentale*, *pharyngeum*, *operculare*, *praeoperculare*, *cleithrum*, *basioccipitale*, *praevomer*, and chewing pads (Carss & Marquiss 1999, Čech et al. 2008, Čech & Vejřík 2011, Čech & Čech 2017, Lyach & Čech 2017).

*Salmon stocking*

Salmon stocking was conducted exclusively on three nursery streams – the River Kamenice, the Ještědský stream, and the Liboc stream (Czech Fishing Union, unpublished data). Salmon stocking is a part of a salmon reintroduction programme named "Salmon 2000". The goal of this programme is to establish a thriving salmon population in the upper Elbe River basin. For this purpose, about 40000-80000 fish have been stocked annually since year 1998. About 400000 fish with total estimated weight of 145 kg were stocked in years 2014 and 2015 (Table 1). Salmon fry (standard length 20-30 mm) and salmon parr (standard length 80-100 mm) were stocked. Salmon spawn originated from fish in the River Götaälv and the River Ätran (western Sweden). Fish from those rivers are genetically related to the extinct salmon population in the upper Elbe River basin (Zahn et al. 2009). Higher survival rates were expected because the populations are genetically close (McCormick et al. 1998). Stocked fish were reared in a hatchery near Langburkersdorf (East Germany) and transported to the Czech Republic in polyethylene bags. Each bag had a volume of 80 l and contained 20 l of water and 60 l of oxygen-enriched air. About 5000 fish were transported in one bag. Salmon fry were released into all three nursery streams during spring. Salmon parr were released into the River Kamenice during autumn. The stocking was conducted by fisheries experts from the Czech Fishing Union and the National Park Bohemian Switzerland. Following the methodology previously published by Crisp (1995) and McMenemy (1995), fish were released in widely dispersed small groups on spots where the flow was slow and the stream was shallow.

*Electrofishing surveys*

All three nursery streams were surveyed by electrofishing. A 100 m section was surveyed each time. The nursery streams were surveyed in spring 2014 to assess fish survival and then in autumns

**Table 2.** Results of electrofishing surveys conducted on nursery streams where Atlantic salmon was stocked in years 2014 and 2015. Note: n, number of fish individuals; %n, percentage share on fish community; SL mean min-max (mm), mean min-max standard length (mm); density, density of fish per 100 m$^2$.

| | | Atlantic salmon *Salmo salar* | | | | brown trout *Salmo trutta* | | | | Total fish | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | n | %n | SL mean min-max (mm) | Density | n | %n | SL mean (mm) | Density | n | Density |
| River Kamenice | | | | | | | | | | | |
| section 1 | 13 Apr 2014 | 3 | 14 | 97 (95-99) | 3 | 9 | 43 | 157 | 9 | 21 | 21 |
| section 2 | 13 Apr 2014 | 22 | 30 | 98 (90-152) | 10 | 33 | 45 | 132 | 15 | 73 | 33 |
| section 1 | 28 Sept 2014 | 35 | 21 | 82 (70-152) | 16 | 99 | 58 | 76 | 45 | 170 | 78 |
| section 2 | 29 Sept 2014 | 49 | 29 | 82 (80-162) | 23 | 92 | 54 | 84 | 43 | 170 | 80 |
| section 1 | 27 Sept 2015 | 58 | 35 | 93 (70-156) | 27 | 69 | 42 | 128 | 32 | 164 | 76 |
| section 2 | 27 Sept2015 | 17 | 13 | 116 (90-160) | 8 | 89 | 67 | 144 | 42 | 133 | 63 |
| Ještědský stream | | | | | | | | | | | |
| section 1 | 8 June 2014 | 36 | 58 | 84 (71-115) | 17 | 23 | 37 | 158 | 11 | 62 | 29 |
| section 2 | 8 June 2014 | 72 | 57 | 92 (88-126) | 33 | 43 | 34 | 163 | 20 | 127 | 58 |
| section 3 | 1 June 2014 | 31 | 26 | 101 (84-110) | 14 | 76 | 64 | 169 | 34 | 119 | 54 |
| section 1 | 6 Sept 2015 | 21 | 31 | 82 (62-100) | 9 | 36 | 54 | 158 | 15 | 67 | 29 |
| section 2 | 6 Sept 2015 | 35 | 35 | 91 (85-95) | 15 | 41 | 41 | 166 | 18 | 101 | 43 |
| section 3 | 13 Sept 2015 | 47 | 34 | 96 (73-127) | 23 | 62 | 45 | 161 | 30 | 137 | 67 |
| Liboc stream | | | | | | | | | | | |
| section 1 | 3 Aug 2014 | 68 | 39 | 54 (50-64) | 33 | 20 | 11 | 130 | 10 | 176 | 85 |
| section 1 | 27 Sept 2014 | 80 | 33 | 107 (97-124) | 39 | 43 | 17 | 247 | 21 | 246 | 120 |
| section 1 | 28 Sept 2015 | 164 | 42 | 109 (99-127) | 81 | 31 | 8 | 138 | 15 | 390 | 193 |

Table 3. The numbers of adult Atlantic salmon observed in the River Kamenice in years 2014 and 2015. Note: n, number of fish; TL (cm), total length (cm); N/A, data not available.

| Date | n | TL (cm) |
|---|---|---|
| 28 October 2014 | 1 | 80 |
| 3 October 2014 | 1 | 80 |
| 1 November 2014 | 1 | 80 |
| 2 November 2014 | 1 | 80 |
| 23 November 2014 | 3 | 80-90 |
| 30 October 2015 | 2 | N/A |
| 30 October 2015 | 1 | 94 |
| 6 November 2015 | 1 | N/A |
| 8 November 2015 | 2 | N/A |

2014 and 2015 to assess fish abundances, densities, and sizes. On the River Kamenice, two sections were surveyed using a portable motorized EFG electrofishing device. On the Ještědský stream, three sections were surveyed using a battery-powered device type Lena 1. On the Liboc stream, one section was surveyed using a battery-powered electrofishing device type Lena 2. Captured fish were determined to species level, measured, and released.

*Adult salmon observations*

Data regarding observations of salmon adults were provided by the Czech Fishing Union, the National Park Bohemian Switzerland, and the Elbe River Authority. Any person who provides a proof of adult salmon observation (a photo or a video footage) is awarded with a free fishing permit for one year. The Czech Fishing Union was also monitoring the nursery streams and the River Elbe for signs of salmon. Observed adult salmon individuals were measured when possible; otherwise, the total length of salmon was estimated from the bank.

*Statistical analysis*

The statistical programme R (R version 3.3.2., R Development Core Team 2016) was used for statistical analysis. Shapiro-Wilk test was used for analysis of distribution of salmon lengths. Wilcoxon test was used to compare lengths of stocked and surveyed fish. Minimum probability level of $p = 0.05$ was accepted for all statistics, and all $p$ values are two-tailed.

## Results

Electrofishing surveys revealed that salmon parr were present in all three nursery streams. Salmon parr density was 3-81 fish per 100 $m^2$. Nursery streams were dominated by brown trout, *Salmo trutta*. Salmon was the second most abundant fish species in the nursery streams (Table 2). Other fish and fish-like species discovered in the nursery streams were the following: bullhead, *Cottus gobio*, stone loach, *Barbatula barbatula*, brook lamprey, *Lampetra planeri*, grayling, *Thymallus thymallus*, European chub, *Squalius cephalus*, European eel, *Anguilla anguilla*, and gudgeon, *Gobio gobio*.

Salmon lengths were not normally distributed (Shapiro-Wilk: n = 738, $p < 0.01$). Surveyed salmon were significantly larger than stocked salmon; this was true for the River Kamenice in autumn 2014 (Wilcoxon: n = 130109, W = 142, $p < 0.01$) and 2015 (Wilcoxon: n = 145075, W = 8804, $p < 0.01$), for the Ještědský stream in autumn 2014 (Wilcoxon: n = 60139, W = 0, $p < 0.01$) and 2015 (Wilcoxon: n = 20103, W = 0, $p < 0.01$), and for the Liboc stream in autumn 2014 (Wilcoxon: n = 40148, W = 0, $p < 0.01$) and 2015 (Wilcoxon: n = 20164, W = 0, $p < 0.01$). Stocked salmon were 20-30 mm and 80-100 mm long (standard length); recorded salmon were 50-162 mm long (standard length) (Table 2).

Only thirteen adult salmon were reported in the River Kamenice during years 2014 and 2015 (Table 3), while no such records were registered in any of both Ještědský and Liboc streams.

Altogether 912 cormorant pellets were collected during winters 2014/2015 and 2015/2016. Together 5482 diagnostic bones were found in the pellets. From those diagnostic bones, together 3915 fish were identified. The overall cormorant diet was composed of 24 fish species from six families. No salmon were identified in cormorant diet.

## Discussion

We discovered that the salmon stocking programme produces a reasonable amount of smolts in individual streams/rivers involved in "Salmon 2000" programme but return rates of adult fish are very low. Ecological conditions in nursery streams were comparable to conditions in similar streams where functional salmon populations exist (Prevost et al. 1992, Jutila et al. 2006, Descroix et al. 2009, Johansen et al. 2010). Presence of other pollution-intolerant fish species (e.g. brown trout, bullhead) was a sign of good ecological conditions in the nursery streams (Weatherley et al. 1995, Geist et al. 2006, Horká et al. 2017). Salmon density was a bit lower than what is considered average but the lower density was somewhat helpful since juvenile salmon display territorial behaviour (Gibson 1966, 1993, McMenemy 1995, Rosengren et al. 2017). Historically, numbers of returned salmon adults were significantly higher in the upper River Elbe and in other rivers in Central and Northern Europe (Frič 1893, Aarestrup et al. 1999, Lajus et al. 2005, Breve et al. 2014, Wolter 2015). Recently, low numbers of salmon are most likely caused by relatively low number of juveniles stocked into a low number of nursery streams (only three streams/rivers in case of the whole upper River Elbe; North Atlantic Salmon Conservation Organisation 2017).

Previous research suggested that migrating smolts are subjected to heavy predation from piscivores (Mather 1998, McCormick et al. 1998, Breve et al. 2014). During smolt run, migrating smolts get killed, delayed, and disoriented by hydropower plants, dams, and weirs (Larinier 1998, McCormick et al. 1998, Aarestrup & Koed 2003, Larinier 2008, Thorstad et al. 2008, Breve et al. 2014). There are two large weirs situated on the River Elbe: the Geesthacht weir (Germany) and the Střekov weir (Czech Republic; causing a potential problem to only the Ohře River basin salmon population). Both weirs have functional fish passes that should allow small and large fish to pass through (Prchalová et al. 2011, Adam et al. 2012, Menzel & Schwevers 2012). Unfortunately, previous research suggested that fish passes can be ineffective (Larinier 1998, Chanseau et al. 1999). Furthermore, migrating salmon smolts suffer from high mortality in estuaries (McCormick et al. 1998, Koed et al. 2006). Anglers and poachers usually catch some adult salmon as well (North Atlantic Salmon Conservation Organisation 2017).

We discovered that the cause of low salmon return rates into the upper River Elbe was definitely not cormorant predation on nursery streams. Cormorants were absent in two out of three of these nursery streams and salmon remains were not identified in regurgitated pellets at nearby cormorant roosting colony. The absence of cormorants in the nursery streams greatly limited predatory impact of cormorants on the salmon population. It is possible that some cormorants caught a small amount of salmon but pellets of those specific birds were not found; Jepsen et al. (2010) discovered that a single cormorant can consume high amount of salmon individuals when the bird locates a salmon school.

Previous research suggested that overwintering cormorants display different diurnal behaviour than salmon parr. In colder temperatures, salmonid juveniles are usually active during night in order to avoid endothermic predators (Fraser et al. 1993, Heggenes et al. 1993). Inversely, cormorants are diurnal predators that mainly feed on diurnally active prey (McCormick et al. 1998).

Our results also suggest that migrating cormorants mostly miss the main smolt run in this area. Other authors claim that smolt run usually occurs from April to June (Blackwell et al. 1997, Rosengren et al. 2017). We observed that flocks of overwintering cormorants leave the upper River Elbe area in April (most birds prior the end of March; M. Čech, R. Lyach, pers. observ.).

We suggest that cormorants in our study area did not prey upon salmon because biomass of other fish in the environment was much higher than biomass of stocked salmon. Total biomass of stocked salmon was 145 kg while biomass of other fish in most streams and rivers in the area usually equals to 250-300 kg per hectare, in eutrophic the River Elbe even exceeds this boundary (Czech Fishing Union, unpublished data). Biomass of stocked salmon was therefore almost negligible when compared to biomass of other fish. Previous research suggested that frequency of salmon in cormorant diet is usually positively correlated to salmon abundance and availability in the environment (Warke & Day 1995, Blackwell et al. 1997). Many authors discovered that cormorants usually prey upon the most abundant and available shoaling fish species (Keller 1995, Suter 1997, Čech et al. 2008, Čech & Vejřík 2011, Emmrich & Duttmann 2011). In case of this study, the upper Elbe River basin is dominated by shoaling cyprinids (Prchalová et al. 2011, Horký et al. 2013, Valová et al. 2014). On the other hand, salmon are definitely an attractive prey for cormorants – salmon parr and smolts are usually 3-25 cm long (Ibbotson et al. 2011) and cormorants often prey upon fish of this size (Keller 1995, Suter 1997, Čech et al. 2008, Emmrich & Duttmann 2011).

Several previous studies showed similar results as our study (Harris et al. 2008, Bostrom et al. 2009). On the other hand, different studies reported heavy cormorant predation on salmon (Warke & Day 1995, Blackwell et al. 1997, Jepsen et al. 1998, Koed et al. 2006, Jepsen et al. 2010). Researchers suggested that heavy cormorant predation on stocked salmon is mainly caused by high vulnerability of stocked fish to bird predation (Jonsson et al. 1991, Maynard et al. 1994, Christensen 1996, Eklov & Greenberg 1998, Dieperink et al. 2001, Jackson & Brown 2011, Salvanes 2017). In those scenarios, stocked fish frequently served as easy prey.

Previous studies confirmed that diagnostic bones of salmonids can be retrieved from cormorant pellets (Suter 1995, Carss & Marquiss 1999, Čech & Vejřík 2011). Therefore, analysis of content of cormorant pellets can be used to estimate effects of cormorant predation on salmonid populations.

In conclusion, the salmon stocking programme is producing a reasonable amount of salmon smolts and the nursery streams are suitable for salmon populations. The main reason for poor salmon return rates is not cormorant predation on nursery streams but, most likely, a low salmon survival rate on the passage downstream. Therefore, we suggest that more studies should focus on monitoring of survival and return rates of salmon in the upper River Elbe to ensure that, in the future, the salmon reintroduction programme will be really successful.


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# A new trend in Central European recreational fishing: More fishing visits but lower yield and catch

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A R T I C L E I N F O

Handled by B. Morales-Nin.

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A B S T R A C T

Recreational fishing is a major leisure activity in many European countries but social aspects of angling are still understudied. This study aimed to examine long-term social trends in recreational fishing. Data was obtained from annual angling reports collected by the Czech Fishing Union. Data from annual angling reports is based on data from individual angling logbooks collected from 238 fishing grounds over the course of 11 years in Prague and Central Bohemia, Czech Republic. It was discovered that the numbers of individual anglers and angling visits on fishing grounds have been increasing. An average angler visits higher diversity of fishing grounds but anglers keep on returning to individual fishing grounds less frequently. Frequency of angling guard controls on fishing grounds has been increasing as well. On the other hand, angling yield and catch have been decreasing. The number of anglers who take home at least one fish has been increasing but percentage of anglers who take home at least one fish has been decreasing. In conclusion, recreational fishing is on the rise but fish catch and yield are decreasing.

## 1. Introduction

Recreational fishing is defined as fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic, or black markets (FAO, 2012). Cooke and Cowx (2004, 2006) roughly estimated that all anglers around the world might catch up to 47 billion fish annually. Further, they claimed that the overall catch in recreational fishing is about 12% of catch in commercial fishing. By studying inland fisheries in developed countries, previous research has suggested that recreational fishing is more widespread than commercial fishing (Arlinghaus et al., 2002; Arlinghaus and Cooke, 2005; FAO, 2010). Arlinghaus et al. (2015) claimed that approximately 10.5% of population in developed countries practice angling. Many studies reported that recreational fishing has been on the rise (Marta et al., 2001; Rasmussen and Geertz-Hansen, 2001; Freire et al., 2012; Gupta et al., 2015). People still seek fishing experience and tranquil natural surroundings despite having access to variety of tempting ways to spend leisure time in the world of electronic gadgets and virtual reality (Morales-Nin et al., 2015). Angling is a major recreational activity in many countries because it holds many socio-economic benefits like recreation, socialization, and escape from reality (Arlinghaus and Cooke, 2009; Tufts et al., 2015). On the other hand, some authors recently reported downfall of recreational fishing in Canada, Finland, Norway, Sweden, England, Wales, Ireland, and USA (Post et al., 2002; Schramm et al., 2003; Salmi et al., 2006; Aprahamian et al., 2010; Cowx, 2015).

Several authors suggested that recreational fishing has been overlooked and understudied even though it has significant effect on fish stocks (Arlinghaus et al., 2002; Cooke and Cowx, 2004; Altieri et al., 2012; Elmer et al., 2017). Post et al. (2002) claimed that recreational fishing has been collapsing but the collapse went unnoticed due to lack of interest between scientists, management, and anglers. Many studies suggested that better monitoring of the aspects in recreational fishing is required in order to understand its current state (Arlinghaus et al., 2002; Post et al., 2002; Ward et al., 2016; Elmer et al., 2017). Anglers throughout the world keep complaining that “fishing is not what it used to be” but scientific proof of this statement is lacking (Post et al., 2002). Humans are a crucial part of freshwater ecosystems and their behaviour should receive more attention because all inland waters are greatly influenced by human activities (Rasmussen and Geertz-Hansen, 2001; Post et al., 2002; Cooke and Cowx, 2004). Several researchers suggested that social aspects of recreational fishing are poorly understood and studies regarding social aspects in fishing are urgently needed (Arlinghaus et al., 2002; Lewin et al., 2006; Beardmore et al., 2015; Ward et al., 2016). It has been stated that social aspects play a very important role in sustainable management of recreational fishing and monitoring of trends in recreational fishing should definitely receive

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**Table 1**
List of variables that were used in statistical analyses in this study.

| Tested parameter |
|---|
| Number of anglers per fishing ground |
| Number of angling visits per fishing ground |
| Number of anglers per hectare of fishing grounds |
| Number of visits of a fishing ground by individual anglers |
| Angling yield [kg] per hectare |
| Angling catch [individual fish] per hectare |
| Angling yield [kg] per angler |
| Angling catch [individual fish] per angler |
| Number of anglers who took at least one fish |
| Percentage of anglers who took at least one fish |
| Number of angling guard controls per fishing ground |
| Number of angling guard controls per hectare of fishing grounds |

more attention (Arlinghaus et al., 2002).

This paper aimed to examine long-term social trends in recreational fishing. Twelve basic parameters in recreational fishing were used to assess the trends (Table 1). It was expected that a majority of the observed parameters would show an increasing trend over time because recreational fishing seems to be gaining popularity. It is believed that an examination of those trends is important in order to understand the complex socio-ecological system of recreational fishing.

## 2. Methods

### 2.1. Study area

The study was carried out in the regions of Prague (50°N, 14.5°E) and Central Bohemia (49.5°–50.5°N, 13.5°–15.5°E), Czech Republic, Central Europe. The region covers an area of 11 500 $km^2$ (Fig. 1). The Central Bohemian region has mostly agricultural character. Prague, the capital of the Czech Republic, has mostly urban character. The study area is dominated by the rivers Elbe and Vltava. Both rivers belong to the upper Elbe River Basin. All rivers in the study area belong to the North Sea Drainage area. Studied fishing grounds are situated in lowlands with an altitude of 200–600 m above sea level. Waters in the study areas are mesotrophic or eutrophic. The study area includes salmonid streams (dominated by salmonids) and non-salmonid rivers and reservoirs (dominated by cyprinids).

### 2.2. Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is organized by the Czech Fishing Union and is centralized for most of the country (with the exception of south-Moravian Region that is under supervision of the Moravian Fishing Union). Approximately 350 000 anglers are registered in the Czech Fishing Union. Professional and amateur angling guards are responsible for monitoring of angling activities in the field. Individual fishing grounds are managed by local angling organizations. One local angling organization usually shelters all anglers from one smaller city or one part of a larger city. Fishing grounds are defined as stream and river stretches where recreational fishing is conducted.

Each angler has to obtain a fishing license and a fishing permit before he or she can start practicing recreational fishing. A fishing licence allows anglers to practice fishing in the Czech Republic. A fishing permit allows anglers to practice fishing on individual fishing grounds (Table 2a).

Anglers are required to fill a report of both visits and catches in their own individual angling logbooks when they go fishing (Table 2b). Each angler is obliged to report a fishing visit even when he or she does not catch or keep any fish. In addition, each angler is obliged to write down every catch he or she wants to keep. Fish that are released back into water are not recorded. Anglers identify and measure each kept fish to the nearest cm. Anglers then assign weight to each fish according to their own measurement or according to official length-weight calculations provided by the Czech Fishing Union for individual fish species. Those calculations are based on general long-term observations of fish in Czech rivers. At the end of the year, anglers are obliged to deliver summaries of their angling logbooks to the Czech Fishing Union (Table 2c). The content of each angling logbook is then checked by administrative workers for errors. Data from all angling logbooks is added to the central fisheries database. The database contains summarized information about each fishing ground for each year. An example of annual angling reports for two very different fishing grounds is provided in Table 3.

### 2.3. Data sources

Data from 238 inland freshwater fishing grounds over the course of years 2006–2016 was used for the purpose of this study. The data was originally collected by the Czech Fishing Union and then processed by the authors of this study. Studied fishing grounds cover an area of 128.5 $km^2$. Overall angling catch on selected fishing grounds over the course of years 2006–2016 was approximately 3.5 million fish and angling yield approximately 6 thousand tons of fish.

### 2.4. Statistical analysis

The statistical programme R (R i386 3.3.2., R Development Core Team, 2017) was used for statistical testing. Shapiro-Wilk test was used to test the data distribution. Generalized linear models (package 'glm') with Poisson data distribution were used to fit the models in statistical testing (Wilkinson and Rogers, 1973). Bonferroni correction was applied when multiple groups were compared in the statistical analysis. Minimum probability level of $p = .05$ was accepted for all the statistics, and all statistical tests were two-tailed. Twelve variables were used in statistical testing (Table 1). One fishing ground was used as one study unit for all the variables.

## 3. Results

### 3.1. Angling visits

The number of individual anglers who visited fishing grounds was increasing over time ($F = 27.6$, $p < .05$, d. f. = 2616). The number of individual anglers per fishing ground increased from 260 to 490 over 10 years but the number dropped to 360 anglers per fishing ground in year 2016; nevertheless, the overall long-term trend was increasing (Fig. 2a).

The number of all angling visits per fishing ground was increasing as well. The number of angling visits per fishing ground increased from 3500 to 4500 over the course of 11 years ($F = 6.78$, $p < .05$, d. f. = 2616). There was a drop in the number of angling visits per fishing ground over the course of years 2009–2012 but the overall long-term trend was increasing (Fig. 2b).

One hectare of fishing grounds was visited by more individual anglers each year ($F = 35.57$, $p < .05$, d. f. = 2616). The number of individual anglers per hectare of fishing grounds increased from 20 to 50 over the course of 11 years. The trend in the number of individual anglers per hectare of fishing grounds was stagnating over the course of years 2009–2013 but the overall long-term trend was increasing (Fig. 2c).

Anglers kept on returning to individual fishing grounds less frequently. The number of angling visits of each fishing ground by individual anglers was decreasing over time ($F = 58.1$, $p < .05$, d. f. = 2616). An individual angler visited one individual fishing ground 11 times a year in 2006 but the number of visits dropped to just 6 visits a year in 2016 (Fig. 2d).

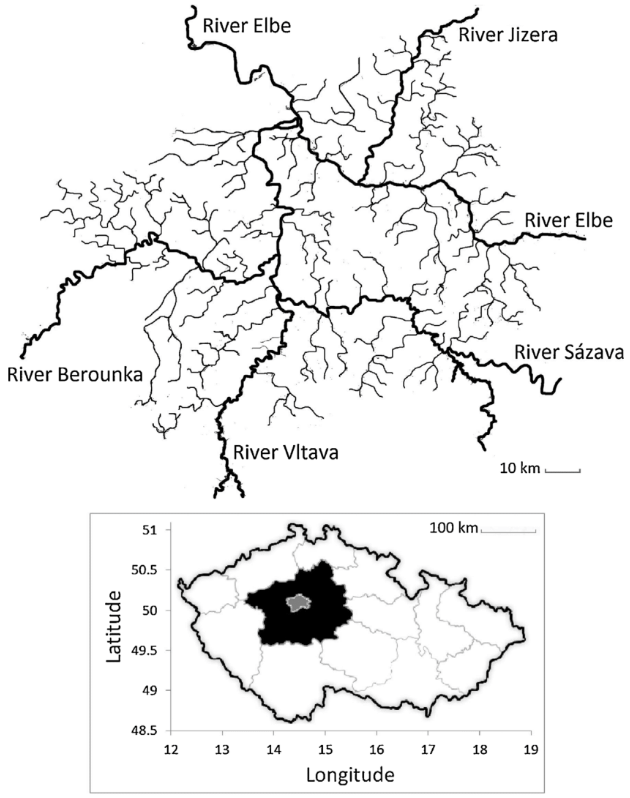


**Fig. 1.** Map of the study area with highlighted regions of Central Bohemia (in black; 49.5°–50.5°N, 13.5°–15.5°E) and Prague (in grey; 50°N, 14.5°E). Data was collected from 238 fishing grounds in the regions of Prague and Central Bohemia, Czech Republic, over the course of years 2006–2016.

### 3.2. Fish yield and catch

Angling yield and catch per hectare of fishing grounds showed a decreasing trend over time (yield: $F = 7.43$, $p < .05$, d. f. = 2616; catch: $F = 11.17$, $p < .05$, d. f. = 2616). Over the course of 11 years, angling yield decreased from 240 kg/ha to 170 kg/ha while angling catch decreased from 141 fish/ha to 99 fish/ha (Fig. 2e, f).

Angling yield and catch per one angler per one fishing ground also decreased over time (yield: $F = 35.44$, $p < .05$, d. f. = 2616; catch: $F = 58.23$, $p < .05$, d. f. = 2616). An average angler took 7.5 kg of fish per fishing ground in year 2006 but only 3.5 kg of fish per fishing ground in year 2016 (Fig. 3a). Similarly, an average angler took 6.2 fish per fishing ground in year 2006 but only 2.6 fish per fishing ground in year 2016 (Fig. 3b).

Over the course of years 2006–2014, the number of anglers who took at least one fish increased from 121 to 206 per fishing ground ($F = 14.79$, $p < .05$, d. f. = 2616). The number of anglers who took at least one fish then dropped from 206 to 122 per fishing ground over the course of years 2015–2016 but the overall long-term trend was increasing (Fig. 3c). However, the percentage of anglers who took at least one fish was decreasing over time ($F = 45.86$, $p < .05$, d. f. = 2616). The percentage of anglers who took at least one fish decreased from 63% to 51% over the course of 11 years (Fig. 3d).

### 3.3. Angling guard controls

Frequency of angling guard controls on fishing grounds was increasing over time ($F = 97.72$, $p < .05$, d. f. = 2616). The number of angling guard controls increased from 31 to 124 per fishing ground over the course of 11 years (Fig. 3e). One hectare of fishing grounds was monitored by angling guards at higher frequency each year as well ($F = 65.69$, $p < .05$, d. f. = 2616). The number of angling guard controls increased from 2.2 to 22.2 per hectare of fishing grounds over the course of 11 years (Fig. 3f).

## 4. Discussion

This paper found that popularity of angling has been increasing in the Czech Republic as more new anglers visit fishing grounds. The main driver is most likely an improvement in economic situation in the Czech Republic (Czech Statistical Office, unpubl. data). People are able to save more money to buy fishing equipment and to support their hobbies. Similar effect of correlation of financial wealth to popularity of fishing was discovered in the USA by Dotson and Charter (2003). Czech people with higher income seem to increasingly prefer outdoor activities like fishing. In case of large cities like Prague, fishing is one of the last remaining ways how people connect with nature. On the other hand, angling is also a low-risk and low-effort sport and generally one of the cheaper hobbies. That is optimal for older people with moderate or low

**Table 2**
An example of a fishing permit (a), a report of catches (b), and a summary of catches for the whole year (c).

a)

Fishing permit

| ID of fishing ground | Validity dates (from – to) | Name, surname | issued by | date of issue |
|---|---|---|---|---|
| 411 046 | 1.1.2010–31.12.2010 | Jan Novak | Prague 2 | 1.1.2010 |

b)

Report of catches

| date | ID of fishing ground | species | number | weight [kg] | size [cm] |
|---|---|---|---|---|---|
| 8.7.2010 | 411 046 | common carp | 1 | 2.8 | 55 |
| 9.7.2010 | 411 046 | common carp | 1 | 2.5 | 65 |
| 21.7.2010 | 411 047 | pike | 1 | 2.1 | 58 |
| 23.7.2010 | 411 047 | pike | 1 | 2.6 | 68 |
| 18.8.2010 | 411 047 | European catfish | 1 | 9.5 | 97 |
| 20.8.2010 | 411 047 | bream | 1 | 1.1 | 41 |
| 21.9.2010 | 411 047 | bream | 1 | 0.8 | 35 |

c)

Summary of catches for the whole year

| | | common carp | | pike | |
|---|---|---|---|---|---|
| ID of fishing ground | name of fishing ground | catches [n] | total weight [kg] | catches [n] | total weight [kg] |
| 411 046 | Elbe 14 | 6 | 12.1 | 2 | 4.4 |
| 411 047 | Elbe 15 | 7 | 14.8 | 2 | 3.8 |

income and Kelch et al. (2006) and Rees et al. (2017) reported that most anglers fall into this socio-economic category. It has already been stated that angling is a popular leisure activity because it has significant economic, social, cultural, and traditional value (Elmer et al., 2017). Studies from other countries also reported increasing popularity of recreational fishing in Europe generally (Wallentin, 2016) and also within individual European countries, e.g. in Denmark (Rasmussen and Geertz-Hansen, 2001), and in Germany (Wedekind et al., 2001). Countries outside of Europe also reported increased popularity of recreational fishing, e.g. Brazil (Freire et al., 2012), and India (Gupta et al., 2015). Cowx (2015) discovered that the increased popularity of inland recreational fishing is positively correlated to decreasing popularity of inland commercial fishing (Cowx, 2015).

On the contrary to our results, Aprahamian et al. (2010) reported decreasing numbers of anglers in England and Wales due to unfavorable angling conditions and introduction of restrictions on angling. Similarly, Salmi et al. (2006) reported decreasing numbers of anglers in Finland, Norway, and Sweden due to loss of interest in angling and also due to lack of time, equipment, and suitable fishing sites. Data collected by the Czech Fishing Union suggests that recreational fishing in the Czech Republic has neither of those issues.

The data shows that anglers return to fishing grounds less often than they used to. Anglers are getting less loyal to their favourite fishing grounds and they switch fishing grounds more frequently. Similar trend was observed in other geographical locations, e.g. in Baltic Sea marine fishery (Hammer, 2009) and in Californian marine fishery (Dotson and Charter, 2003). It is possible that people are getting pickier when it comes to choosing fishing grounds because they can now easily afford to travel—Wallentin (2016) discovered that wealthy anglers travel to

**Table 3**
An example of annual angling reports from two very different fishing grounds: a) a large popular fishing ground on the Vltava River (Slapy Reservoir); b) a small and less popular fishing ground on the Šembera stream.

a)

| ID of fishing ground | Name of fishing ground | Area [ha] |
|---|---|---|
| 401 022 | Vltava River | 1000 |
| Fish species | Catch [individual fish] | Yield [kg] |
| carp | 22 266 | 57 424.9 |
| tench | 153 | 154.1 |
| bream | 1844 | 1939.4 |
| chub | 22 | 13.6 |
| perch | 1237 | 495.2 |
| barbel | 0 | 0.0 |
| nase | 0 | 0.0 |
| vimba bream | 0 | 0.0 |
| pike | 672 | 1513.3 |
| zander | 1600 | 3283.0 |
| European catfish | 567 | 3720.2 |
| European eel | 189 | 184.1 |
| brown trout | 3 | 3.0 |
| rainbow trout | 19 | 12.1 |
| grayling | 1 | 0.3 |
| brook trout | 4 | 2.0 |
| asp | 37 | 145.8 |
| whitefish | 0 | 0.0 |
| common huchen | 1 | 4.5 |
| grass carp | 188 | 804.3 |
| silver carp | 7 | 97.4 |
| crucian carp | 165 | 123.6 |
| burbot | 0 | 0.0 |
| other fish species | 1969 | 236.3 |
| Total | 30 944 | 70 157.1 |
| **Parameters** | | |
| Catches per ha [individual fish] | | 30.94 |
| Yield per ha [kg] | | 70.16 |
| Number of individual anglers | | 8585 |
| Number of anglers that caught at least one fish | | 4231 |
| Number of all angler visits | | 88 193 |
| Number of visits per angler | | 10.27 |
| Catches per angler [individual fish] | | 3.60 |
| Yield per angler [kg] | | 8.17 |
| Number of visits per ha | | 88.19 |
| Number of angler guard notes in all angling logbooks | | 1445 |

b)

| ID of fishing ground | Name of fishing ground | Area [ha] |
|---|---|---|
| 413 031 | Šembera stream | 3 |
| Fish species | Catch [individual fish] | Yield [kg] |
| carp | 0 | 0.0 |
| tench | 0 | 0.0 |
| bream | 0 | 0.0 |
| chub | 0 | 0.0 |
| perch | 0 | 0.0 |
| barbel | 0 | 0.0 |
| nase | 0 | 0.0 |
| vimba bream | 0 | 0.0 |
| pike | 0 | 0.0 |
| zander | 0 | 0.0 |
| European catfish | 0 | 0.0 |
| European eel | 0 | 0.0 |
| brown trout | 4 | 1.2 |
| rainbow trout | 51 | 15.9 |
| grayling | 0 | 0.0 |
| brook trout | 2 | 0.6 |
| asp | 0 | 0.0 |
| whitefish | 0 | 0.0 |
| common huchen | 0 | 0.0 |
| grass carp | 0 | 0.0 |
| silver carp | 0 | 0.0 |
| crucian carp | 0 | 0.0 |
| burbot | 0 | 0.0 |
| other fish species | 0 | 0.0 |

(continued on next page)

**Table 3** (*continued*)

| b) | | |
|---|---|---|
| ID of fishing ground | Name of fishing ground | Area [ha] |
| 413 031 | Šembera stream | 3 |
| Fish species | Catch [individual fish] | Yield [kg] |
| Total | 57 | 17.70 |
| **Parameters** | | |
| Catches per ha [individual fish] | | 19.00 |
| Yield per ha [kg] | | 5.90 |
| Number of individual anglers | | 17 |
| Number of anglers that caught at least one fish | | 9 |
| Number of all angler visits | | 45 |
| Number of visits per angler | | 2.65 |
| Catches per angler [individual fish] | | 3.35 |
| Yield per angler [kg] | | 1.04 |
| Number of visits per ha | | 15.00 |
| Number of angler guard notes in all angling logbooks | | 0 |

distant fishing ground more often. It has been suggested that this is because European anglers are becoming increasingly adventurous, selective, and demanding (Cooke and Cowx, 2006). Anglers were reported to travel tens of kilometers from home to catch specific fish species that are unavailable on their home fishing grounds (Sipponen and Gréboval, 2001; Wedekind et al., 2001; Dotson and Charter, 2003; Kelch et al., 2006). At that point, it probably pays off to be selective in terms of choosing between fishing grounds.

Increased desire to visit distant fishing grounds is most likely driven by improved economic situation in the Czech Republic. The economic recession from year 2008 ended in Europe several years ago (approximately in years 2012–2014) and people are compensating by spending more money on their hobbies (Czech Statistical Office, unpubl. data). Anglers are discovering new hobbies but they still want to maintain fishing as one of those hobbies. Anglers can also afford to buy various fishing equipment that is needed for different types of angling waters (e.g. small salmonid streams versus large non-salmonid rivers or reservoirs). The Czech Fishing Union has been promoting advertisement of intensive stocking of large-sized and commercially valuable fish into Czech rivers. The goal of similar fish stocking is to lure new anglers to different fishing grounds. Positive effect of similar advertisement on angling visit rates is well known because anglers usually prefer sites with high fish abundance and clean environment (Schramm et al., 2003; Aprahamian et al., 2010; Turpie and Goss, 2014; Melstrom et al., 2015; Curtis and Breen, 2017).

Results of this study showed that the number of anglers who take home at least one fish is increasing. On the contrary, the results also showed that the percentage of anglers who take home at least one fish is decreasing. Those two results seem contradictory but their coexistence can be explained. The data shows that the number of anglers who take no fish is increasing more rapidly than the number of anglers who take at least one fish.

This study discovered that the two most important parameters in recreational fishing—fish yield and catch—have been decreasing in the last decade. In addition, individual anglers take home fewer fish than they used to. In those cases, fish yield and catch are becoming less important than the actual angling experience. Decreased yield and catch corresponds well with the increased mobility of anglers and desire of anglers to visit new fishing grounds. Newly incoming and inexperienced anglers have lower chances to land a catch because they firstly need to discover the best fishing spots and learn the most suitable fishing techniques for individual localities in order to maximize their chances of successfully landing a catch. Lower yield and catch are also caused by world-widely increased popularity of catch-and-release

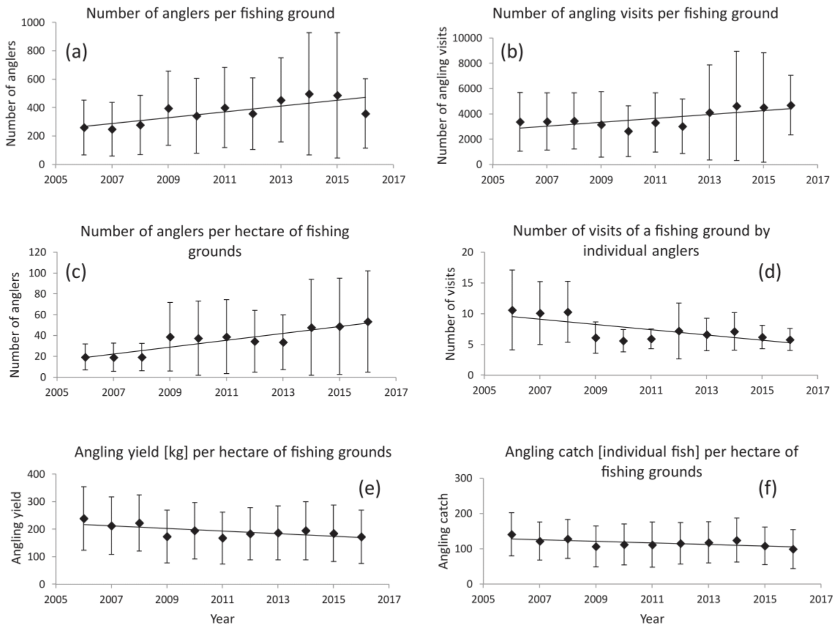


**Fig. 2.** Time trends displayed for basic parameters in recreational fishing over the course of time (values with 95% confidence intervals). Note: (a) the number of individual anglers per fishing ground, (b) the number of angling visits per fishing ground, (c) the number of individual anglers per one hectare of fishing grounds, (d) the number of visits of a fishing ground by individual anglers, (e) angling yield [kg] per one hectare of fishing grounds, (f) angling catch [individual fish] per one hectare of fishing grounds. Data is for 238 fishing grounds in the Czech Republic over the course of years 2006–2016.

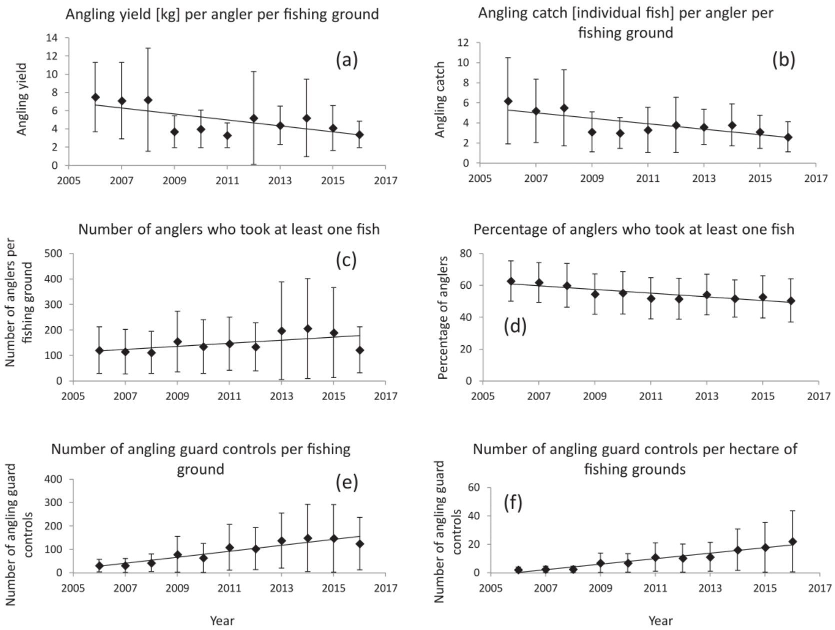


**Fig. 3.** Time trends displayed for basic parameters in recreational fishing over the course of time (values with 95% confidence intervals). Note: (a) angling yield [kg] per angler per fishing ground, (b) angling catch [individual fish] per angler per fishing ground, (c) the number of anglers who took at least one fish per fishing ground, (d) the percentage of anglers who took at least one fish per fishing ground, (e) the number of angling guard controls per fishing ground, (f) the number of angling guard controls per hectare of fishing grounds. Data is for 238 fishing grounds in the Czech Republic over the course of years 2006–2016.

fishing strategy (Bartholomew and Bohnsack, 2005; Cooke and Cowx, 2006; Arlinghaus et al., 2007; Gaeta et al., 2013; Brownscombe et al., 2017). People release fish back to water because they are getting increasingly interested in fish well-being and protection (Kearney, 1999). Increase in fish timidity and vigilance due to elevated fishing pressure also negatively affects chances of landing a catch (Arlinghaus et al., 2017). It has been reported that recreational fishing became more about enjoying tranquil natural surroundings than about the actual act of fishing (Smallwood and Beckley, 2012; Morales-Nin et al., 2015). The improvement in economic situation means that people will rather buy fish at local supermarket instead of eating fish from unknown environment—it is much easier to buy fish in the store than to prepare it at home.

This paper found that the frequency of angling guard controls in the field has been increasing. It is a response to increasing number of both anglers and poachers in the field (Czech Fishing Union, unpubl. data). Angling guards have also gotten more mobile. The increased frequency of guard controls in the field is mainly caused by increased numbers of professional angling guards in the region of Central Bohemia; the number of professional angling guards increased from 250 guards over years 2006–2010 to 940 guards over years 2011–2016 (Czech Fishing Union, unpubl. data). In the Czech Republic, professional angling guards possess similar status as police officers. That serves as prevention against poaching. Data from the Czech Fishing Union suggests that the number of active angling guards (guards who check > 10 anglers per year) has been increasing as well.

This study found that the number of angling visits per hectare of fishing grounds is increasing more rapidly than the number of angling visits per one individual fishing ground. Similarly, the number of angling guard controls per hectare is increasing more rapidly than the number of angling guard controls per one individual fishing ground. Such observation suggests that the trends in angling visits and guard controls depend on type of fishing ground—previous studies found that different fishing grounds might show different trends (Humpl et al., 2009; Jankovsky et al., 2011; Boukal et al., 2012).

## 5. Conclusion

It was discovered that the numbers of anglers and angling visits have been increasing but angling catch and yield have been decreasing. Individual fishing grounds are visited by higher diversity of anglers each year. Anglers are returning to individual fishing grounds less frequently and they choose to visit different fishing grounds instead. The number of anglers who take home at least one fish is increasing but percentage of anglers who take home at least one fish is decreasing. Catch and yield per angler are also decreasing. Frequency of angling guard controls is increasing. Increasing popularity of recreational fishing is probably caused by improvement in economic situation in the Czech Republic. The decreasing catch and yield is probably a result of increased popularity of catch-and-release strategy. This study suggests that future studies should focus on extracting more information from angling logbooks and annual angling reports. For example, evaluation of angling catch and yield of important game fish species over time would certainly be useful to scientists, fisheries management, and public.

## Data statement

The data is owned by and was provided by the Czech Fishing Union—the main authority in recreational fishing in the Czech Republic. Therefore, we did not include the dataset with this article.

## Acknowledgements

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# Great Cormorants (*Phalacrocorax carbo*) feed on larger fish in late winter

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Short title: Prey size in Cormorant diet

**Summary**

**Capsule** Information regarding diet composition and size of Great Cormorant *Phalacrocorax carbo* prey is crucial in order to understand the scale of Pan-European conflict between fisheries and environmental protection.

**Aims** This study aimed to describe Cormorant diet and to discover whether the size of fish in the diet changes during winter.

**Methods** The diet of Cormorant was studied using regurgitated pellets collected from roosting places at the upper Elbe River, Czech Republic, during winter (from December to March).

**Results** The diet consisted of 24 fish species from 6 fish families. Roach *Rutilus rutilus* dominated in the diet (over 50 % of biomass). Size of fish in the diet increased over time during the whole winter. Except for European Chub *Squalius cephalus,* the increased size applied for the majority of the most frequently consumed fish species like Roach, European Perch *Perca fluviatilis*, or White Bream *Abramis brama*. Cormorants consumed mostly fish species of lower commercial and angling value.

**Conclusion** Fisheries management should reflect on the fact that competition for larger-sized fish is the highest in late winter and in early spring. For that reason, e.g. stocking of potentially vulnerable fish could be delayed to the time when overwintering birds leave the area, and recreational fishing could be restricted in late winter.

Keywords: regurgitated pellets; diet composition; fish vulnerability; pharyngeal bones; prey shift; the upper Elbe River

## Introduction

The Great Cormorant *Phalacrocorax carbo* is one of the most important fish-eating avian predators and a widespread water bird. It is an opportunistic predator that feeds almost entirely on fish (Cramp & Simmons 1977, Johnsgard 1993). Cormorant populations have been increasing since 1970 in the European range mainly due to legal protection, availability of prey, intensive fish farming, and eutrophication of freshwater habitats (Debout *et al*. 1995, Van Eerden & Gregersen 1995, Russell *et al*. 1996, Marion 2003, European Commision 2013). In particular, numbers of the continental subspecies *Phalacrocorax carbo sinensis* have increased greatly, and Cormorants have moved to previously unoccupied areas (Carss & Marzano 2005). Conflicts between environmentalists and ornithologists on one side and fisheries and anglers on the other have been reported in many countries (Russel *et al*. 1996, Cowx 2003, Čech & Vejřík 2011). In Central Europe, wintering Cormorants cause conflicts with fisheries. The numbers of Cormorants in freshwater ecosystems in Central Europe significantly increase during winter due to migration, and Cormorants consume more fish during winter than during the rest of the year (Čech & Vejřík 2011). Since wintering Cormorants have become one of the most important (and the most debated) piscivores in European freshwater ecosystems (Čech & Vejřík 2011), it is becoming more important to assess their diet preferences at different overwintering areas.

Cormorant diet usually fluctuates seasonally, especially from summer to winter (Keller 1995, Carss & Ekins 2002, Liordos & Goutner 2007, Emmrich & Duttman 2011). Differences in diet composition are caused by seasonal changes in fish abundance and availability (Gwiazda & Amirowicz 2010, Bostrom et al. 2012).

The Cormorant-based conflict between fisheries and environmental protection has been escalating in Central Europe for decades (Suter 1995), yet diet composition of Cormorants has never been studied at the upper Elbe River before. Cormorants play a very important role in fisheries research and management (Čech & Vejřík 2011). Due to climate change and river fragmentation, large rivers in Central Europe do not freeze over during winter (Čech & Vejřík 2011). That allows migrating Cormorants to overwinter in Central Europe. Therefore, it is very important to assess diet of overwintering Cormorants in this geographical area.

The goal of this study was to describe Cormorant diet at the upper Elbe River during one whole winter. This study aimed to discover whether the size of fish in Cormorant diet changes during winter. We expected that Cormorant diet composition in this area would be comparable to Cormorant diet composition in other countries in Central Europe (Keller 1995, Suter 1997, Emmrich and Duttmann 2011).

## Materials and Methods

***Study area***

This study was carried out at the upper Elbe River (50°40'34.2"N, 14°07'28.5"E, Velké Březno, North Bohemia, 100 km north of Prague, Czech Republic, Central Europe) during winter 2014/2015 (Figure 1). (Figure 1 near here). Cormorants roosted in this area from October to April during winter 2014/2015. Approximately 100 Cormorants roosted in the area in October. The number of Cormorants increased to approximately 500 birds in November and remained constant till February. Then the number of Cormorants dropped to approximately 100 birds in March and April. All birds were gone by May (Lyach & Čech 2017b).

***Pellet analysis***

Cormorant diet was investigated using analysis of regurgitated pellets (for description of the method see Barrett *et al*. 2007). Pellets were collected during five visits in winter 2014/2015 at roosting places in Velké Březno during daylight (late morning till midday) when no birds (or only individual birds) were present in the area (Table 1). (Table 1 near here). About 600 $m^2$ of the ground was searched for pellets during each visit. All available pellets were collected during each visit and put individually into plastic bags. Those bags were sealed, labelled, and stored in a freezer (-18 °C). Each pellet was then thawed and soaked in a solution of 300 ml warm tap water (50 °C) and 15 g of 1 M, 97–99 % Na(OH) for approximately one minute until the gastric mucosa was completely dissolved. Remaining hard parts were washed through a sieve (mesh size 0.5 mm) several times to remove any remaining dirt or mucosa and wash away remaining Na(OH). Cleaned hard parts were then put into Petri dishes. All recognizable hard parts were separated, dried at room temperature, and analysed under a stereo microscope (magnification 8 - 16 ×). Fish species were identified to the lowest possible taxonomic level based on morphological differences of diagnostic bones (*os pharyngeum, maxillare, dentale, intermaxillare, operculare, praeoperculare, praevomer, cleithrum, basioccipitale, mesethmoid, vertebra, coracoid, vomer* and pectoral spine) (Čech *et al*. 2008, Čech & Vejřík 2011, Čech & Čech 2013, 2017, this study). In case of Brown Bullhead *Ameiurus nebulosus* and Burbot *Lota lota*, altogether 136 new fish originated from the Elbe River basin were caught using electrofishing, fyke nets, fishing rods and dip nets and their diagnostic bones were dissected (Table 2, Figure 2).

All diagnostic bones found in regurgitated pellets were measured to the nearest 0.1 mm and paired within each individual pellet whenever possible. The number of fish represented in a pellet was determined by the highest total of any identifiable parts. Our own collection of diagnostic bones was used to determine original size of worn bones. Length of worn bones was estimated by comparing the least worn parts of the extracted bone to the same parts of fully preserved bones from our collection. This collection was also used in our previous studies dealing with the diet of fish-eating predators (Čech *et al*. 2008, Čech & Vejřík 2011, Čech & Čech 2013, 2017, Lyach & Čech 2017a, b). Length of fully preserved diagnostic bones was then used for calculation of the original prey fish length ($L_T$, *longitudo totalis* in cm) using length-length equations provided by Čech *et al*. (2008), Čech & Vejřík (2011), Čech & Čech (2013, 2017) and this study (Table 2). Subsequently, prey fish weight was calculated from the length-weight equations from the work of Čech & Čech (2017) and from FishBase (FishBase.org).

***Statistical analysis***

The R Commander (package Rcmdr) in the statistical programme R (R version 3.4.1, R Development Core Team 2017) was used for data analysis. Shapiro-Wilk test of normality was used to test the distribution of estimated fish lengths and weights. Generalized linear models (package 'glm' in the statistical programme R) were used to test the changes of fish weights over the course of winter (Wilkinson and Rogers, 1973). Changes of fish size over the course of time were tested for all fish species pooled together, separately for the most important fish species (Roach *Rutilus rutilus*), for the rest of the fish species (non-Roach fish species), and separately for each frequently consumed fish species (> 5 % by numerical frequency). We pooled all species together to discover if the overall fish weight changes over the course of winter, and then we tested each of the most frequently consumed fish species separately to discover if the change in size over winter is significant for each of the most frequently consumed fish species. Bonferroni correction was applied when multiple fish species and multiple dates were included in the analysis. Minimum probability level of $P < 0.05$ was accepted for all the statistics, and all statistical tests were two-tailed.

**Results**

Altogether 1 214 Cormorant pellets were collected and examined (Table 1). Those pellets included 8 108 diagnostic elements which gave 5 216 individual fish after pairing. We paired 4 485 (55 %) diagnostic elements out of 8 108, leaving the remaining 3 623 (45 %) unpaired. Total estimated weight of all fish identified in Cormorant pellets was 451.75 kg. Cormorant diet was composed of 24 fish species from 6 fish families (Cyprinidae, Percidae, Esocidae, Gadidae, Ictaluridae, Cottidae; ordered based on the importance in the diet by weight). Cormorants consumed fish in a size range of 3–49 cm $L_T$ and weight of 0.5–1 366 g. Median fish length was 17 cm $L_T$ (mean 18 cm $L_T$) and median fish weight was 47 g (mean 87 g). Roach strongly dominated in the diet by both numbers (64.5%) and weight (50.9%; Table 3). (Table 3 near here).

Fish weights (all species pooled together) were not normally distributed (for each date: $P < 0.01$). Weights of the most important fish species in the diet – Roach, European Perch *Perca fluviatilis*, European Chub *Squalius cephalus*, White Bream *Abramis bjoerkna*, and Ide *Leuciscus idus* – were also not normally distributed (for each species: $P < 0.01$).

The size of fish in Cormorant diet was increasing over the course of winter (Table 4). Weight of fish (all fish species pooled together) increased over time, being 12.6 g at the beginning of winter and 68 g at the end of winter (median; Figure 3a). Weight of Roach increased over time (Figure 3b) as well as the weight of non-Roach fish (Figure 3c), of European Perch (Figure 3d), and of White Bream (Figure 3e). In contrast, weight of Ide was constant over time (Figure 3f) and the weight of European Chub decreased over time (Figure 3g). (Table 4 and Figure 3 near here).

**Discussion**

This paper found that size of fish in Cormorant diet was increasing over the course of winter. There are two possible explanations for this trend – Cormorants either selected larger fish in late winter, or larger fish were more available in late winter. Both explanations are based on discoveries of other researchers (see discussion below). Those discoveries are based on well-known facts regarding ecology of Cormorants and their prey (fish). The main problem of studies that analyse Cormorant diet is the difficulty to obtain reliable and representative information on fish availability in study areas. The main reason is that Cormorants commonly utilise feeding grounds within a radius of 20–30 (or even 50) km around their roosting colony (Cramp and Simmons 1977; Carss and Ekins 2002). In case of this study, there are tens of rivers and adjacent water bodies where Cormorants could potentially feed. Therefore, it was not possible to discover if Cormorants select larger fish in late winter or if large fish were just more available in late winter. For that reason, we discuss both possible explanations for the increased size of fish in the diet over the course of winter – prey selectivity and prey availability.

Firstly, increased fish size in the diet could be caused by prey selectivity of Cormorants. First winter birds have higher overwintering and migration mortality than adults (Buehler & Piersma 2008, Fort *et al*. 2009). Young birds are also more likely to perish in nets or get shot (Wernham & Peach 1999). Those first winter birds prey on smaller fish than adults (Stewart *et al*. 2005, Fontaneau *et al*. 2009, Liordos & Goutner 2009), although they switch to larger fish as they learn to search and hunt for prey in overwintering areas. Cormorants are social animals that often fish in flocks of young and adult birds. Young birds then learn to hunt by observing adult birds in action. Young birds need to learn how to hunt in order to maximize their energetic income (Fortin *et al*. 2013, Gourley & Liu 2015). Simply, an average first winter Cormorant in December is more naïve and worse at hunting than an average Cormorant in March.

Secondly, increased fish size in the diet could be caused by higher abundance of large-sized fish in the study area during late winter. First winter fish have higher mortality in cold winter conditions than adults (Fullerton *et al*. 2000), especially if energy stores become limiting (McCollum *et al*. 2003), or when predation pressure forces them to exhaust their energy reserves (Garvey *et al*. 2004). Smaller fish are significantly more vulnerable to short-time starvation than larger ones (McCollum *et al*. 2003). Vegetation cover is limited in winter, and smaller fish aggregate in open water which makes them exposed to bird predation (Van Eerden & Voslamber 1995). Larger fish are significantly harder to catch and swallow because of their larger body size, faster movement in the water, and more developed anti-predation behaviour (Christensen 1996, Čech et al. 2008). Ectothermic fish are also significantly disadvantaged against endothermic birds in cold winter conditions. Cormorants exploit this weakness by switching to prey that a) is the easiest to catch and b) offers the highest energetic payoff (Čech et al. 2008). In colder conditions, fish are also more vulnerable to parasites and predation which makes fish more vulnerable to predation (Francová & Ondráčková 2013). Piscivorous fish species reproduce during late winter or early spring while omnivorous fish species reproduce later in spring (Hladík & Kubečka 2003). This whole reproduction process that includes feeding and spawning makes fish more exposed to predation. Fish growth is usually slower or stagnant during cold winter conditions (Fullerton *et al*. 2000, Griffiths & Kirkwood 1995, Francová & Ondráčková 2013) and therefore does not reliably explain the increased size in the diet.

Lastly, increased fish size in the diet could be caused by Cormorants switching feeding sites. Fish abundance and availability varies in time, e.g. different rivers and ponds are frozen and unavailable for Cormorants during early and late winter. The shift in diet could therefore be partly explained by climatic variations.

The study found that Roach dominated in Cormorant diet. Dominance of Roach in Cormorant diet is typical for freshwater ecosystems in Central Europe (Suter 1997, Čech *et al*. 2008, Gwiazda & Amirowicz 2010). Roach is a shoaling species and is very abundant in nutrient-rich rivers and lakes in Central Europe (Dirksen *et al*. 1995, Keller 1995, Suter 1997, Keller 1998, Marquiss *et al*. 1998, Engstrom 2001, Wziatek *et al*.

2003, Čech *et al*. 2008, Čech & Vejřík 2011, Emmrich & Duttman 2011, Prchalova *et al*. 2011, Valova *et al*. 2014). Cormorants were reported to selectively prey on shoaling fish species (Kirby *et al*. 1996, Suter 1997, Lorentsen *et al*. 2004, Gwiazda & Amirowicz 2010, Bostrom *et al*. 2012, Magath *et al*. 2016). It is likely that abundant, shoaling (moreover winter active), torpedo-shaped and relatively large growing Roach represents an ideal prey for Cormorants overwintering in Central Europe (M. Čech, R. Lyach, pers. observation; cf. Suter 1997).

In conclusion, this study discovered that size of fish in Cormorant diet was increasing over the course of winter. Fisheries management should reflect on the fact that competition for larger-sized fish (and therefore potential for conflict between Cormorants and fisheries) is the highest in late winter and in early spring. In light of this finding, fisheries management could, for example, postpone stocking of potentially vulnerable fish to middle or late spring (May or June). The suggested delay of fish stocking should be considered especially in areas with high density of overwintering Cormorants. Fisheries management could also focus on protection of larger-sized fish in late winter and in early spring by, for example, restricting recreational fishing and other fish-disturbing activities in late winter.

In accordance with other studies (e.g. Suter 1997, Čech *et al*. 2008, Čech & Vejřík 2011), the present study also found that Cormorants consumed mostly low value fish species like Roach, European Chub, White Bream, Ide, Nase *Chondrostoma nasus*, Rudd *Scardinius erythrophthalmus* or Bleak *Alburnus alburnus* (82.6% of the diet by numbers, 74.1% of the diet by weight). Therefore, the Cormorant-based conflict between fisheries and environmental protection at the upper Elbe River is lower than what is generally proclaimed by fisheries management.

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**Table 1**. The number of Great Cormorant pellets collected at roosting places at the upper Elbe River (50°40'27.0"N, 14°07'32.6"E) during winter 2014/2015.

| Date | Pellets collected | Diagnostic elements identified | Fish identified | Fish species identified |
|---|---|---|---|---|
| 5 Dec 2014 | 253 | 1 524 | 960 | 21 |
| 6 Jan 2015 | 501 | 2 345 | 1 587 | 24 |
| 20 Jan 2015 | 102 | 644 | 399 | 19 |
| 15 Feb 2015 | 202 | 1 690 | 1 061 | 23 |
| 3 Mar 2015 | 156 | 1 906 | 1 208 | 23 |
| Total | 1 214 | 8 108 | 5 216 | 24 |

**Table 2.** Regression equations of total length ($L_T$; cm) on bone dimensions (mm) for Brown Bullhead *Ameiurus nebulosus* and Burbot *Lota lota*. The range of fish lengths (cm) from which the equations are derived is provided. Note: DeL, dental length; PeSL, pectoral spine length; CleT, cleithrum tip; MeW, mesethmoid width; VerW, vertebra width; CorL, coracoid length; VoW, vomer width; VoTR, vomer thorn range (for details of individual measurements see Figure 2).

| species | n | Range of fish lengths (cm) | Diagnostic bone | Equation | $r^2$ |
|---|---|---|---|---|---|
| Brown Bullhead *Ameiurus nebulosus* | 49 | 4.8−25.8 | Dentale | $L_T$=0.9145DeL+1.4866 * | 0.990 |
| | | | Pectoral spine | $L_T$=0.9015PeSL−0.9847 | 0.979 |
| | | | Cleithrum | $L_T$=0.5771CleT+0.0599 * | 0.990 |
| | | | Mesethmoid | $L_T$=1.5446MeW+1.9371 | 0.968 |
| | | | Vertebra | $L_T$=0.769VerW+0.607 * | 0.989 |
| | | | Coracoid | $L_T$=0.8705CorL+0.2386 | 0.986 |
| Burbot *Lota lota* | 87 | 6.2−48.0 | Dentale | $L_T$=1.3821DeL+0.9074 * | 0.984 |
| | | | Vomer | $L_T$=1.9048VoW+4.209 | 0.963 |
| | | | Vomer | $L_T$=4.2907VoTR+1.496 | 0.968 |

*These linear regressions were preferably used to calculate $L_T$ due to the higher correlation of bone dimension with fish length.

**Table 3**. Composition of Cormorant diet over winter 2014/2015. Note: n, total number of fish identified in pellets; %n, percentage of fish prey; b, total biomass of fish identified in pellets [kg]; %b, percentage of prey biomass; $L_{med}$, median fish length [cm]; $L_{mean}$, mean fish length [cm]; $L_{min.-max.}$, minimum-maximum fish length [cm]; $W_{med}$, median fish weight [g]; $W_{mean}$, mean fish weight [g]; $W_{min.-max.}$, min-max fish weight [g].

| Species | n | %n | b[kg] | %b | $L_{med}$ [cm] | $L_{mean}$ [cm] | $L_{min-max}$ [cm] | $W_{med}$ [g] | $W_{mean}$ [g] | $W_{min-max}$ [g] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cyprinidae** | | | | | | | | | | |
| Asp *Aspius aspius* | 11 | 0.2 | 1.7 | 0.4 | 25 | 24 | 9.1 - 39 | 136 | 158 | 8.3 - 471 |
| Barbel *Barbus barbus* | 58 | 1.1 | 20.2 | 4.5 | 31 | 31 | 7.7 - 49 | 280 | 349 | 4.3 - 1 043 |
| Bleak *Alburnus alburnus* | 34 | 0.7 | 0.9 | 0.2 | 14 | 14 | 8.7- 22 | 18 | 26 | 3.8 - 92 |
| Bream *Abramis brama* | 64 | 1.2 | 8.8 | 2.0 | 21 | 22 | 10.9 - 35 | 88 | 139 | 11.4 - 477 |
| Common Carp *Cyprinus carpio* | 85 | 1.6 | 17.6 | 3.9 | 22 | 21 | 3.4 - 37 | 185 | 208 | 0.6 - 908 |
| Common Dace *Leuciscus leuciscus* | 12 | 0.2 | 0.6 | 0.1 | 16 | 16 | 8.4 - 27 | 35 | 47 | 4.5 - 201 |
| European Chub *Squalius cephalus* | 341 | 6.5 | 30.1 | 6.7 | 17 | 18 | 4.1 - 45 | 46 | 88 | 0.7 - 854 |
| Grass Carp *Ctenopharyngodon idella* | 17 | 0.3 | 7.7 | 1.7 | 29 | 31 | 18.7 - 44 | 290 | 453 | 76.4 - 1 099 |
| Gudgeon *Gobio gobio* | 3 | 0.1 | 0.0 | 0.0 | 12 | 12 | 11.5 - 13 | 15 | 16 | 12.2 - 19 |
| Ide *Leuciscus idus* | 171 | 3.3 | 13.2 | 2.9 | 19 | 19 | 4.2 - 40 | 56 | 77 | 0.4 - 679 |
| Nase *Chondrostoma nasus* | 62 | 1.2 | 20.7 | 4.6 | 31 | 29 | 12.8 - 48 | 312 | 334 | 17.7 - 1 366 |
| Prussian Carp *Carassius auratus* | 15 | 0.3 | 2.9 | 0.7 | 22 | 20 | 11.1 - 30 | 192 | 195 | 22.6 - 552 |
| Roach *Rutilus rutilus* | 3 361 | 64.5 | 229.9 | 50.9 | 15 | 17 | 4.8 - 46 | 30 | 68 | 1.0 - 848 |
| Rudd *Scardinius erythrophthalmus* | 53 | 1.0 | 3.1 | 0.7 | 16 | 16 | 5.4 - 27 | 46 | 59 | 1.5 - 214 |
| Tench *Tinca tinca* | 26 | 0.5 | 1.4 | 0.3 | 13 | 14 | 5.6 - 27 | 30 | 55 | 2.3 - 296 |
| Vimba Bream *Vimba vimba* | 6 | 0.1 | 1.7 | 0.4 | 28 | 26 | 19.6 - 29 | 232 | 280 | 85.9 - 325 |
| White Bream *Abramis bjoerkna* | 284 | 5.5 | 36.7 | 8.1 | 17 | 17 | 6.2 - 30 | 121 | 129 | 2.2 - 738 |
| **Percidae** | | | | | | | | | | |
| European Perch *Perca fluviatilis* | 404 | 7.8 | 33.7 | 7.5 | 16 | 17 | 7.6 - 32 | 55 | 83 | 4.5 - 497 |
| Ruffe *Gymnocephalus cernuus* | 32 | 0.6 | 0.4 | 0.1 | 10 | 10 | 6.8 - 14 | 13 | 14 | 4.9 - 30 |
| Zander *Sander lucioperca* | 90 | 1.7 | 7.5 | 1.7 | 21 | 21 | 6.8 - 43 | 63 | 83 | 1.8 - 647 |
| **Esocidae** | | | | | | | | | | |
| Northern Pike *Esox lucius* | 57 | 1.1 | 11.3 | 2.5 | 28 | 31 | 17.9 - 49 | 124 | 198 | 27.3 - 802 |
| **Cottidae** | | | | | | | | | | |
| Bullhead *Cottus gobio* | 2 | 0.0 | 0.0 | 0.0 | 9 | 9 | 9.0 - 9 | 10 | 10 | 8.3 - 13 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Gadidae** | | | | | | | | | | |
| Burbot *Lota Lota* | 4 | 0.1 | 1 | 0.2 | 27 | 27 | 25.6 - 29 | 212 | 238 | 207.8 - 315 |
| **Ictaluridae** | | | | | | | | | | |
| Brown Bullhead *Ameiurus nebulosus* | 20 | 0.4 | 0.5 | 0.1 | 15 | 15 | 12.0 - 18 | 25 | 26 | 13.9 - 47 |
| Total | 5 212 | 100.0 | 451.6 | 100.0 | 17 | 18 | 3.4 - 49 | 47 | 87 | 0.4 - 1 366 |

**Table 4**. Changes in fish weights in Cormorant diet over the course of winter 2014/2015.

Note: coef, Time coefficient; SE, standard error; DF, degrees of freedom.

| species | Trend | coef | p value | SE | DF |
|---|---|---|---|---|---|
| all fish species | increasing | 0.78 | < 0.01 | 0.058 | 5 211 |
| Roach *Rutilus rutilus* | increasing | 0.81 | < 0.01 | 0.058 | 3 360 |
| non-Roach fish species | increasing | 0.31 | < 0.01 | 0.137 | 1 850 |
| European Perch *Perca fluviatilis* | increasing | 0.22 | < 0.01 | 0.19 | 403 |
| White Bream *Abramis bjoerkna* | increasing | 0.08 | < 0.01 | 0.23 | 283 |
| Ide *Leuciscus idus* | no observed trend | 0.19 | > 0.01 | 0.82 | 170 |
| European Chub *Squalius cephalus* | decreasing | -0.25 | < 0.01 | 0.28 | 340 |

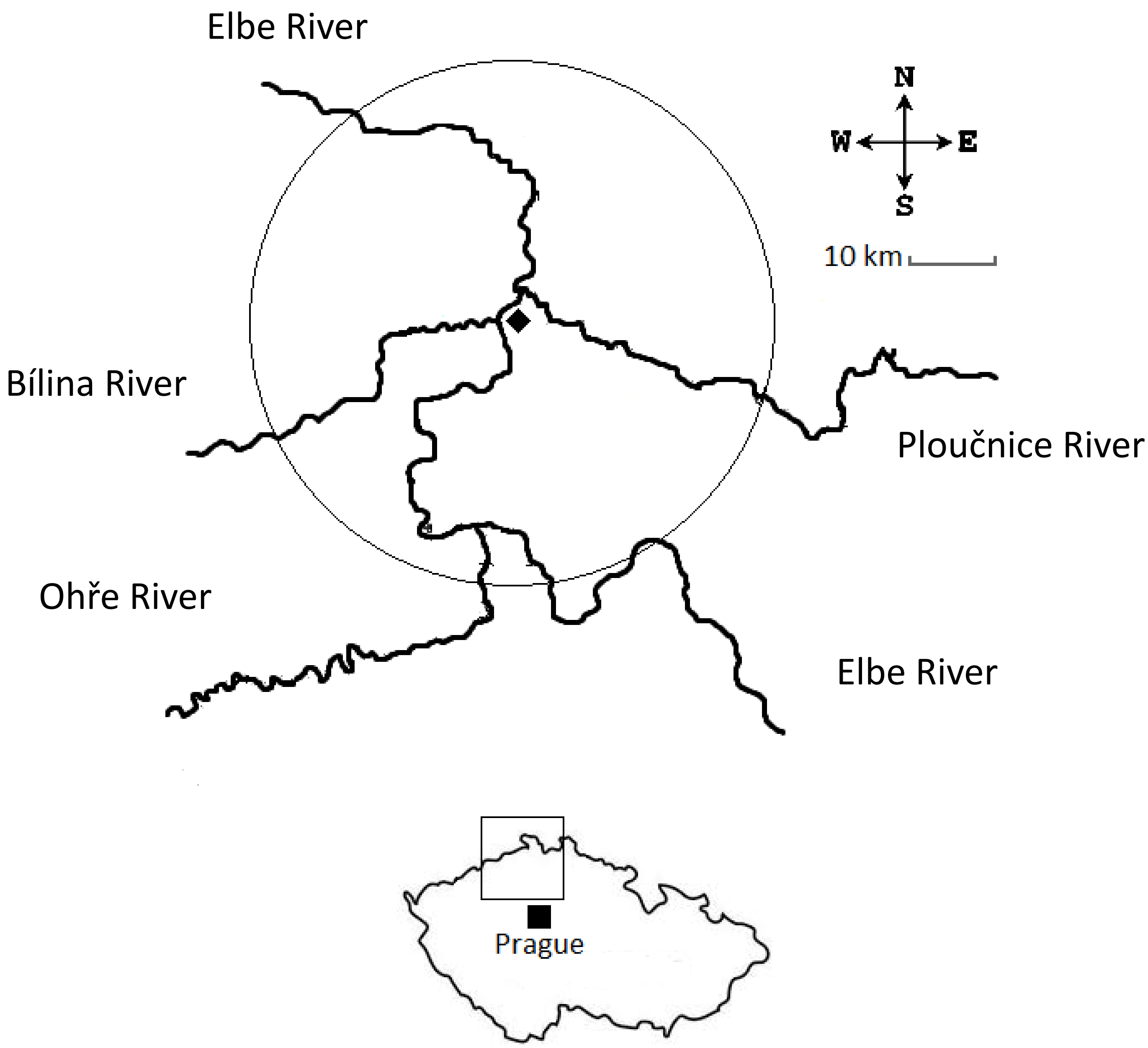



**Figure 1.** Map of the study area with position of Cormorant *Phalacrocorax carbo* roosting site (50°40'34.2"N, 14°07'28.5"E; full black diamond) and its location in the Czech Republic. The estimated daily reach of Cormorants roosting in the study area is provided (wide black circle).

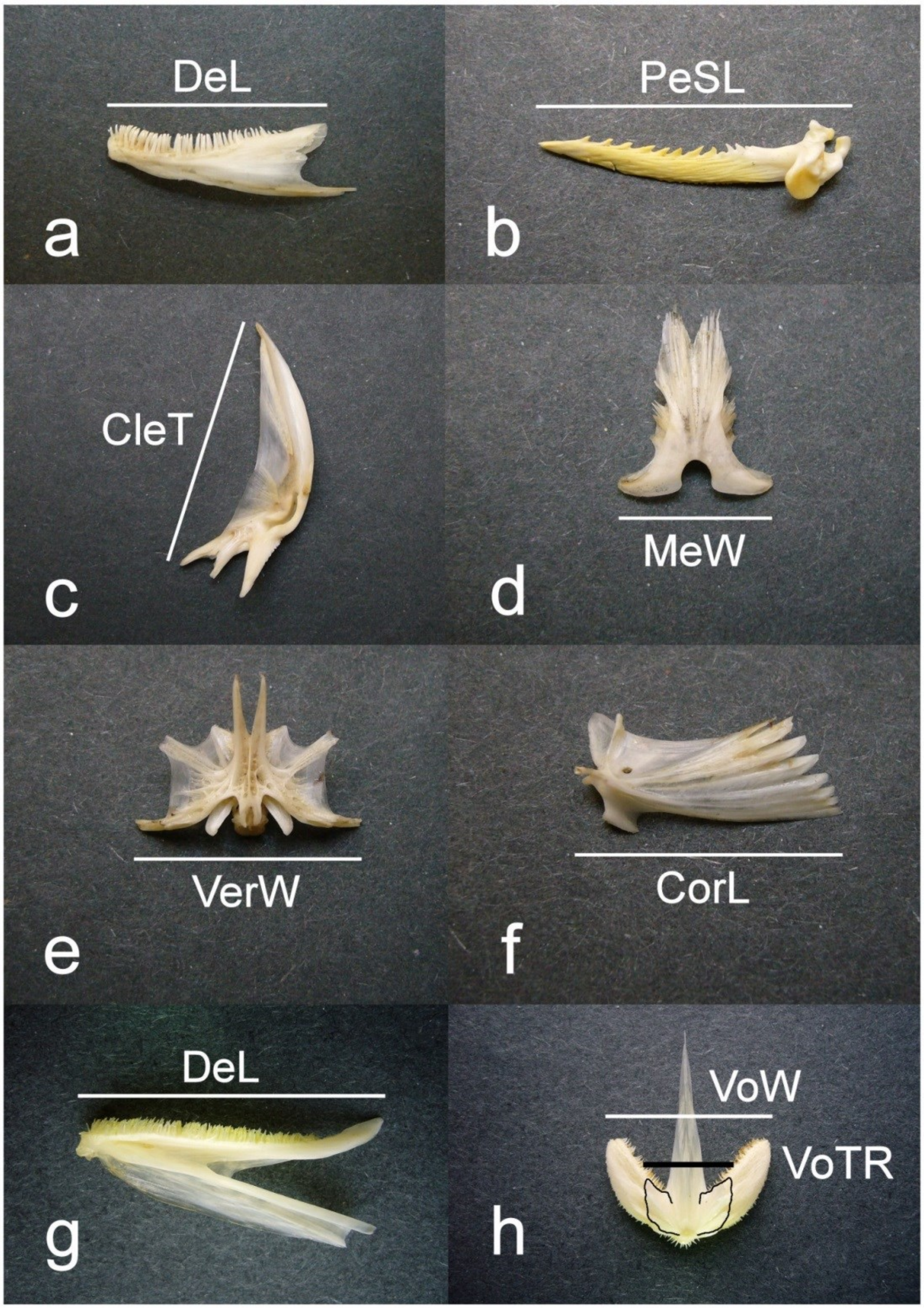
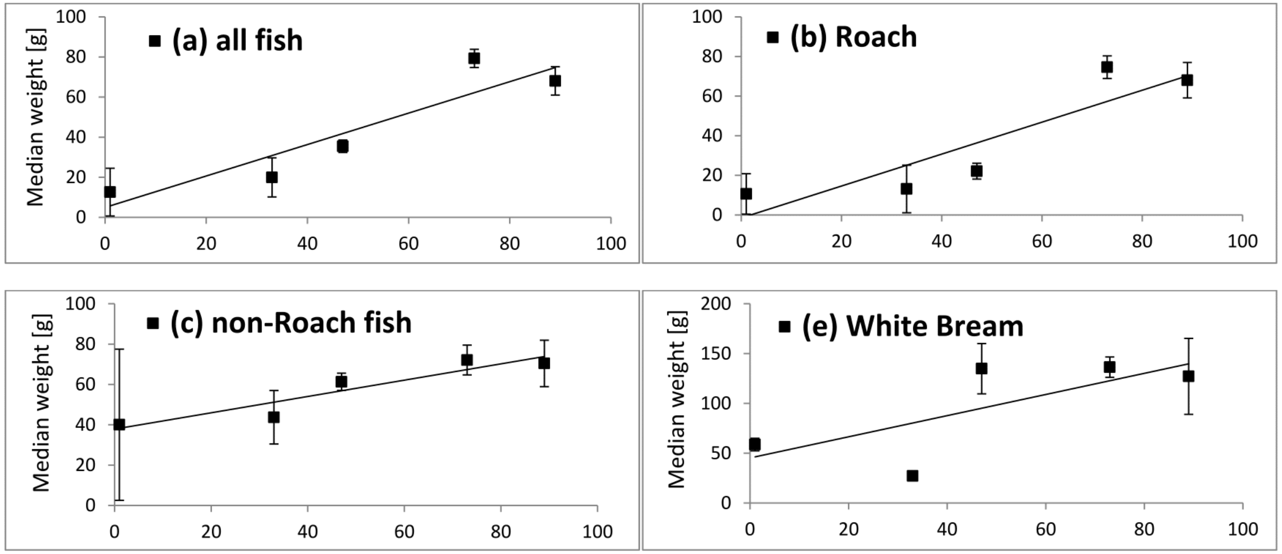



**Figure 2.** Diagnostic bones of Brown Bullhead *Ameiurus nebulosus* (a−f) and Burbot *Lota lota* (g, h). Note: (a, g) Dentale. (b) Pectoral spine. (c) Cleithrum. (d) Mesethmoid. (e) Vertebra (complex). (f) Coracoid. (h) Vomer. The white/black line indicates the measurement. DeL, dental length; PeSL, pectoral spine length; CleT, cleithrum tip; MeW, mesethmoid width; VerW, vertebra width; CorL, coracoid length; VoW, vomer width; VoTR, vomer thorn range (massive thorns highlighted by black contour line). Photo: M. Čech


(a) all fish
Median weight [g]
100
80
60
40
20
0
0
20
40
60
80
100
(b) Roach
(c) non-Roach fish
(e) White Bream
200
150
50

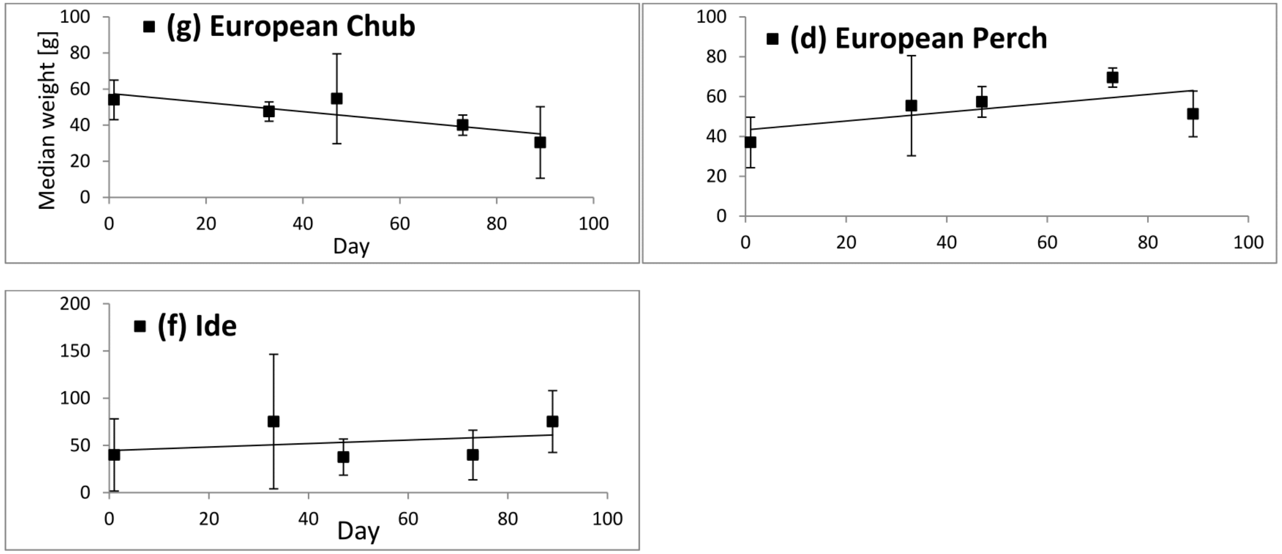



**Figure 3.** The relationship between the weight (median with 95 % confidence intervals) of fish prey found in the diet of Cormorant *Phalacrocorax carbo* over the course of the winter 2014/2015 (upper Elbe River, Czech Republic). Note: (a) All fish species pooled together. (b) Roach *Rutilus rutilus*. (c) Non-Roach fish (all fish species pooled together except for Roach). (d) European Perch *Perca fluviatilis*. (e) White Bream *Abramis bjoerkna*. (f) Ide *Leuciscus idus*. (g) European Chub *Squalius cephalus*. Note that day 1 on x-axis represents 5 December 2014.

# Differences in catch, yield, fishing visits, and angling guard controls on differently sized fishing grounds

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## Abstract

This study aimed to assess the relationship between basic metrics in recreational fishing and the size of a fishing ground. Data were obtained from individual angling logbooks collected by the Czech Fishing Union during 12 years on 212 fishing grounds located in the regions of Prague and Central Bohemia, Czech Republic, Central Europe. Small fishing grounds had the highest catch, yield, numbers of fishing visits, and numbers of angling guard controls per hectare. Medium-sized fishing grounds showed the highest catch, yield, and numbers of both fishing visits and angling guard controls per fishing ground. Anglers kept on returning to medium-sized fishing grounds the most frequently. The percentage of anglers who caught and took home at least one fish was decreasing with the increasing size of a fishing ground. In conclusion, basic metrics in recreational fishing are related to the size of a fishing ground. Therefore, the size of a fishing ground plays an important role in fisheries management.

Keywords: angling statistics, fish harvest, fisheries management, inland fishing, non-linear models, sports fishing

## 1. Introduction

Recreational fishing has been on the rise in many countries and can be counted among the most popular outside leisure activities (Marta, Bochechas & Collares-Pereira, 2001; Rasmussen & Geertz-Hansen, 2001; Freire, Machado & Crepaldi, 2012; Gupta, Bower, Raghavan, Danylchuk & Cooke, 2015). On the other hand, several countries have been recently reporting fall in popularity of recreational fishing (Post et al., 2002; Salmi, Toivonen & Mikkola, 2006; Cowx, 2015). By studying fishing in European inland freshwater ecosystems, previous researchers stated that recreational fishing has become more important and impactful than commercial fishing (Arlinghaus, Mehner & Cowx, 2002; Arlinghaus & Cooke, 2005; FAO, 2010). In addition, recreational fishing has been recognized as one of the main factors that influence populations of commercially valuable fish species in inland freshwater ecosystems (Cooke & Cowx, 2004; Elmer et al., 2017).

Despite the importance of recreational fishing in inland freshwaters, social aspects of angling are still significantly understudied (Arlinghaus, Mehner & Cowx, 2002; Lewin, Arlinghaus & Mehner, 2006; Beardmore, Hunt, Haider, Dorow & Arlinghaus, 2015; Ward et al., 2016). In order to improve the management of fishing grounds (and in order to maintain the sustainable development of recreational fishing), it is very important to understand how basic metrics in recreational fishing work on different types of fishing grounds (Arlinghaus et al., 2002; Beardmore et al., 2015). Moreover, suboptimal management of fishing grounds could have a negative effect on fish populations and also on satisfaction of anglers (Arlinghaus, Mehner & Cowx, 2002; Arlinghaus, Schwab, Cooke & Cowx, 2009).

This study aimed to compare basic metrics in recreational fishing (catch, yield, fishing visits, angling guard controls etc.) on differently sized fishing grounds (Table 1). The goal was to estimate the relationship between the size of a fishing ground (ha) and each basic metric in recreational fishing. The aim was to discover if differently sized fishing grounds show differences in basic metrics in recreational fishing. It was hypothesised that the absolute metrics (catch, yield, fishing visits, angling guard controls per fishing ground) would show an increasing trend with an increasing size of the fishing ground. This study also aimed to discover if differently sized fishing grounds show differences in standardized basic metrics in recreational fishing (catch, yield, fishing visits, and angling guard controls per hectare and per angler).

## 2. Methods

### 2.1 Study area

This study was carried out in the regions of Central Bohemia (49.5°–50.5° N, 13.5°–15.5° E) and Prague (50° N, 14.5° E), Czech Republic, Central Europe (Figure 1). Both regions together cover an area of 11 500 km$^2$. The region of Prague (the capital of the Czech Republic) has mostly urban character while the region of Central Bohemia has mostly agricultural character. The study area is dominated by the rivers Elbe and Vltava. Both rivers belong to the upper Elbe River Basin. All rivers in the study area belong to the North Sea Drainage area. Studied fishing grounds are situated in lowlands with an altitude of 200–600 m above sea level. Waters in the study areas are mostly mesotrophic and eutrophic with production of 150-300 kg/ha and fish biomass of 150-300 kg/ha (Lyach & Čech, 2017 b). The study area includes salmonid streams (dominated by salmonids) and non-salmonid rivers (dominated by cyprinids). There are no lakes in the study area.

### 2.2 Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is organized by the Czech Fishing Union (the main authority in recreational fishing in the Czech Republic) and is centralized for the whole country (Humpl, Pivnicka & Jankovský, 2009; Jankovský, Boukal, Pivnicka & Kubecka, 2011; Boukal, Jankovsky, Kubecka & Heino, 2012, Lyach & Čech, 2018). The absolute majority of fishing grounds in the Czech Republic is managed by the Czech Fishing Union. Therefore, the Czech Fishing Union has approximately 250 000 registered members (anglers) which is approximately 2.5 % of inhabitants of the Czech Republic. Individual fishing grounds are managed by local angling organisations. One local angling organization usually shelters the majority of anglers from one smaller city or one part of a larger city. Fishing grounds are defined as stream stretches, river stretches, or rarely other water bodies where recreational fishing can be legally conducted. Anglers are predominantly fishing from the shore.

Each angler has to obtain two documents – a fishing license and a fishing permit – before he or she can start practicing recreational fishing. A fishing licence allows anglers to practice fishing in general. A fishing permit allows anglers to practice fishing on all fishing grounds in one larger area. An angler has to obtain a fishing permit for salmonid and non-salmonid fishing grounds separately; fishing rules for salmonid and non-salmonid fishing grounds are different.

The catch (individual fish) and yield (kg of fish) per angler and per time period is limited by the Law on Fisheries (99/2004), the Directive on Fisheries (197/2004), and by angling rules on individual fishing grounds. Minimum and maximum legal catchable fish body size is limited for commercially important and endangered fish species as well. Limits for catch, yield, and minimum fish body size are set in order to protect populations of commercially important and endangered fish species. The goal of the maximum body size limit is to protect trophy-sized fish individuals.

Professional and amateur angling guards are responsible for monitoring of angling activities in the field and for reporting of any violations of fishing rules. Angling guards are also allowed to confiscate illegal fish catches and fishing permits if necessary. Angling guards are not present on the fishing grounds at all times but rather travel to fishing grounds and perform controls of anglers randomly. When checking an angler in the field, an angling guard checks fishing permit, fishing license, fish catches, and fishing gear. After that, the angling guard writes a note into the owner´s angling logbook. One angling guard control equals one note in one angling logbook.

Each angler is required to fill in a report of catches in his or her own individual angling logbook when he or she goes fishing. Each angler is also obliged to write down each fish catch that he or she wants to keep. Fish that are released back into water are not recorded in angling logbooks. Anglers identify and measure each kept fish to the nearest cm. Anglers then assign estimated body weight to each kept fish according to length-weight calculations provided by the Czech Fishing Union. Those calculations are based on general long-term observations of fish in Czech rivers. At the end of the year, anglers are obliged to deliver summaries of their angling logbooks to the Czech Fishing Union.

The content of each angling logbook is checked by administrative workers in the Czech Fishing Union for errors. Processed data from all angling logbooks are afterwards added to the central fisheries database of the Czech Fishing Union. The database contains summarized information about each fishing ground for each year. An example of annual angling report is shown in Table 2.

## 2.3 Data Sources

Data from annual angling summaries for each fishing ground were used in this study. Data from 212 inland freshwater fishing grounds over the course of years 2005–2016 were used. The same 212 fishing grounds were used throughout the time period. The analysed fishing grounds did not change in size during the time period. The fishing grounds covered an area of 102.8 $km^2$. The data were originally collected by the Czech Fishing Union and then processed by the authors of this study.

### 2.4 Measured metrics

This study was comparing the differences in basic metrics in recreational fishing on fishing grounds of different sizes. The goal was to estimate the relationship between the size of a fishing ground and each of those metrics. Overall 13 metrics were used in this study (Table 1). Small fishing grounds are stretches of smaller streams (1-5 m wide). Medium-sized and large fishing grounds are stretches of larger rivers (10-300 m wide). Studied fishing grounds ranged from 0.2 to 160 ha in size. Small, medium-sized, and large fishing grounds ranged from 0.2 to 10, from 11 to 100, and from 101 to 160 ha in size, respectively.

### 2.5 Statistical analysis

The statistical programme R (R i386 3.4.1., R Development Core Team 2017) was used for statistical testing. Shapiro-Wilk test was used for analysis of data distribution. Generalized non-linear models (package 'gnm') were used to fit the models in statistical testing (Turner & Firth, 2015). Bonferroni correction was applied when multiple groups were compared in the statistical analysis. Minimum probability level of $p = 0.05$ was accepted for all the statistical tests, and all statistical tests were two-tailed. One fishing ground was used as one sample in all analyses. The value of each metric on each fishing ground was calculated as the mean value of the metric on the fishing ground over the course of 12 years.

## 3. Results

### 3.1 Overall data summary

Over the course of 12 years, angling catch on analysed fishing grounds was 3 467 081 individual fish and yield was 6 333 591.1 kg of fish.  Anglers visited fishing grounds 9 101 782 times and angling guards made 247 502 controls on the fishing grounds.

3.2 Metrics per hectare of fishing grounds

Both angling catch [individual fish] and yield [kg] per hectare of fishing grounds were logarithmically decreasing with an increasing size of a fishing ground (for catch: SE = 0.016, p < 0.001, DF = 211; for yield: SE = 0.001, p < 0.001, DF = 211). Small fishing grounds had catch of 0-500 fish and yield of 0-900 kg per hectare. Large fishing grounds had lower catch of < 100 fish and lower yield of < 200 kg of fish per hectare (Figure 2 a, b).

The numbers of both individual anglers and all fishing visits per hectare of fishing grounds were logarithmically decreasing with an increasing size of a fishing ground (for individual anglers: SE = 0.018, p < 0.001, DF = 211; for fishing visits: SE = 0.006, p = 0.002, DF = 211). Small fishing grounds had 0-800 anglers per hectare and 0-1 500 fishing visits per hectare. Large fishing grounds had < 50 anglers and < 400 fishing visits per hectare (Figure 2 c, d).

The numbers of angling guard controls per hectare of fishing grounds were logarithmically decreasing with an increasing size of a fishing ground (SE = 0.032, p = 0.011, DF = 211). Small fishing grounds had 0-460 angling guard controls per hectare. Large fishing grounds had < 50 angling guard controls per hectare (Figure 2 e).

3.3 Metrics per fishing ground

Both catch [individual fish] and yield [kg] per fishing ground were the highest on medium-sized fishing grounds (for catch: SE = 4.346, p < 0.001, DF = 211; for yield: SE = 8.220, p < 0.001, DF = 211). Small fishing grounds had catch of 0-5 000 fish and yield of 0-13 000 kg. Medium-sized fishing grounds had catch 600-14 000 fish and yield of 800-31 000 kg. Large fishing grounds had catch of 340-6 800 fish and yield of 640-12 300 kg. The peak for catch occurred on fishing grounds with size of 38-43 ha. The peak for yield occurred on fishing grounds with size of 43-55 ha (Figure 3 a, b).

The numbers of both individual anglers and all fishing visits per fishing ground were the highest on medium-sized fishing grounds as well (for individual anglers: SE = 0.002, p < 0.001, DF = 211; for fishing visits: SE < 0.001, p < 0.001, DF = 211). Small fishing grounds had 0-2 000 anglers and 0-3 000 fishing visits. Medium-sized fishing grounds had 500-5 000 anglers and 3 000-50 000 fishing visits. Large fishing grounds had 500-2 900 anglers and 2 500-22 000 fishing visits. The peak for both anglers and fishing visits occurred on fishing grounds with size of 43-55 ha (Figure 3 c, d).

The numbers of angling guard controls per fishing ground were also the highest on medium-sized fishing grounds (SE = 0.006, $p < 0.001$, DF = 211). Small, medium-sized, and large fishing grounds had 0-1 200, 200-2 200, and 100-1 100 angling guard controls, respectively. The peak for angling guard controls occurred on fishing grounds with size of 48-55 ha (Figure 3 e).

The numbers of anglers who caught and took home at least one fish per fishing ground were the highest on medium-sized fishing grounds as well (SE = 0.006, $p = 0.003$, DF = 211). Smaller, medium-sized, and larger fishing grounds had 0-800, 150-2 100, and 110-950 anglers who took at least one fish, respectively. The peak for anglers who caught and took home at least one fish occurred on fishing grounds with size of 43-55 ha (Figure 3 f).

### 3.4 Metrics per angler

Both catch [individual fish] and yield [kg] per angler per fishing ground did not show any significant trend with increasing size of a fishing ground (for catch: SE = 0.717, $p = 0.14$, DF = 211; for yield: SE = 0.686, $p = 0.50$, DF = 211). Fishing grounds had catch of 0-30 fish (average 2.8 fish) per angler and yield of 0-19 kg (average 3.9 kg) per angler (Figure 4 a, b).

The number of fishing visits per angler was the highest on small and medium-sized fishing grounds (SE = 0.580, $p = 0.001$, DF = 211). Small, medium-sized, and large fishing grounds had 0-27, 4-12, and 4-10 fishing visits per angler, respectively. The peak for fishing visits per angler occurred on fishing grounds with size of 4-31 ha (Figure 4 c).

The percentage of anglers who caught and took home at least one fish was decreasing with an increasing size of a fishing ground (SE = 0.112, $p = 0.001$, DF = 211). Small fishing grounds had mostly 20-80 % of anglers who took at least one fish. Large fishing grounds had mostly 20-50 % of anglers who took at least one fish (Figure 4 d).

## 4. Discussion

An important parameter that influences catch and yield is ecosystem productivity. Analysed fishing grounds were mostly located on mesotrophic and eutrophic streams and rivers. In addition, fish stocking is conducted annually on fishing grounds in the Czech Republic (Humpl, Pivnicka & Jankovský, 2009; Jankovský, Boukal, Pivnicka & Kubecka, 2011; Boukal, Jankovsky, Kubecka & Heino, 2012, Lyach & Čech, 2018). Therefore, analysed fishing grounds have high fish biomass (150-300 kg per hectare). In comparison, fishing grounds that are located on oligotrophic rivers might show different patterns because catch and yield of anglers would be limited by low ecosystem productivity. It is possible that there is a correlation between ecosystem productivity and size of a fishing ground (i.e. small fishing grounds have higher productivity per hectare). In that case, catch and yield may be driven mainly by ecosystem productivity.

Another important parameter that influences catch and yield is the relatively strict legal regulation of recreational fishing in the Czech Republic. Most importantly, anglers are strictly limited in maximum catch, yield, and minimum-maximum fish body size (Lyach & Čech, 2018). In countries where similar regulations are less strict (e.g. Sweden, Portugal, New Zealand, Norway: Naslund et al., 2010; Veiga et al., 2013; Thomas, Milfont & Gavin, 2015; Lennox, Falkengard, Vollestad, Cooke & Thorstad, 2016), we expect that catch and yield would show higher variability or even different patterns. Fishing grounds with no bag and slot limits could show higher variance in catch and yield. In addition, anglers in the study area are predominantly fishing from the shore. Other geographical areas with boat fishing and large lakes (> 1000 ha) could also show different results.

When small and large fishing grounds were compared, results showed that small fishing grounds have higher variability of all metrics in recreational fishing. We believe that the high variability is caused by high variance in accessibility of smaller fishing grounds for anglers. Fishing grounds that are situated near cities and near asphalt roads are easily accessible and therefore frequently visited. Inversely, fishing grounds that are situated in the countryside along agricultural fields and forests are usually accessible only by dusty roads, and that significantly limits their potential visit rates (Arlinghaus, Bork & Fladung, 2008; Schramm 2008; Navratil, Martinat & Kallabova, 2009). As a result, several small fishing grounds have zero fishing visits and therefore zero catch, yield, and angling guard controls (Czech Fishing Union, unpubl. data). Inversely, large fishing grounds are used by anglers at relatively similar rates. It is because large fishing grounds are located on two of the largest rivers in the Czech Republic (Vltava and Elbe) and are therefore easily accessible by roads. In addition, there are not that many large fishing grounds in the study area in general, although they are all very well-known among anglers (Czech fishing Union, unpubl. data).

Small fishing grounds showed higher catch, yield, visit rates, and angling guard controls per hectare than large fishing grounds. It corresponds well with the higher primary production of smaller streams (Randall, Minns & Kelso, 1995; Dodds, 2006; Dodds & Smith, 2016). In this area, smaller streams and rivers run through agricultural fields with surface fertilizer runoff or through forests with allochthonous sources of nutrients. In addition, smaller streams have longer bank lines where anglers can spread along the stream banks without disturbing each other. Previous research found that anglers actually prefer tranquillity and lack of competition of other anglers (Arlinghaus, Beardmore, Riepe, Meyerhoff & Pagel, 2014).

In addition, smaller streams in the study area are mostly dominated by commercially valuable salmonids (Zavorka, Horky & Slavik, 2013; Zavorka, Horky, Kohout, Kalous & Slavik, 2015; Lyach & Čech, 2017a; Matena et al., 2017; Zavorka et al., 2017). Previous authors also confirmed dominance of salmonids in smaller streams in Central Europe in general (Klementsen et al., 2003). Commercially valuable fish species are easier to locate and catch in smaller streams when compared to large rivers (Naslund et al., 2010). For example, salmonids like brown trout (*Salmo trutta* L.) or rainbow trout (*Oncorhynchus mykiss* L.) can be often observed in smaller streams with the naked eye. It is because smaller streams usually have shallow and clear water (Randall, Minns & Kelso, 1995; Dodds, 2006; Dodds & Smith, 2016). For those reasons, commercially valuable species are more available (and therefore easier to catch) in smaller streams (Naslund et al., 2010). On the other hand, anglers on larger rivers usually target rare and less abundant fish species, especially common carp (*Cyprinus carpio* L.) and larger piscivorous species (Humpl, Pivnicka & Jankovský, 2009; Jankovský, Boukal, Pivnicka & Kubecka, 2011; Boukal, Jankovsky, Kubecka & Heino, 2012). Inversely, the most abundant fish species within larger rivers in Central Europe, i.e. bleak (*Alburnus alburnus* L.) and roach (*Rutilus rutilus* L.), are of lower interest to anglers (Prchalova, Kubecka, Vasek, Peterka, Seda et al., 2008; Jurajda, Janac, Valova & Streck, 2010; Prchalova, Horky, Slavik, Vetesnik & Halacka, 2011). Those commercially less attractive fish are mostly released back to water after being caught (Arlinghaus et al., 2007). In result, high abundance of unattractive fish in the ecosystem further increases the amount of time needed to catch the desirable fish species on large fishing grounds (Britton, Pegg, Sedgwick & Page, 2007). Especially selective targeting of large-growing piscivorous fish species is quite time-consuming (Rees et al., 2017).

Importantly, size of a fishing ground explained only 6-11 % of the variability in metrics per hectare. The residual variability was most likely caused by other factors. We believe that the differences in accessibility of small fishing grounds could partially explain the rest of the variability. Still, the importance of other factors does not eliminate the usefulness of results of this study – size of a fishing ground seems to be an important variable in fisheries management.

This paper also found that the percentage of anglers who catch and take home at least one fish per fishing ground decreases with an increasing size of a fishing ground. Only 5 % of the variability in the percentage of anglers was explained by size of a fishing ground, meaning that the residual variability should to be explained by other factors. We believe that those factors are either accessibility of fishing grounds (anglers prefer catch-and-release strategy on distant fishing grounds) or the increased abundance of commercially unattractive fish in larger rivers.

Surprisingly, medium-sized fishing grounds showed the highest catch, yield, and visit rates in general. It was initially expected that large fishing grounds would show the highest catch, yield, and rate of visits. We believe that medium-sized fishing grounds represent a compromise between accessibility of fishing grounds and selectivity of anglers. Similar compromise in selectivity of anglers was previously discovered by other authors (Manfredo, 1984; Arlinghaus & Mehner, 2004; Arlinghaus, Bork & Fladung, 2008). On one hand, medium-sized fishing grounds have reasonably high fish biomass due to allochthonous sources of nutrients and availability of spawning substrates. On the other hand, medium-sized fishing grounds also maintain natural character, are not urbanized (unlike large fishing grounds on the Vltava River in Prague), and are not significantly influenced by distracting elements (mainly boat traffic). When compared to small fishing grounds, anglers on medium-sized fishing grounds also have a higher chance to catch the most valuable fish species (common carp and large piscivores; Changeux & Zylberblat, 1993). In addition, large fishing grounds provide variety of non-fishing activities for the whole family, e.g. swimming, water sports, and beach sports (Smallwood & Beckeley, 2012). In that case, anglers on large fishing grounds often prefer catch-and-release fishing strategy (Cooke & Cowx, 2006; Gaeta, Beardmore, Latzka, Provencher & Carpenter, 2013; Brownscombe, Danylchuk, Champan, Gutowsky & Cooke, 2017). In case of catch, yield, and visit rates, size of a fishing ground explained 30-50 % of the variability. It means that the size of a fishing ground is a reasonably good predictor of basic metrics in recreational fishing.

As expected, fishing grounds with the highest catch, yield, and visit rates had also the highest rates of angling guard controls. This is good fisheries management because angling guards should be focusing on fishing grounds with the highest angling frequency. On the other hand, it also means that large fishing grounds are not in the centre of angling guards´ attention. This fact could potentially be misused by poachers and dishonest anglers. Angling guards are significantly outnumbered in the field by anglers (in case of the Czech Republic, thousands of angling guards versus hundreds of thousands of anglers), and especially small salmonid streams in rural areas are rarely checked by angling guards (Czech Fishing Union, unpubl. data). Report rates for fish catches and angling visits are basically never at 100 % (Schill & Kline, 1995; Rudd & Branch, 2017). In the Czech Republic, the numbers of caught poachers are increasing (Czech Fishing Union, unpubl. data). However, angling guards are catching more poachers mostly due to increasing activity of angling guards in the field (Lyach & Čech, 2018). Lewis (2015) discovered that local anglers are less likely to break rules than visitors; however, our previous study (Lyach & Čech, 2018) found that anglers are getting more mobile and keep visiting different fishing grounds more often. Other authors found that anglers usually do not break fishing rules as long as those rules are logical (Carrofino, 2013; Bergseth & Roscher, 2018).

This study also found that anglers keep on returning to medium-sized fishing grounds more frequently. Medium-sized fishing grounds were therefore not only the most visited but also the most popular among anglers. A fishing permit allows anglers to fish in different waters in a larger area; therefore, the low return rates of anglers on small fishing grounds should not be caused by additional cost of moving between fishing grounds.

This paper did not prove that the size of a fishing ground is a good predictor for two important metrics in recreational fishing - catch and yield per angler (the size of a fishing ground explained only 1-2% of the variability). This result suggests that the relationship between the size of a fishing ground and the number of anglers explains the catch and yield. In the Czech Republic, maximum catch per angler and per day is strictly limited (The Directive on Fisheries, 2004). Catch and yield per angler was relatively stable for all sizes of fishing grounds. We believe that the strict fishing regulation is the main reason why no differences in catch and yield per angler were observed on different fishing grounds. Better accessibility of a fishing ground leads to more anglers, and more anglers mean higher catch and yield. Other authors also reported that changes in fishing regulations may significantly affect angling catch and yield (Schill and Kline, 1995; Naslund, Nordwall, Eriksson, Hannersjo & Eriksson, 2005; Naslund et al., 2010; Van Poorten, Cox and Cooper, 2013; Askey, 2016).

## Conclusion

In conclusion, this study found that differently sized fishing grounds showed differences in basic metrics in recreational fishing. The absolute metrics (catch, yield, fishing visits, angling guard controls per fishing ground) peaked at medium levels. In addition, anglers kept on returning to medium-sized fishing grounds the most frequently. Large fishing grounds did not show the highest catch and yield nor the most fishing visits or angling guard controls. On the other hand, small fishing grounds showed the highest catch, the highest yield, the highest percentage of anglers who took at least one fish, and also the most fishing visits and angling guard controls per hectare of a fishing ground. No relationship was found between catch or yield per angler and the size of a fishing ground. This study showed that the basic metrics in recreational fishing are related to the size of a fishing ground. Therefore, the size of a fishing ground is important in fisheries management. In the future, we suggest that studies should focus on finding a relationship between the accessibility of fishing grounds and basic metrics in recreational fishing. Other studies could focus on the question whether the higher catch, yield, and numbers of fishing visits per hectare on smaller streams also indicate higher fishing pressure on resident fish populations.

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**Table 1** List of basic metrics in recreational fishing that were analysed in this study. Range represents the maximum and minimum value for each metric.

| Metric | Range (min-max) |
|---|---|
| Catch [individual fish] per hectare of fishing grounds | 0-776 |
| Yield [kg] per hectare of fishing grounds | 0-895 |
| Catch [individual fish] per angler | 0-74 |
| Yield [kg] per angler | 0-124 |
| Number of individual anglers who visited the fishing ground | 0-8 699 |
| Number of individual anglers per hectare of fishing grounds | 0-1 625 |
| Number of fishing visits per fishing ground | 0-99 522 |
| Number of fishing visits per hectare of fishing grounds | 0-2 858 |
| Number of fishing visits per individual angler | 0-101 |
| Number of angling guard controls per fishing ground | 0-2 211 |
| Number of angling guard controls per hectare of fishing grounds | 0-672 |
| Number of anglers who caught and took home at least one fish | 0-4 648 |
| Percentage of anglers who caught and took home at least one fish | 0-100 |

**Table 2** An example of annual angling report from a fishing ground on the River Elbe.

| ID of fishing ground | Name of fishing ground | Area [ha] |
|---|---|---|
| 411 049 | River Elbe 16 | 72 |

| Fish species | Catch [individual fish] | Yield [kg] |
|---|---|---|
| carp | 358 | 712.4 |
| tench | 3 | 7.5 |
| bream | 205 | 215.4 |
| chub | 10 | 12.3 |
| perch | 5 | 6.1 |
| barbel | 0 | 0.0 |
| nase | 0 | 0.0 |
| vimba bream | 0 | 0.0 |
| pike | 45 | 92.2 |
| zander | 22 | 57.1 |
| European catfish | 58 | 112.9 |
| European eel | 25 | 59.7 |
| brown trout | 7 | 3.3 |
| rainbow trout | 2 | 0.7 |
| grayling | 0 | 0.0 |
| brook trout | 0 | 0.0 |
| asp | 21 | 62.8 |
| whitefish | 0 | 0.0 |
| common huchen | 0 | 0.0 |
| grass carp | 10 | 26.1 |
| silver carp | 0 | 0.0 |
| crucian carp | 77 | 41.7 |
| burbot | 1 | 1.0 |
| other fish species | 156 | 124.7 |
| Total | 1 010 | 1 539.9 |

| **Parameters** | |
|---|---|
| Catches per ha [individual fish] | 11.28 |
| Yield per ha [kg] | 31.11 |
| Number of individual anglers | 698 |
| Number of anglers that caught at least one fish | 459 |
| Number of all angler visits | 6 407 |
| Number of visits per angler | 8.01 |
| Catches per angler [individual fish] | 0.87 |
| Yield per angler [kg] | 2.06 |
| Number of visits per ha | 81.27 |
| Number of angler guard notes in all angling logbooks | 412 |

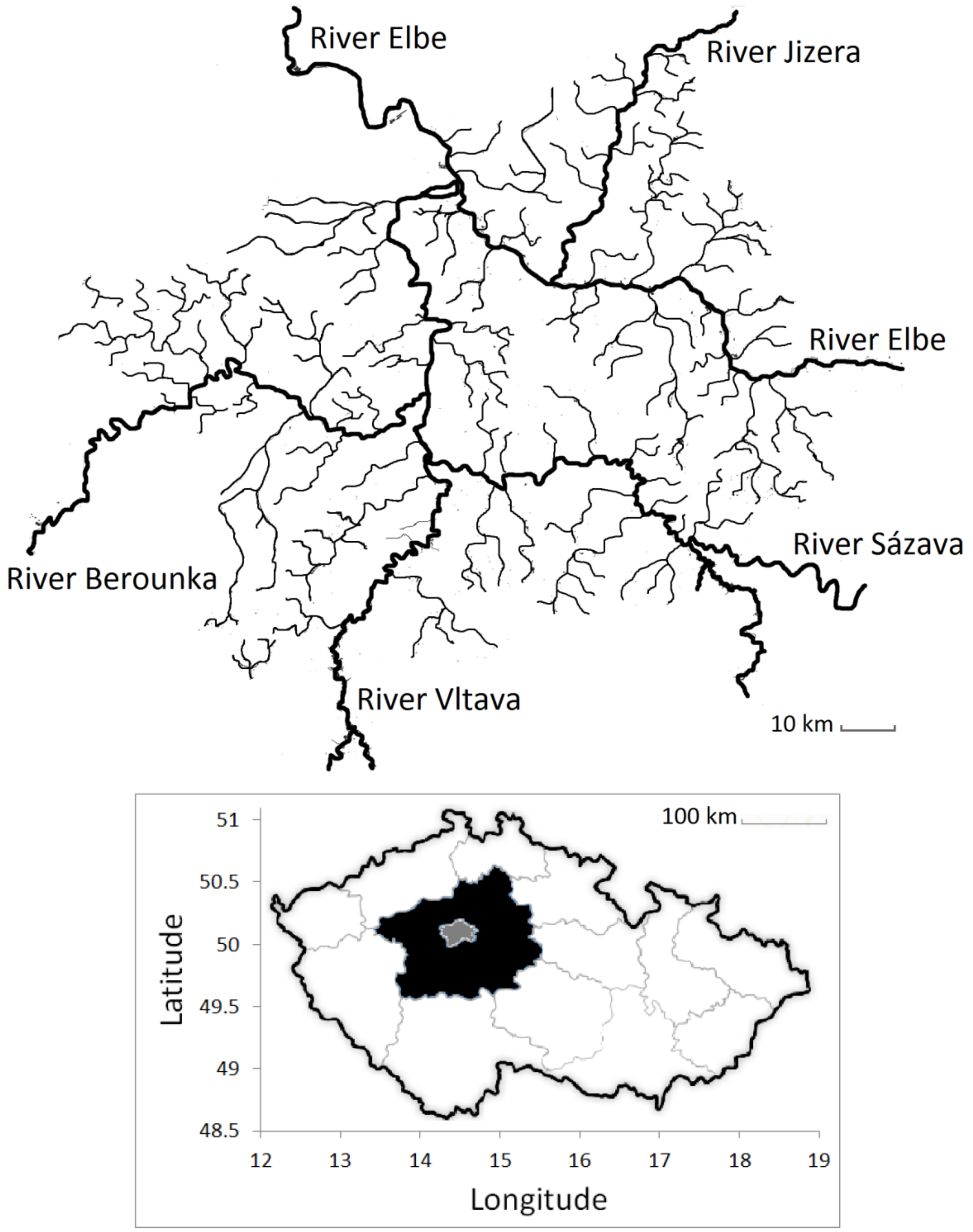
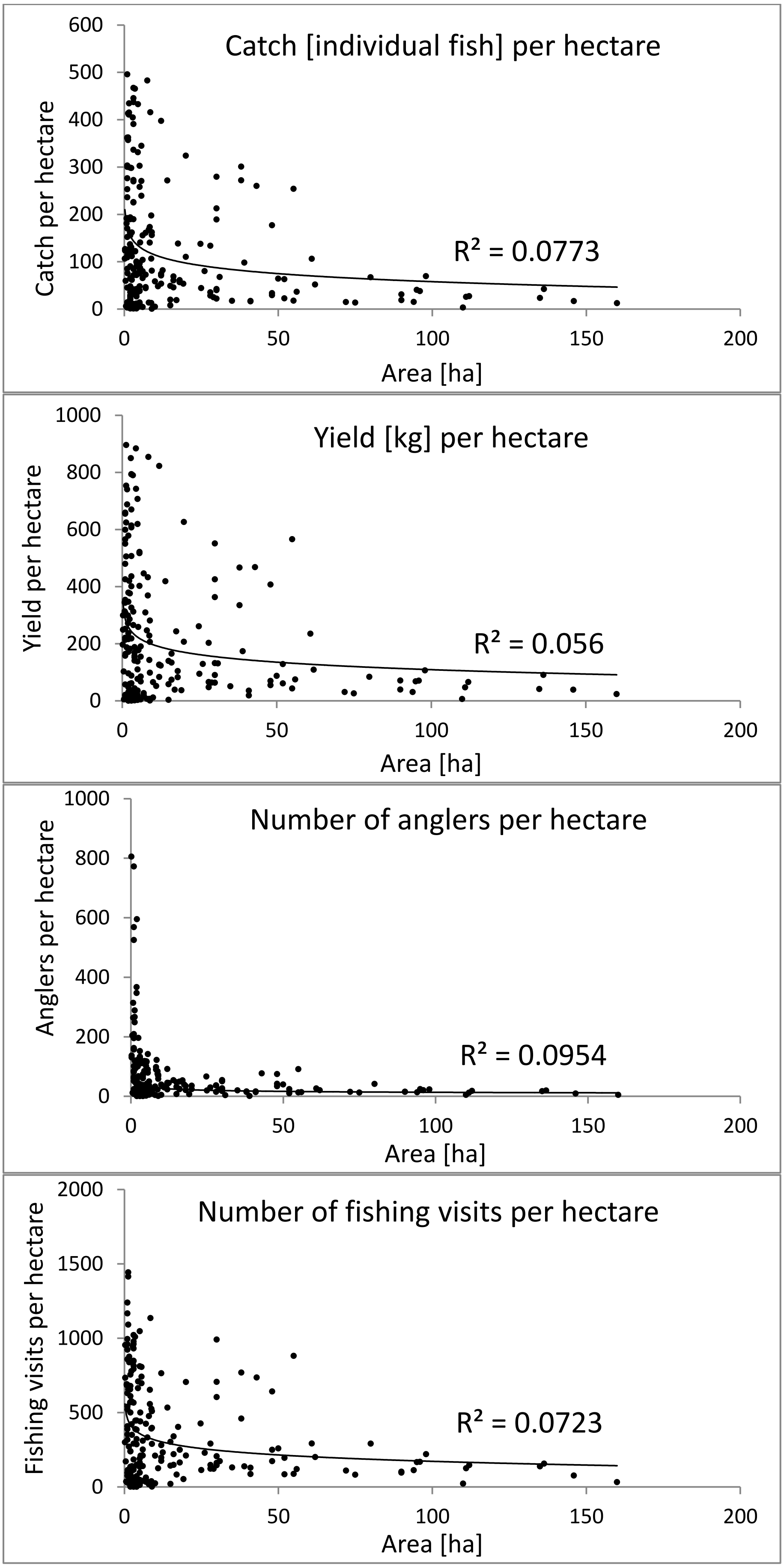



**Figure 1** Map of the study area with highlighted regions of Central Bohemia (in black; 49.5°–50.5° N, 13.5°–15.5° E) and Prague (in grey; 50° N, 14.5° E). Data were collected on 212 fishing grounds in the regions of Prague and Central Bohemia, Czech Republic, Central Europe, over the course of years 2005–2016.



Catch [individual fish] per hectare
Catch per hectare
R² = 0.0773
Area [ha]
Yield [kg] per hectare
Yield per hectare
R² = 0.056
Area [ha]
Number of anglers per hectare
Anglers per hectare
R² = 0.0954
Area [ha]
Number of fishing visits per hectare
Fishing visits per hectare
R² = 0.0723
Area [ha]

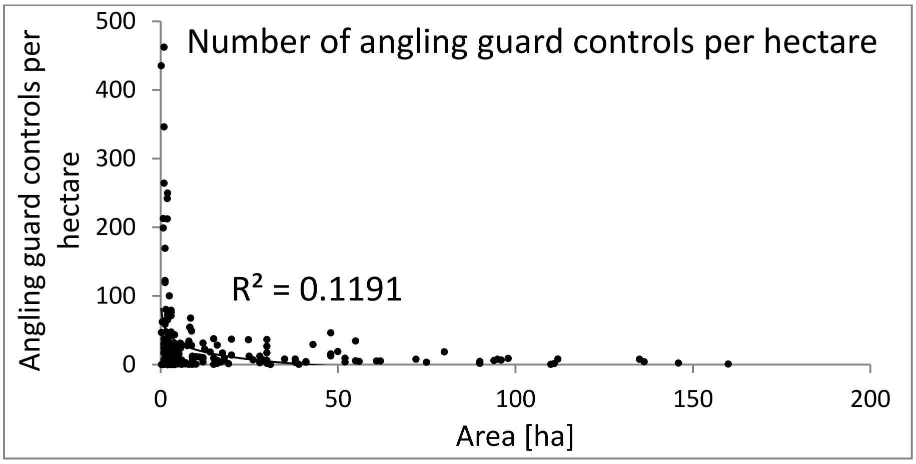
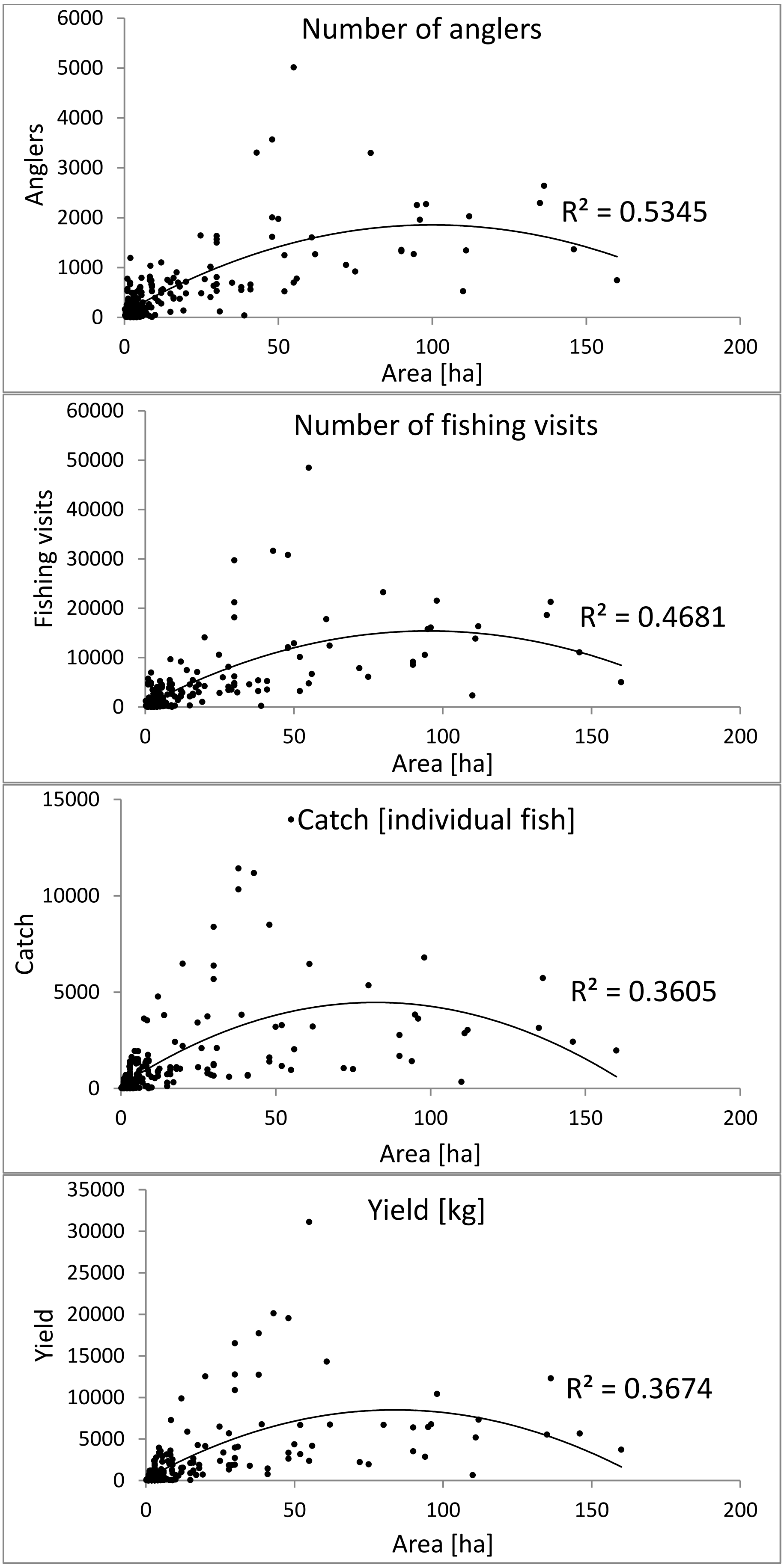



**Figure 2** The relationship between the size of a fishing ground in hectares and a) catch per hectare of a fishing ground, b) yield per hectare of a fishing ground, c) the number of anglers per hectare of a fishing ground, d) the number of fishing visits per hectare of a fishing ground, and e) the number of angling guard controls per hectare of a fishing ground.


Number of anglers
Anglers
Area [ha]
R² = 0.5345
Number of fishing visits
Fishing visits
Area [ha]
R² = 0.4681
Catch [individual fish]
Catch
Area [ha]
R² = 0.3605
Yield [kg]
Yield
Area [ha]
R² = 0.3674

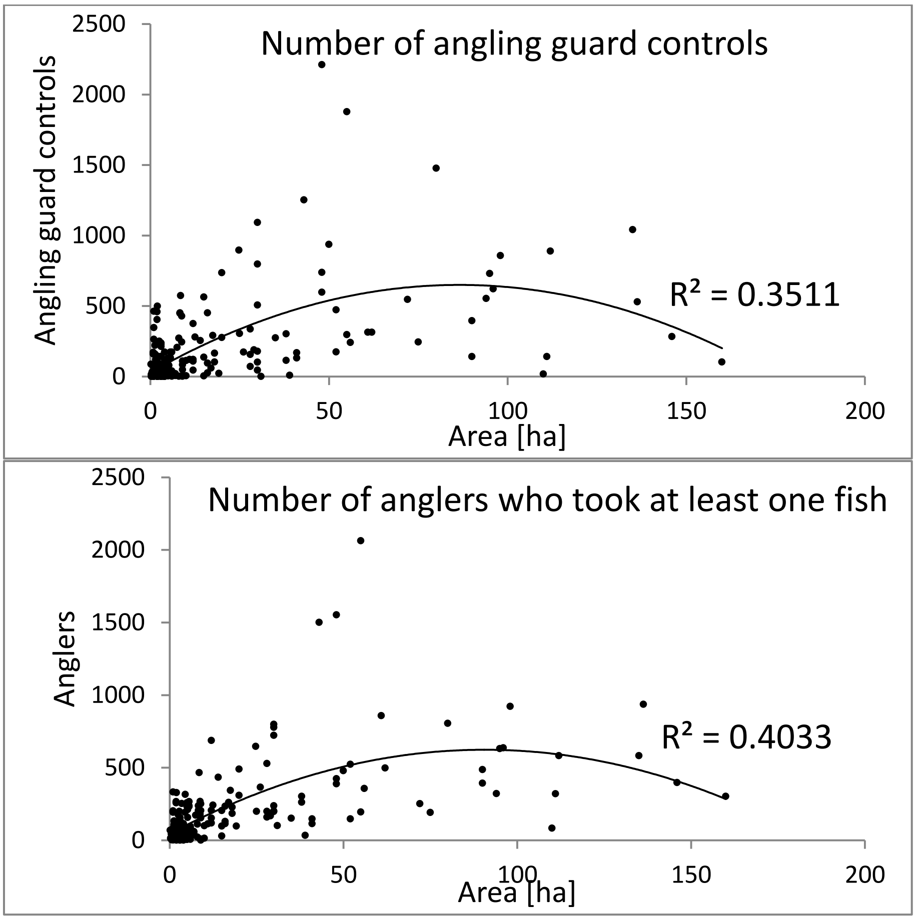



**Figure 3** The relationship between the size of a fishing ground in hectares and a) catch per fishing ground, b) yield per fishing ground, c) the number of anglers per fishing ground, d) the number of fishing visits per fishing ground, e) the number of angling guard controls per fishing ground, and f) the number of anglers who caught and took at least one fish per fishing ground.

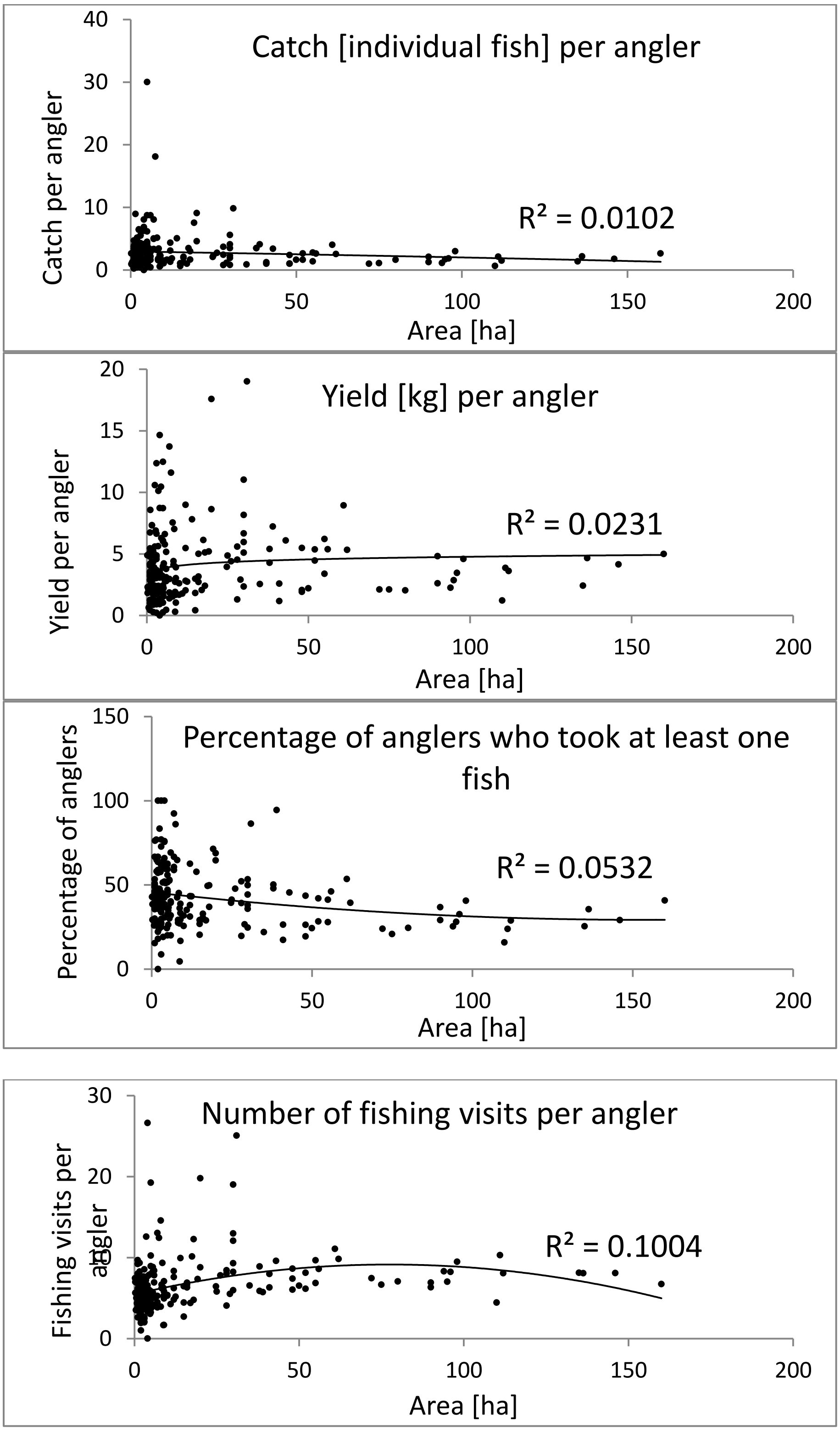



**Figure 4** The relationship between the size of a fishing ground in hectares and a) catch per angler per fishing ground, b) yield per angler per fishing ground, c) the number of fishing visits per angler per fishing ground, and d) the percentage of anglers who caught and took home at least one fish per fishing ground.

# The differences in catch, yield, fishing visits, and angling guard controls on natural and urban fishing grounds

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Running head: recreational angling on fishing grounds

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## Abstract

Recreational fishing is a very popular outdoor leisure activity. Assessing the differences in recreational fishing on different types of fishing grounds is very important in fisheries management. The goal was to discover how basic variables in recreational fishing (such as catch, yield, visit rates of fishing grounds, and rates of angling guard controls in the field) differ on natural and urban fishing grounds. Data was obtained from individual angling logbooks collected by the Czech Fishing Union on the River Elbe and the River Vltava (the Czech Republic, Central Europe). Visit rates of anglers were similar on natural and urban fishing grounds. Angling catch and yield was higher on urban fishing grounds. The number of anglers who caught and took home at least one fish was also higher on urban fishing grounds. Individual anglers kept on returning to urban fishing grounds more frequently. On the other hand, there were more angling guard controls on natural fishing grounds. Higher catch and yield on urban fishing grounds was caused by higher rates of intensively stocked fish species (mainly common carp *Cyprinus carpio*) in catches of anglers. Inversely, bream *Abramis brama* and large-growing piscivores showed higher catch and yield on natural fishing grounds. Average body weight of caught fish was higher on natural fishing grounds. We suggest that fisheries management should reflect on the differences in fishing on natural and urban fishing grounds by adjusting management of individual fishing grounds.

Keywords: angling statistics, fisheries management, inland fishing, rural fishery, sport fishing

## 1. Introduction

Recreational fishing is widely accepted as one of the most popular outdoor leisure activities (Marta et al. 2001; Rasmussen and Geertz-Hansen 2001; Freire et al. 2012). Several studies claim that recreational fishing is more important and impactful in European inland freshwaters than commercial fishing (Arlinghaus et al. 2002; Arlinghaus and Cooke 2005; FAO 2010). In addition, recreational fishing has been recognized by several authors as one of the main factors that influence populations of commercially valuable fish species (Cooke and Cowx 2004; Elmer et al. 2017).

Recreational fishing, despite its importance in inland freshwaters, still remains significantly understudied in comparison to commercial fishing (Arlinghaus et al. 2002). Several experts in the field of fisheries claim that especially social and socio-economic aspects of recreational fishing have been overlooked (Arlinghaus et al. 2002; Lewin et al. 2006; Beardmore et al. 2015; Ward et al. 2016). In particular, social aspects of recreational fishing in reference to different types of fishing grounds have not been studied enough. Studies suggest that better monitoring of key aspects in recreational fishing is required in order to understand its current state (Arlinghaus et al. 2002; Post et al. 2002; Ward et al. 2016; Elmer et al. 2017). For example, it is important to understand how basic variables in recreational fishing (such as catch, yield, and visit rates) change on different types of fishing grounds (Arlinghaus et al. 2002; Beardmore et al. 2015). This information is then critical for optimization of fisheries management (e.g. fish stocking, advertising, adjusting angling rules) on different types of fishing grounds (Schramm and Dennis 1993; Schramm and Edwards 1994; Schramm 2003; Schramm 2008).

Several studies have already focused on assessing the differences in socio-economic behaviour of anglers from urban and rural areas (Manfredo et al. 1984; Schramm and Dennis 1993; Schramm and Edwards 1994; Arlinghaus and Mehner 2004; Arlinghaus et al. 2008; Arlinghaus et al. 2014). Those studies discovered that anglers from urban and rural areas have different expectations when it comes to fishing. On the other hand, there is no study that would describe the differences in fishing in urban and rural areas. Specifically, there is no study that would describe differences in basic variables in recreational fishing between rural and urban fishing grounds. However, such study is needed in order to adjust management of different fishing grounds.

Previous studies speculated that recreational fishing might be different in urban and rural areas because rivers have usually different characteristics between those areas. Urban rivers are usually more polluted, have artificially straightened flows, have different scenery (roads, houses, artificial banks), and are more influenced by human-based elements (mainly traffic) (Wolter et al. 2000). On the other hand, natural rivers in rural areas are usually less polluted, the flow is meandering and heterogeneous with naturally occurring obstacles and shelters, scenery is more natural with fields and forests, and there is less traffic in adjacent areas (Eades et al. 2008). In addition, fishing in rural areas provides a stress-free and relaxing way to mentally escape from the modern world. Studies suggested that such opportunity is attractive to anglers (Arlinghaus and Mehner 2004; Arlinghaus et al. 2008; Arlinghaus et al. 2014). The role of urban fishing grounds in the world of recreational fishing is becoming more important because – as previous studies suggested – people should have the opportunity to fish where they live (Balsman and Shoup 2008; Schramm and Edwards 1994).

This paper aimed to examine differences in basic variables in recreational fishing (Table 1) between natural fishing grounds (located in rural areas) and urban fishing grounds (located in urban areas). The goal of this study was to discover if basic variables in recreational fishing (catch, yield, the number of anglers, visit rates of fishing grounds, and rates of angling guard controls in the field) show differences between natural and urban fishing grounds. We expected that natural fishing grounds would display higher catch and yield, higher numbers of anglers, and more visit rates. It is because natural fishing grounds are located on less polluted rivers with diversified habitats and overall better conditions for natural fish reproduction. Inversely, we expected that urban fishing grounds would show higher rates of angling guard controls. It is because urban fishing grounds are located in highly populated areas and are therefore easily accessible.

## 2. Materials and Methods

### 2.1 Study area

The study was carried out on the River Vltava in the region of Prague (50° N, 14.5° E) and on the River Elbe in the region of Central Bohemia (49.5°–50.5° N, 13.5°–15.5° E). Both regions, Prague and Central Bohemia, are located in the Czech Republic in Central Europe (Figure 1).

Overall 11 fishing grounds (located on the Elbe River in Central Bohemia) were chosen as natural fishing grounds. The 11 natural fishing grounds had total length of 94.5 km and covered an area of 934 hectares. Selected natural fishing grounds were located in rural areas in the countryside, were outside of larger cities, had naturally meandering flow, were surrounded mostly by agricultural fields with crops and surface fertilizer runoff, and had mostly natural banks with limited amount of artificial elements (building, roads etc.).

Similarly, three fishing grounds (located on the Vltava River in Prague) were chosen as urban fishing grounds. The three urban fishing grounds had total length of 26 km and covered an area of 378 hectares. Selected urban fishing grounds were located in strongly urbanized area in a large city (> 1 mil. inhabitants), had artificially straightened flow, were mostly surrounded by buildings and roads, and had mostly artificially straightened banks with limited amount of natural elements (trees etc.).

Fishing grounds in both study areas were located on larger non-salmonid rivers (dominated by cyprinids), had eutrophic character, and were located in lowlands with an altitude of 200–500 m above the sea level. Both rivers, Vltava and Elbe, belong to the upper Elbe River Basin which belongs to the North Sea Drainage.

## 2.2 Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is organized by the Czech Fishing Union (the main authority in recreational fishing in the Czech Republic) and is centralized for the whole country (Lyach and Čech 2018). The absolute majority of fishing grounds in the Czech Republic is managed by the Czech Fishing Union. Therefore, the Czech Fishing Union has approximately 250 000 registered members (anglers) which is approximately 2.5 % of inhabitants of the Czech Republic. Individual fishing grounds are managed by local angling organisations. One local angling organization usually shelters the majority of anglers from one smaller city or one part of a larger city. Fishing grounds are defined as stream stretches, river stretches, ponds, and other water bodies where recreational fishing can be legally conducted.

Each angler has to obtain two documents – a fishing license and a fishing permit – before he or she can start practicing recreational fishing. A fishing licence allows anglers to practice fishing in general. A fishing permit allows anglers to practice fishing on individual selected fishing grounds (Table 2 a).

The catch (individual fish) and yield (kg of fish) per angler and per time period is limited by the Law on Fisheries (99/2004), the Directive on Fisheries (197/2004), and by angling rules on individual fishing grounds. Minimum and maximum legal catchable fish body size is limited for commercially important and endangered fish species as well. Limits for catch, yield, and minimum fish body size are set in order to protect populations of commercially important and endangered fish species. The goal of the maximum body size limit is to protect trophy-sized fish individuals.

Professional and amateur angling guards are responsible for monitoring of angling activities in the field and for reporting of any violations of fishing rules. Professional angling guard is a full-time job with a prescribed number of working hours per month. Angling guards are also allowed to confiscate illegal fish catches and fishing permits if necessary. Angling guards are not present on the fishing grounds at all times but rather travel to fishing grounds and perform controls of anglers randomly.

Each angler is required to fill in a report of catches in his or her own individual angling logbook when he or she goes fishing (Table 2 b). Each angler is also obliged to write down each fish catch that he or she wants to keep. Fish that are released back into water are not recorded in angling logbooks. Anglers identify and measure each kept fish to the nearest cm. Anglers then assign estimated body weight to each kept fish according to length-weight calculations provided by the Czech Fishing Union. Those calculations are based on general long-term observations of fish in Czech rivers. At the end of the year, anglers are obliged to deliver summaries of their angling logbooks to the Czech Fishing Union (Table 2 c).

The content of each angling logbook is then checked by administrative workers in the Czech Fishing Union for errors. Processed data from all angling logbooks is afterwards added to the central fisheries database of the Czech Fishing Union. The database contains summarized information about each fishing ground for each year. An example of annual angling report is shown in Table 3.

## 2.3 Data sources

Data from 14 inland freshwater fishing grounds over the course of years 2013-2015 was used for the purpose of this study. This data was originally collected from individual angling logbooks by the Czech Fishing Union and later processed and analysed by authors of this research paper.

## 2.4 Measured variables

This study was comparing differences in basic variables in recreational fishing between natural and urban fishing grounds. Overall 14 basic variables were measured and compared for the purpose of this study (Table 1).

In addition, this study was also comparing differences between natural and urban fishing grounds for catch [individual fish] and yield [kg] in individual fish species. Those fish species included 24 commercially important fish species plus a group of commercially less important fish species listed as 'others' (Table 3). The category 'others' included mainly white bream (*Abramis bjoerkna*), gudgeon (*Gobio gobio*), ruffe (*Gymnocephalus cernuus*), bleak (*Alburnus alburnus*), rudd (*Scardinius erythrophthalmus*), roach (*Rutilus rutilus*), common dace (*Leuciscus leuciscus*), brown bullhead (*Ameirus nebulosus*), and bullhead (*Cottus gobio*). This study was also comparing differences between natural and urban fishing grounds for catch and yield of intensively stocked fish species (common carp, tench, pike, zander, European catfish, European eel, rainbow trout, grayling, brook trout, asp, grass carp, and silver carp) and species that are not intensively stocked (remaining 12 fish species listed in Table 3).

2.5 Statistical analysis

The statistical programme R (R i386 3.4.1., R Development Core Team 2017) was used for statistical testing. Shapiro-Wilk test was used for analysis of data distribution. Student t-test and Wilcoxon test were used for statistical testing of data with normal and non-normal distribution, respectively. Minimum probability level of $p = 0.05$ was accepted for all the statistical tests, and all statistical tests were two-tailed. Data from one fishing ground in one year was used as one sample in all statistical analyses.

## 3. Results

3.1 Overall data summary

Over the course of three years, angling catch on selected fishing grounds was 100 thousand individual fish and yield was 215 tons of fish. Anglers visited selected fishing grounds 390 thousand times.

3.2 Basic variables in recreational fishing

Urban fishing grounds showed higher angling catch [individual fish] and yield [kg] per hectare ($p < 0.01$, DF = 1, Figure 2a). Urban fishing grounds had also more anglers who caught at least one fish ($p < 0.01$, DF = 1, Figure 2b). However, angling guards made more controls on natural fishing grounds ($p < 0.01$, DF = 1, Figure 2b). Natural and urban fishing grounds showed similar numbers of individual anglers and similar rates of fishing visits ($p > 0.05$, DF = 1, Figure 2c). An average angler caught more fish on urban fishing grounds ($p < 0.01$, DF =

1, Figure 2d). Anglers also kept on returning to urban fishing grounds more frequently ($p < 0.01$, DF = 1, Figure 2d). However, the percentage of anglers who took at least one fish was similar on both types of fishing grounds ($p > 0.05$, DF = 1, Figure 2e).

### 3.3 Individual fish species

Common carp dominated in catches of anglers on both types of fishing grounds. However, the dominance of common carp was even more prevalent on urban fishing grounds ($p < 0.01$, DF = 1, Figure 3).

Approximately half of the fish species showed higher catch and yield on urban fishing grounds (for all: $p < 0.01$, DF = 1). Cyprinids, salmonids, European eel, and European perch fell into this category (Figure 4). Only a small amount of fish species showed higher catch and yield on natural fishing grounds (for all: $p < 0.01$, DF = 1). Large-growing piscivores, bream, and grass carp fell into this category (Figure 5). Remaining fish species showed similar catch and yield on both types of fishing grounds (for all: $p > 0.05$, DF = 1). Rheophilic cyprinids, species with overall low catch and yield, and a group of commercially less valuable fish species fell into this category (Figure 6).

Intensively stocked fish species were caught prevalently on urban fishing grounds ($p < 0.01$, DF = 1). On the other hand, other fish species (that are not intensively stocked) showed similar catch and yield on both types of fishing grounds ($p > 0.05$, DF = 1). However, intensively stocked fish species dominated in catches of anglers on both types of fishing grounds (Figure 7).

Half of the fish species showed higher average body weight on natural fishing grounds (for all: $p < 0.01$, DF = 1). On the other hand, only five fish species showed higher average body weight on urban fishing grounds (for all: $p < 0.01$, DF = 1). Remaining six fish species showed similar average body weight on both types of fishing grounds (for all: $p > 0.05$, DF = 1, Figure 8).

## 4. Discussion

### 4.1 Level of urbanization

A very important methodological factor in this study is that the Vltava River in Prague has been urbanized for centuries. This affects hydrology and hydromorphology of the river as well as abundance and distribution of fish species within the river. The Vltava River can therefore provide different conditions for fish populations when compared to a different river that has been urbanized only recently. Resident fish populations in the Vltava River have already stabilized and adapted to the conditions of the artificially altered river. On the other hand, populations of fish species that do not tolerate artificially altered rivers (e.g. species that require submerged terrestrial flora as a substrate for reproduction) have already declined (Slavík and Bartoš 2001). In the future, if other authors decide to replicate the presented study, the level of urbanization of the river should be taken into account. It is possible that recently urbanized rivers will show different results because resident fish populations have not yet stabilized.

4.2 Fishing visits

This study did not find any significant difference between numbers of individual anglers or fishing visits between natural and urban fishing grounds. This discovery was surprising; it was initially hypothesised that natural fishing grounds would show higher numbers of anglers and visits because natural fishing grounds are located on less polluted rivers with diversified habitats and overall better conditions for natural fish reproduction. There are several possible explanations for this outcome. Firstly, in urban areas, there are generally more potential anglers who live in close proximity to the river. In addition, urban areas have better connection via public transport (trams, buses) and close proximity of services (Balsman and Shoup 2008). Importantly, recreational fishing provides one of the last remaining connections to nature for city people (Manfredo et al. 1984; Arlinghaus et al. 2008; Balsman and Shoup 2008; Freudenberg and Arlinghaus 2010). Secondly, urban fishing grounds that are located on the Vltava River have beautiful scenery with a view on the Prague Castle and the Charles Bridge. Urban fishing grounds on the Vltava River might be therefore more attractive for anglers. Thirdly, stocking policy provides lots of fish in urban areas on the Vltava River.

As previous studies found, recreational fishing provides more ecosystem services than just fish catch and yield (Martin et al. 2017). Even though one of the main goals in recreational fishing is to catch a lot of large-sized fish, there are other goals that are independent of catch and yield (Arlinghaus et al. 2008; Arlinghaus et al. 2014). Those goals are mainly to enjoy the scenery, enjoy the moment in tranquil natural environment, and the fishing experience itself (Lang et al. 2008). This means that fishing grounds provide more ecosystem services than just fish for food. In those cases, fish catch and yield is often not the main criterion for good fishing experience. Therefore, catch and yield may not the main indicator of the demand for fishing grounds (Lang et al. 2008). The customer (recreational angler) focuses not only on fish catches but also on social and cultural aspects of fishing. The angler therefore demands not only biological ecosystem services (fish) but also cultural services (scenery). As a result, the attractiveness of fishing grounds is viewed differently by fisheries management and by anglers – the management evaluates fishing grounds based on catch and yield but anglers place high importance on the scenery and clean environment as well. In some cases, fishing grounds with beautiful scenery but low catch are then viewed by the management as unattractive.

In the Czech Republic, allocation of financial resources for fisheries management on individual fishing grounds is based on 1) the number of sold fishing permits, 2) fish catch and yield, and 3) the number of fishing visits. Those financial resources are then used to bolster resident fish populations by stocking. Therefore, the 'low catch-high visit' fishing grounds might be significantly underfinanced even though anglers view them as attractive. For example, by studying usage of ecosystem services in fisheries in a marine gulf in France, Martin et al. (2017) discovered that majority of services consumed by households were indirect (social and cultural) while, on the other hand, direct services (catch and yield) were less significant. This supports the idea that the attractiveness of a fishing ground should be evaluated also by satisfaction of anglers. So far, only variables that are easily quantified (number of sold permits, catch and yield, fishing visits) have been taken into account.

This study also found that natural and urban fishing grounds have comparable visit rates. In natural areas, anglers can enjoy fresh air and natural surroundings. In addition, anglers can also catch different fish species that may not be available in urbanized rivers. By studying preferences of urban and rural anglers, other authors discovered that anglers actually prefer natural fishing grounds to urban ones (Manfredo et al. 1984; Arlinghaus and Mehner 2004; Arlinghaus et al. 2008). Natural fishing grounds might be less frequently visited because they are out of reach for most anglers. Inversely, urban fishing grounds are easily accessible but less preferred by anglers. Therefore, the choice of fishing grounds is often a compromise between preferences of anglers and accessibility of fishing grounds (Manfredo et al. 1984; Arlinghaus and Mehner 2004; Arlinghaus et al. 2008). In case of this study, the easy access to urban fishing grounds (with intensive fish stocking) outweighed the attractiveness of natural fishing grounds.

There are reasons why urban fishing grounds, despite being located in highly populated areas, did not have more visits than natural fishing grounds. For one, urban areas in Prague have high levels of air and water pollution (Czech Hydrometeorological Institute, unpubl. data). In addition, there are more disturbing elements (e.g. tourists, ships, pedal boats, traffic, and water birds) in urban areas than in natural areas (own observation). Those elements are disturbing for both anglers and fish, and are therefore negatively perceived by anglers (Arlinghaus et al. 2014). Anglers generally claim that disturbed fish get scared and do not bait (own observation). Urban rivers are also less suitable for populations of fish species that rely on natural spawning substrates (e.g. submerged terrestrial flora). Migration barriers (typically dams) that are frequent in urban areas can also prevent fish reproduction (Wolter et al. 2000). All these aspects are negatively perceived by anglers (Arlinghaus et al. 2014). Cities also offer additional ways to spend leisure time.

This study also discovered that anglers return to urban fishing grounds more often than to natural ones. The main reason is that urban fishing grounds are in close proximity to anglers´ homes. That makes it easier to return to favourite urban fishing grounds more frequently. Inversely, a trip to natural fishing grounds takes several hours. That is usually out of reach for employed anglers.

### 4.3 Angling guard controls

One of the most interesting discoveries was that there are less angling guard controls in the field on urban fishing grounds. Initially, it was hypothesized that urban fishing grounds would have more guard controls because urban fishing grounds are located in highly populated areas. It is possible that urban anglers are perceived by angling guards as 'being watched' enough by public and by other anglers that further guard controls are perceived as unnecessary.

### 4.4 Catch and yield

This study found that catch and yield was higher on urban fishing grounds. That is the exact opposite of what we expected in our hypotheses. In urban areas, anglers have to transport dead fish through the city which is highly suboptimal since other people negatively perceive the odour of dead fish. Moreover, anglers who live in urban areas can easily visit local supermarkets and purchase an already-prepared fish in there. For example, people in Prague have on average significantly higher income than people from rural areas (Czech Statistical Office, unpubl. data). In addition, consumption of a fish that was caught in a partially polluted urban river is often perceived by anglers as disgusting (Westphal et al. 2008, Pulford et al. 2017). In case of this study, the higher catch and yield on urban fishing grounds was most likely due to easy access to fishing grounds in urban areas, and also due to intensive fish stocking.

Majority of fish species showed higher catch and yield on urban fishing grounds. This was true mostly for common carp – the most important fish species in Czech recreational fishing (approximately 80 % of all fish catches, Humpl et al. 2009; Jankovský et al. 2011; Boukal et al. 2012). Anglers showed preference for common carp in both areas but urban anglers were selecting common carp even more frequently. Interestingly enough, most salmonid species were also caught more often on urban fishing grounds. Salmonids are usually taken on smaller streams (< 10 m wide and < 1 m deep; Czech Fishing Union, unpubl. data) but this study was conducted on large rivers. On the other hand, dominance of intensively stocked fish species on urban rivers was not surprising because urban rivers are frequently stocked with those fish species (Czech Fishing Union, unpubl. data).

Inversely, several fish species showed higher catch and yield on natural fishing grounds. It was mainly bream – the second most important fish in catches of anglers in the Czech Republic (Czech Fishing Union, unpubl. data). Anglers frequently catch bream because bream is a common species in Czech rivers and it resembles common carp (Slavík et al. 2009). Prevalence of large-growing piscivores on natural fishing grounds was even higher in yield than in catch. This phenomenon was caused by naturally high average body weight of piscivores (especially European catfish). When compared to omnivorous cyprinids, piscivores are also more demanding on environmental conditions because they require migration-free rivers, access to spawning substrates (i.e. submerged terrestrial flora), and a critical abundance of fish prey (Wolter et al. 2000).

In half of the studied fish species, average fish body weight of caught fish was higher on natural fishing grounds. It makes sense because natural rivers have generally better environmental conditions for fish life and growth (Wolter et al. 2000). In addition, natural fishing grounds on the Elbe River are significantly eutrophic due to surface fertilizer runoff from agricultural fields (Havlíková et al. 2017). It is generally known that eutrophication of aquatic ecosystems significantly improves fish growth (Wolter et al. 2000). Surprisingly enough, salmonid species showed higher average body weight on urban fishing grounds. Salmonids have overall higher demands on environmental conditions (water quality and dissolved oxygen levels) than cyprinids and, for that reason, it would make more sense if salmonids showed higher body weights in natural areas. Interestingly enough, silver carp (a non-native, stocked fish species) showed higher average body weight than European catfish (the largest freshwater non-migratory fish species in Europe).

Dominance of stocked fish species in angling catches on urban fishing grounds was mainly caused intensive fish stocking on the River Vltava in Prague (Czech Fishing Union, unpubl. data). On the other hand, there was no significant difference in catch of fish species than are not intensively stocked. It means that the overall higher fish catch on urban fishing grounds was mostly driven by catches of intensively stocked species.

### 4.5 Management implications

Firstly, we suggest that the fisheries management should make urban fishing grounds more suitable for natural reproduction of high-demanding fish species (mainly piscivores). That could make urban fishing grounds more attractive for anglers, mostly because piscivores are commercially very valuable. Secondly, we suggest that individual fishing grounds should be evaluated not only by variables that are easily quantified (sold permits, catch and yield, fishing visits) but also by satisfaction of anglers. Thirdly, we suggest that angling guards should slightly re-focus their controls to urban fishing grounds in urban areas. When visit rates of anglers are similar on both types of fishing grounds, the rates of angling guard controls should be similar as well.

## 5. Conclusion

It was discovered that natural and urban fishing grounds have similar visit rates but urban fishing grounds have overall higher fish catch and yield. Natural fishing grounds have lower rates of angling guard controls even though visit rates of anglers are similar on both types of fishing grounds. Higher catch and yield on urban fishing grounds was mainly caused by higher rates of intensively stocked fish species in catches of anglers in urban areas. On the other hand, several fish species, mainly bream and large-growing piscivores, showed higher catch and yield on natural fishing grounds. Average body weight of caught fish was higher on natural fishing grounds as well. We suggest that future studies should focus on perception of the differences between natural and urban fishing grounds from the anglers´ point of view.

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**Table 1** List of basic variables in recreational fishing that were used in statistical analysis in this study.

| Variable |
|---|
| Angling catch [individual fish] per hectare of fishing grounds |
| Angling yield [kg] per hectare of fishing grounds |
| Number of all angling visits per hectare of fishing grounds |
| Number of individual anglers per hectare of fishing grounds |
| Number of angling guard controls per hectare of fishing grounds |
| Number of anglers who caught at least one fish per hectare of fishing grounds |
| Average number of visits per one individual angler |
| Angling catch [individual fish] per angler |
| Angling yield [kg] per angler |
| Percentage of anglers who caught at least one fish |
| Intensively stocked fish - catch [individual fish] per hectare of fishing grounds |
| Other fish - catch [individual fish] per hectare of fishing grounds |
| Intensively stocked fish - yield [kg] per hectare of fishing grounds |
| Other fish - yield [kg] per hectare of fishing grounds |

**Table 2** An example of a fishing permit (a), a report of catches (b), and a summary of catches for the whole year (c).

a)

**Fishing permit**

| ID of fishing ground | date (from - to) | Name, surname | issued by | date of issue |
|---|---|---|---|---|
| 401 016 | 1.1.2017 - 31.12.2017 | John Smith | Prague 1 | 1.1.2017 |

b)

**Report of catches**

| date | ID of fishing ground | species | number | weight [kg] | size [cm] |
|---|---|---|---|---|---|
| 8.6.2017 | 401 016 | common carp | 1 | 2.8 | 58 |
| 18.6.2017 | 401 016 | common carp | 1 | 2.5 | 61 |
| 23.7.2017 | 401 016 | common carp | 1 | 2.1 | 52 |
| 24.7.2017 | 401 016 | pike | 1 | 2.9 | 58 |
| 18.8.2017 | 401 017 | pike | 1 | 4.8 | 87 |
| 20.9.2017 | 401 017 | bream | 1 | 1.1 | 32 |
| 29.9.2017 | 401 017 | European catfish | 1 | 0.3 | 31 |

c)

**Summary of catches for the whole year**

| | | common carp | | pike | |
|---|---|---|---|---|---|
| ID of fishing ground | name of fishing ground | catches [n] | total weight [kg] | catches [n] | total weight [kg] |
| 401 016 | Vltava 4 | 10 | 22.8 | 5 | 18.1 |
| 401 017 | Vltava 5 | 15 | 35.4 | 8 | 25.5 |

**Table 3** An example of annual angling report from a fishing ground on the River Vltava.

| ID of fishing ground | Name of fishing ground | Area [ha] |
|---|---|---|
| 401 016 | Vltava 4 | 86 |

| Fish species | Catch [individual fish] | Yield [kg] |
|---|---|---|
| Common carp (*Cyprinus carpio*) | 2115 | 5523.4 |
| Tench (*Tinca tinca*) | 48 | 24.5 |
| Bream (*Abramis brama*) | 444 | 228.4 |
| European chub (*Squalius cephalus*) | 325 | 206.3 |
| European perch (*Perca fluviatilis*) | 82 | 27 |
| Barbel (*Barbus barbus*) | 48 | 76.6 |
| Nase (*Chondrostoma nasus*) | 5 | 2.3 |
| Vimba bream (*Vimba vimba*) | 411 | 143.8 |
| Northern pike (*Esox lucius*) | 252 | 679.2 |
| Zander (*Sander lucioperca*) | 147 | 318.5 |
| Wels catfish (*Silurus glanis*) | 26 | 448.9 |
| European eel (*Anguilla anguilla*) | 201 | 159.7 |
| Brown trout (*Salmo trutta*) | 7 | 2.3 |
| Rainbow trout (*Oncorhynchus mykiss*) | 2 | 0.6 |
| Grayling (*Thymallus thymallus*) | 0 | 0 |
| Brook trout (*Salvelinus fontinalis*) | 0 | 0 |
| Asp (*Aspius aspius*) | 75 | 122.8 |
| Whitefish (*Coregonus maraena*) | 0 | 0 |
| Common huchen (*Hucho hucho*) | 0 | 0 |
| Grass carp (*Ctenopharyngodon idella*) | 5 | 27.1 |
| Silver carp (*Hypophthalmichthys molitrix*) | 0 | 0 |
| Prussian carp (*Carassus auratus*) | 88 | 31.7 |
| Burbot (*Lota Lota*) | 3 | 1 |
| Ide (*Leuciscus idus*) | 5 | 11 |
| 'Others' | 1169 | 124.7 |
| Total | 5458 | 8159.8 |

| Variables | |
|---|---|
| Catches per ha [individual fish] | 61.28 |
| Yield per ha [kg] | 89.11 |
| Number of individual anglers | 1256 |
| Number of anglers that caught at least one fish | 459 |
| Number of all angler visits | 15409 |
| Number of visits per angler | 12.05 |
| Catches per angler [individual fish] | 4.18 |
| Yield per angler [kg] | 6.66 |
| Number of visits per ha | 150.28 |
| Number of angler guard notes in all angling logbooks | 101 |

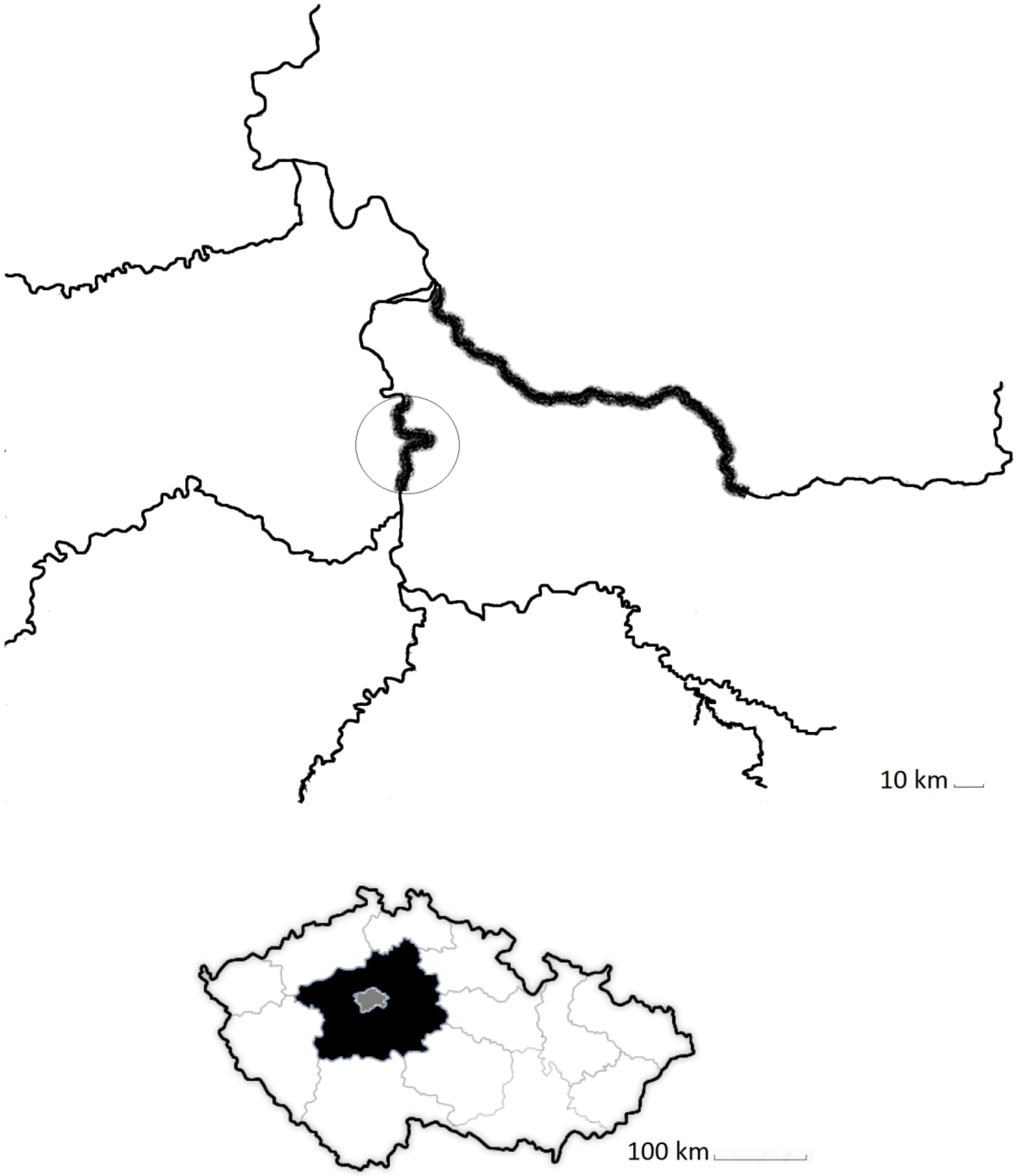
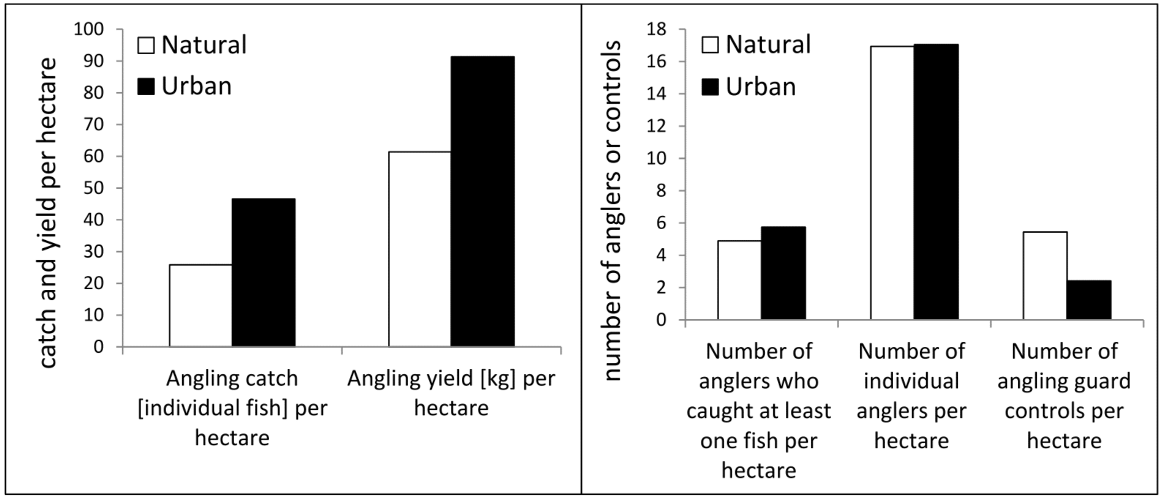



**Fig 1** Map of the study area. Thick black line in a circle on the River Vltava represents urban fishing grounds in urban areas in Prague (50° N, 14.5° E). Thick black line on the River Elbe represents natural fishing grounds in rural areas in Central Bohemia (49.5°–50.5° N, 13.5°–15.5° E).



catch and yield per hectare
100
90
80
70
60
50
40
30
20
10
0
Natural
Urban
Angling catch [individual fish] per hectare
Angling yield [kg] per hectare
number of anglers or controls
18
16
14
12
10
8
6
4
2
0
Natural
Urban
Number of anglers who caught at least one fish per hectare
Number of individual anglers per hectare
Number of angling guard controls per hectare

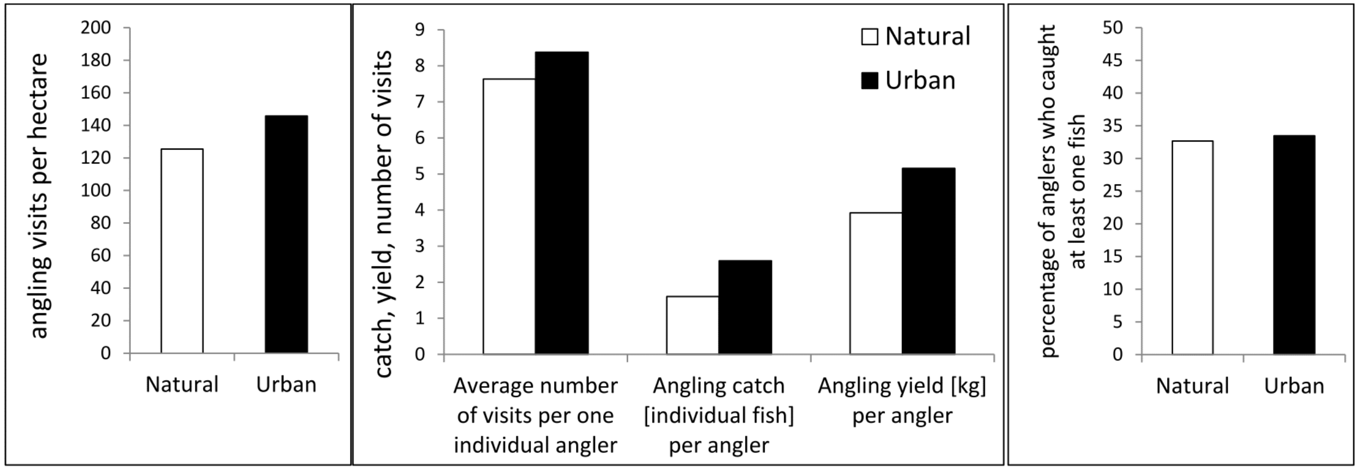



**Fig 2** Differences between natural and urban fishing grounds displayed for basic variables in recreational fishing

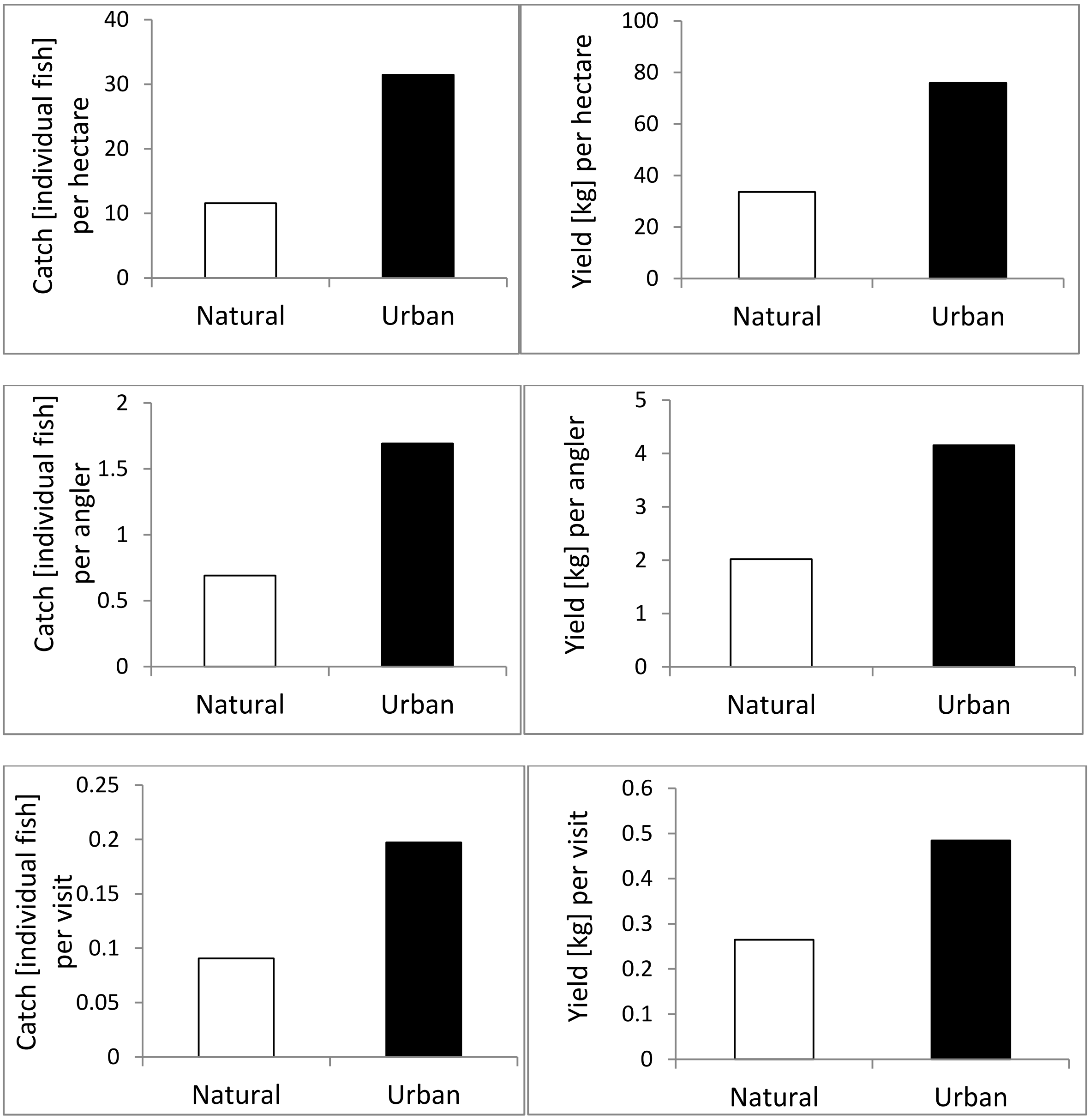
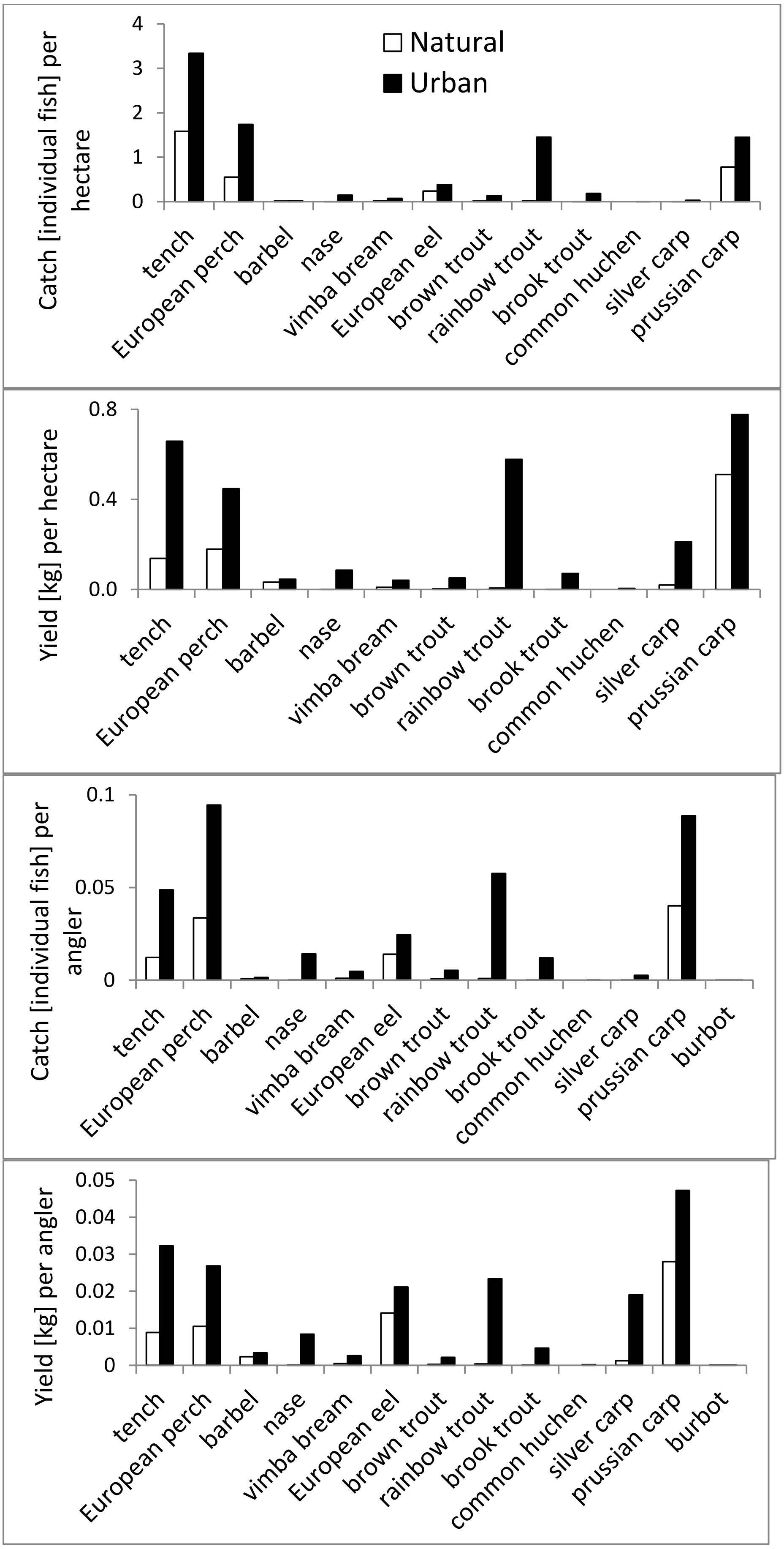



**Fig 3** Differences in catch and yield on natural and urban fishing grounds displayed for common carp (*Cyprinus carpio*)


Catch [individual fish] per hectare
4
3
2
1
0
Natural
Urban
tench
European perch
barbel
nase
vimba bream
European eel
brown trout
rainbow trout
brook trout
common huchen
silver carp
prussian carp
Yield [kg] per hectare
0.8
0.4
0.0
tench
European perch
barbel
nase
vimba bream
brown trout
rainbow trout
brook trout
common huchen
silver carp
prussian carp
Catch [individual fish] per angler
0.1
0.05
0
tench
European perch
barbel
nase
vimba bream
European eel
brown trout
rainbow trout
brook trout
common huchen
silver carp
prussian carp
burbot
Yield [kg] per angler
0.05
0.04
0.03
0.02
0.01
0
tench
European perch
barbel
nase
vimba bream
European eel
brown trout
rainbow trout
brook trout
common huchen
silver carp
prussian carp
burbot

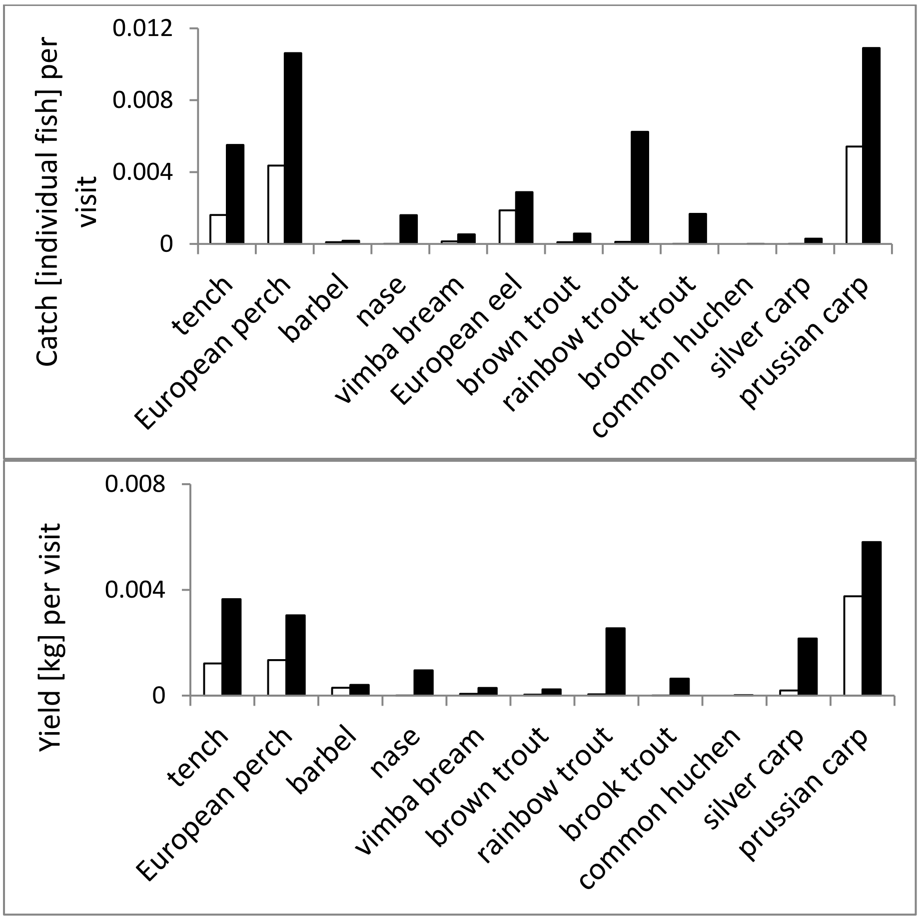
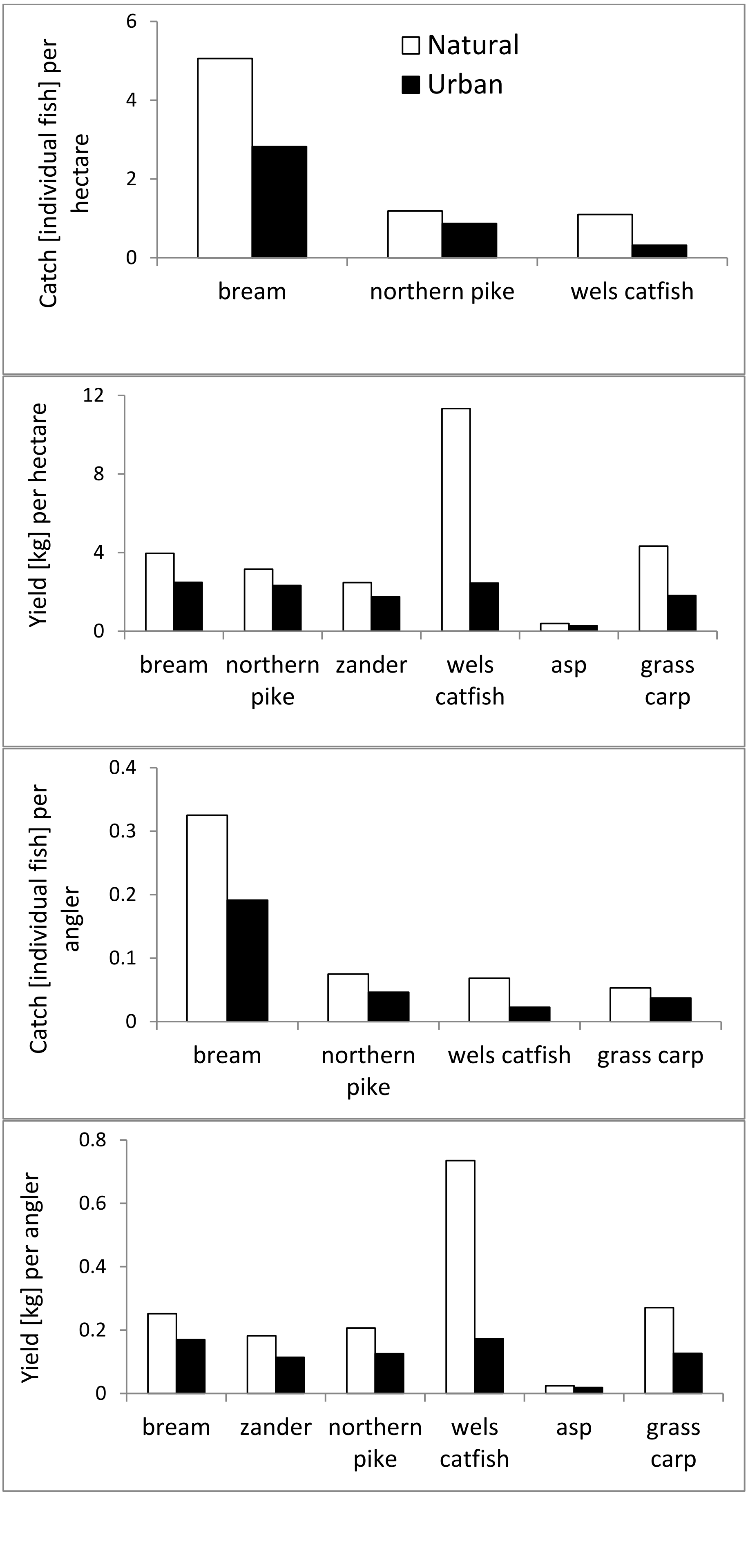



**Fig 4** Differences in catch and yield displayed for individual fish species that prevailed on urban fishing grounds in urban areas



Natural
Urban
Catch [individual fish] per hectare
bream
northern pike
wels catfish
Yield [kg] per hectare
bream
northern pike
zander
wels catfish
asp
grass carp
Catch [individual fish] per angler
bream
northern pike
wels catfish
grass carp
Yield [kg] per angler
bream
zander
northern pike
wels catfish
asp
grass carp

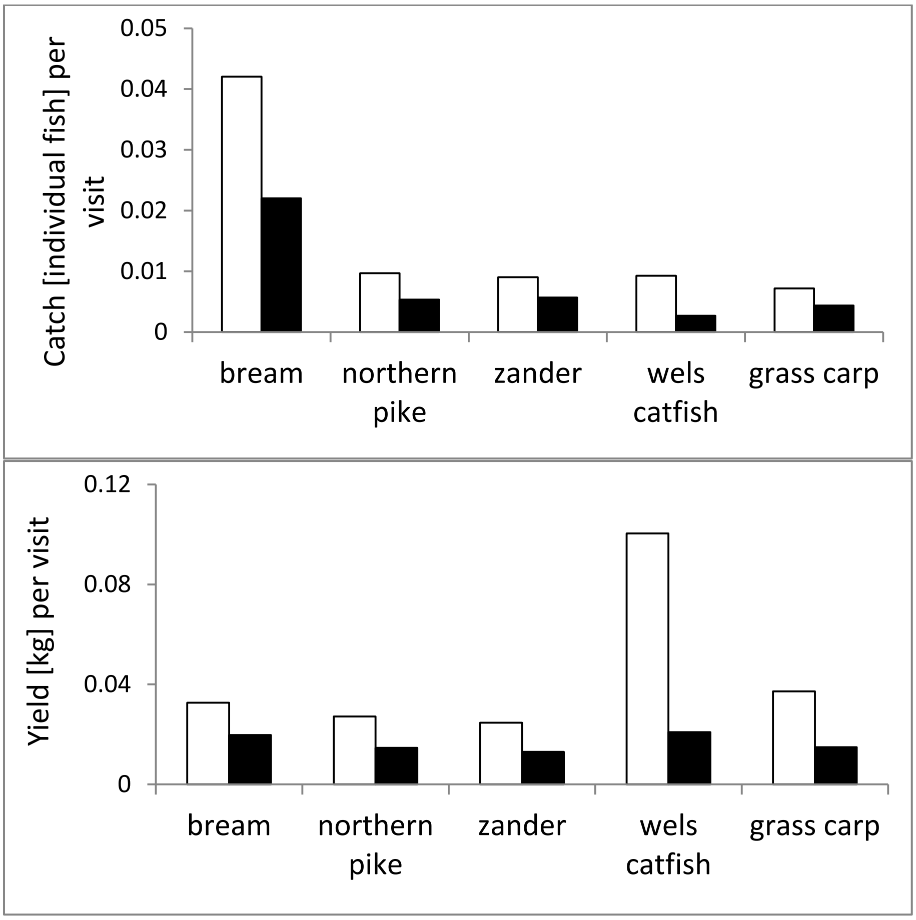
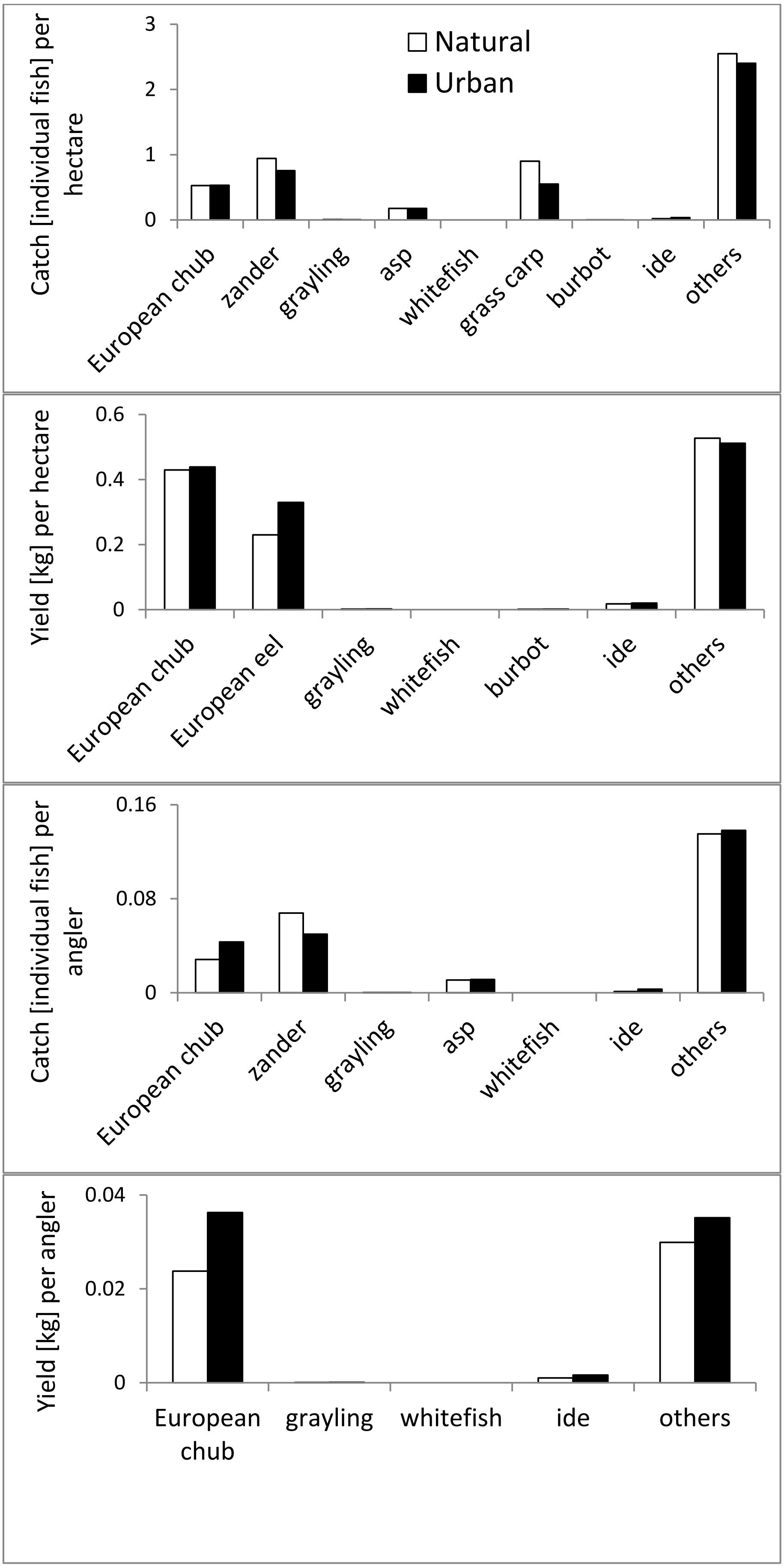



**Fig 5** Differences in catch and yield displayed for individual fish species that prevailed on natural fishing grounds in rural areas



Catch [individual fish] per hectare
3
2
1
0
Natural
Urban
European chub
zander
grayling
asp
whitefish
grass carp
burbot
ide
others
Yield [kg] per hectare
0.6
0.4
0.2
0
European chub
European eel
grayling
whitefish
burbot
ide
others
Catch [individual fish] per angler
0.16
0.08
0
European chub
zander
grayling
asp
whitefish
ide
others
Yield [kg] per angler
0.04
0.02
0
European chub
grayling
whitefish
ide
others

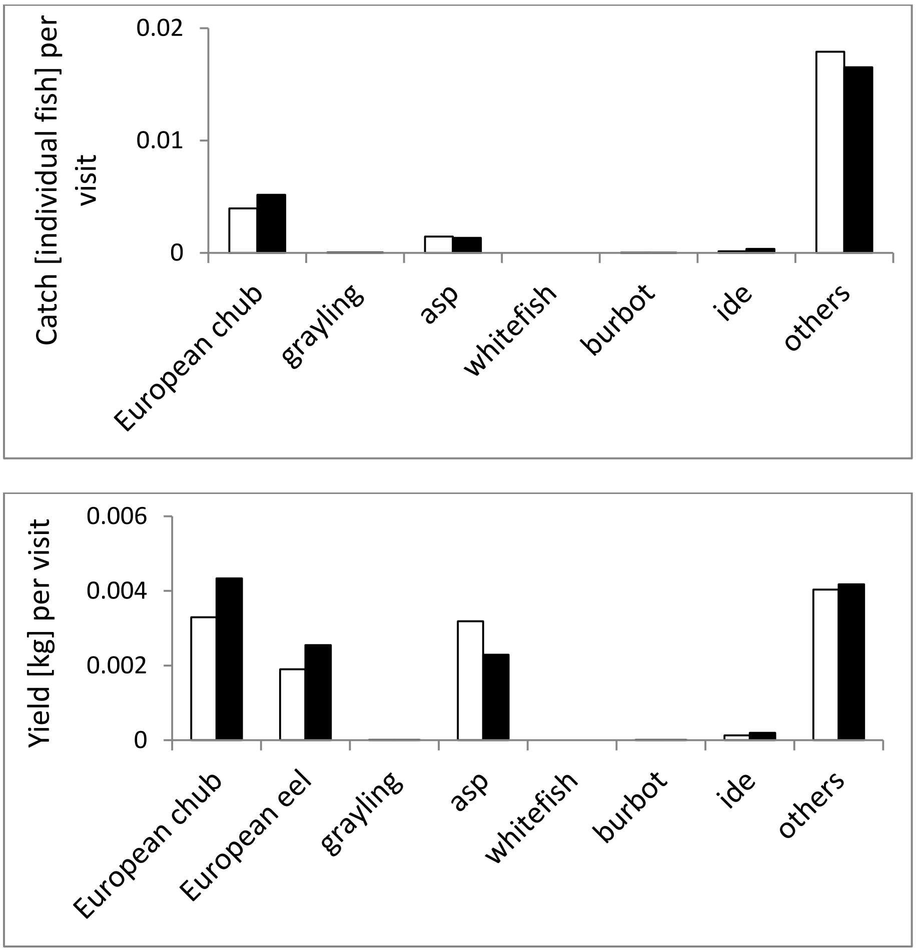



**Fig 6** Individual fish species that showed similar catch and yield on natural and urban fishing grounds

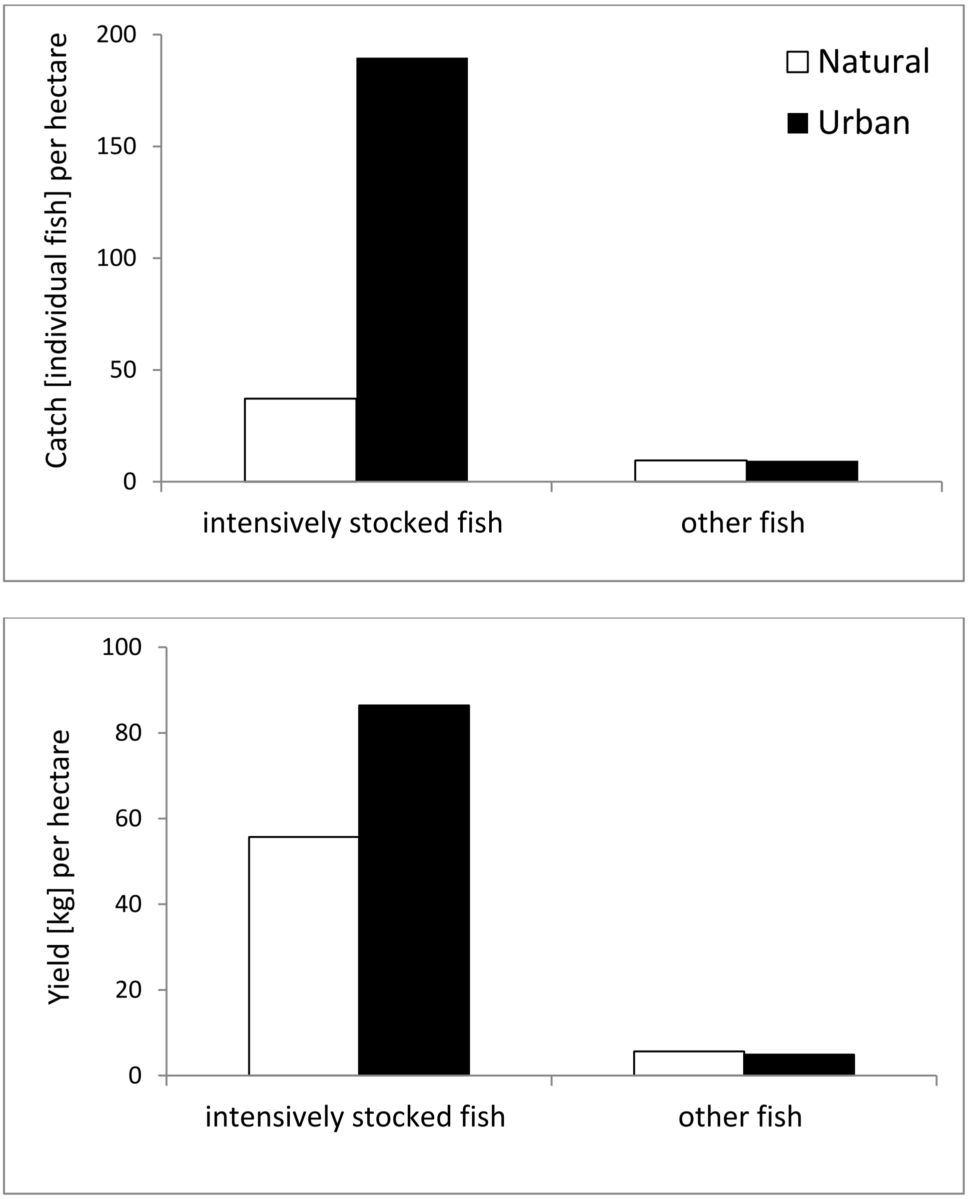



**Fig 7** Differences in catch and yield on natural and urban fishing grounds displayed for intensively stocked and other fish species

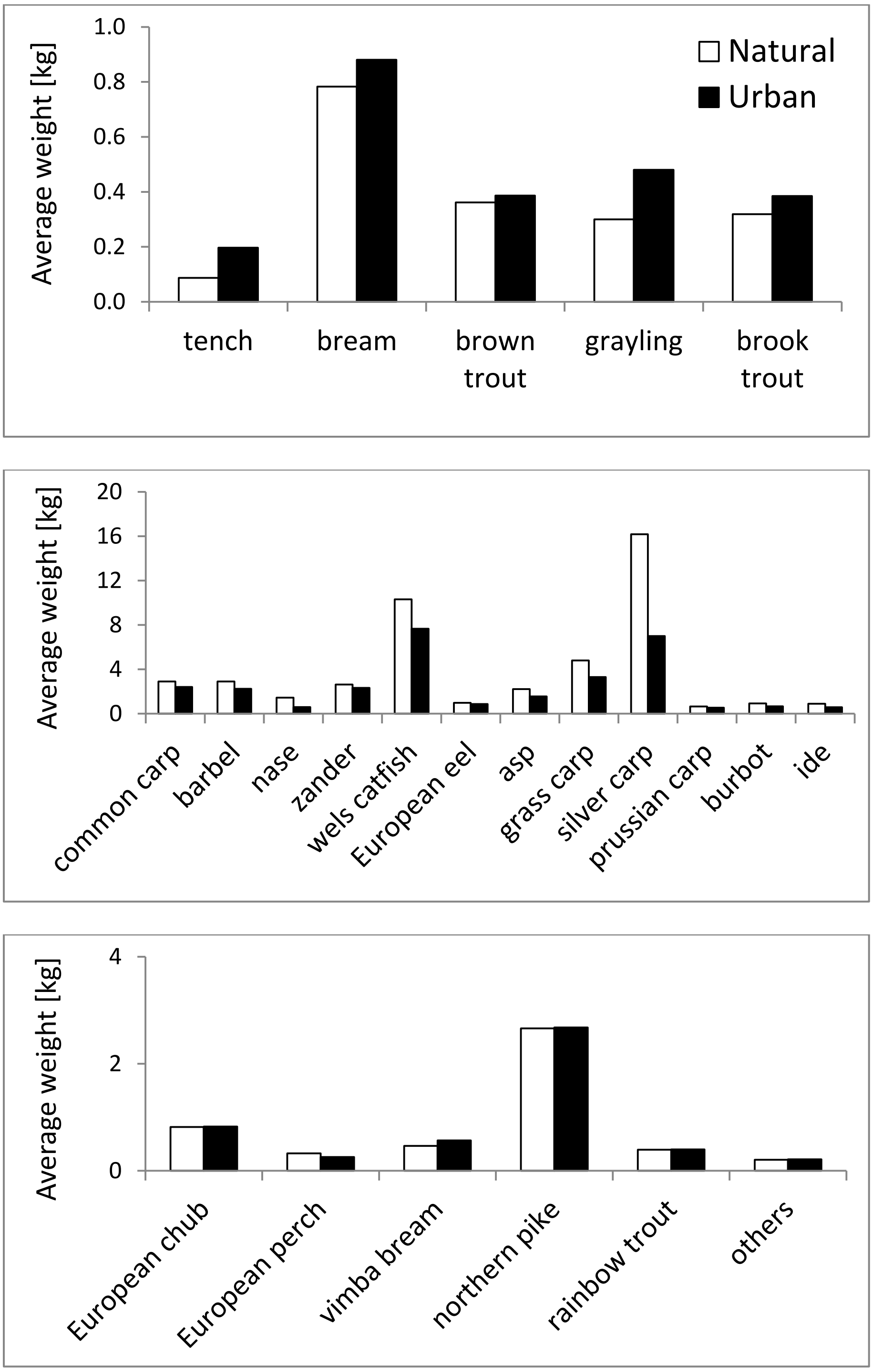



**Fig 8** Differences in average body weight [kg] in individual fish species on natural and urban fishing grounds. The figure shows species (a) with higher average body weight on urban fishing grounds, (b) with higher average body weight on natural fishing grounds, (c) with no significant differences between urban and natural fishing grounds. Two fish species (common huchen and whitefish) were not compared due to missing data

# Do cormorants and recreational anglers take fish of the same species and sizes?

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Running head: fish catches of cormorants and anglers

Abstract

The Great Cormorant *Phalacrocorax carbo* is a widespread piscivorous water bird. The competition for resources between recreational anglers and cormorants has been causing serious conflicts between fisheries and environmentalists. This study aimed to assess differences between fish catches of cormorants and recreational anglers. This study was carried out on the upper Elbe River in Central Europe (Czech Republic). Cormorant diet was investigated using regurgitated pellets. Catches of anglers were obtained from annual angling reports. Altogether 1 478 cormorant pellets were collected. Altogether 6 903 fish were identified in the pellets. Altogether 93 413 fish were caught by anglers and identified to species. Cormorant diet consisted of 24 fish species in 6 fish families. Cormorants caught smaller-sized fish (median weight 90 g) while anglers caught large-sized fish (median weight 1 700 g). Majority of fish caught by cormorants was under minimum legal catchable size for anglers. Species of moderate interest to anglers (mainly roach *Rutilus rutilus*) dominated in cormorant diet while common carp *Cyprinus carpio* dominated in catches of anglers. In conclusion, the direct competition for fish between anglers and cormorants was lower but cormorants still consumed small fish that a) serve as prey for piscivorous fish species and b) would grow into legally sized fish for angling purposes.

Keywords: angling statistics, diet composition, fisheries conflict, game fishing, pharyngeal bones, prey selection

## Introduction

The Great Cormorant *Phalacrocorax carbo* is a widespread piscivorous water bird. Being driven close to extinction during the second half of the 20th century (Debout *et al*. 1995, Suter 1995a, Marion 2003, European Commission 2013), cormorant numbers have increased dramatically in last decades (Van Eerden & Gregersen 1995, Carss & Marzano 2005). Recent studies suggested that cormorant numbers have stabilized in the last decade (Debout *et al*. 1995, Marion 2003, Andersen *et al*. 2007) but fisheries managers claim that predatory pressure of cormorants on fish stocks is exceeding acceptable limits (Russell *et al*. 1996). The conflict between man and cormorants has been known for a long time and fisheries managers often complain that cormorants prey upon fish of high interest to anglers (Milton *et al*. 1995, Suter 1995b, Takahashi *et al*. 2006, Čech & Vejřík 2011).

Previous research stated that it is very complicated to assess and quantify competition between man and cormorants (Čech & Vejřík 2011). The reason is that the competition works on many different levels and it can be viewed from many different angles. The issue is that cormorants are able to utilise feeding grounds within a radius of 20–30 (sometimes even 50) km from their roosts or breeding colonies (Cramp & Simmons 1977, Carss & Ekins 2002, Lehikoinen *et al*. 2012). Therefore, it is complicated to assess to what extent cormorants use specific feeding grounds (streams, rivers, lakes) and specific zones of those feeding grounds (littoral, pelagial, or benthic zone). It is also complicated to evaluate if cormorant predation on fish stocks is additive or compensatory.

Several studies tried to describe the competition between cormorants and man. Some previous studies estimated the competition for resources between cormorants and fisheries using fish tagging and capture-recapture methods (VanDeValk *et al*. 2002, Rudstam *et al*. 2004, Diana *et al*. 2006, Skov *et al*. 2014). Other studies tried to estimate removal of fish biomass by cormorants using the number of cormorants on a particular water body multiplied by the number of days that birds are there for (i.e. the number of 'cormorant days'). In other research studies, fish abundance was estimated using various net-sampling methods or electrofishing surveys (Suter 1995b, VanDeValk *et al*. 2002, Rudstam *et al*. 2004, Fielder 2008, Carpentier *et al*. 2009, Lehikoinen *et al*. 2012, Kumada *et al*. 2013, Gagliardi *et al*. 2015).

The goal of this study was to evaluate the conflict between fisheries and cormorants on the upper Elbe River. Firstly, this study aimed to estimate total fish consumption by overwintering cormorants in the study area during one season. Secondly, it aimed to estimate representation of fish of very high/high/medium/low interest to anglers in cormorant diet. Thirdly, it aimed to assess differences in fish catches of recreational anglers and cormorants in the study area. Lastly, it aimed to estimate financial loss of cormorant predation on fish stocks in the study area.

## Methods

### Study area

This study was carried out at four cormorant roosting places located on the upper Elbe River (Velké Březno, 100 km north of Prague, 50°40'34.2"N, 14°07'28.5"E, altitude 138 m above the sea level). The area is situated in Central Bohemia, Czech Republic, Central Europe (Figure 1). Diet of overwintering cormorants was studied from October 2014 to April 2015.

### Cormorant census

In season 2014/2015, overwintering cormorants roosted in the study area from October 2014 to April 2015. Approximately 100 birds were counted in October and then in March and April. Approximately 500 birds were counted in November, December, January, and February. Data regarding cormorant numbers were obtained from the International Waterbird Census (Agency of Nature and Landscape Protection, unpubl. data), from observations of members of the Agency of Nature and Landscape Protection, and from our own observations.

### Cormorant diet analysis

Cormorant diet was investigated from cormorant pellets (for description of the method see Barrett *et al*. 2007). It was stated by Zijlstra & Van Eerden (1995) that one cormorant produces one pellet per day. Cormorant pellets were collected at four roosting sites (Table 1). About 150 $m^2$ of ground was searched for pellets at each of those roosting sites. All pellets were collected and packed individually into plastic bags, then stored into a freezer (-18°C). After thawing, each pellet was soaked in a solution of 15 g sodium hydroxide (1 M NaOH, 97-99%) and 300 ml of hot water (50°C). Remaining hard parts were washed through a sieve (0.5 mm mesh size) and separated under a stereo microscope (8-16 ×). Fish species were identified based on morphological differences of identifiable diagnostic bones (*os maxillare*, *intermaxillare*, *dentale*, *pharyngenum*, *operculare*, *praeoperculare*, *cleithrum*, *basioccipitale*, *praevomer*) and chewing pads. Diagnostic bones were paired within individual pellets when possible and measured to nearest 0.1 mm. Our own collection of diagnostic bones and prey items was used to determine original size of worn and damaged bones. This collection was used in our previous research (Čech *et al*. 2008, Čech & Vejřík 2011, Čech & Čech 2017, Lyach & Čech 2017). Estimated original fish length (TL, total length) was calculated from length of identifiable parts using length-length equations from the work of Čech *et al*. (2008), Čech & Vejřík (2011), and Čech & Čech (2017). Estimated original fish weight was calculated from the TL using length-weight equations from the work of Čech *et al*. (2008), Čech & Vejřík (2011), Čech & Čech (2017), and FishBase (fishbase.org).

Total fish consumption

Total biomass of fish consumed by cormorants was estimated separately for each month.
Monthly fish consumption was calculated as [number of birds * number of days * daily food intake]. Total price of consumed fish was calculated as [number of birds * number of days * daily food intake * fish price per kg]. Daily food intake was estimated to be between 250 g (min) and 500 g (max) per bird per day. Information regarding daily food intake was obtained from studies of Marquiss & Carss (1994), Carss *et al*. (1997), and Čech & Vejřík (2011).

Fish Prices

Fish prices per kg were obtained from the official tariff for fish poaching in the Czech Republic. The overall price per kg in the tariff includes market price, stocking price, transport price, and administration price. The tariff for fish poaching is used to calculate financial losses on illegally killed fish. Original prices in the tariff were in Czech Crowns (CZK). The prices in CZK were converted to prices in Euro at exchange rate of 1 Euro = 26 CZK.

## Evaluation of fish interest to anglers

Fish species were divided into groups based on their interest to recreational anglers (Czech Fishing Union, pers. comm.). Common carp and northern pike were classified as species of 'very high interest to anglers'; zander, grass carp, perch, asp, bream, European chub, tench, and Prussian carp were classified as species of 'high interest to anglers'; roach, white bream, barbel, rudd, vimba bream, burbot, ide, and nase were classified as species of 'moderate interest to anglers'; ruffe, bleak, common dace, brown bullhead, bullhead, and gudgeon were classified as species of 'low interest to anglers'. For Latin names of fish species see Tables 2 and 3 in the Results section.

## Angling data sources

Data from annual angling reports in years 2014 and 2015 was used in this study. Fish catches on the most important angling grounds within a radius of 30 km from the cormorant colony were used. Angling grounds were defined as stream stretches, river stretches, ponds, gravel pits, and other water bodies where recreational fishing is conducted. The angling grounds were selected based on observations of foraging cormorants on those angling grounds. Overall 19 angling grounds were selected. Those angling grounds were situated on the Elbe River (nine), the Ploučnice River (three), the Bílina River (two), the Ohře River, Žernoseky gravel pit, Cihlářský pond, Malhostický pond, and Nový pond (one each) (Figure 1).

## Angling rules in the Czech Republic

Data regarding catches by anglers was provided by the Czech Fishing Union – the official authority in fishing in the Czech Republic. Recreational fishing in the Czech Republic is organized by the Czech Fishing Union and is centralized for the whole country. Anglers are required to write down fish catches into their own angling logbooks. Only kept fish are recorded while fish that are released back into water are not recorded. Anglers are obliged to measure every kept fish to the nearest cm. Anglers then assign weight to each kept fish according to length-weight calculations provided by the Czech Fishing Union. Those calculations are based on general long-term observations of fish in Czech rivers. At the end of the year, anglers are obliged to deliver summaries of their angling logbooks to the Czech Fishing Union. The content of each angling logbook is then checked by administrative workers for errors. Data from all angling logbooks is then added to the central fisheries database. The database contains summed information about each fishing ground for each year. Fish of very high, high, and moderate interest to anglers are listed by individual species while fish of low interest to anglers are listed together as 'others'. Minimum legal catchable size is set for fish species of very high and high interest to anglers. Closed season is set for those fish species during their reproductive period.

Statistical analysis

The statistical programme R (R version 3.3.2, R Development Core Team 2016) was used for data testing. Shapiro-Wilk test was used to test the distribution of estimated fish weights in cormorant diet and in catches of anglers. Pearson´s chi-square test was used to test: a) differences in proportion of fish species in cormorant diet and in catches of anglers; b) the disproportion of the dominant fish species in cormorant diet and in catches of anglers. Wilcoxon test was used to test differences in estimated fish weights in cormorant diet and in catches of anglers. Pianka´s overlap index was used to compare overlap between cormorant diet and catches of anglers (range 0-1; Pianka & Pianka 1976, Cupples *et al*. 2011). The overlap was calculated by comparing relative frequency and estimated biomass of each fish species in cormorant diet to relative frequency and estimated biomass of each fish species in overall catches of anglers, respectively. Minimum probability level of $P < 0.05$ was accepted for all the statistics, and all $P$-values are two-tailed.

## Results

Overall 1 478 cormorant pellets were collected in the study area during season 2014/2015. Altogether 9 354 diagnostic elements (fish hard parts) were identified in the pellets (Table 1). Together 6 903 fish in 24 fish species from 6 fish families (Cyprinidae, Percidae, Esocidae, Cottidae, Gadidae, and Ictaluridae) were identified in the diet. Altogether 93 413 fish with biomass of 183 223 kg were caught by anglers on selected fishing grounds.

In October, cormorants in the study area consumed approximately 800–1 600 kg of fish. The number then increased to 3 800–7 800 kg of fish per month in November and stayed constant till February. In March and April, the number dropped back to 800–1600 kg per month. Cormorants mostly fed on fish of moderate interest to anglers but fish of high and very high interest to anglers appeared in the diet as well (Figure 2).

Estimated fish weights in cormorant diet were not normally distributed ($W$=0.87, $P$<0.01) and the same was held true for fish weights in catches of anglers ($W$=0.80, $P$<0.01). There was a significant difference between catches of cormorants and catches of anglers. Cormorants caught significantly smaller-sized fish than anglers did (W=0, P<0.01). Majority of fish caught by cormorants was under minimum legal catchable size for anglers (Table 2). Cormorants also caught different fish species than anglers did ($\chi^2$=69 703, DF=28, $P$<0.01). Roach dominated in cormorant diet (45 % of estimated biomass) while common carp dominated in catches of anglers (59 % of yield) (Figure 3). Roach was recorded in cormorant pellets more frequently than other fish species ($\chi^2$= 61,604, DF = 20, $P$ < 0.01) while common carp was recorded in catches of anglers more frequently than other fish species ($\chi^2$= 61,604, DF = 20, $P$ < 0.01). Pianka´s index of overlap between catches of cormorants and anglers was low (I = 0.10 for relative frequency of caught fish; I = 0.09 for estimated biomass of caught fish).

Cormorants in the study area consumed fish with estimated price of 2 066–35 542 Euro per month. Total estimated price of consumed fish for the whole season 2014/2015 (7 months) was 65 638–131 276 Euro depending on daily food intake (Table 3).

## Discussion

The number of collected cormorant pellets and identified fish diagnostic bones was relatively high and comparable to other large-scale studies of cormorant diet in Central Europe (Keller 1995, Suter 1995b, Čech & Vejřík 2011, Emmrich & Dutmann 2011). We identified large number of small diagnostic bones (2–3 mm) that belonged to small fish (3–4 cm total length). Previous studies suggested that 3–4 cm large fish are the smallest prey that appears in cormorant diet (Keller 1995, Suter 1995b, 1997, Čech & Vejřík 2011, Emmrich & Dutmann 2011). Therefore, we conclude that fish of all possible prey sizes were retrieved from cormorant pellets.

The dataset regarding the number of fish catches by recreational anglers was relatively strong as well (90 000 individual fish; 180 tons of fish). Data on fish catches by recreational anglers was collected from annual angling reports. The Czech Fishing Union has been collecting and analysing data on fish catches in recreational fishing for decades and the method is standardized for the whole Czech Republic (Jankovský *et al*. 2011). This method of data collection allowed us to make a relatively precise comparison of differences between catches of cormorants and anglers. Anglers are lawfully obliged to write down all fish that they kill, and violation of this rule is punishable by law. For that reason, we believe that the accuracy of this dataset is reasonable. The combination of two relatively strong datasets (cormorant diet and catches of anglers) allowed us to create a relatively unique study with strong data background.

We estimated that overwintering cormorants consumed 17–34 tons fish in the study area in one season. The real consumption was probably approximately 30 tons of fish (for daily food intake of approximately 400 g/bird/day; Čech & Vejřík 2011). The highest consumption was during winter (December-February) when the bird numbers were the highest. The main problem in the conflict between man and cormorants is that fish (ectothermic organisms) are most vulnerable to bird predation during winter when the numbers of fish-eating cormorants are the highest in this area. That is a significant problem for fisheries and fish protection in all cormorant overwintering areas in Central Europe. Other authors who studied cormorant diet in Central Europe also reported increased cormorant predation pressure on fish stocks during winter (Keller 1995, Suter 1995b, 1997, Čech & Vejřík 2011, Emmrich & Dutmann 2011). In areas with high abundance of overwintering cormorants, we suggest that fisheries management should focus on stricter fish protection in winter season.

Fish of moderate interest to anglers dominated in cormorant diet. Those fish species are not the primary target for recreational anglers but they are still frequently taken because of their high abundance in the rivers. Especially cyprinids like roach, bream, white bream, and European chub are frequent in both catches of anglers (Czech Fishing Union, unpubl. data) and in our study area (Prchalová *et al*. 2011, Horký *et al*. 2013, Valová *et al*. 2014). On the other hand, previous research suggested that large populations of shoaling cyprinids are too robust to be significantly affected by cormorant predation (Suter 1997).

The most significant problem in the angler-cormorant conflict was representation of fish of high and very high interest to anglers (piscivorous fish species and common carp) in cormorant diet. Those fish species are primary targets for recreational anglers (common carp forms 80 % of all fish catches in the Czech Republic; Jankovský *et al*. 2011). Tons of common carps and piscivorous fish species are annually stocked into Czech rivers for the purpose of recreational fishing (Czech Fishing Union, unpubl. data). Common carp populations in Czech rivers are almost entirely dependent on intensive fish stocking because common carp rarely reproduces in natural conditions of Czech rivers. Common carps that were identified in cormorant diet are mostly fish that were reared in fish hatcheries; cormorant predation on those fish can therefore be perceived as financial loss and direct competition between fisheries and cormorants. Evaluation of competition for piscivorous fish species is more complicated because those fish usually reproduce in natural conditions of Czech rivers (Valová *et al*. 2014). Fish stocking is then used to bolster fish populations and to provide trophy-sized fish for angling purposes (Czech Fishing Union, unpubl. data). In this case, cormorants most likely prey upon both stocked and naturally occurring fish.

We discovered that cormorants caught significantly different fish species than anglers did. Roach dominated in cormorant diet while common carp dominated in catches of anglers. Roach is a typical fish of moderate interest to anglers while common carp is the most important fish species in Czech recreational fishing (Jankovský *et al*. 2011). Cormorants mostly preyed upon fish that were undersized for angling purposes but that does not necessarily mean that competition between cormorants and anglers was low. The main issue is that cormorants consume small fish that would otherwise grow into legal size for fishing purposes. Fish stocking programmes mostly concentrate on stocking of large trophy fish for angling purposes but small fish (yearlings, 5–15 cm total length) are stocked into rivers as well (Boukal *et al*. 2012). Previous studies confirmed that 5–15 cm large fish are the main prey item in cormorant diet in Central Europe (Keller 1995, Suter 1995b, 1997, Čech & Vejřík 2011, Emmrich & Duttmann 2011).

The low overlap in fish species between cormorant diet and catches of anglers was mainly caused by high selectivity of anglers. Anglers catch many different fish species but they take and kill mostly common carp, bream, and piscivorous fish species (Jankovský *et al*. 2011, Boukal *et al*. 2012) and they release the rest back into water. Inversely, cormorants usually prey upon the most abundant and available fish species (e.g. Suter 1997, Čech *et al*. 2008, Bostrom *et al*. 2012, Gagliardi *et al*. 2015, Magath *et al*. 2016). Nevertheless, low overlap does not imply low competition because cormorants consume fish that would otherwise serve as prey for other piscivorous fish species; previous studies discovered that 5–20 cm large fish are important prey items in diet of both cormorants and piscivorous fish species (e.g. Keller 1995, Suter 1995b, 1997, Nilsson &

Bronmark 1999, 2000, Čech & Vejřík 2011, Emmrich & Dutmann 2011). It is clear that cormorants indirectly compete with fisheries even in case of fish species of moderate or low interest to anglers because those species are important prey for highly valued piscivorous fish.

We estimated financial loss of cormorant predation on fish stocks to be approximately 65 000–130 000 Euro for one whole season in the study area. Species of moderate interest to anglers (and low financial price) represented significant part in the financial sum because they dominated in the diet. This estimate of financial loss did not include indirect effects of cormorant predation on fish stocks (loss of fitness due to attack wounds, enforced fish movement, and increased levels of stress hormones). The actual financial loss was therefore higher since previous studies suggested that indirect cormorant predation can have significant negative effect on fish fitness (Kortan *et al*. 2011, Kortan & Adamek 2011).

There are many different ways to perceive competition between cormorants and man and it is very complicated to cover all of them. We estimated the competition from the point of view that is often suggested to be the most important (VanDeValk *et al*. 2002, Takahashi *et al*. 2006, Čech *et al*. 2011, Lehikoinen *et al*. 2012, Gagliardi *et al*. 2015). The competition between cormorants and man certainly exists but it is very important to carefully choose the right tools in order to estimate its magnitude. Using only one way of estimating the competition can be misleading. Above all, majority of dietary studies cannot reliably state if cormorant predation is additive or compensatory. Those studies also cannot reliably estimate indirect effects of cormorant predation on fish mortality. That makes any estimation of the competition between cormorants and man complicated.

In conclusion, we discovered that fish of moderate interest to anglers dominated in cormorant diet and the overlap in fish species between cormorant diet and catches of anglers was overall low. However, the financial loss of cormorant predation on fish stocks was still significant. Cormorants caught smaller-sized fish while anglers caught large-sized fish. Therefore, majority of fish consumed by cormorants was undersized for angling purposes. The direct competition for fish catches between man and cormorants was lower but cormorants still consumed small fish that a) serve as prey for piscivorous fish species and b) would grow to legally sized fish for angling purposes.

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**Table 1** Numbers of cormorant pellets collected at cormorant roosting places on the Elbe River in season 2014 /2015. Note: date, date when pellets were collected; pellets, number of collected pellets; prey items, number of prey items identified in the pellets.

| Date | Pellets | Prey Items |
|---|---:|---:|
| October 2014 | 121 | 448 |
| November 2014 | 253 | 1 260 |
| December 2014 | 501 | 1 481 |
| January 2015 | 102 | 631 |
| February 2015 | 202 | 1 054 |
| March 2015 | 156 | 1 003 |
| April 2015 | 143 | 1 037 |
| Total | 1 478 | 6 903 |

**Table 2** Composition of fish sizes in diet of cormorants and in catches of anglers. Note: angl (min), minimum legal fish length for anglers; angl (avr), average weight of fish in catches of anglers; corm (min-max), minimum and maximum length and weight of fish in cormorant diet; corm (avr), average length and weight of fish in cormorant diet.

| | Length [cm] | | | Weight [g] | | |
|---|---|---|---|---|---|---|
| species | Angl (min) | Corm (min-max) | Corm (avr) | Angl (avr) | Corm (min-max) | Corm (avr) |
| Grass carp (*Ctenopharyngodon idella*) | 50 | 19–45 | 31 | 2 900 | 76.4–1 099 | 450 |
| Northern pike (*Esox lucius*) | 50 | 17–49 | 31 | 2 200 | 27.3–802 | 205 |
| Zander (*Sander lucioperca*) | 45 | 9–44 | 22 | 2 500 | 1.8–647 | 84 |
| Asp (*Aspius aspius*) | 40 | 9–39 | 14 | 2 000 | 8.3–471 | 165 |
| Common carp (*Cyprinus carpio*) | 40 | 4–37 | 21 | 2 200 | 0.6–908 | 209 |
| Barbel (*Barbus barbus*) | 40 | 8–49 | 28 | 2 000 | 4.3–1 043 | 315 |
| Burbot (*Lota Lota*) | 30 | 16–30 | 23 | 1 100 | 207.8–315 | 237 |
| Nase (*Chondrostoma nasus*) | 30 | 10–49 | 20 | 1 200 | 17.7–1 351 | 307 |
| Ide (*Leuciscus idus*) | 25 | 4–40 | 19 | 1 300 | 0.4–679 | 74 |
| Vimba bream (*Vimba vimba*) | 25 | 20–32 | 26 | 1 100 | 85.9–325 | 197 |
| European chub (*Squalius cephalus*) | 25 | 4–45 | 18 | 1 200 | 0.7–854 | 91 |
| Tench (*Tinca tinca*) | 20 | 6–29 | 16 | 1 100 | 2.3–296 | 53 |
| Bream (*Abramis brama*) | 0 | 11–35 | 12 | 1 200 | 11.4–477 | 135 |

| | | | | | | |
|---|---|---|---|---|---|---|
| White bream (*Abramis bjoerkna*) | 0 | 4–31 | 22 | 300 | 2.2–738 | 127 |
| Prussian carp (*Carassus auratus*) | 0 | 11–30 | 24 | 900 | 22.6–552 | 195 |
| European perch (*Perca fluviatilis*) | 0 | 8–31 | 17 | 500 | 4.5–497 | 81 |
| Rudd (*Scardinius erythrophthalmus*) | 0 | 7–28 | 12 | 300 | 1.5–214 | 68 |
| Roach (*Rutilus rutilus*) | 0 | 5–47 | 17 | 300 | 1.0–848 | 73 |
| Together | | 5–49 | 18 | 1 700 | 0.4–1 351 | 91 |

**Table 3** Estimated financial price of fish consumed by overwintering cormorants in the study area on the Elbe River in season 2014/2015. Prices are in Euro.

Note: min, minimum estimated financial loss; max, maximum estimated financial loss; others, ruffe (*Gymnocephalus cernuus*), bleak (*Alburnus alburnus*), common dace (*Leuciscus leuciscus*), gudgeon (*Gobio gobio*), vimba bream (*Vimba vimba*), brown bullhead (*Ameiurus nebulosus*), bullhead (*Cottus gobio*).

| | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | | Apr | | Together | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | min | max | min | max | min | max | min | max | min | max | min | max | min | max | min | max |
| Roach (*Rutilus rutilus*) | 384 | 767 | 2 289 | 4 578 | 3 273 | 6 547 | 3 562 | 7 124 | 3 481 | 6 963 | 849 | 1 697 | 823 | 1 646 | 14 661 | 29 322 |
| Northern pike (*Esox lucius*) | 554 | 1107 | 1 865 | 3 731 | 842 | 1 684 | 7 169 | 14 338 | 1 872 | 3 743 | 271 | 542 | 244 | 488 | 12 816 | 25 633 |
| European perch (*Perca fluviatilis*) | 1 161 | 2 321 | 2 643 | 5 287 | 2 049 | 4 098 | 2 282 | 4 564 | 1 265 | 2 530 | 536 | 1 072 | 266 | 531 | 10 202 | 20 403 |
| Zander (*Sander lucioperca*) | 1 297 | 2 595 | 3 829 | 7 658 | 766 | 1 532 | 343 | 685 | 504 | 1 008 | 136 | 272 | 67 | 134 | 6 942 | 13 884 |
| Barbel (*Barbus barbus*) | 1 166 | 2 333 | 3 327 | 6 654 | 937 | 1 874 | 163 | 325 | 527 | 1 054 | 86 | 171 | 33 | 66 | 6 238 | 12 476 |
| White bream (*Abramis bjoerkna*) | 35 | 70 | 340 | 680 | 1 643 | 3 286 | 375 | 751 | 1 469 | 2 938 | 118 | 235 | 109 | 218 | 4 089 | 8 177 |
| Common carp (*Cyprinus carpio*) | 162 | 324 | 1 978 | 3 956 | 199 | 399 | 954 | 1 908 | 129 | 258 | 30 | 59 | 200 | 400 | 3 652 | 7 303 |
| European chub (*Squalius cephalus*) | 28 | 57 | 633 | 1 265 | 565 | 1131 | 607 | 1 214 | 294 | 588 | 81 | 163 | 56 | 113 | 2 265 | 4 530 |
| Ide (*Leuciscus idus*) | 46 | 92 | 394 | 787 | 78 | 156 | 175 | 351 | 194 | 389 | 18 | 35 | 78 | 156 | 983 | 1 966 |
| Bream (*Abramis brama*) | 5 | 10 | 123 | 246 | 165 | 330 | 423 | 846 | 63 | 127 | 29 | 58 | 18 | 37 | 827 | 1 653 |
| Burbot (*Lota Lota*) | 0 | 0 | 103 | 206 | 24 | 49 | 604 | 1 208 | 61 | 122 | 0 | 0 | 0 | 0 | 792 | 1 584 |
| Nase (*Chondrostoma nasus*) | 20 | 40 | 15 | 30 | 398 | 797 | 10 | 19 | 102 | 204 | 28 | 56 | 109 | 219 | 683 | 1 366 |
| Grass carp (*Ctenopharyngodon idella*) | 0 | 0 | 151 | 303 | 39 | 79 | 0 | 0 | 56 | 111 | 233 | 466 | 16 | 33 | 496 | 991 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tench (*Tinca tinca*) | 9 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 240 | 480 | 53 | 106 | 4 | 8 | 306 | 613 |
| Asp (*Aspius aspius*) | 0 | 0 | 12 | 24 | 108 | 216 | 0 | 0 | 122 | 243 | 0 | 0 | 9 | 17 | 250 | 501 |
| Rudd (*Scardinius erythrophthalmus*) | 4 | 8 | 26 | 52 | 30 | 60 | 31 | 61 | 65 | 130 | 21 | 41 | 10 | 20 | 186 | 372 |
| Prussian carp (*Carassus auratus*) | 0 | 0 | 29 | 58 | 71 | 142 | 0 | 0 | 23 | 46 | 1 | 1 | 11 | 21 | 134 | 268 |
| Others* | 5 | 10 | 15 | 29 | 48 | 95 | 11 | 22 | 24 | 48 | 3 | 5 | 13 | 25 | 117 | 234 |
| Together | 4 876 | 9 753 | 17 771 | 35 542 | 11 236 | 22 472 | 16 708 | 33 415 | 10 490 | 20 981 | 2 491 | 4 982 | 2 066 | 4 131 | 65 638 | 131 276 |

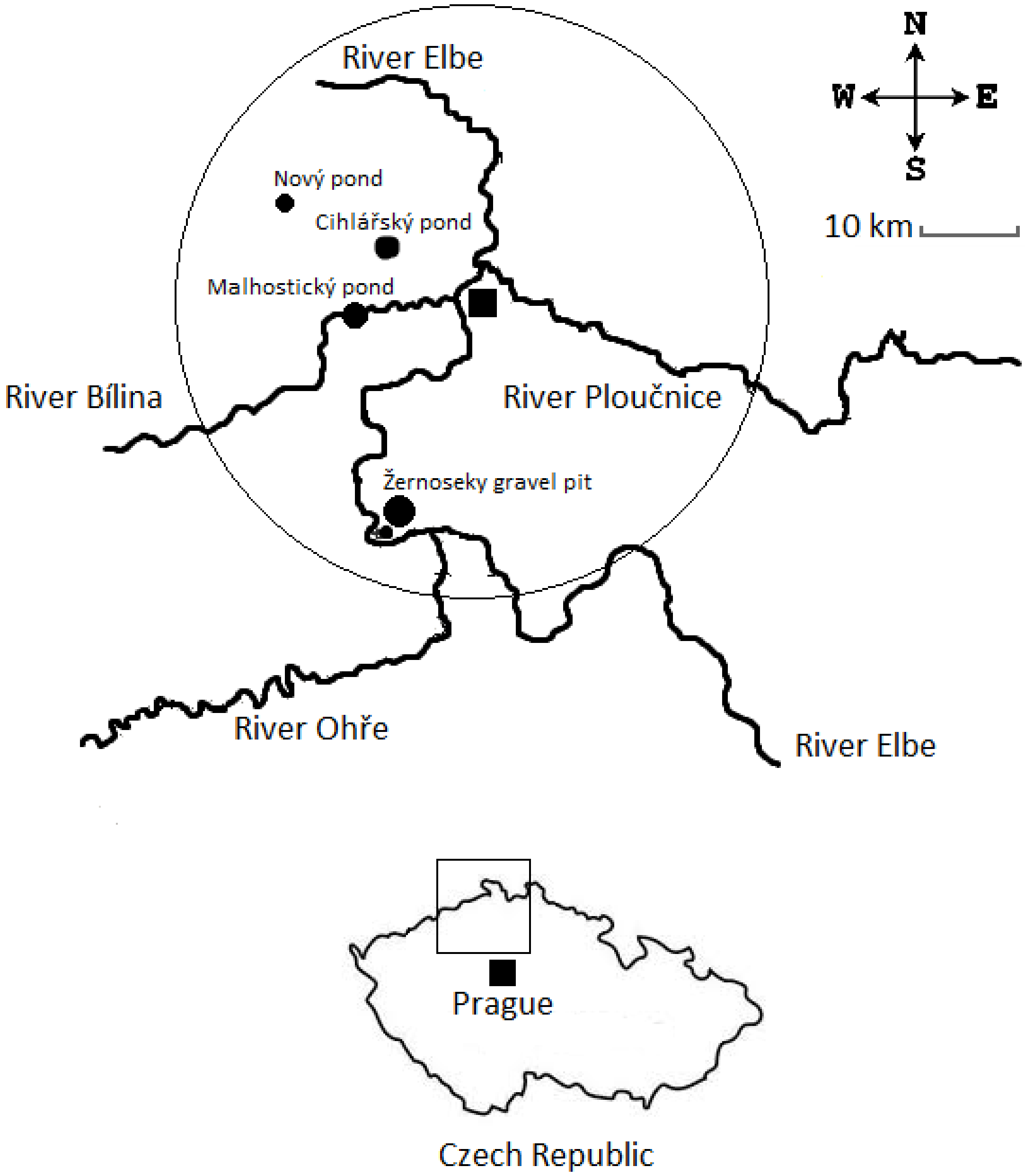


**Figure 1** Map of the study area. The full black rectangle represents the cormorant colony where cormorant pellets were collected in season 2014/2015. The wide black circle represents estimated reach of the cormorant colony.

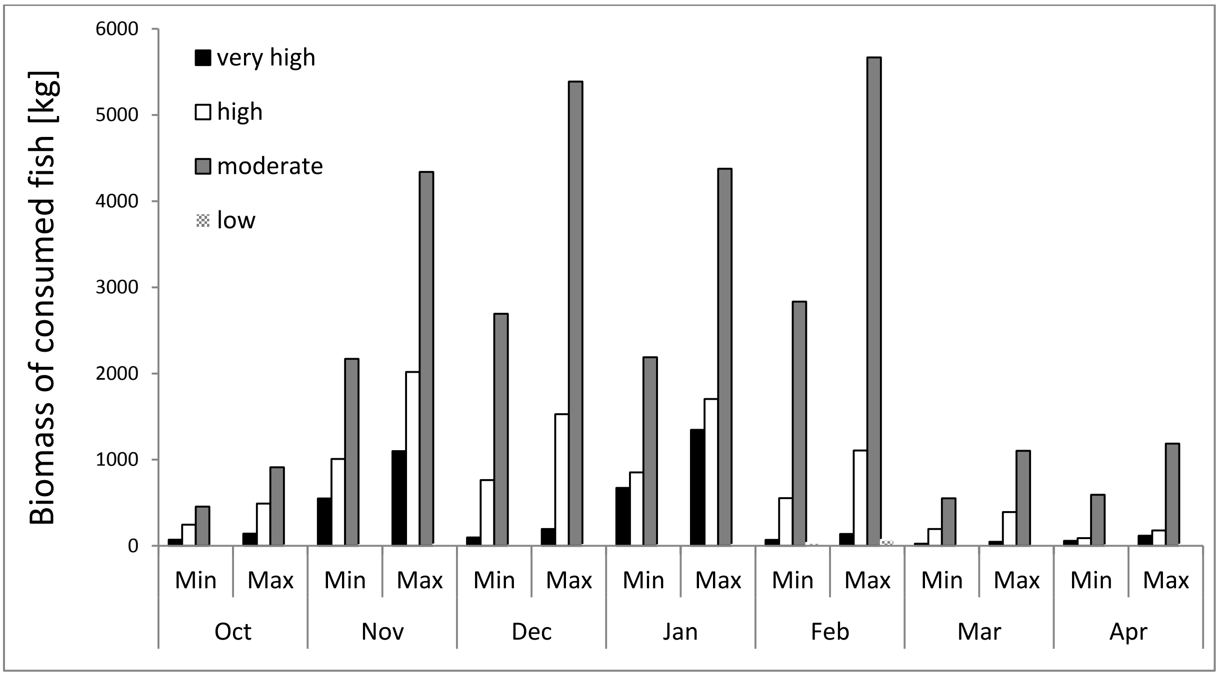


**Figure 2** Biomass of fish consumed by overwintering cormorants in the study area on the Elbe River in season 2014/2015. Note: very high, fish species of very high interest to anglers; high, fish species of high interest to anglers; moderate, fish species of moderate interest to anglers; low, fish species of low interest to anglers; min, minimum fish biomass consumed; max, maximum fish biomass consumed.

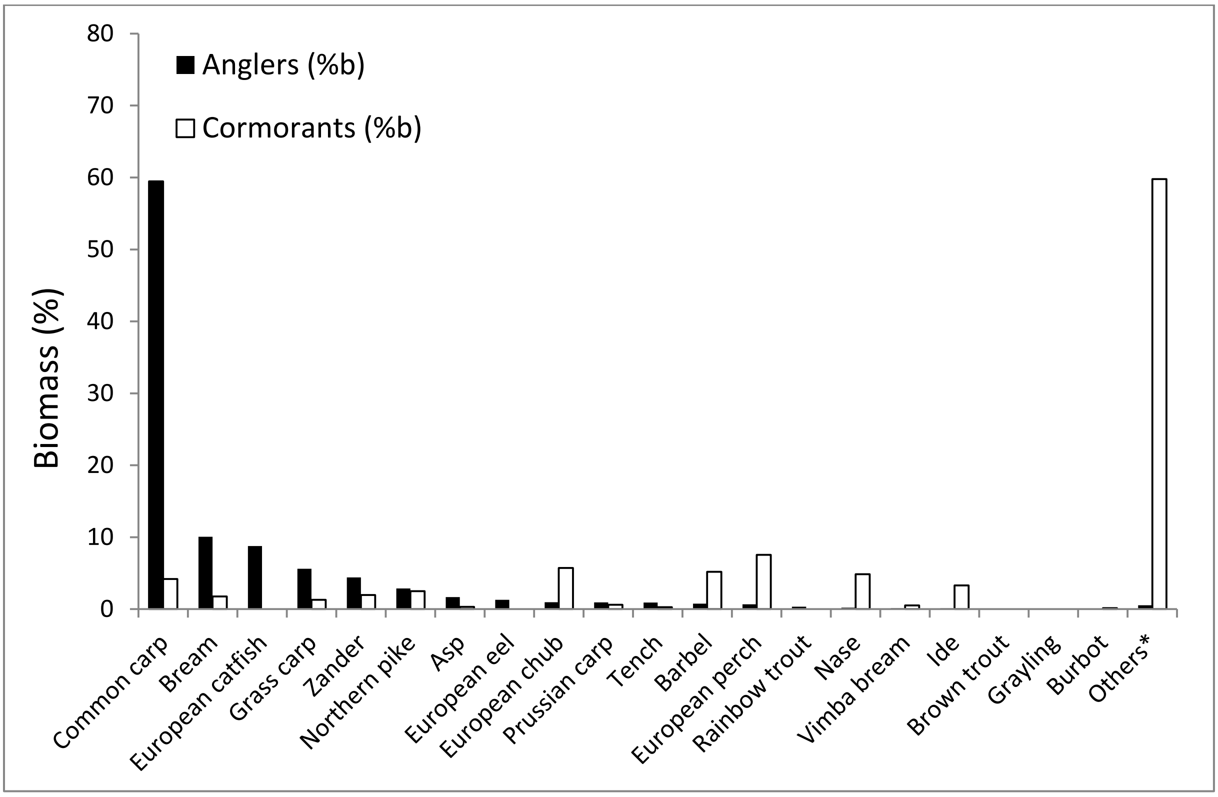


**Figure 3** Percentage of biomass of fish species in cormorant diet in the study area on the Elbe River in season 2014/2015 and percentage of biomass in catches of anglers in the study area in years 2014 and 2015. Note: anglers (%b), percentage of biomass in catches of anglers; cormorants (%b), percentage of biomass in diet of cormorants; others, roach (*Rutilus rutilus*), bullhead (*Cottus gobio*), white bream (*Abramis Bjoerkna*), rudd (*Scardinius erythrophthalmus*), ruffe (*Gymnocephalus cernuus*), common dace (*Leuciscus leuciscus*), bleak (*Alburnus alburnus*), gudgeon (*Gobio gobio*), brown bullhead (*Ameiurus nebulosus*).

# Solidarity of anglers is more important than any fishing regulation: a case study of grayling *Thymallus thymallus* in the Czech Republic

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Running head: Fishing regulations and angler behaviour

## Abstract

Grayling *Thymallus thymallus* is an endangered fish species with high recreational angling value. For that reason, starting from January 2016, the minimum legal angling size of grayling was increased from 30 to 40 cm in the whole Czech Republic. This study aimed to discover if the increase in angling size had any effect on the overall catch and yield of grayling. The Czech Fishing Union collected data from individual angling logbooks on 229 fishing grounds. Furthermore, this study searched fisheries discussion forums on the Internet to assess the overall opinion of anglers on grayling conservation. In result, the size restriction had no effect on the overall catch of grayling. However, the percentage of fishing grounds with any grayling catches decreased. Average weight of caught grayling increased due to the restriction. Discussion forums revealed that anglers release all caught grayling, support strict grayling conservation, and act to improve environmental conditions on grayling streams at their own expenses. In conclusion, the angling size restriction had no effect on catches of grayling, mostly because anglers were already releasing caught grayling back to water, being aware of its poor population status. Fisheries regulations are usually effective, but in this case, solidarity of anglers with an endangered species was more important than the actual fishing regulation.

Keywords: angling catch and yield, fisheries management, game fishing, inland fishing, salmonid, sports fishing

## 1. Introduction

Recreational fishing is a popular leisure activity all around the world. Previous studies claim that around 10 % of the people in developed countries practice angling (Cooke and Cowx 2004, 2006; Arlinghaus et al, 2015). In the last decades, as far as inland freshwaters are concerned, recreational fishing has become more important than commercial fishing (Arlinghaus et al., 2002; Arlinghaus and Cooke, 2005; FAO, 2010). Researchers claim that inland freshwater ecosystems are significantly affected by angling activities (Rasmussen and Geertz-Hansen, 2001; Post et al., 2002; Cooke and Cowx, 2004). Some studies even suggest that recreational fishing is the main driver in population dynamics of commercially important fish species in freshwater ecosystems (Cooke and Cowx, 2004; Lewin et al., 2006). Overexploitation of fish populations by anglers can have significantly negative effect on commercially important fish species (Cooke and Cowx, 2004, 2006).

Fisheries management has access to several regulations that can be used to enhance protection of wild fish populations. For example, fisheries management can introduce catch-and-release fishing strategy, introduce or prolong closed season, ban fishing strategies that are harmful to fish, restrict access to fishing grounds for anglers, decrease the legal amount of fish taken (bag limits) per angler and per time period, or change the minimum and maximum angling size (slot limits) for individual fish species (Naslund et al. 2005, 2010; Powell et al., 2010; van Poorten et al., 2013; Lenker et al., 2016; Lenox et al., 2016; Rahel, 2016). Studies claim that fisheries regulations greatly influence both behaviour of anglers and fish harvest (Beard et al., 2003; Fulton et al., 2011; Johnston et al., 2013; van Poorten et al., 2013).

In the Czech Republic, setting a minimum angling size for commercially valuable and threatened fish species is one of the most frequently used conservation measures in fisheries management. The goal of this restriction is to protect young fish individuals and to prevent anglers from removing an excessive amount of fish from the ecosystem. In theory, this management strategy should lead to restoration of the fish populations (Humpl et al., 2009; Jankovsky et al., 2011; Boukal et al., 2012).

Grayling *Thymallus thymallus* is one of the most threatened fish species in Central Europe (Persat, 1996). In the past, grayling used to be a species of high angling value in the Czech Republic. Today, the collapse of grayling populations is one of the most problematic issues in Czech recreational fishing (Horka et al., 2015). Perhaps the most convincing proof of importance of grayling in Czech recreational fishing is that the Czech Fishing Union –

the main authority in recreational fishing in the Czech Republic – has grayling displayed in its emblem. However, grayling populations have been recently decreasing in the whole Europe (Gum et al., 2009; Weiss et al., 2013). The reasons for the population decrease are mainly climate change, droughts, suboptimal management of natural water sources, water shortage in streams and small rivers, poorly conducted flood-protection measurements, construction of migration barriers, increasing predation pressure from piscivorous birds and mammals, and also fishing pressure (Northcote, 1995; Persat, 1996; Uiblein et al., 2001; Gum et al., 2003; Duftner et al., 2005).

Interaction with anglers is a very important factor in the dynamic of grayling populations (Duftner et al., 2005; Naslund et al., 2005, 2010; Horka et al., 2015). Angler-grayling interactions can affect grayling populations either positively (when anglers are educated on the poor state of its populations) or negatively (when they are not). We believe that more studies should focus on the interaction between grayling and anglers. So far, we have discovered only two studies that deal with this topic (Naslund et al., 2005, 2010).

In the Czech Republic, the minimum angling size for grayling was set to 30 cm over the course of years 2006-2015. However, grayling populations in the wild have been steadily decreasing (Horka et al., 2015). For that reason, the minimum angling size was increased to 40 cm from the year 2016 onwards. This measure was effective from 1 January 2016 for all fishing grounds in the whole Czech Republic with no exception (Czech Fishing Union, unpubl. data). In theory, this measurement should protect the entire grayling population, mostly because the maximum length of grayling usually does not exceed 40-50 cm (Kottelat and Freyhof, 2007). The goal of this measurement was to decrease angling catch and yield of grayling in the whole Czech Republic.

The goal of this study was to discover if the increased minimum angling size had any effect on catches of grayling on selected fishing grounds. Firstly, this study compared catch, yield, and average body weight of grayling. Secondly, it compared the percentage of fishing grounds with and without catches of grayling. Thirdly, it compared catch and yield of grayling in comparison to other salmonids. The study compared all listed variables between years 2015 and 2016, i.e. before and after the restriction took place.

Firstly, it was expected that catch and yield of grayling would decrease. On the other hand, it was expected that average body weight of grayling would increase. Secondly, it was expected that the percentage of fishing grounds with grayling catches would decrease. Thirdly, it was expected that the percentage of grayling in the overall catch and yield of all salmonids would decrease.

Furthermore, this study assessed opinions of anglers on the topics regarding catches of grayling, conservation, and the overall status of grayling populations. The goal was to discover what anglers think about the role of grayling in recreational fishing.

## 2. Methods

### 2.1 Study area

This study was carried out in the regions of Prague (50° N, 14.5° E) and Central Bohemia (49.5°–50.5° N, 13.5°–15.5° E), Czech Republic, Central Europe (Figure 1). Both regions together cover an area of 11 500 $km^2$. The region of Prague (the capital of the Czech Republic) has mostly urban character while the region of Central Bohemia has mostly agricultural character. The study area is dominated by the rivers Elbe and Vltava. Both rivers belong to the upper Elbe River Basin. All rivers in the study area belong to the North Sea Drainage area. Studied fishing grounds are situated in lowlands with an altitude of 200–600 m above sea level. Waters in the study areas are mostly mesotrophic and eutrophic. The study area includes salmonid streams and reservoirs (dominated by salmonids) and non-salmonid rivers and reservoirs (dominated by cyprinids).

### 2.2 Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is organized by the Czech Fishing Union (the main authority in recreational fishing in the Czech Republic) and is centralized for the whole country. For detailed description of recreational fishing in the Czech Republic see Lyach and Čech (2018).

### 2.3 Angling rules for grayling

Grayling *Thymallus thymallus* is an important fish species in recreational fishing in the Czech Republic. The bag limit for salmonids is either three fish or 7 kg of fish per angler per day, whichever comes first. The minimum legal angling size of grayling was 30 cm (TL, tail length) over the course of years 2006-2015. Since 1 January 2016, the minimum legal angling size of grayling was changed to 40 cm. This change was effective immediately for all fishing grounds that are under administration of the Czech Fishing Union. The purpose of this change was mainly to protect grayling populations from overexploitation by recreational anglers. Any grayling that does not reach this size has to be returned to water without any unnecessary delay.

## 2.4 Data sources

Data from annual angling summaries was used for the purpose of this study. This data originated from angling logbooks that were collected from individual anglers. Data from 229 inland freshwater fishing grounds over the course of years 2015-2016 was used. Fishing grounds are defined as stream stretches, river stretches, ponds, water reservoirs, gravel pits, retention basins, and other water bodies where recreational fishing can be legally conducted. The selected fishing grounds covered an area of 116 $km^2$. This data was originally collected by the Czech Fishing Union and later processed by the authors of this study.

Data from discussions on Web pages on the Internet were used to obtain opinions of anglers and the public. We searched the Internet for Web pages that contained at least one discussion on the topic of catches of grayling, closed season for grayling, legal angling size of grayling, grayling protection, grayling population dynamics, grayling rearing and stocking, fishing techniques and grayling, grayling reproduction, grayling and other salmonids, and prey of grayling. Only discussions where people actually responded to each other were used in this study. Only discussions on Czech Web pages where people discussed topics in the Czech language were used.

## 2.5 Measured variables

This study was comparing the overall catch [individual fish], overall yield [kg], catch per fishing ground, yield per fishing ground, and median body weight [kg] of grayling in years 2015-2016. It was also comparing the percentage of fishing grounds with catches of grayling in years 2015-2016. The calculation of catch and yield per fishing ground includes only fishing grounds where grayling was caught during the study period; fishing grounds with no grayling catches were excluded. Other calculations include all fishing grounds in the study area.

## 2.6 Statistical analysis

The statistical programme R (R i386 3.4.1., R Development Core Team 2017) was used for statistical testing. Shapiro-Wilk test of normality was used to analyse distribution of the data. Wilcoxon rank sum test was used to compare catch, yield, and median body weight. Pearson´s Chi-squared test was used to compare percentages of fishing grounds. Minimum probability level of p = 0.05 was accepted for all the statistical tests, and all statistical tests were two-tailed. One fishing ground was used as one sample in all analyses.

## 3. Results

### 3.1 Overall data summary

Over the course of years 2015 and 2016, anglers caught altogether 158 grayling with total weight of 72.9 kg. In comparison, anglers also caught 30 854 other salmonids (brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, and brook trout *Salvelinus fontinalis*) with total weight of 13 167.1 kg. In addition, we also analysed 5 151 comments of anglers regarding grayling on five Web pages. Three of the Web pages were targeted at anglers, one at environmentalists, and one at regular people.

### 3.2 Catch and yield

The restriction had no effect on the overall catch and yield of grayling. There was no significant difference in overall catch and yield of grayling between years 2015 and 2016 (for catch: W = 28 000, p = 0.09, n = 229; for yield: W = 27 988, p = 0.09, n = 229). Anglers caught 80 grayling in 2015 and 78 grayling in 2016 (Figure 2 a). Anglers caught 36.1 kg of grayling in 2015 and 36.8 kg of grayling in 2016 (Figure 2 b).

The catch of grayling stagnated, yet the catch of other salmonids increased. The percentage of grayling in the overall catch and yield of salmonids on individual fishing grounds was significantly higher in 2015 when compared to 2016 (for catch: W = 225, p < 0.01, n = 23; for yield: W = 221, p < 0.01, n = 23). In 2015, grayling made 1.7 % and 2.6 % by catch and yield, respectively. In 2016, grayling made 0.2 % and 0.5 % by catch and yield, respectively (Figure 2 c).

The restriction had a significant effect on the redistribution of grayling catches among fishing grounds – it led to decrease in catch and yield per fishing ground. Catch and yield of grayling per fishing ground was significantly higher in 2015 when compared to 2016 (for catch: W = 2015, p = 0.01, n = 23; for yield: W = 204, p = 0.04, n = 23). Anglers caught 2 grayling per fishing ground in 2015 but only 1 grayling per fishing ground in 2016 (median value). Similarly, yield of grayling per fishing ground was 1 kg in 2015 but only 0.5 kg in 2016 (median value) (Figure 2 d).

Due to the restriction, the percentage of fishing grounds with at least one catch of grayling also decreased. The percentage of fishing grounds with catches of grayling was significantly higher in 2015 when compared to 2016 (Chi-squared = 6.46, DF = 1, p = 0.01). Anglers caught grayling on 7.4 % of fishing grounds in 2015 but only on 3.8 % of fishing grounds in 2016 (Figure 3).

Only three fishing grounds (out of 23) showed catches of grayling in both years 2015 and 2016. In addition, the catches of grayling were un-evenly distributed. There was always one fishing ground that dominated in grayling catch and yield in that year. In 2015, one fishing ground stood out with catch of 37 fish and yield of 14.1 kg. This fishing ground made 46 % and 40 % of overall catch and yield in 2015. In 2016, one fishing ground stood out with catch of 61 fish and yield of 25.9 kg. This fishing ground made 75 % and 68 % of overall catch and yield in 2016 (Figure 4). The fishing ground with the highest catch and yield was a different one in each year. In addition, the fishing ground that showed the highest catch and yield in 2015 showed no catch at all in 2016.

3.3 Median fish body weight

The restriction led to increased body weight of caught grayling. The median body weight of grayling in catches of anglers was significantly lower in 2015 when compared to 2016. The median body weight of grayling in 2015 was only 0.5 kg but the median body weight of grayling in 2016 was 0.7 kg (Figure 5).

3.4 Behaviour and opinions of anglers

3.4.1 Catch and release strategy

Overall, anglers were strongly supporting protection of grayling. Anglers stated that they have been releasing caught all grayling of all sizes back to water. That goes for legal-sized fish (over 30 cm) as well. Their angling colleagues have been releasing grayling as well, partially because anglers convinced them to do so. They claimed that the goal is to save grayling populations for next generation of anglers. They claim that, 10-20 years ago, grayling used to be more common, and they want to bring those times back. They would like to have grayling available in rivers that are located in close proximity to their homes. They acknowledge that anglers are partially responsible for decrease of grayling populations in the wild. They are aware of the poor state of grayling populations in the wild, and they are trying to actively contribute to protection of grayling. Anglers claimed that they treat caught grayling with maximum caution. They do not drag caught grayling from water to the bank. They do not take photographs of grayling on the bank. They also always release caught fish carefully and gently back to water. They photograph grayling only in the water. They do not disturb fish in closed season. Anyone who does not respect angling rules and kills grayling (even legal-sized) is negatively perceived by anglers. They suggest not only bag limits, but also conquer limits: if an angler catches (and therefore conquers) three grayling per day, he should end his fishing trip right away – even if the fish are released.

3.4.2 Closed season

Anglers are supporting all-year-long closed season for grayling, especially on streams and smaller rivers that have potential for grayling reproduction. Anglers feel like the increase of minimum angling size to 40 cm is unnecessary, mostly because nobody has ever seen a grayling of this size. They claim that fishing grounds in the Czech Republic do not support environmental conditions that would allow grayling to grow to this size. Grayling is a relatively slow-growing and short-living fish, and it does not grow fast enough or live long enough to reach 40 cm in those conditions. That is why anglers suggest closed season instead of size limits. They also want to ban fishing in areas when grayling naturally reproduces.

3.4.3 Financial resources

Anglers would allocate more financial resources to rearing and production of grayling. They would take this money away from programmes that support production of non-native fish, especially rainbow trout. They support stocking of young grayling into very small streams where fishing is generally banned. Anglers believe that fish stocking is essential for survival of grayling populations in the wild. On the other hand, anglers point out that grayling stocking is ineffective. Anglers do not mind paying extra money for fishing permit as long as the extra money is spent on production of grayling. Numerous anglers have already founded their own groups of grayling fans. Those groups specialise in conservation of grayling – they rear and/or buy grayling yearlings and release them into suitable streams to bolster resident grayling populations. They contribute financially and materially to a group of grayling fans called 'Save our grayling'. This group cooperates with the Czech Fishing Union and specialises in protection of the last remaining spawning habitats of grayling. Anglers suggest that more money should be used to maintain the remaining spawning habitats. In addition, anglers claim that fishing should be banned in streams where grayling naturally spawns. They also suggest that the Czech Fishing Union should hire professional aquaculture experts for production of grayling. The idea of extra financial benefits for people who produce grayling is also supported among anglers. They call for cooperation between fisheries management, environmental protection organisations, and authorities of the Rivers Vltava and Elbe.

3.4.3 Fishing techniques

Anglers claim that they do not use potentially harmful fishing techniques (such as triple-hooks, backward hooks, and live bait) when fishing on smaller streams. When they target rainbow trout, anglers use fishing techniques and baits that have low chances to attract a grayling. Anglers are generally aware of the fact that some released fish die because of post-release stress. They are especially cautious when dealing with 20-30 cm large fish. They believe that 20-30 cm large grayling is at the most fertile stage of its life. Anglers further suggest that the amount of sold fishing permits should be limited on smaller streams, and they believe that this restriction will help grayling populations. Anglers do not hesitate to actively tell on another angler who breaks fishing rules. Especially anglers who take undersized grayling and display unnecessarily risky behaviour towards fish are perceived negatively. They also suggest stricter punishment for poachers and rule-breakers.

3.4.4 Environmental conditions

Anglers claim that they are actively trying to improve environmental conditions for grayling populations in the wild. Anglers are using submerged wood to build shelters and obstacles in smaller streams. They also organize cleaning parties that walk along streams and collect garbage. The goal is to improve conditions for grayling and its prey (benthos and other insects). Anglers believe that they need to take an action because the future of grayling is solely in their hands. They do not believe that the Czech Fishing Union will solve the grayling problem by itself. They suggest revitalisations of straightened and urbanized streams. They prefer natural spawning of grayling over rearing of fish in a hatchery. They actively participate in meetings of city officials in order to speak up against land-use management measures that alter regime of water flows (flow straightening, removal of obstacles in the flow). They speak up against suboptimal management of streams where grayling prospers (e.g., they are against releases of eutrophic and muddy water from upstream ponds). They also want to decrease the amount of drugs (especially residuals of hormonal contraception) released into streams. They call for stricter limits of water treatment facilities located upstream of grayling habitats. They would like to close any facility that might be potentially threatening to grayling populations located downstream. When fishing, anglers actively select and remove non-native salmonids (rainbow trout and brook trout) and other piscivorous fish that could potentially threaten grayling eggs and fry.

#### 3.4.5 Piscivorous predators

Anglers claim that piscivorous birds and mammals (mostly cormorant *Phalacrocorax carbo* and otter *Lutra lutra*, partially heron *Ardea cinerea* and mink *Neovison vison*, rarely kingfisher *Alcedo atthis*) are responsible for collapse of grayling populations. They claim that the less effective anti-predation behaviour of grayling is not sufficient to withstand the predation pressure from the increasing numbers of piscivores in Central Europe.

#### 3.4.6 Research

Anglers are actively trying to communicate the current grayling situation with research institutions and Universities. They would also welcome tighter cooperation between anglers, research institutions, and the Czech Fishing Union. They call for studies that would find out the true reason for collapse of grayling populations in the Czech Republic in the last 10-20 years.

#### 3.4.7 Education

Anglers actively visit angling groups that work with children. They lecture children on the need for grayling protection, and encourage children to treat caught grayling with caution. They also suggest that the Czech Fishing Union should be educating all anglers on proper handling of caught fish.

## 4. Discussion

### 4.1 Restriction on angling size of grayling

The increase in minimum legal angling size of grayling had no effect on the overall catch and yield. However, that does not necessarily mean that this restriction was a poor idea. It should function as a supportive measure and a safety net for grayling populations. Even though the restriction had no immediate effect on grayling catches, it should ensure that grayling populations will not be overexploited in the future. The restriction had no effect because anglers showed high solidarity with grayling. Anglers are aware of the poor status of grayling populations, and they take grayling conservation seriously. Results showed that releasing caught grayling is a matter of honour for Czech anglers. The increase in size from 30 to 40 cm had no effect because most anglers were already releasing all caught grayling.

As other studies found, fishing restrictions are usually a great tool in species conservation (Schill and Kline, 1995; van Poorten et al., 2013). Restriction of minimum size is even more effective than bag limits (van Poorten et al., 2013; Askey, 2016). However, the outcome of similar restrictions mainly depends on behaviour of anglers in the field. For example, Caroffino (2013) stated that anglers usually comply with a minimum size limit regulation. On the other hand, maximum size regulation is much less likely to be effective. That makes sense for two reasons – the minimum size limit regulation is far more common, and small fish are much less attractive for anglers (Caroffino, 2013; Johnston et al., 2013). Therefore, the most important question is whether anglers are willing to accept the fishing restriction or not. In this case, anglers showed that similar restriction is not necessary. In other cases, authors discovered that similar restriction may be useful and even necessary in species conservation (Naslund et al., 2005, 2010; van Poorten et al., 2013; Lew and Larson, 2015). However, different studies showed that such restriction is ineffective if anglers do not comply with the newly established fishing rules (Gigliotti and Taylor, 1990; Veiga et al., 2013). Either way, the main limitation of similar studies is that the practical effect of such restriction is difficult to evaluate (Lewin et al., 2006). However, similar studies are needed because angling regulations greatly influence angler-fish dynamics (Beard et al., 2003; Fulton et al., 2011; Johnston et al., 2013).

There is another way to approach restrictions in fishing – Cooke et al. (2013) suggested softer restrictions via angler educational programmes. Similar restrictions are already in use and functional in the Czech Republic. Anglers are actively supporting conservation of grayling in fisheries discussion forums. In addition, the Czech Fishing Union also supports protection of grayling on their official Web pages. Those Web pages show approximately 15 000 hits per week (Czech Fishing Union, unpubl. data). The goal is usually to promote catch-and-release fishing strategy. In general, this strategy is gaining popularity not only in the Czech Republic (Lyach and Čech, 2018) but also in the rest of the world (Quinn, 1996; Aas et al., 2002).

4.2 Conservation of grayling

Grayling is a species that rarely reaches 40 cm in the conditions of Central European streams (Kottelat and Freyhof, 2007). Anglers claim that, in their experience, similarly large grayling individuals are basically non-existent in the wild. Grayling is a relatively slow-growing and short-living species (Persat, 1996; Kottelat and Freyhof, 2007). On top of that, environmental conditions of streams in the Czech Republic are mostly suboptimal for grayling populations (Horka et al., 2015). Individual fish would have to grow faster or live longer to reach 40 cm, and current environmental conditions in most streams do not support either. For that reason, anglers suggest closed season for grayling for the whole year. On the other hand, anglers also claim that a 40 cm large grayling has already passed its prime and is less fertile. Anglers could potentially see a reason to catch and kill grayling of this size. However, previous studies disagree with this opinion – Arlinghaus (et al., 2010) claims that removal of large individuals can have negative effect on the whole population, mainly because large old fish are usually highly fecund females. In case of grayling, it is not a priority to protect trophy-sized fish. Anglers who specialise at catches of trophy-sized fish are usually interested in other species, mainly piscivores (pike, European catfish) and common carp (Jankovsky et al., 2011).

Grayling populations are overall vulnerable to environmental changes, fishing pressure, and predation pressure (Northcote, 1995; Persat, 1996; Uiblein, et al. 2001; Gum et al., 2003; Duftner et al., 2005). Therefore, previous studies stated that conservation of grayling should be a high priority of fisheries management (Northcote, 1995; Naslund, et al., 2005, 2010). We further suggest that streams with functional grayling populations should be placed under strict conservation measurements and should be closely monitored.

Anglers know that the catch-and-release strategy is not without victims. They are aware that some released fish die due to post-release mortality. For that reason, they support bag limits, closed season, and even closed fisheries. This is very important for the survival of grayling populations. Tetzlaff (et al., 2013) claims that the post-release mortality is up to 20 %, meaning that even the catch-and-release strategy can lead to overfishing.

### 4.3 Fisheries data

Fisheries data on angling catches can provide scientists with a large and interesting dataset. That being said, this dataset should be interpreted with caution. Studies that use data from individual angling logbooks have several limitations (Essig and Holliday, 1991; Pollock et al., 1994; Cooke et al., 2000; Bray and Schramm, 2001; Mosindy and Duffy, 2007; Lyach and Čech, 2018). However, this dataset is probably the most reasonable option available for this kind of study. Other studies also used data collected by the Czech Fishing Union (Humpl et al., 2009; Jankovsky et al., 2011; Boukal et al., 2012; Lyach and Čech, 2017, 2018). As other authors suggested, anglers may occasionally catch and kill fish without mentioning it in their logbooks (Schill and Kline, 1995). However, this kind of behaviour is illegal, and anglers who break rules could potentially lose their fishing licence. In addition, the amount of angling guard controls in the field has greatly increased in the last decade (Lyach and Čech, 2018). In our experience, rule-breaking anglers would most likely take fish of high commercial value like rainbow trout, piscivores, or common carp.

4.4 Discussion forums

Anglers were strongly supporting conservation of grayling in fisheries discussion forums on the Internet. In addition, they were actively contributing to conservation of grayling at their own expenses. Anglers were also trying to persuade other anglers to support the conservation strategy as well. Discussing anglers displayed great knowledge of grayling habitat selection – they suggested and actively supported habitat enhancement measures that are beneficial to grayling populations (Vehanen et al., 2003; Van Leuween et al., 2018).

The method of analysis of angler opinions from discussion forums has several strengths and weaknesses. As far as the strengths are concerned, anglers can express their opinion without the fear of being exposed. Anglers from the whole country are actively participating in those discussions. On the other hand, this method has its weaknesses as well. Firstly, only anglers who use the Internet to discuss topics on fisheries are included in this analysis. However, data from the Czech Statistical Office shows that most people in the Czech Republic (82 % in the year 2016) have access to the Internet. Secondly, this method may partially underestimate opinions of poor people and seniors (Shiffiman et al., 2017). However, fishing is a fairly expensive hobby. Thirdly, it is possible that people who do not support grayling protection are not involved in similar discussions. However, we also searched other (non-grayling) discussions regarding fisheries, and we found that anglers express their negative opinions as well. In addition, anglers who discussed on the forums were exclusively supporting conservation of grayling. Basically no signs of negative opinions on conservation of grayling were found. Previous studies also showed that fishing forums provide great insight into behaviour and opinions of anglers (Martin et al., 2012, 2014; Shiffiman et al., 2017). To sum this up, this method should reflect the overall opinion of anglers reasonably enough.

This study showed that fisheries discussion forums can provide valuable information to both fisheries management and scientists. Anglers share their ideas and experiences in discussion forums very freely and frequently, and scientists believe that those ideas and experiences should be further analysed (Martin et al., 2012, 2014; Shiffiman et al., 2017). After all, anglers have spent more time in the field than any researcher possibly could. So why not ask them what they have discovered?

## 5. Conclusion

The restriction in minimum legal angling size did not affect the overall catch and yield of grayling. Even though this particular regulation had no effect on grayling catches, it does not necessarily mean that similar management tools are not effective. This management tool can still function as a safety net and an insurance policy against potential overfishing. In this case, the regulation was not necessary because anglers were already releasing caught grayling. Anglers showed high solidarity with grayling, mostly because they were aware of its poor population status. This study showed that perception and behaviour of anglers can be more important than any fishing restriction. However, solidarity of anglers is most likely not going to be enough to save grayling populations by itself. The poor status of grayling populations also requires great improvement of environmental conditions in grayling streams. In the light of this discovery, we suggest that future studies should focus on the next big question that anglers call for: What needs to be done to bolster grayling populations in our streams?

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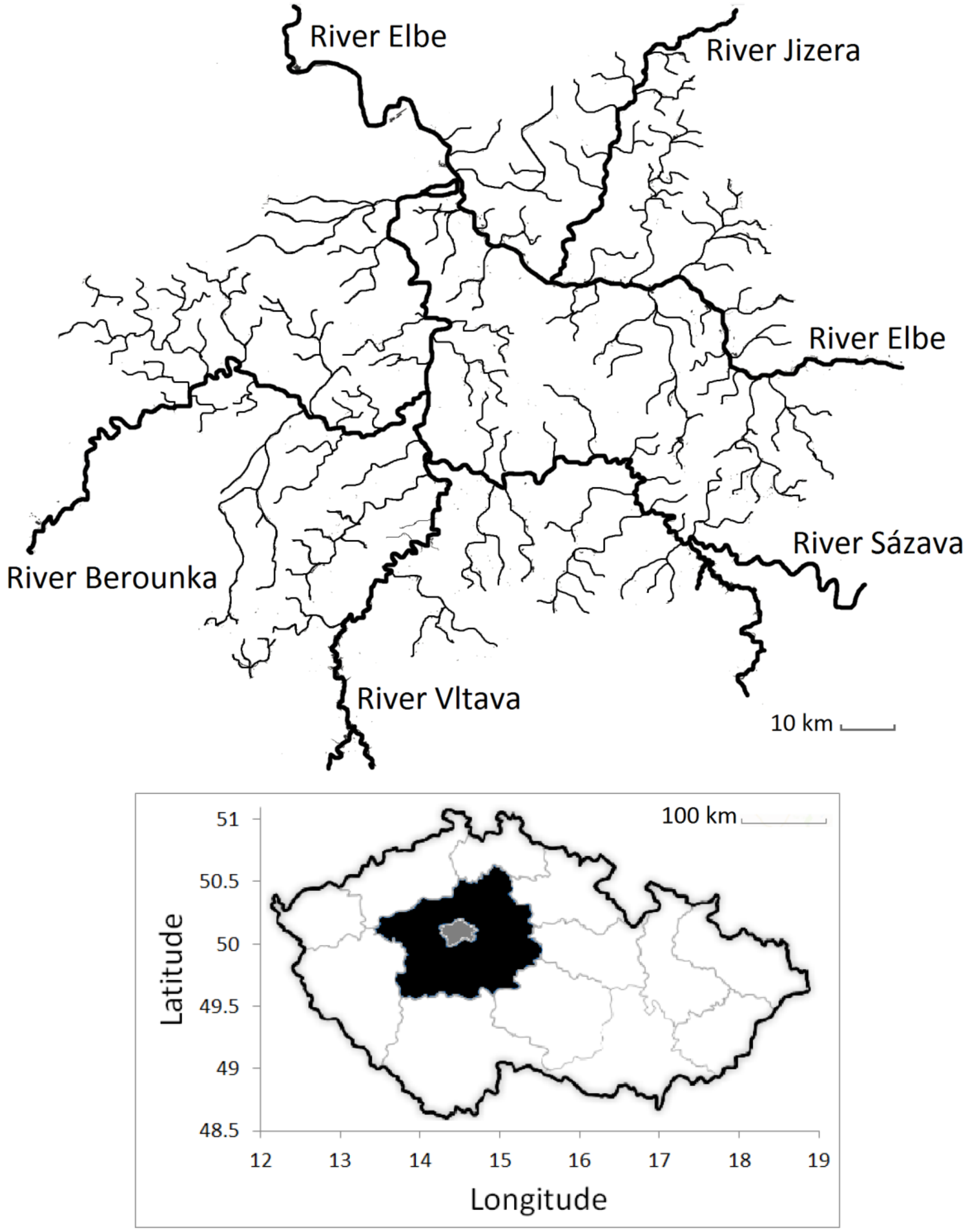



**Figure 1** Map of the study area with highlighted regions of Central Bohemia (in black; 49.5°–50.5° N, 13.5°–15.5° E) and Prague (in grey; 50° N, 14.5° E). Data was collected on 229 fishing grounds in the regions of Prague and Central Bohemia, Czech Republic, Central Europe, over the course of years 2015–2016.

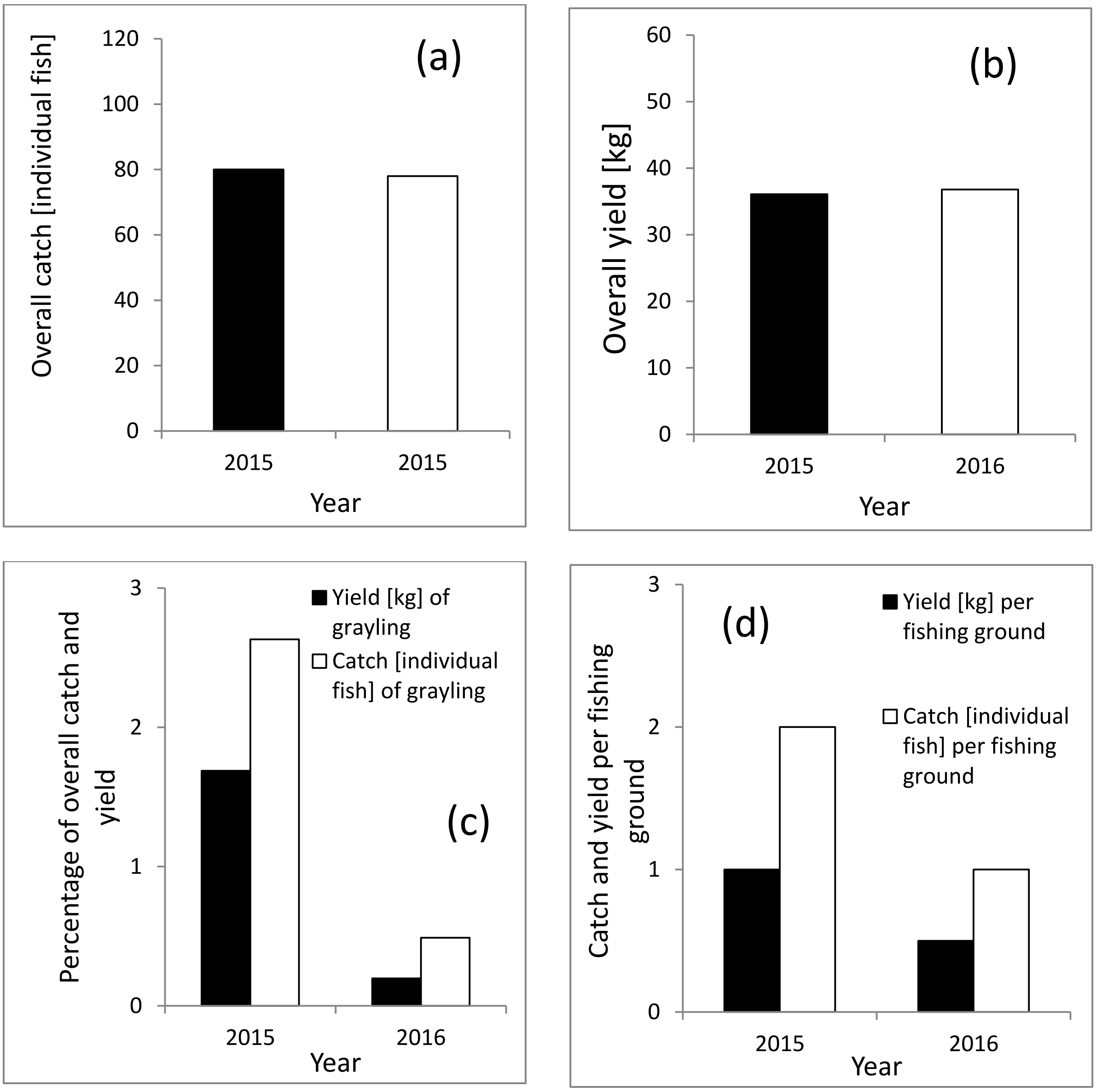



**Figure 2** Catch [individual fish] and yield [kg] of grayling *Thymallus thymallus* on fishing grounds in the study area in years 2015 and 2016. Note: (a) overall catch of grayling, (b) overall yield of grayling, (c) the percentage of grayling in overall catch of all salmonids, (d)

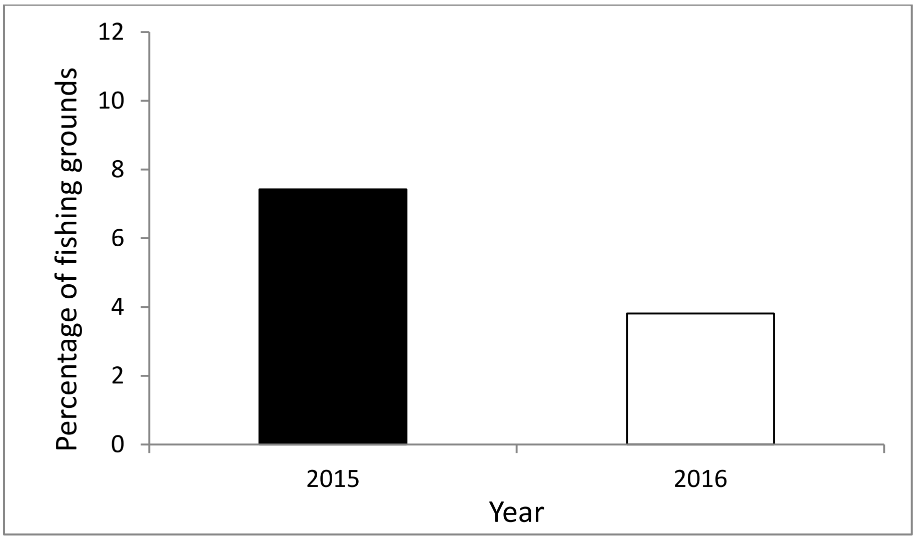
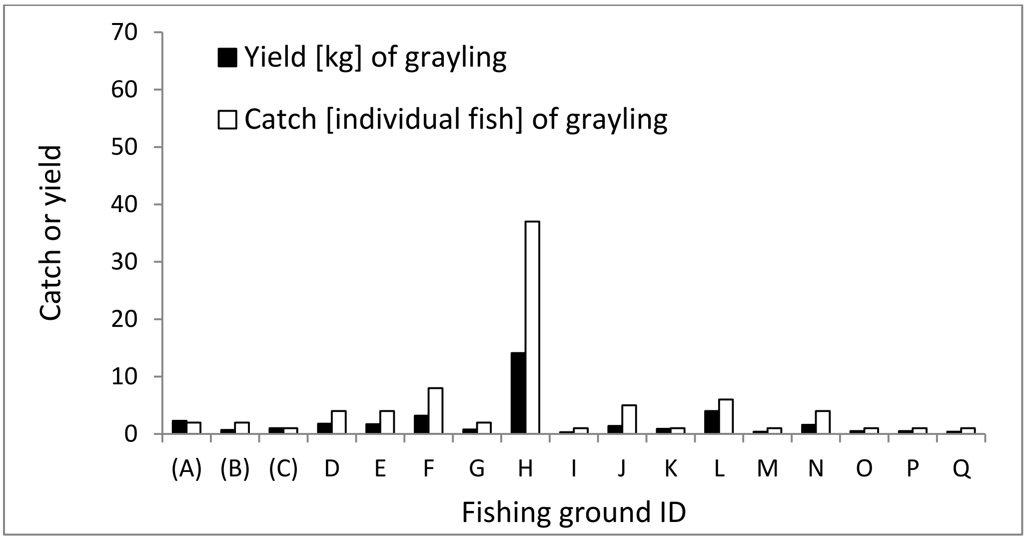



**Figure 3** The percentage of fishing grounds where grayling *Thymallus thymallus* was caught by anglers in years 2015 and 2016



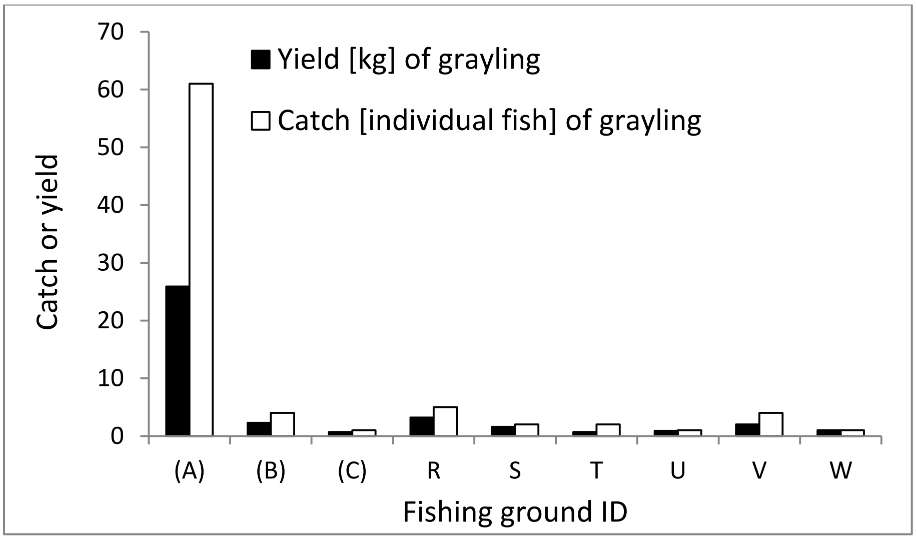




**Figure 4** Catch [individual fish] and yield [kg] of grayling *Thymallus thymallus* on selected fishing grounds. Only fishing grounds that showed at least one catch of grayling in either year 2015 or 2016 are displayed. Note: fishing grounds labelled as (A), (B), and (C) showed catches of grayling in both years 2015 and 2016. Other fishing ground showed catches of grayling in only one year.

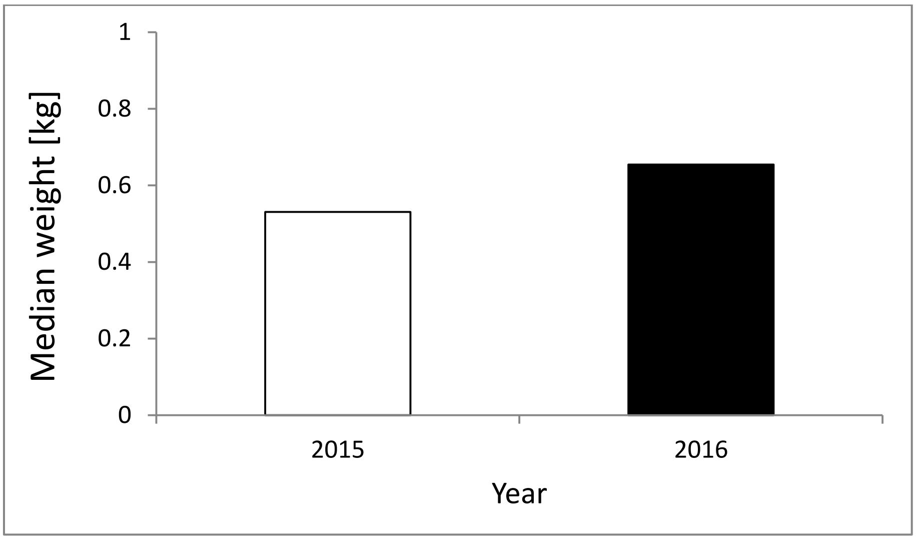



**Figure 5** The average body weight of grayling *Thymallus thymallus* in catches of anglers on fishing grounds in the study area in years 2015 and 2016.

# A tale of two trout: the intensively stocked, non-native rainbow trout *Oncorhynchus mykiss* is not replacing the native brown trout *Salmo trutta* in catches of recreational anglers

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Running head: Fishing regulations and angler behaviour

## Abstract

Intensive stocking and high yield of rainbow trout (*Oncorhynchus mykiss* L.) are considered to be among the main reasons for decreasing catches of brown trout (*Salmo trutta* L.). This study aimed to assess long-term trends in yield and body size of caught brown and rainbow trout. Data collected from individual angling logbooks on 229 fishing grounds over the course of 12 years were used for this study. Recreational anglers caught altogether 35 000 brown trout and 126 000 rainbow trout. Yield of both brown and rainbow trout has been increasing. The size of caught brown trout has been increasing. The size of caught rainbow trout has not changed over time. The number of fishing grounds with catches of brown and rainbow trout has not changed over time. Rainbow trout is not replacing brown trout in catches of anglers – the representation of both species in the overall yield has been constant over time. Fishing grounds with higher yield of rainbow trout also display higher yield of brown trout. Fish size of both trout species is also positively correlated on individual fishing grounds. The perceived competition between both trout species is not apparent from angling statistics.

Keywords: angling statistics, competition, fish harvest, inland fishing, recreational fisheries, the Czech Republic

## 1. Introduction

Salmonids are commercially important fish species with high angling value and high importance in aquaculture industry (Balon, 2004; Arismendi & Nahuelhual, 2007; Fausch, 2007; Kottelat & Freyhof, 2007). Salmonids are also considered flagship species in smaller water streams, mainly because of their high demands on water quality and shelters (Armstrong, Kemp, Kennedy, Ladle & Milner, 2003; Kottelat & Freyhof, 2007). For that reason, several salmonid species like brown trout (*Salmo trutta* L.), rainbow trout (*Oncorhynchus mykiss* L.), and brook trout (*Salvenius fontinalis* L.) have been introduced in many countries across the world (Welcomme, 1992; Rahel, 2000; Balon, 2004; Fausch, 2007; Musil, Jurajda, Adámek, Horký & Slavík, 2010; Kizak, Guner, Turel, Can & Kayim 2011; Stankovic, Crivelli & Snoj, 2015). In Europe, the native brown trout is very popular among anglers, mainly because it is prized for its speed and stamina. On the other hand, rainbow trout is a non-native salmonid species that has been introduced to European waters in the 19$^{th}$ century for commercial and angling purposes (Lusk, 1983; Andreska, 1987; Fausch, 2007; Musil, Jurajda, Adámek, Horký & Slavík, 2010; Stankovic, Crivelli & Snoj, 2015).

In many European countries (including the Czech Republic), rainbow trout is a subject of intensive stocking. This intensive stocking is quite expensive because rainbow trout is usually not able to reproduce in natural conditions of waters in Western and Central Europe (Saegrov, Hinder & Urdal, 1996; Delacoste, Baran, Lascaux, Abad & Besson 1997; Peter, Staub, Ruhle & Kindle 1998; Stankovic, Crivelli & Snoj, 2015). Rainbow trout is highly valued by recreational anglers, mostly because it displays even bolder and more aggressive behaviour than brown trout (Weber & Fausch, 2003; Hafen & Budy, 2015; Van Zwol, Neff & Wilson, 2012). When compared to brown trout, rainbow trout displays faster growth and lower mortality in conditions of aquaculture (Weber & Fausch, 2003; Kizak, Guner, Turel, Can & Kayim, 2011; Karvonen et al., 2016). For that reason, it is cheaper and much more profitable to rear and stock the non-native rainbow trout than the native brown trout.

In reality, fisheries managers are mostly interested in the cost/benefit ratio of fish rearing, and therefore they prefer to rear and stock the non-native rainbow trout instead of the native brown trout. Every year, fisheries managers are obliged to set annual stocking plan for each individual fishing ground (Czech Fishing Union, unpubl. data). Fisheries managers are then obliged to fulfil the plan and make sure that the promised fish stocking actually occurs. The main problem is that the cheap and intensively reared non-native rainbow trout is always available for stocking, while, on the other hand, brown trout is often out-of-stock and not available for long time periods (Czech Fishing Union, unpubl. data). For that reason, fisheries managers keep on stocking rainbow trout because stocking of rainbow trout is cheaper, easier, and more reliable. Fisheries managers are required to deliver a critical mass of fish into recreational waters, mainly because anglers who pay for fishing permits are demanding fish catches. Rainbow trout is perfect for this kind of management because it grows quickly and does not spend its energy on reproduction (Fausch, 2007; Kizak, Guner, Turel, Can & Kayim, 2011; Meyer, High & Elle, 2012; Stankovic, Crivelli & Snoj, 2015). Many anglers are still more interested in actual fish catches rather than conservation of native species, and for those anglers, stocking and catching a non-native rainbow trout is not perceived negatively (Hyman, McMullin & DiCenzo, 2016; Lyach & Čech, 2017). As anglers claim, another problem is that massive stocking of rainbow trout attracts additional anglers to stocked streams. Fish populations in streams where intensive stocking occurs are then under heavy fishing pressure from recreational anglers. For those reasons, the annual intensive stocking of non-native fish species is becoming one of the most important conflicts between environmental protection and fisheries (Jones, Koonce & O'Gorman, 1993; Stankovic, Crivelli & Snoj, 2015).

Previous studies have already discovered that non-native salmonids can have negative ecological effect on native biodiversity. Stocking of non-native salmonids can negatively affect fitness of native salmonids (brown trout, grayling *Thymallus thymallus* L.), amphibians, crayfish, and other invertebrates (e.g. Larson & Moore, 1985; Denoel, Dzukic & Kalenic, 2005; Van Zwol, Neff & Wilson, 2012; Houde, Wilson & Neff, 2015; Zavorka et al., 2017). Both stocked and native salmonids are highly territorial and share similar ecological niche (Hayes, 1987; Scott & Irvine, 2001). Therefore, they compete for food, living space, shelters, and spawning substrates (Hayes, 1987; Scott & Irvine, 2001). Non-native salmonids can also feed on eggs and fry of native salmonids, actively decreasing their fitness (Hayes, 1987; Scott & Irvine, 2001; Uiblein, Jagsch, Honsig-Erlenburg & Weiss, 2001). This competition between native and non-native salmonids is even more important and elevated in artificially straightened streams with limited obstacles (Greenberg, 1994; Warnock & Rasmussen, 2013). Anglers are complaining that it is becoming harder to catch native brown trout, and they claim that intensive stocking of the non-native rainbow trout is one of the reasons why. While the competition between native and non-native salmonids has been described in many research papers, no study actually describes if the perceived competition affects angling catches of those species. In addition to that, there is no study that describes general long-term trends in angling catches of native and non-native salmonids. Anglers claim that the decreasing numbers of wild brown trout populations correlate with decreasing angling catches.

The aim of this study was to discover the long-term trends in catches and yield of brown trout and rainbow trout in recreational fishing. Another aim was to discover trends in the average body weight of caught trout. This study also aimed to discover changes in the representation of both species in the overall angling yield. In addition, this study assessed if the number of fishing grounds with actual catches of both species changes in time. Lastly, this study assessed correlations in yield of brown trout and rainbow trout on individual fishing grounds. Similarly, this study also assessed correlations in the average body weight of caught trout on individual fishing grounds.

It was hypothesised that the yield of the non-native, intensively stocked rainbow trout is increasing while the yield of native brown trout is decreasing. It was also hypothesised that the average body weight of caught rainbow trout is stagnating or increasing while the average body weight of caught brown trout is decreasing. It was also expected that the percentage of brown trout in the overall yield is decreasing while, inversely, the percentage of rainbow trout is increasing. In addition, it was hypothesised that the number of fishing grounds with catches of rainbow trout is stagnating or increasing, while the number of fishing grounds with catches of brown trout is decreasing. Lastly, it was expected that yield of brown trout is negatively correlated to yield of rainbow trout. Similarly, it was expected that average body weight of caught brown trout is negatively correlated to average body weight of caught rainbow trout.

## 2. Methods

### 2.1 Study area

This study was carried out in the regions of Prague (50° N, 14.5° E) and Central Bohemia (49.5°–50.5° N, 13.5°–15.5° E), Czech Republic, Central Europe (Figure 1). Both regions together cover an area of 11 500 km$^2$. The region of Prague (the capital of the Czech Republic) has mostly urban character while the region of Central Bohemia has mostly agricultural character. The study area is dominated by the rivers Elbe and Vltava. Both rivers belong to the upper Elbe River Basin. All rivers in the study area belong to the North Sea Drainage area.

Studied fishing grounds are situated in lowlands with an altitude of 200–600 m above sea level. Waters in the study areas are mostly mesotrophic and eutrophic. The study area includes salmonid streams (dominated by salmonids) and non-salmonid rivers (dominated by cyprinids).

2.2 Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is organized by the Czech Fishing Union (the main authority in recreational fishing in the Czech Republic) and is centralized for the whole country. For detailed description of recreational fishing in the Czech Republic see Lyach & Čech (2018).

2.3 Angling rules for brown trout and rainbow trout

Brown trout (*Salmo trutta* L.) is a native fish species in central European waters. Rainbow trout (*Oncorhynchus mykiss* L.) is a non-native and intensively stocked fish species in Central European waters. Rainbow trout populations are fully dependant on fish stocking because rainbow trout is not able to reproduce in natural conditions. The minimum legal catchable size for both brown trout and rainbow trout is 25 cm TL (tail length). The bag limit for salmonids is either three fish or 7 kg of fish per angler per day, whichever comes first. When an angler reaches this bag limit, he or she is obliged to stop fishing for that day. The closed season for fishing is different on salmonid and non-salmonid fishing grounds. The closed season for brown trout is set from 1 September to 15 April on all types of fishing grounds. In addition, the closed season for rainbow trout is set from 1 December to 15 April on salmonid fishing grounds. No closed season is set for rainbow trout on non-salmonid fishing grounds. Listed fishing regulations are effective for all fishing grounds in the study area.

2.4 Data sources

Data from annual angling summaries were used for the purpose of this study. This data originated from angling logbooks. The angling logbooks were collected from individual anglers. Data from 229 inland freshwater fishing grounds over the course of years 2005-2016 were used. The selected fishing grounds covered an area of 116 $km^2$. This data were originally collected by the Czech Fishing Union and later processed by the authors of this study. Fishing grounds are defined as stream and river stretches where recreational fishing can be legally conducted.

2.5 Measured metrics

This study assessed catches [individual fish], yield [kg], the representation of both species in the overall angling yield, and the percentage of fishing grounds with and without trout catches. In those cases, all fishing grounds were used in the statistical analyses. In addition, this study also assessed average body weight of caught fish [kg], and correlation in both yield [kg] and average body weight [kg] of both species on individual fishing grounds. In those cases, only fishing grounds with trout catches were used in the statistical analyses.

### 2.6 Statistical analysis

The statistical programme R (R i386 3.4.1., R Development Core Team 2017) was used for statistical testing. Shapiro-Wilk test of normality was used to analyse distribution of the data. The package for generalized linear mixed models (GLMM) was used to fit the models. One fishing ground was used as one sample in the analysis. The variable 'Fishing ground' was marked as random effect in the mixed models. Minimum probability level of $p = 0.05$ was accepted for all the statistical tests, and all statistical tests were two-tailed.

## 3. Results

### 3.1 Overall data summary

Over the course of years 2005-2016 (12 years), recreational anglers in the study area caught altogether 162 002 individual trout with total weight of 64 135.1 kg (Table 1).

### 3.2 Yield

Yield of both brown and rainbow trout has been increasing over the course of time (for brown trout: $SE < 0.01$, $p = 0.01$, $DF = 2\ 475$; for rainbow trout: $SE = 0.60$, $p = 0.025$, $DF = 2\ 680$). On average, anglers caught 3-6 kg of brown trout per fishing ground. Yield of brown trout has increased from 3.3 kg to 5.6 kg per fishing ground over the course of 11 years. In the year 2006, yield of brown trout was high at 5.6 kg per fishing ground, but after that, the yield dropped and has been increasing ever since. On average, anglers also caught 11-28 kg of rainbow trout per fishing ground. Yield of rainbow trout has increased from 11 to 28 kg over the course of 12 years (Figure 2).

### 3.3 Body weight of caught fish

Anglers catch larger brown trout than they used to. The average body weight of caught brown trout has been increasing over the course of time (SE < 0.01, $p = 0.03$, DF = 973). Anglers caught brown trout with average body weight of 0.41 kg and 0.47 kg in the year 2005 and 2016, respectively. Over the course of 12 years, the average body weight of caught brown trout has increased by 60 g. On the other hand, anglers are still catching rainbow trout of similar size (Figure 3). The average body weight of caught rainbow trout has not significantly changed over the course of time ($p = 0.63$).

### 3.4 Fishing grounds with trout catches

The number of fishing grounds that display catches of brown trout has not changed over the course of time. Anglers are catching brown trout on similar number of fishing grounds each year. In addition, the number of fishing grounds with catches of rainbow trout has also not changed over the course time (Figure 4). Majority of the fishing grounds (55-65 %) in the study area showed no catches of brown and/or rainbow trout. Only 35-45 % of fishing grounds showed catches of either brown trout or rainbow trout.

### 3.5 Representation of trout in the overall yield

The representation of both brown trout and rainbow in the overall angling yield has not changed in time (for brown trout: $p = 0.40$, for rainbow trout: $p = 0.45$). Rainbow trout dominated in the overall yield of anglers. Brown trout made only 13-33 % of the overall yield while rainbow trout made 67-87 % of the overall yield (Figure 5).

### 3.6 Correlation in yield

There was a positive correlation between yield of brown trout and yield of rainbow trout on individual fishing grounds (SE < 0.01, $p < 0.01$, DF = 2 680). The same was true for catch [individual fish] of brown trout and rainbow trout (SE < 0.01, $p < 0.01$, DF = 2 680). Fishing grounds with higher yield of brown trout had also higher yield of rainbow trout (Figure 6).

### 3.7 Correlation in body weight of caught fish

There was a positive correlation between average body weight of caught brown trout and rainbow trout in catches of anglers on individual fishing grounds (SE < 0.04, p < 0.01, DF = 785). Fishing grounds with larger caught brown trout also displayed larger caught rainbow trout (Figure 7).

## 4. Discussion

### 4.1 Catch and yield

The catch and yield of both brown trout and rainbow trout has been increasing in the last decade. The increase was expected in rainbow trout, mainly because catch and yield of rainbow trout is strongly dependent on fish stocking (Czech Fishing Union, unpubl. data). Still, the increased yield of rainbow trout is interesting because our previous results showed that the overall catch and yield of fish has been decreasing in Central Europe in the last decade (Lyach & Čech, 2018). This result means that anglers are removing more rainbow trout from rivers and streams. The demand for rainbow trout is high, and that further encourages fisheries managers in intensive stocking of this non-native salmonid species. This management policy further deepens the conflict between fisheries and environmental protection. As previous studies found, intensive stocking of non-native salmonids can have negative effect on populations of native salmonids (brown trout and grayling) and other native fish species (e.g. Larson & Moore, 1985; Krueger & May, 1991; Meyer, High & Elle, 2012; Van Zwoll, Neff & Wilson, 2012; Houde, Wilson & Neff, 2015; Zavorka et al., 2017). Moreover, Williams, Bowman, Todd, Bivin & Moore (2004) found that multi-species trout management is usually not effective.

Intensive rainbow trout stocking is a complicated issue. The stocking has to be done annually and costs a lot of money because rainbow trout is usually not able to reproduce in natural conditions of waters in Western and Central Europe (Saegrov, Hindar & Urdal, 1996; Delacoste, Baran, Lacaux, Abad & Besson, 1997; Peter, Staub, Ruhle & Kindle, 1998; Stankovic, Crivelli & Snoj, 2015). Rainbow trout is being stocked at legally catchable sizes (25 cm LT and bigger) as a part of put-and-take fish stocking strategy. Those fish are then usually caught within days or weeks after stocking by anglers who specialise on catching of naïve stocked fish (Weiland & Hayward, 1997; Baer, Blasel & Diekmann, 2007). Intensive stocking of rainbow trout is often advertised on social media, and anglers frequently follow the fish-stocking team, waiting downstream just below the stocking spots, catching stocked fish immediately (own observation). Stocked rainbow trout usually do not remain in the rivers for very long. For that reason, the competition with brown trout is limited. Previous studies also found that hatchery-reared rainbow trout display high post-stocking mortality (North et al., 2006; Berrill, MacIntyre, Noble, Kankainen & Turnbull, 2012; Meyer, High & Elle, 2012). The lack of long-term competition between both species is probably the main reason why brown trout catches were not decreasing. Similarly, Baer, Blassel & Diekmann (2007) also reported fast removal of stocked trout by anglers.

It was not expected that catch and yield of brown trout would be increasing, mainly because the majority of fisheries managers and anglers are convinced that wild populations of brown trout are decreasing. Anglers are also saying that it is becoming harder to actually find and catch brown trout in the wild. On the other hand, Baer & Brinker (2010) found that anglers in Germany consider brown trout stocking unnecessary to maintain angling catch satisfaction. Previous studies found that populations of brown trout in Central Europe are declining due to fish stocking, climate change, and suboptimal environmental conditions (Zavorka, Horky & Slavik, 2013; Zavorka, Horky, Kohout, Kalous & Slavik, 2015; Zavorka et al., 2017). This study points out that environmental conditions for brown trout populations may be getting better, or at least they are not getting worse. Unlike in rainbow trout, populations of brown trout in Central Europe are not dependent on intensive stocking (Musil, Jurajda, Adamek, Horky, & Slavik, 2010; Stankovic, Crivelli & Snoj, 2015, Zavorka et al. 2017). Brown trout is being stocked mainly as yearlings, and the goal is to bolster resident trout populations.

Even though data on catches of recreational anglers have their limitations (Essig & Holliday, 1991; Pollock, Jones & Brown, 1994; Cooke, Dunlop, McLennan & Power, 2000; Bray & Schramm, 2001; Mosindy & Duffy, 2007; Lyach & Čech, 2017, 2018), this method was found to be comparable to other methods of surveying fish populations (Cowx & Broughton, 1986; Ebbers, 1987; Cooke, Dunlop, McLennan & Power, 2000; Gudbergson, 2002; Mosindy & Duffy, 2007; Younk & Pereira, 2007). Previous studies found that fisheries data can provide insight into long-term trends in fish populations (Ebbers, 1987; Cooke, Dunlop, McLennan & Power, 2000). Other studies have already successfully used data provided by the Czech Fishing Union (Humpl, Pivnicka & Jankovsky, 2009; Jankovsky, Boukal, Pivnicka & Kubecka 2011; Boukal, Jankovsky, Kubecka & Heino, 2012; Lyach & Čech, 2017, 2018). Increase in catch and yield of brown trout could potentially mean that brown trout populations are recovering.

The representation of brown trout and rainbow trout in the overall yield has not changed in time. That was surprising - we expected that rainbow trout will be getting more dominant in angling catches over the course of time. Most anglers in the Czech Republic claim that rainbow trout is replacing brown trout in angling catches (own observation). However, this study does not support such statement. On the contrary to our results, Vehanen (1997) found that intensive stocking of larger rainbow trout attracts anglers and leads to increased representation of rainbow trout in the overall yield.

4.2 Body size of caught fish

The average body weight of caught rainbow trout has not changed over time – anglers keep on catching rainbow trout of the same size. That was expected since the size of caught rainbow trout is usually heavily dependent on the size of stocked rainbow trout (Weiland & Hayward, 1997; Baird, Kruger & Josephson, 2006; Baer, Blasel & Diekmann, 2007). Rainbow trout is stocked at constant individual body weights (300-500 g). This weight corresponds to fish of legally catchable body size (25-40 cm TL). Rainbow trout is often caught in a few days after stocking, and therefore it usually does not have enough time to grow in size (Weiland & Hayward, 1997; Blasel & Diekmann, 2007).

Anglers keep on catching larger brown trout, which was surprising. We expected the catch and average body weight of brown trout to be decreasing. However, results of this study showed an increase in both yield and body size. In the Czech Republic, brown trout is usually stocked as yearlings (5-10 cm TL). Stocking of larger brown trout (25-30 cm TL) is not common but occurs from time to time (Czech Fishing Union, unpubl. data). Even if anglers caught predominantly stocked trout, the stocked fish have to grow to legally catchable size (25 cm TL) first. This shows that streams with brown trout populations have potentially good conditions for fish growth. Other authors who studied native brown trout populations in the Czech Republic also support this statement (Zavorka, Horky & Slavik, 2013; Zavorka, Horky, Kohout, Kalous & Slavik, 2015; Zavorka et al., 2017). In general, anglers are aware of the poor population status of brown trout in Central Europe, and therefore anglers keep on releasing caught brown trout back to water (Boyd, Guy, Horton & Leathe, 2010; Simonovic et al., 2018; own observation). This is mostly true for smaller fish (25-30 cm LT) – larger fish are killed by anglers more often (own observation). Previous studies confirmed that anglers are often interested in catches of large-sized fish (Beardmore, Hunt, Haider, Dorow & Arlinghaus, 2015; Lew & Larson, 2015). Preference for larger fish then leads to increased size of caught fish in general. The increase in size cannot be reliably explained by changes in fishing regulations; the minimum legally catchable size of trout has not changed over the course of years 2005-2016 (Czech Fishing Union, unpubl. data).

4.3 Fishing grounds with trout catches

The number of fishing grounds with catches of brown trout and rainbow trout has not changed over time, mostly because catches of rainbow trout are fully dependent on fish stocking. Therefore, it was not surprising to see that yield of rainbow trout is constant. On the other hand, it was expected that the number of fishing grounds with brown trout catches would be decreasing. Anglers often claim that it is getting harder to find streams where brown trout can be caught (own observation). Presented study does not support this statement. The number of streams with brown trout catches (and therefore populations) is not decreasing, and that is good news for conservation of this species.

4.4 Correlation in yield and body size

Rivers and streams with higher yield and average body weight of rainbow trout had also higher yield and average body weight of brown trout. This result is interesting because it does not support the popular opinion regarding high competition of both species (Gatz, Sale & Loar, 1987; Baran, Decacoste, Lascaux, Dauba & Segura, 1995; Van Zwol, Neff & Wilson, 2012). It potentially shows that both trout species do not significantly compete for resources. It also shows that high catches of intensively stocked rainbow trout do not lead to decreased catches of native brown trout. The two main reasons are probably a preference of put-and-take fishing strategy together with high mortality of stocked rainbow trout; previous studies found that stocked fish can have high post-stocking mortality (Meyer, High & Elle, 2012). Other studies also showed that larger salmonids are highly territorial and significantly compete with each other (Armstrong, Kemp, Kennedy, Ladle & Milner, 2003; Houde, Wilson & Neff, 2015). This competition usually leads to population decreases of native salmonids (Armstrong, Kemp, Kennedy, Ladle & Milner, 2003; Houde, Wilson & Neff, 2015).

4.5 Conclusion

In conclusion, the intensively stocked, non-native rainbow trout is not replacing the native brown trout in catches of anglers. In addition, the potential competition between both species is not apparent from angling catches. On top of that, the yield of brown trout is actually increasing, which is something that anglers and managers did not expect. However, results of this study do not support the idea of stocking non-native rainbow trout. If the intensive trout stocking continues, the trout-based conflict between environmental protection and fisheries will also continue to escalate. We suggest that future studies should focus on how anglers perceive the intensive stocking of non-native salmonids. We believe that any significant changes in the fish stocking system should be initiated by anglers themselves. If anglers actively oppose stocking of non-native species, then the fish stocking system could potentially change. The fisheries management is mainly financed by anglers, mostly through buying fishing licences and permits. Therefore, the fish stocking system relies on anglers buying fishing permits. With every bought fishing permit, anglers are expressing their preferences of fishing grounds and different types of management. In recreational fishing, anglers are basically customers. And the customer is always right.

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**Table 1** Overall angling catch and yield of brown trout and rainbow trout on fishing grounds in the study area over the course of years 2005-2016.

| Species | Catch [individual fish] | Yield [kg] |
|---|---:|---:|
| Brown trout *Salmo trutta* | 35 570 | 12 887.6 |
| Rainbow trout *Oncorhynchus mykiss* | 126 434 | 51 247.5 |

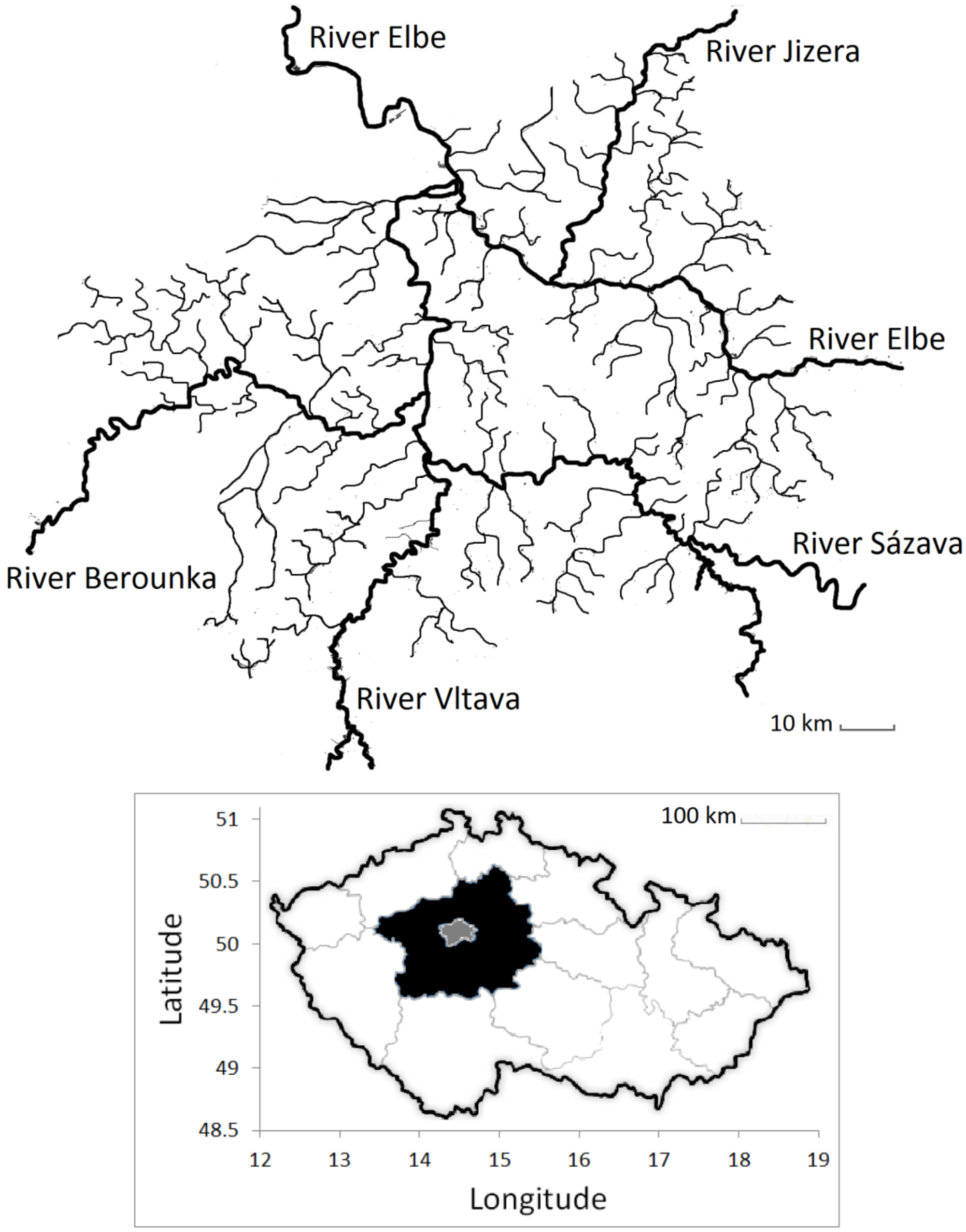



**Figure 1** Map of the study area with highlighted regions of the Central Bohemia (in black; 49.5°–50.5° N, 13.5°–15.5° E) and Prague (in grey; 50° N, 14.5° E). Data were collected on 229 fishing grounds in the regions of Prague and Central Bohemia, Czech Republic, Central Europe, over the course of years 2015–2016.

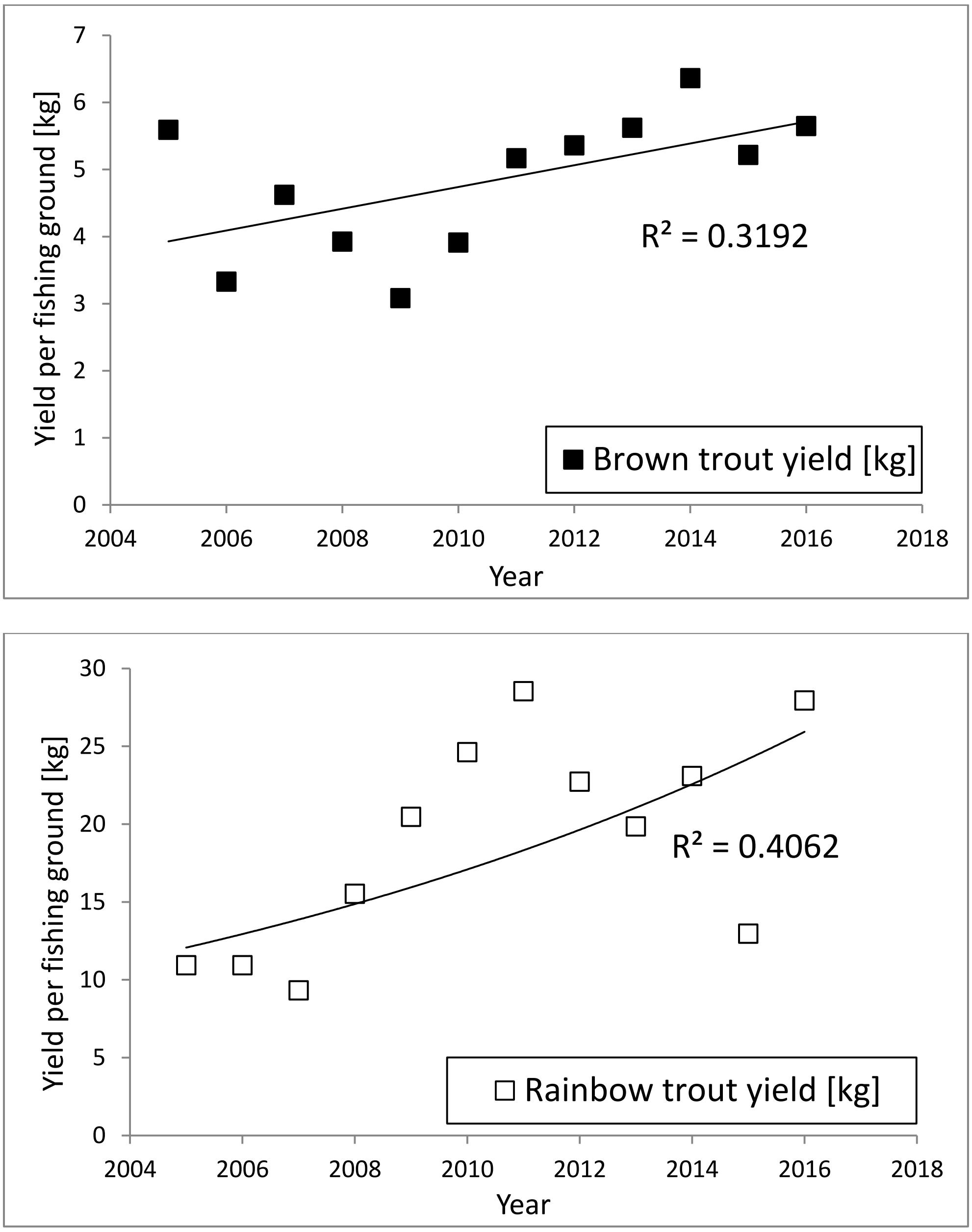
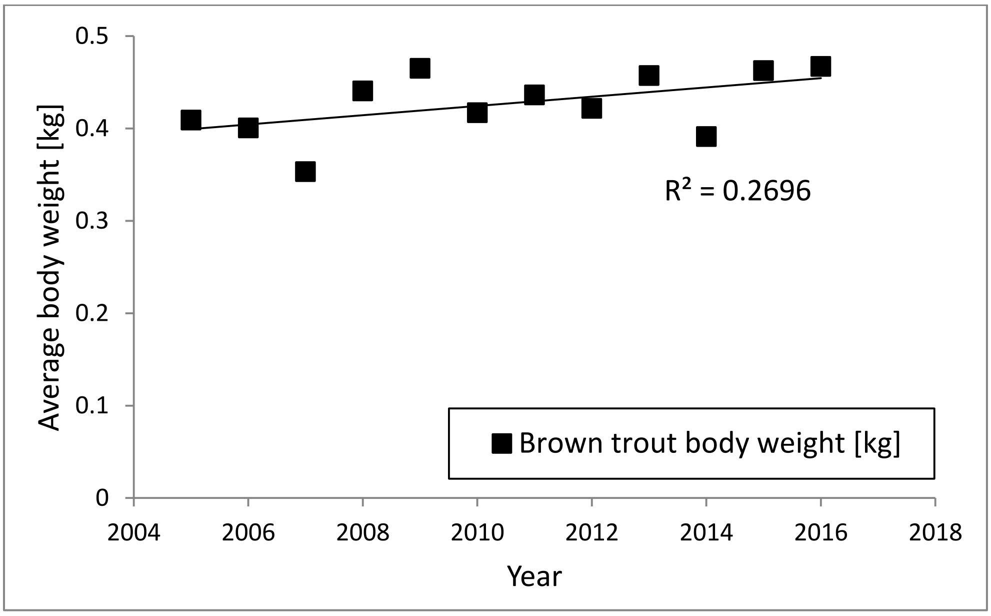



**Figure 2** Average yields [kg] of brown trout (left graph) and rainbow trout (right graph) on individual fishing grounds over the course of years 2005-2016.



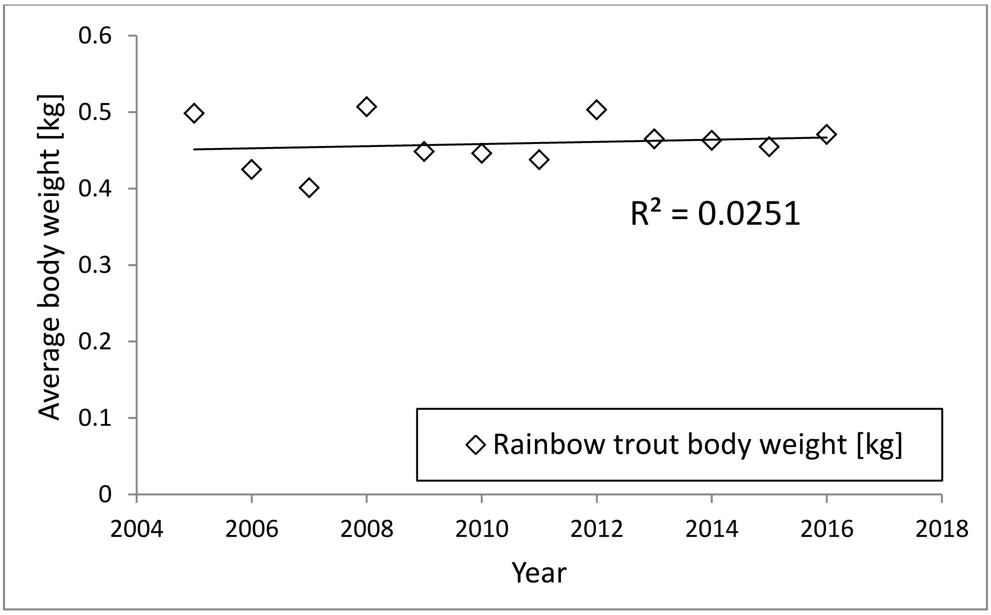
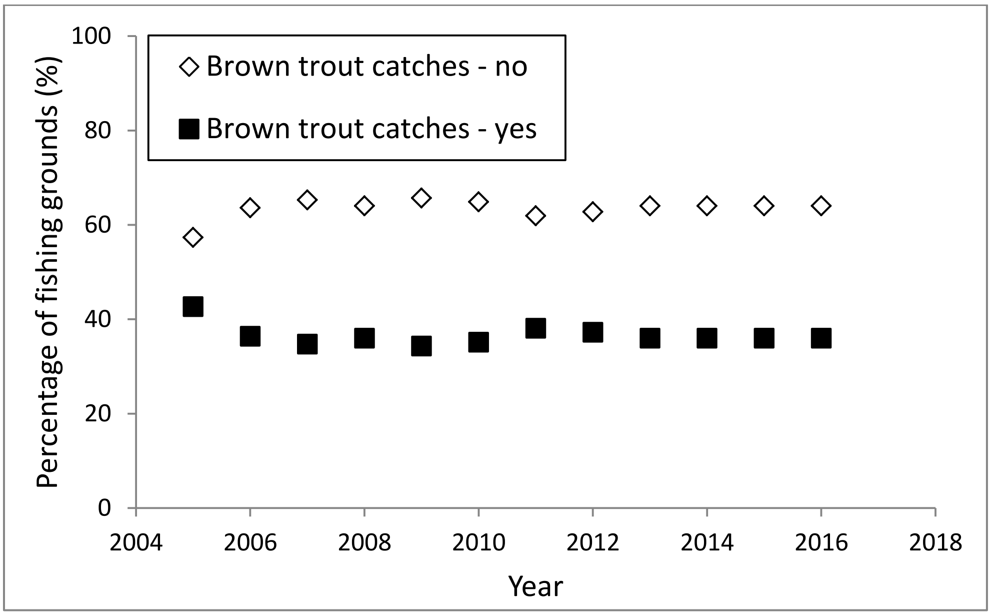




**Figure 3** Average body weights [kg] of brown trout (left graph) and rainbow trout (right graph) in catches of recreational anglers on individual fishing grounds over the course of years 2005-2016.



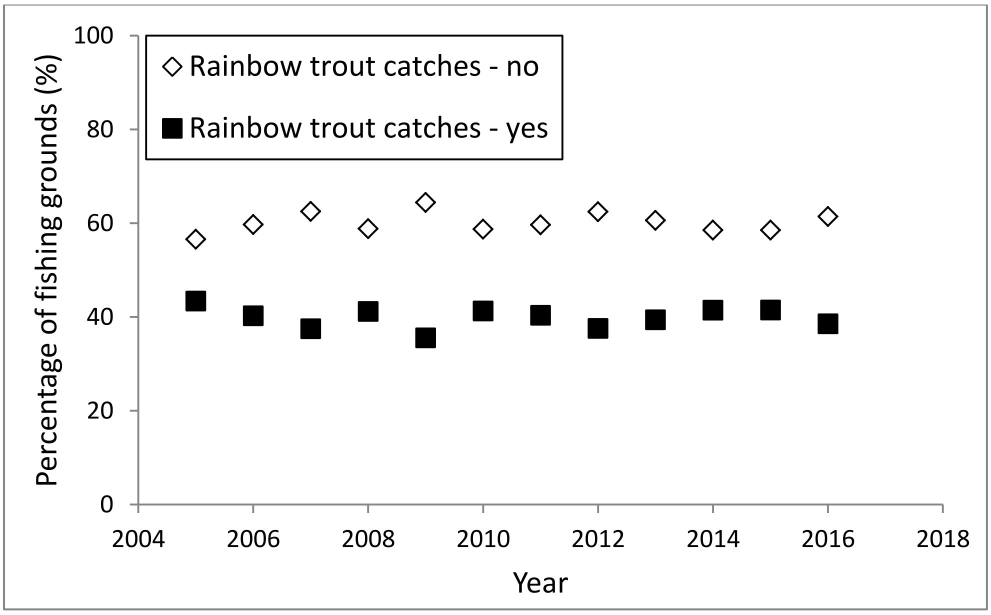




**Figure 4** The overall percentages of fishing grounds with (yes) and without (no) catches of brown trout (left graph) and rainbow trout (right graph) over the course of years 2005-2016.

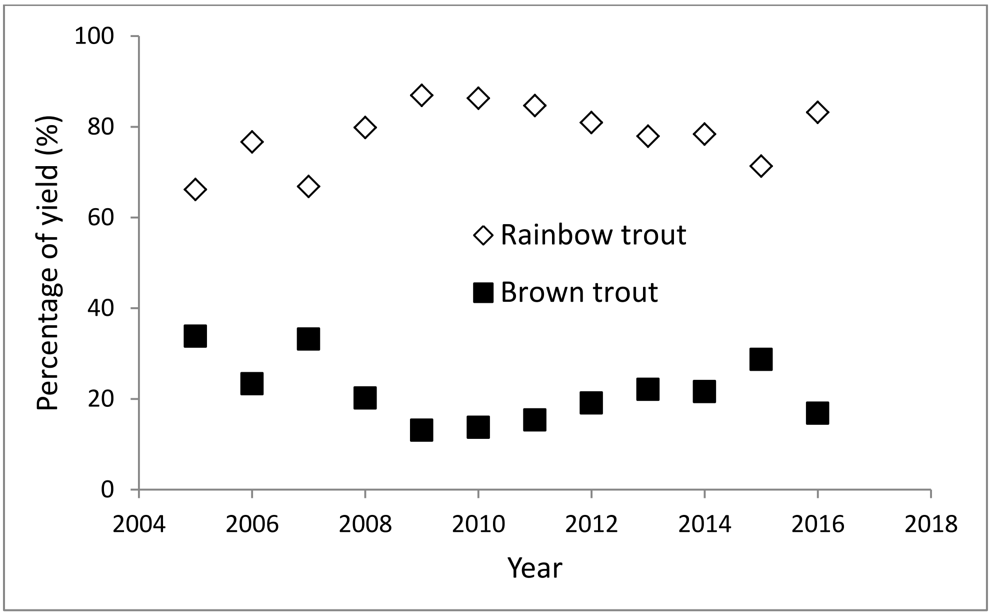



**Figure 5** The representation (in % of yield) of brown trout and rainbow trout in the overall trout yield [kg] over the course of years 2005-2016.

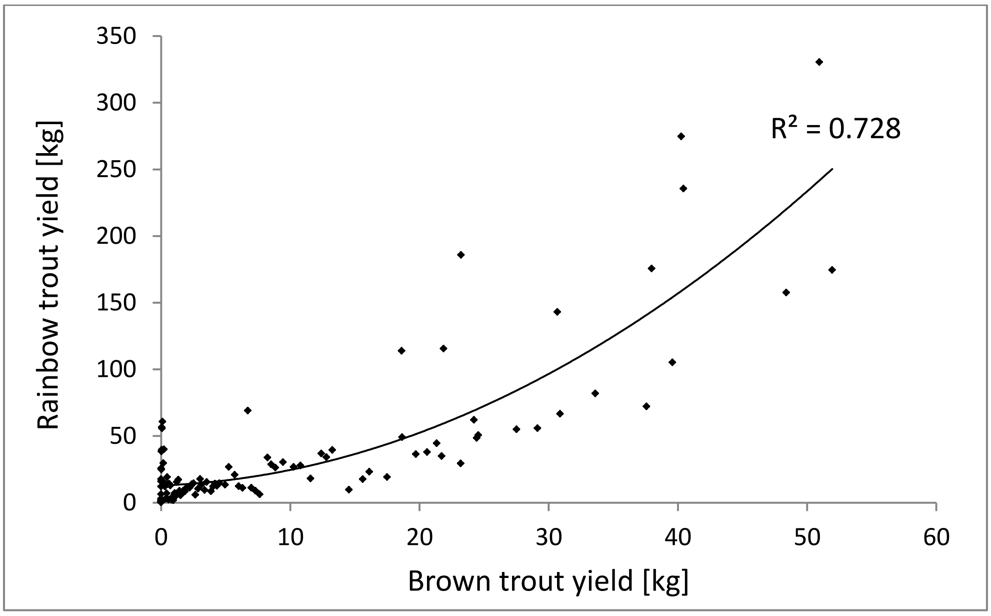



**Figure 6** The correlation in yield [kg] of brown trout and rainbow trout on individual fishing grounds over the course of years 2005-2016.

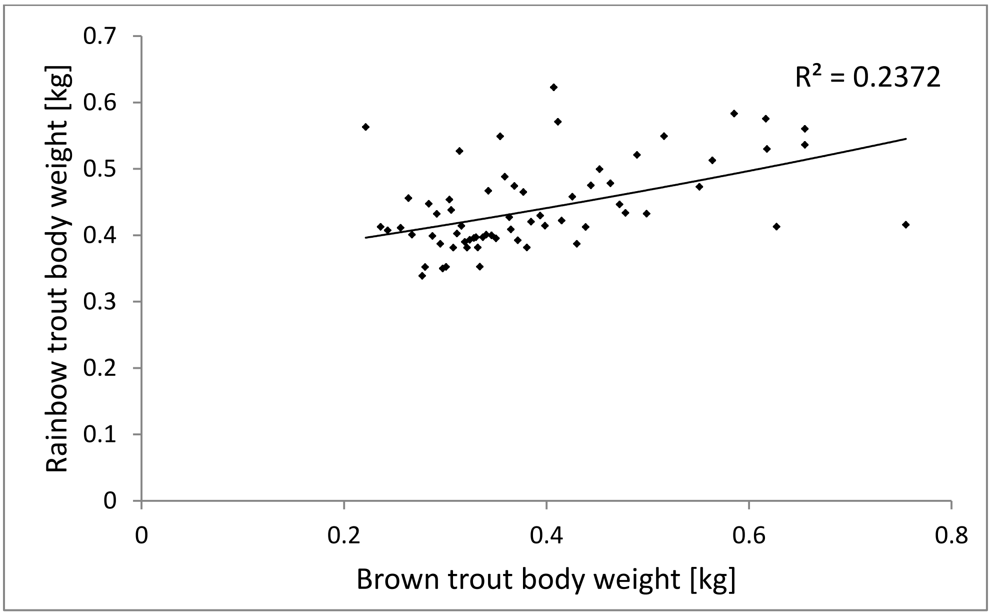



**Figure 7** The correlation in average body weight [kg] of brown trout and rainbow trout in catches of recreational anglers on individual fishing grounds over the course of years 2005-2016.

# Global participation in and public attitudes towards recreational fishing: international perspectives and developments

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## Central Europe

Recreational angling has, for the past few decades, been considered one of the leading forms of outdoor recreation in both Poland and the Czech Republic. However, and despite methodical difficulties that arise when attempting to precisely estimate the number of active anglers, the angling participation has substantially declined over the past 35 years. The Polish Angling Association (PAA), which remains the largest exploiter of inland waters in Poland, boasted a count of over 1 million memberships in the early 1980s; yet the number has since then diminished to roughly 0.63 million. Highly precise data on the status of one of the two largest regional departments of the PAA (Katowice) shows that over the last 22 years the member count has diminished from 58,0000 to 43,000, which indicates a downward rate of 26%. The lake commercial fisheries enterprises have also noted a decline in selling the more expensive long-term permits for angling in favor of affordable short-term licenses in Poland. The reverse of this trend has been observed in sea waters, wherein the number of anglers has, over the years, shown a steady rate of pronounced growth.

In the Czech Republic, recreational fishing is considered a very important leisure activity. Fishing has a long and rich tradition, and for many anglers, it is considered to be a key social activity. There are 320,000 registered recreational anglers in the Czech Republic (effective to date 31.12.2016). That makes 3 % of Czech population. So far, three socio-economic studies have been conducted on trends in fisheries (in years 2003, 2009, and 2017). Studies showed that anglers are usually older men above 40 years (60 %), and the majority of anglers (58 %) have moderate or low economic status. (Czech and Moravian Fishing Union, 2003, 2009, 2017). In Poland, the average age of the angling population has also sharply increased – in the 1970s, the most populous age demographic consisted of people between 40-49 years of age (30.2%), whereas the most recent statistic presents seniors above the age of 60 (34.7%), with over 30 years of angling experience (56.6%), as the dominant group. When comparing both periods, the average time spent on the field throughout the year has decreased from 61 to 48 days, which, when the decrease in the number of anglers is taken into account, denotes a vast decline in pressure exerted on the fish populations in Poland

In the Eastern Europe, the two most important factors – the perception of angling by the public and the behaviour of anglers - have been greatly affected by the communist regime and the revolution that brought the regime down in 1990´s. Before the revolution in 1990´s, angling used to be a social activity for masses. Fishing was a very popular activity because many other activities (like travelling to Western Europe) were prohibited. The majority of anglers specialized on intensive fish harvesting, and many anglers considered fishing as a source of food. After the revolution, the numbers of anglers strongly decreased, and recreational fishing became more of a hobby than an actual source of food. Recently, after the sharp drop after the collapse of the communist regime in the Czech Republic recreational fishing has been on the rise again, and anglers are leaning towards releasing of caught fish at least, particularly the younger anglers (Lyach and Čech, 2018). Studies showed that 50 % of anglers practice catch-and-release fishing, while only 28 % of anglers keep caught fish (Czech and Moravian Fishing Union, 2003, 2009, 2017). Many anglers believe that the catch-and-release strategy is the future of recreational fishing and suggest elevated enforcement. The same trend is seen in Poland. Here, voluntary catch-and-release is publically accepted and generally preferred by anglers, especially by younger people. Over 70% of the angling population declares to often or always release the angled fish.

Recreational angling, and being an angler, is generally considered socially acceptable by the Polish society, as opposed to its increasing negative attitude on recreational hunting. The most common factors, problems and conflicts that limit the expansion and growth of angling are unrelated to public constraints and rather relate to the following issues: growing cormorant populations (more fish are consumed by these birds than is the sum of combined commercial and recreational catches), growing numbers of Eurasian otters, conflicts arising between anglers and commercial fishing (especially on waters belonging to the PAA), poaching (a survey conducted among the members of the State Fisheries Guard has denoted illegal angling as the most common form of poaching), the conflict between environmental protection and fisheries (mainly focused on fish stocking), and multiple cultural and socio-economic factors causing a drastic decline in angler recruitment among children and youths. In addition, angling has to compete with other leisure activities like sports, gaming, watching movies etc.

Similar to Poland, in the Czech Republic, the perception of anglers by the public is generally positive. While there is no study that describes the perception of anglers by the society, some insights can be gathered from discussion forums on the Internet. People who take walks around rivers often chat with anglers, and they consider anglers as an integral part of the riverine scenery. However, environmentalists perceive anglers and fisheries managers more negatively. They mostly criticize intensive stocking of non-native fish species, mostly common carp *Cyprinus carpio* and rainbow trout *Oncorhynchus mykiss*. Recently, an increasing group of anglers is criticizing intensive fish stocking as well. Environmentalists claim that the put-and-take fishing strategy works as a 'temporary fridge' for anglers. They point out that the main issue is the fisheries policy itself. Fisheries managers are obliged to keep stocking fish for angling purposes, and mainly the non-native species - common carp and rainbow trout - can be obtained easily, cheaply, and reliably. In addition, environmentalists also claim that angling pressure is responsible for decreasing the abundance of fish. Thus, in general again, while we see impacts of biocentrism, there is very little active pathocentrism affecting recreational fishing in Eastern Europe.