Aquat. Living Resour. 2019, 32, 11
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https://doi.org/10.1051/alr/2019010

Aquatic Living Resources
Available online at:
www.alr-journal.org

RESEARCH ARTICLE

The effect of a large-scale fishing restriction on angling harvest: a case study of grayling *Thymallus thymallus* in the Czech Republic

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Received 24 January 2019 / Accepted 5 April 2019

Handling Editor: Verena Trenkel

Abstract – In Central Europe, European grayling *Thymallus thymallus* is an endangered and vanishing fish species with high recreational angling value. For that reason, in January 2016, the minimum legal angling size for grayling was increased from 30 to 40 cm in the Czech Republic. This study evaluated if the increase in minimum angling size had any effect on grayling harvest. Data from 229 fishing sites covering the years 2011–2017 were used in this study. The data originated from individual angling logbooks, collected in the regions of Prague and Central Bohemia, Czech Republic. Over the 7 yr, anglers visited the studied fishing sites 3.6 million times and harvested 105 000 salmonids. Grayling made up only 0.5% of the overall salmonid harvest. The fishing restriction caused a decrease in grayling harvest per visit. It also decreased the contribution of grayling to the overall harvest as well as the number of fishing sites where anglers successfully harvested graylings. Fish stocking was constant during the study period. Increased minimum angling size led to increased average body weight of harvested fish. In conclusion, the increase in minimum angling size significantly affected fish harvest and composition.

Keywords: Angling diaries / fisheries management / game fishing / inland fishing / salmonids / sports fishing

1 Introduction

Recreational fishing is one of the most important drivers of population dynamics in commercially important fish species in freshwater ecosystems (Cooke and Cowx, 2004; Lewin et al., 2006). Fisheries managers use several restrictions and regulations to enhance the protection of wild fish populations. Managers can introduce catch-and-release fishing or closed seasons, ban fishing strategies that are harmful to fish, restrict access to fishing sites for anglers, decrease the amount of fish taken per angler and per year, and restrict minimum/maximum angling sizes (Naslund et al., 2005, 2010; Powell et al., 2010; Van Poorten et al., 2013; Lenker et al., 2016; Lenox et al., 2016; Rahel, 2016). Several studies reported that fisheries regulations greatly influence both the behavior of anglers and fish harvest (Beard et al., 2003; Fulton et al., 2011; Johnston et al., 2013; Van Poorten et al., 2013). Setting a minimum angling size for commercially valuable and threatened fish species is a common conservation measure. The goal of this restriction is to protect young 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 fish populations (Humpl et al., 2009; Jankovský et al., 2011; Boukal et al., 2012). The success of this management measure depends on how many fish reproductive age classes are protected by the restriction. Restrictions in minimum legal angling size should address limiting factors (slow fish growth, low survival rates, and low reproduction rates) in the fish population.

In Central Europe, grayling *Thymallus thymallus* is a threatened and vanishing fish species. In the past, grayling used to be a species of high angling value. Recently, the gradual decrease of wild grayling populations in Central Europe became a problematic issue in recreational fishing. The reasons for the population decrease are thought to be mainly 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; Duftner et al., 2005; Gum et al., 2009). The interaction between grayling and anglers is an important factor for the dynamics of grayling populations

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(Duftner et al., 2005; Naslund et al., 2005,2010). However, there are only a few studies that describe angler–grayling interactions (Naslund et al., 2005, 2010).

In the Czech Republic, minimum angling size for grayling was 30 cm (TL, total length) during the period 2005–2015. However, grayling populations in the wild have been steadily decreasing (Czech Fishing Union, unpublished data). For that reason, the minimum angling size was increased to 40 cm (TL) in the entire study area (Czech Fishing Union, unpublished data) from January 1, 2016. The purpose of this change was to protect grayling populations from overexploitation by recreational anglers. The maximum length of graylings usually does not exceed 40–50 cm (Kottelat and Freyhof, 2007).

The goal of this study was to evaluate if the fishing restriction (increased minimum angling size from 30 to 40 cm) had any effect on harvest of grayling on selected fishing sites.

Firstly, this study compared harvest per effort and average body weight of harvested grayling before (2011–2015) and after (2016 and 2017) the change in minimum harvest size. It was expected that the harvest would have decreased as fish above 40 cm are significantly less abundant than fish above 30 cm. We further expected that the increased minimum angling size led to increased body weight of harvested fish. Secondly, the study compared the percentage of fishing sites with and without harvest of grayling. It was expected that the percentage of fishing sites with harvested grayling might have decreased as anglers would have been less likely to encounter legally sized grayling. This could potentially have led to an increased percentage of fishing sites without harvested graylings. Lastly, the study compared the harvest of graylings to other salmonids. Since there was no restriction in minimum legal angling size for other salmonids, we expected that the harvest of grayling would have decreased more rapidly than the harvest of other salmonids.

2 Materials and 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 (Fig. 1). Together both regions 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 is mostly agricultural. 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. The studied fishing sites 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 fish biomass of 150–300 kg per hectare (Lyach and Čech, 2017b, 2018a). The study areas include salmonid streams and reservoirs (dominated by salmonids) and non-salmonid rivers and reservoirs (dominated by cyprinids or percids).

2.2 Recreational fishing in the Czech Republic

Recreational fishing in the Czech Republic is managed centrally by the Czech Fishing Union (the main authority for recreational fishing). For a detailed description of recreational fishing in the Czech Republic, see Lyach and Čech, 2018a, b).

2.3 Angling rules for grayling

Grayling *T. thymallus* is an important fish species for 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 for grayling was 30 cm (TL) during 2005–2015. Since January 1, 2016, the minimum legal angling size of grayling was changed to 40 cm (TL). This change was effective immediately in the entire study area. All graylings below 40 cm have to be returned to water without any unnecessary delay. All harvested grayling must be noted in individual angling logbooks, including the date of harvest, size of harvested fish (cm), and the ID of the fishing site.

2.4 Grayling stocking

Annual stocking of grayling is common and traditional in the study area (Tab. 1). Most stocking is performed on smaller salmonid streams and rivers (<10–20 m wide). Grayling is mostly stocked as 1–2-yr old fish (5–10 cm TL). Fish are usually stocked in hundreds or thousands per stream. The main goal of fish stocking is to support wild populations. Before fish stocking occurs, stocked fish are weighed together (in one bag) to the nearest 100 g. The number of stocked fish is then estimated from the overall weight by applying species-specific length–weight equation (for grayling: $W = 0.00741\ TL^{3.05}$; Froese et al., 2014). Fish stocking is performed by local fisheries managers. The data on fish stocking were available for each individual fishing site.

2.5 Data sources

Data from annual angling summaries were used for the purpose of this study. These data originated from angling logbooks that were collected from individual anglers. Data from 229 inland freshwater fishing sites for the years 2011–2017 were used. Fishing sites 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 sites covered an area of 116 km^2. These data were originally collected by the Czech Fishing Union and later processed by the authors of this study. A similar dataset has been previously used for scientific purposes (Humpl et al., 2009; Jankovský et al., 2011; Boukal et al., 2012; Lyach and Čech, 2017a, 2018a, b).

2.6 Metrics

This study compared annual harvest (individual fish, kg) per fishing visit, harvest per visit per stocked fish (individual fish, kg), and average body weight (kg) of grayling between two time periods: before the fishing restriction was introduced (years 2011–2015) and after the restriction was introduced (years 2016–2017). The study also used models to describe (1)

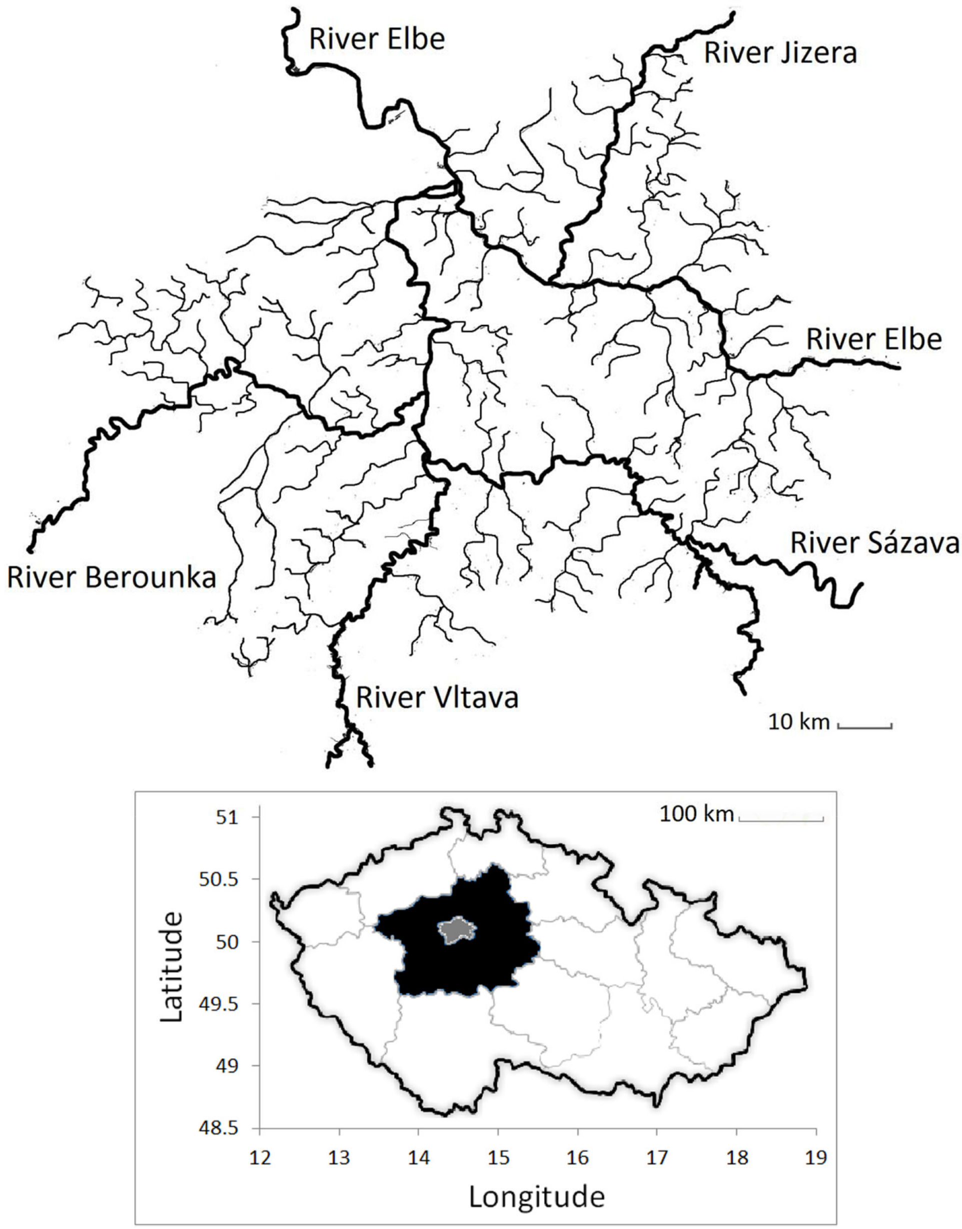

Fig. 1. Map of the study area with highlighted regions of Central Bohemia (in black; 49.5°–50.5° N, 13.5°–15.5°E) and Prague (in grey; 50° N, 14.5° E). Data were collected on 229 fishing sites in the regions of Prague and Central Bohemia, Czech Republic, Central Europe, during 2011–2017.

Table 1. Amount of stocked grayling in the study area.

Year	Stocked fish (*n*)	Stocked biomass (kg)	Number of rivers with stocked grayling
2011	18 000	305	19
2012	19 000	315	20
2013	18 000	310	21
2014	18 000	305	18
2015	17 000	300	19
2016	19 000	315	21
2017	18 000	305	18

the relationship between fish stocking and fish harvest, and (2) the relationship between fish harvest and fishing effort.

To evaluate the effect of fish stocking on harvest, the average fish stocking was calculated for the years 3, 4, and 5 before the fish were caught. We did not include data on fish stocking from 0 to 2 yr prior to the catch because stocked fish were small (10 cm TL) and unlikely to have grown to legal angling size (30 and 40 cm) over 2 yr. We also did not include data on earlier fish stocking, mainly for two reasons: (1) the usual life span of grayling is 5–6 yr maximum, and (2) stocked fish usually display high mortality due to stocking stress, predation, angling, and inability to adapt to natural conditions.

Stocked fish were therefore unlikely to have survived for more than 5 yr in the study area.

2.7 Statistical analyses

A Shapiro–Wilk test of normality was used to analyze data distributions. Wilcoxon tests were used to compare fish harvest, average body weight, and the percentage of fishing sites with grayling harvest between the two time periods, while Kruskal–Wallis tests were used to compare all years. An alpha level of 0.05 was used for all tests. A Bonferroni correction was applied when multiple groups were compared.

Linear mixed effects models were used for modeling harvest per visit per fishing site (229) and year (7) as a function of the number or biomass of stocked fish, with fishing sites modeled as random effects to account for differences between sites. For this Gamma distributions with log link function were used. Only the fishing sites with actual grayling stocking were used in this analysis. Linear mixed effects models were also used for modeling harvest per visit per fishing site (229) and year (7) as a function of the number of fishing visits per year.

The statistical programme R (R i386 3.4.1., R Development Core Team 2017) was used for all statistical testing and modeling. The package for generalized linear mixed models (GLMM) was used to fit linear models (Hadfield, 2010). The function *lmer* in the package *lme4* (version 0.999375-42; Bates et al., 2015) was used to calculate R^2 values (Nakagawa et al., 2013).

3 Results

3.1 Exploratory analysis

Cumulated over 2011–2017, anglers harvested 592 graylings with a total weight of 195 kg. In comparison, anglers also harvested 105 646 other salmonids (brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, and brook trout *Salvelinus fontinalis*) with a total weight of 45 566 kg. Anglers visited fishing sites in the study area 3 613 581 times. Data on fish harvest, fishing effort, fish stocking, and fish body weights were not normally distributed ($p < 0.001$ for each metric). Fishing effort increased steadily between 2011 and 2017 from 500 000 to 540 000 fishing visits (Fig. 2).

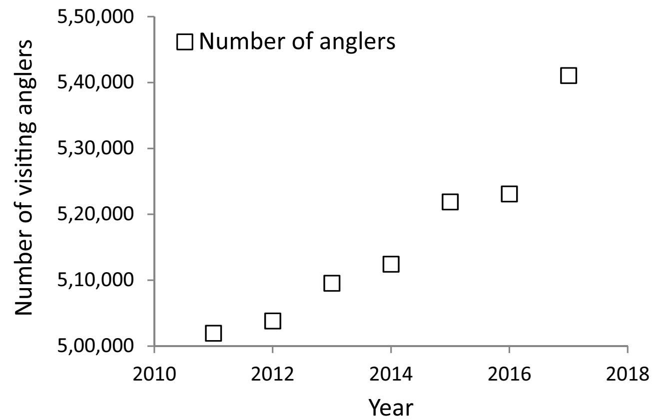

Fig. 2. Number of fishing visits per year in the study area. Minimum angling size was increased from 2016.

3.2 Harvest per visit

Total harvest of grayling was already relatively low before the restriction was introduced in 2016. Anglers harvested <100 grayling (<50 kg of fish) per year. In comparison, anglers also harvested approximately 5000–20 000 other salmonids and 150 000–300 000 non-salmonid fishes per year in the study area. Harvest decreased significantly after the increase in minimum angling size was introduced (number: $W = 245$, $p = 0.04$, $n = 229$; biomass: $W = 260$, $p = 0.07$, $n = 229$). Anglers harvested fewer grayling after the restriction was introduced (Fig. 3a and b). In addition, harvest decreased significantly for all salmonid species (number: $W = 96$, $p < 0.01$, $n = 229$; biomass: $W = 95$, $p < 0.01$, $n = 229$; Fig. 3c and d). However, grayling harvest decreased more rapidly than harvest of other salmonid species. As a result, the proportion of grayling in the total harvest of salmonids decreased after 2016 (number: $W = 258$, $p < 0.01$, $n = 229$; biomass: $W = 221$, $p < 0.01$, $n = 229$). Before the restriction was introduced, grayling made up 1.53% and 2.48% (in number and biomass) of the total harvest of salmonids. After the restriction was introduced, the contribution of graylings was 0.13% in numbers and 0.38% in biomass (Fig. 4a and b). There was only a weak linear relationship between grayling harvest and number of fishing visits (Tab. 2).

There was high variability in harvest between individual fishing sites (numbers: Kruskal–Wallis = 1141.1, df = 228, $p < 0.001$; biomass: Kruskal–Wallis = 1141.2, df = 228, $p < 0.001$). There was also a significant difference in annual harvest among years (2011–2015) before the restriction was introduced (numbers: Kruskal–Wallis = 61, df = 4, $p = 0.04$; biomass: Kruskal–Wallis = 44, df = 4, $p = 0.04$), while no difference was found after the restriction was introduced (numbers: $W = 1415$, $p = 0.11$; biomass: $W = 1896$, $p = 0.13$).

3.3 Harvest per fish stocked

Grayling harvest per fishing site was significantly positively related to the intensity of fish stocking per fishing site. When fisheries managers stocked higher numbers of grayling, the overall fish harvest increased in subsequent years (Tab. 2). However, when fisheries managers stocked higher biomass of grayling, the overall harvest did not change (Tab. 2). Many fishing sites with fish stocking displayed no harvest. Inversely, several fishing sites without fish stocking displayed actual harvest of grayling (Fig. 4c and d).

There was no difference in total fish stocking between years (numbers: Kruskal–Wallis = 330, $p = 0.76$, $n = 229$; biomass: Kruskal–Wallis = 970, $p = 0.69$, $n = 229$). Fisheries managers stocked approximately 18 000 grayling with a total weight of 310 kg annually (Tab. 1). There was high variability in harvest per stocked fish per one fishing site between individual fishing sites (numbers: Kruskal–Wallis = 1425.5, df = 29, $p < 0.001$; biomass: Kruskal–Wallis = 1399.8, df = 29, $p < 0.001$). There was no significant difference in annual harvest per stocked fish between years before the restriction was introduced (numbers: Kruskal–Wallis = 0.78, df = 4, $p = 0.98$; biomass: Kruskal–Wallis = 0.38, df = 4, $p = 0.98$),

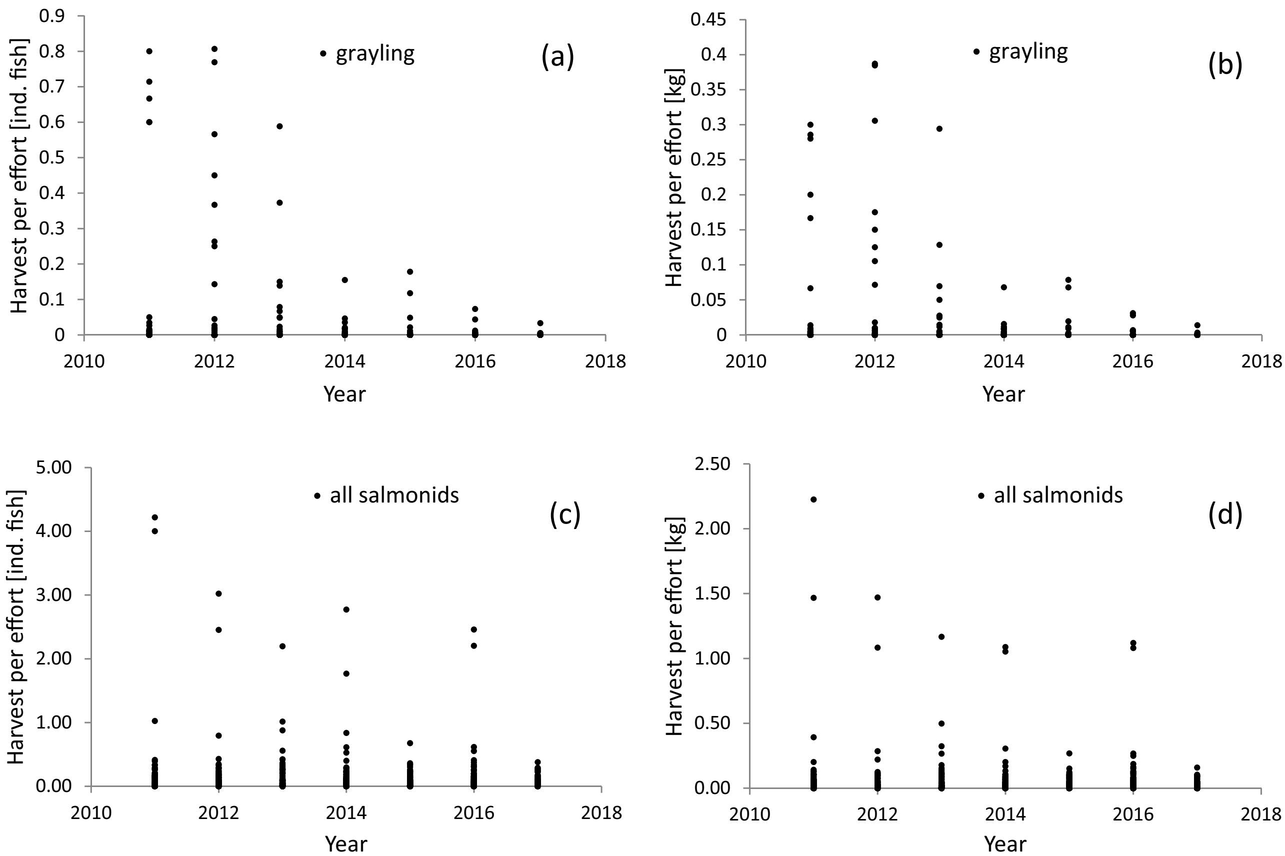

Fig. 3. Grayling harvest per visit (a, b) and for all salmonids (c, d). Minimum angling size was increased from 2016.

similarly after the restriction was introduced (numbers: $W = 40$, $n = 229$, $p = 0.12$, biomass: $W = 43$, $n = 229$, $p = 0.09$).

3.4 Fishing sites with harvest of grayling

The number of fishing sites with actual harvest of grayling decreased significantly after the restriction was introduced ($W = 266$, $n = 229$, $p = 0.02$), from an average 7.4% to an average 3.8% after the restriction was introduced (Fig. 5).

There was no significant difference in the number of fishing sites with catch of grayling between years before the restriction was introduced (Kruskal–Wallis = 0.82, df = 4, $p = 0.94$) and also after the restriction was introduced ($W = 22\ 160$, $n = 229$, $p = 0.76$).

3.5 Average body weight

Average body weight of harvested grayling increased significantly after the restriction was introduced ($W = 711$, $n = 229$, $p = 0.02$), from 0.42 kg to 0.68 kg (Fig. 6). Further, there was no difference in average body weight of harvested fish between individual fishing sites (Kruskal–Wallis = 17.107, df = 18, $p < 0.52$), between years before the restriction was introduced (Kruskal–Wallis = 3.89, df = 4, $p = 0.42$), and between years after it was introduced ($W = 14.1$, $n = 229$, $p = 0.31$).

4 Discussion

Fisheries data from angling logbooks 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, e.g. missing reports of fish harvest, misinterpretation of fish size, wrong identification of species, and noncompliance of anglers with fishing rules (Essig and Holliday, 1991; Pollock et al., 1994; Cooke et al., 2000; Bray and Schramm, 2001; Mosindy and Duffy, 2007; Lyach and Čech, 2018a, b). However, this dataset is still the most reliable option that is available for this kind of study, mostly because it provides observations on fish harvest in large areas. Previous studies already successfully used similar dataset for scientific purposes (Humpl et al., 2009; Jankovský et al., 2011; Boukal et al., 2012; Lyach and Čech, 2017a; Lyach and Čech, 2018a, b).

The study showed a decrease in the harvest of grayling as well as a decrease in the proportion of grayling in the overall fish harvest. Decreasing harvest of grayling is a common trend in Central Europe. Fisheries researchers believe that lower harvest is often linked to decrease of grayling populations in the wild (Gum et al., 2009; Weiss et al., 2013; Mueller et al., 2018). However, other studies have shown that decreased harvest can also be linked to increasing popularity of catch-and-release fishing, decreased popularity of angling, increased interest of anglers in conservation of grayling, and legal

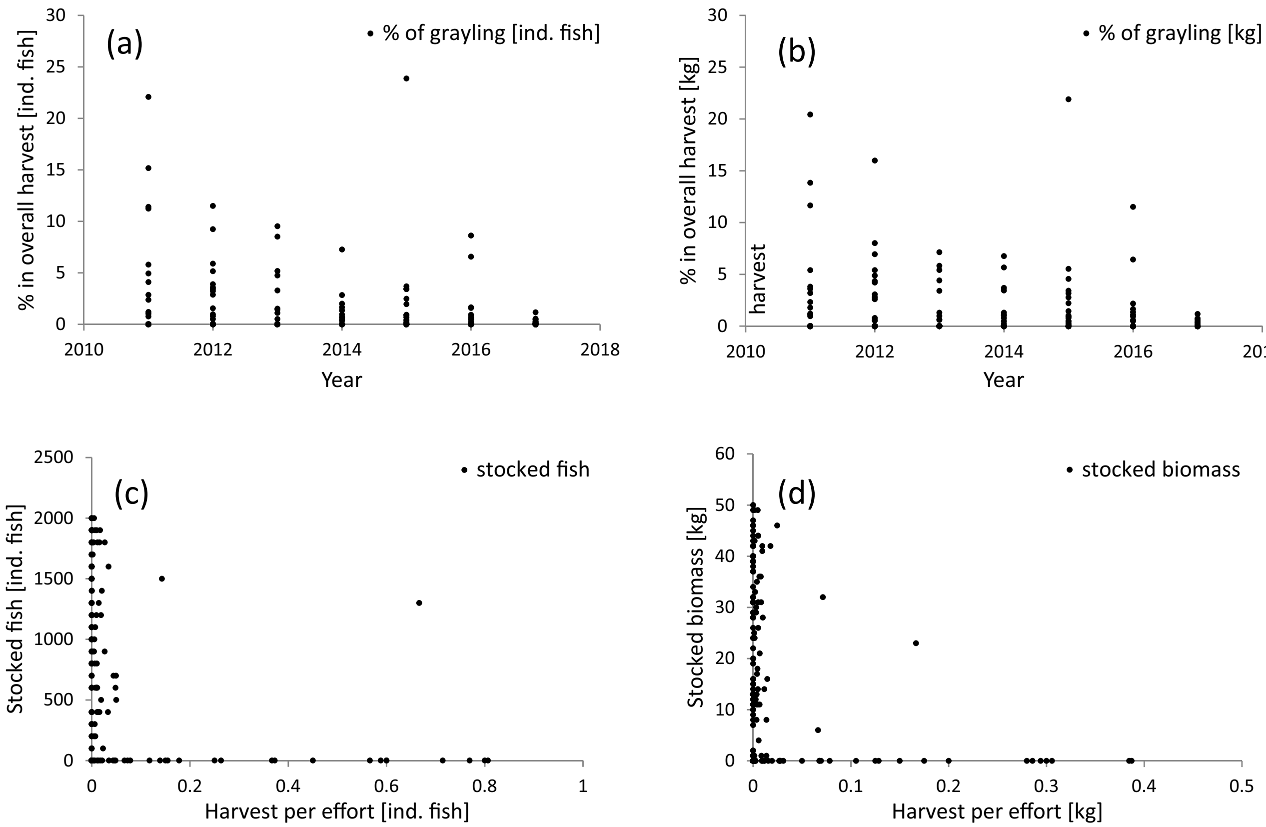

Fig. 4. Proportion of grayling in salmonids harvest in numbers (a) and biomass (b). Relationship between grayling harvest per visit and stocked fish in numbers (c) and biomass (d). Minimum angling size was increased from 2016.

Table 2. Model results for grayling harvest. SD = standard deviation, variance (RE) = variance for random effect, df = degrees of freedom, NA = not applicable.

Dependent variable	Explanatory variable	Intercept (SD)	Slope (SD)	*p*-value	Variance (RE)	R^2	df
Harvest (numbers) per visit	Number of stocked fish	0.0033 (0.0013)	0.000006 (0.000002)	0.003	0.000038	0.150	1602
Harvest (kg) per visit	Biomass of stocked fish (kg)	0.0018 (0.0006)	0.000028 (0.000019)	0.150	0.000018	0.006	1602
Harvest (numbers)	Fishing effort	5.24 (0.45)	0.000088 (0.000056)	0.12	NA	0.003	1602
Harvest (kg)	Fishing effort	2.27 (0.19)	0.000033 (0.000023)	0.16	NA	0.002	1602

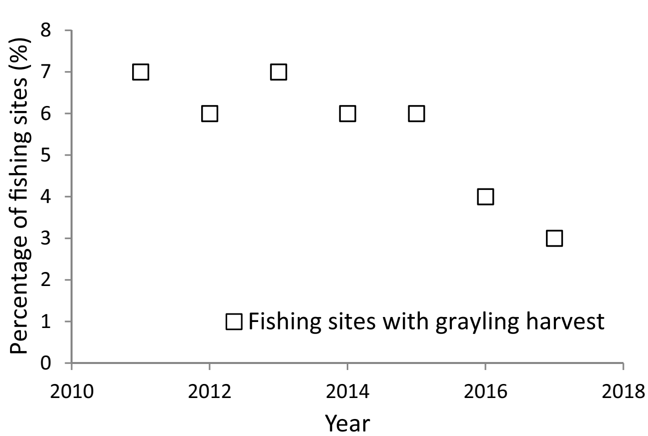

Fig. 5. Percentage of fishing sites where anglers successfully harvested grayling. Minimum angling size was increased from 2016.

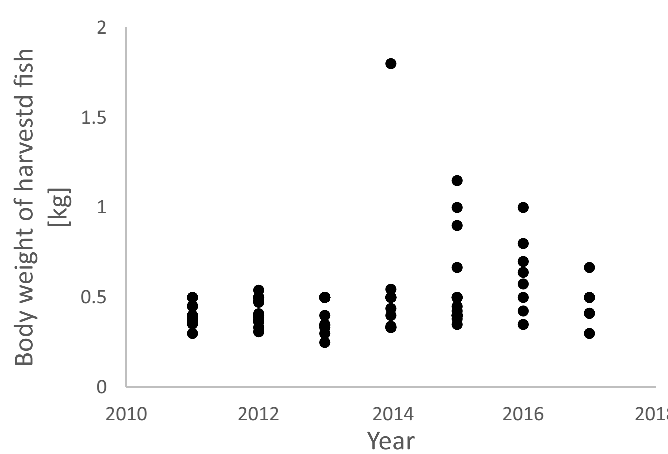

Fig. 6. Average body weight of harvested grayling. Minimum angling size was increased from 2016.

restrictions to fishing (Cha and Melstrom, 2018; Lyach and Čech, 2018a; Lyach and Čech, 2018b). The catch-and-release fishing strategy is usually responsible for some amount of fish mortality (especially in salmonids), and even a strict protection of fish species usually does not lower angling mortality to zero (Tetzlaff et al., 2013).

The increase in minimum harvest size had a negative effect on the number of fishing sites with harvest of grayling. It is likely that grayling >40 cm are harder to encounter compared to grayling >30 cm. According to FishBase (Fishbase.org), an average adult grayling usually reaches size around 30 cm. Maximum size of adult grayling is usually <40 cm. It is also possible that anglers started releasing caught grayling back to water, either because caught fish were too small, or because the introduction of the restriction made anglers realize the need for grayling conservation.

Interestingly, several fishing sites with high intensity of fish stocking (up to 50 kg and 3000 individuals per year) showed only two to three harvested grayling. It is possible that several individual fishing sites had high mortality of stocked fish. It seems that fish stocking is effective only when smaller fish are stocked. Studying grayling populations in the Vienne River (France), Persat et al. (2016) also concluded that intensive stocking of grayling had only a small positive effect on wild grayling populations. Thorfve (2002) found that hatchery-reared grayling often start losing weight and stop feeding after being released into the wild. Other studies (Lenox et al., 2016; Pinder et al., 2019) described that longer air exposure significantly increases post-release mortality in grayling. Longer air exposure is typical for catch-and-release fishing. In conclusion, releasing hatchery-reared grayling into rivers with high fishing pressure will likely lead to high mortality of stocked fish.

The fishing restriction potentially led to higher angling mortality in the biggest fish individuals in the studied grayling populations. It is likely that the proportion of female fish in catches of anglers increased due to the restriction, mainly because anglers stared harvesting bigger fish in general. The biggest fish in grayling populations are usually females with high fecundity (Kottelat and Freyhof, 2007). By killing more grayling females, anglers could have negatively affected the reproductive ability of grayling populations in the study area. Other studies (Arlinghaus et al., 2010; Mullon et al., 2012) have argued that killing the biggest individuals can negatively affect fished populations.

The restriction probably had an effect on grayling harvest. As other studies found, fishing restrictions are usually useful for species conservation (Schill and Kline, 1995; Van Poorten et al., 2013). Implementing a minimum harvest size is more effective than bag limits (Van Poorten et al., 2013; Askey, 2016). However, the outcome of any restriction depends on the compliance of the anglers. The outcome also depends on which age classes are protected by the regulation. For example, Caroffino (2013) stated that anglers usually comply with a minimum size regulation. In contrast, a maximum size regulation is much less likely to be effective for two reasons: minimum size limit regulations are far more common and small fish have less angling value (Caroffino, 2013; Johnston et al., 2013). Therefore, the most important question is whether anglers are willing to comply with the fishing restriction. If they don't, such restriction is ineffective (Gigliotti and Taylor, 1990; Veiga et al., 2013). Either way, the main limitation in similar studies is that the practical effect of such restriction is difficult to evaluate (Lewin et al., 2006).

The restriction in minimum angling size was expected to reduce harvest. However, the restriction probably did not decrease the amount of caught-and-released grayling. Catch-and-release mortality in salmonids is often high (Lenox et al., 2016; Pinder et al., 2019), meaning anglers still likely indirectly kill many grayling even once the restriction was implemented. In contrast, banning fishing in the entire study area would minimize catch-and-release mortality in grayling. Alós and Arlinghaus (2013) showed that creating protected areas from marine recreational fishing significantly helped the conservation of commercially important fish species.

Fishing pressure in the study area increased despite the fishing regulation. Anglers did not abandon fishing sites when the regulation was introduced. By studying bull trout recreational fishing in Canada, Johnston et al. (2011) discovered that anglers mostly abandoned fishing sites where strict fishing regulations on harvest were introduced. The difference in findings may be caused by the popularity and abundance of both species in the respective countries.

Lastly, we recommend that field surveys of age and size of grayling in the study area should be carried out to gain more insight into the effects of the change in regulation.

Acknowledgements. The Czech Fishing Union (namely Jaroslava Fryšová and Pavel Horáček) provided necessary data. Pavel Vrána and Martin Čech provided helpful insights into recreational fishing. Anglers and angling guards in the Czech Republic made this study possible. This study was funded by the Charles University Grant Agency (Grant GA UK No. 112 218), by Charles University, and by the Ministry of Education, Youth, and Sports.

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Cite this article as: Lyach R, Remr J. 2019. The effect of a large-scale fishing restriction on angling harvest: a case study of grayling *Thymallus thymallus* in the Czech Republic. *Aquat. Living Resour.* 32: 11