The effect of cormorant predation on newly established Atlantic salmon population

Authors: Lyach, Roman, and Čech, Martin

Source: Folia Zoologica, 66(3) : 167-174

Published By: Institute of Vertebrate Biology, Czech Academy of Sciences

URL: https://doi.org/10.25225/fozo.v66.i3.a4.2017

Folia Zool. – 66 (3): 167–174 (2017)

The effect of cormorant predation on newly established Atlantic salmon population

Roman LYACH* and Martin ČECH

Institute for Environmental Studies, Faculty of Science, Charles University, Benátská 2, 128 01 Praha, Czech Republic; e-mail: roman.lyach@natur.cuni.cz, carcharhinusleucas@yahoo.com

Received 30 June 2017; Accepted 9 November 2017

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

* *Corresponding Author*

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

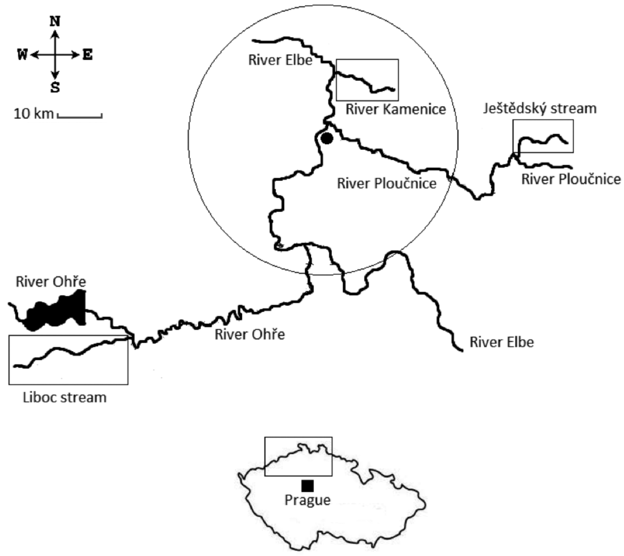

Fig. 1. Map of the study area with location of the cormorant colony (full black circle), estimated reach of cormorants roosting in the study area (wide black circle), the River Kamenice, the Ještědský stream, and the Liboc stream (black rectangles).

other permanent colonies were identified in the study area (Agency of Nature and Landscape Protection, unpublished data).

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.

Acknowledgements

The Agency of Nature and Landscape Protection (namely Eva Mikolášková and Bořek Franěk) provided data regarding cormorant counts in the study area. The North Bohemian Branch of the Czech Fishing Union (namely Tomáš Kava) and the Office of the National Park Bohemian Switzerland (namely Miloš Trýzna, Tomáš Salov, and Boleslav Lang) provided data regarding cormorant counts on nursery streams, salmon stocking, electrofishing surveys, and adult salmon observations. Pavel Vrána from the Czech Fishing Union provided important contacts. Students from the Czech University of Life Sciences helped in the field. Offices of the Ohře River Authority and the Elbe River Authority made the field work possible. Tens of volunteers participated in salmon stocking. Thousands of people donated money to support the salmon stocking programme. Clemens Fieseler and Peter Hutchinson from NASCO provided important contacts. The Institute for Environmental Studies, Faculty of Science, Charles University provided financial support to both authors. The Ministry of the Environment of the Czech Republic, the State Environmental Fund of the Czech Republic, and the European Union co-financed the salmon reintroduction programme.

Literature

Aarestrup K., Jepsen N., Rasmussen G. & Oakland F. 1999: Movements of two strains of radio tagged Atlantic salmon, *Salmo salar* L., smolts through reservoir. *Fish. Manag. Ecol. 6: 97–107.*

Aarestrup K. & Koed A. 2003: Survival of migrating sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) smolts negotiating weirs in small Danish rivers. *Ecol. Freshw. Fish 12: 169–176.*

Adam B., Faller M., Gischkat S. et al. 2012: Results of one year fish-ecological monitoring at the double slot pass Geesthacht. *Wasserwirtschaft 102: 49–57.*

Benda P. & Šmíd J. 2002: Return of Atlantic salmon into the waters of Bohemian Switzerland. *Bohemian Switzerland, Bulletin of the National Park Bohemian, Switzerland 1: 7.*

Blackwell B.F., Krohn W.B., Dube N.R. & Godin A.J. 1997: Spring prey use by double-crested cormorants on the Penobscot River, Maine, USA. *Colon. Waterbird 20: 77–86.*

Bostrom M.K., Lunneryd S.G., Karlsson L. & Ragnarsson B. 2009: Cormorant impact on trout (*Salmo trutta*) and salmon (*Salmo salar*) migrating from the river Dalalven emerging in the Baltic Sea. *Fish. Res. 98: 16–21.*

Breve N., Vis H., Spierts I. et al. 2014: Exorbitant mortality of hatchery-reared Atlantic salmon smolts *Salmo salar* L., in the Meuse river system in the Netherlands. *J. Coast. Conserv. 18: 97–109.*

Carss D.N. & Ekins G.R. 2002: Further European integration: mixed sub-species colonies of great cormorants *Phalacrocorax carbo* in Britain – colony establishment, diet, and implications for fisheries management. *Ardea 90: 23–41.*

Carss D.N. & Marquiss M. 1999: Skeletons in the cupboard? Quantifying bird predation on Atlantic salmon: atlas vertebra: length equations revised. *J. Zool. Lond. 248: 272–276.*

Chanseau M., Croze O. & Larinier M. 1999: The impact of obstacles on the Pau River (France) on the upstream migration of returning adult Atlantic salmon (*Salmo salar* L.). *Bull. Fr. Pêche Piscic. 353–54: 211–237.*

Christensen B. 1996: Predator foraging capabilities and prey antipredator behaviours: pre- versus postcapture constraints on size-dependent predator-prey interactions. *Oikos 7: 368–380.*

Crisp D.T. 1995: Dispersal and growth rate of O-group salmon (*Salmo salar* L.) from point-stocking together with some information from scatter-stocking. *Ecol. Freshw. Fish 4: 1–8.*

Čech M. & Čech P. 2017: Effect of brood size on food provisioning rate in common kingfisher *Alcedo atthis*. *Ardea 105: 5–17.*

Čech M., Čech P., Kubečka J. et al. 2008: Size selectivity in summer and winter diets of great cormorant (*Phalacrocorax carbo*): does it reflect season-dependent difference in foraging efficiency? *Waterbirds 31: 438–447.*

Čech M. & Vejřík L. 2011: Winter diet of great cormorant (*Phalacrocorax carbo*) on the River Vltava: estimate of size and species composition and potential for fish stock losses. *Folia Zool. 60: 129–142.*

Descroix A., Desvilettes C., Martin P. et al. 2009: Feeding, growth and nutritional status of restocked salmon parr along the longitudinal gradient of a large European river: the Allier. *Ecol. Freshw. Fish 18: 282–296.*

Dieperink C., Pedersen S. & Pedersen M.I. 2001: Estuarine predation on radiotagged wild and domesticated sea trout (*Salmo trutta* L.) smolts. *Ecol. Freshw. Fish 10: 177–183.*

Eklov A.G. & Greenberg L.A. 1998: Effects of artificial instream cover on the density of 0+ brown trout. *Fish. Manag. Ecol. 5: 45–53.*

Emmrich M. & Duttmann H. 2011: Seasonal shifts in diet composition of the great cormorants *Phalacrocorax carbo sinensis* foraging at a shallow eutrophic inland lake. *Ardea 99: 207–216.*

Fraser N.H.C., Metcalfe N.B. & Thorpe J.E. 1993: Temperature-dependent switch between diurnal and nocturnal foraging in salmon. *Proc. R. Soc. Lond. B 252: 135–139.*

Frič A. 1893: The Elbe salmon, biological and anatomical study. *Fr. Řivnáč's Committee, Praha. (in Czech with English abstract)*

Geist J., Porkka M. & Kuehn R. 2006: The status of host fish populations and fish species richness in European freshwater pearl mussel (*Margaritifera margaritifera*) streams. *Aquat. Conserv. 16: 251–266.*

Gibson R.J. 1966: Some factors influencing the distributions of brook trout and young Atlantic salmon. *J. Fish. Res. Board Can. 23: 1977–1980.*

Gibson R.J. 1993: The Atlantic salmon in fresh-water- spawning, rearing and production. *Rev. Fish Biol. Fish. 3: 39–73.*

Grémillet D. & Argentin G. 1998: Cormorants, shags and fisheries in the Chausey Islands area. *Le Cormoran 10: 196–202.*

Harris C.M., Calladine J.R., Wernham C.V. & Park K.J. 2008: Impacts of piscivorous birds on salmonid populations and game fisheries in Scotland: a review. *Wildlife Biol. 14: 395–411.*

Heggenes J., Krog O.M.W., Lindas O.R. et al. 1993: Homeostatic behavioral responses in a changing environment – brown trout (*Salmo trutta*) become nocturnal during winter. *J. Anim. Ecol. 62: 295–308.*

Horká P., Sychrová O., Horký P. et al. 2017: Feeding habits of the alien brook trout *Salvelinus fontinalis* and the native brown trout *Salmo trutta* in Czech mountain streams. *Knowl. Manag. Aquat. Ec. 418: doi: 10.1051/kmae/2016038.*

Horký P., Horká P., Jurajda P. & Slavík O. 2013: Young-of-the-year (YOY) assemblage sampling as a tool for assessing the ecological quality of running waters. *J. Appl. Ichthyol. 29: 1040–1049.*

Ibbotson A.T., Beaumont W.R.C. & Pinder A.C. 2011: A size-dependent migration strategy in Atlantic salmon smolts: small smolts favour nocturnal migration. *Environ. Biol. Fishes 92: 151–157.*

Jackson C.D. & Brown G.E. 2011: Differences in antipredator behaviour between wild and hatchery-reared juvenile Atlantic salmon (*Salmo salar*) under seminatural conditions. *Can. J. Fish. Aquat. Sci. 68: 2157–2165.*

Jepsen N., Aarestrup K., Okland F. & Rasmussen G. 1998: Survival of radiotagged Atlantic salmon (*Salmo salar* L.) and trout (*Salmo trutta* L.) smolts passing a reservoir during seaward migration. *Hydrobiologia 371–372: 347–353.*

Jepsen N., Sonnesen P., Klenke R. & Bregnballe T. 2010: The use of coded wire tags to estimate cormorant predation on fish stocks in an estuary. *Mar. Freshwater Biol. 61: 320–329.*

Johansen M., Thorstad E., Rikardsen A.H. et al. 2010: Prey availability and juvenile Atlantic salmon feeding during winter in a regulated subarctic river subject to loss of ice cover. *Hydrobiologia 644: 217–229.*

Jonsson B. & Jonsson N. 2004: Factors affecting marine production of Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci. 61: 2369–2383.*

Jonsson B., Jonsson N. & Hansen L.P. 1991: Differences in life-history and migratory behavior between wild and hatchery-reared Atlantic salmon in nature. *Aquaculture 98: 69–78.*

Jutila E., Jokikokko E. & Julkunen M. 2006: Long-term changes in the smolt size and age of Atlantic salmon, *Salmo salar* L., in a northern Baltic river related to parr density, growth opportunity and postsmolt survival. *Ecol. Freshw. Fish 15: 321–330.*

Keller T. 1995: Food of cormorants *Phalacrocorax carbo sinensis* wintering in Bavaria, southern Germany. *Ardea 83: 185–192.*

Koed A., Baktoft H. & Bak B.D. 2006: Causes of mortality of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) smolts in a restored river and its estuary. *River Res. Appl. 22: 69–78.*

Koed A., Jepsen N., Aarestrup K. & Nielsen C. 2002: Initial mortality of radio-tagged Atlantic salmon (*Salmo salar* L.) smolts following release downstream of a hydropower station. *Hydrobiologia 483: 31–37.*

Kortan D., Adámek Z. & Vrána P. 2010: Otter, *Lutra lutra*, feeding pattern in the Kamenice River (Czech Republic) with newly established Atlantic salmon, *Salmo salar*, population. *Folia Zool. 59: 223–230.*

Lajus D.L., Lajus J.A., Dmitrieva Z.V. et al. 2005: The use of historical catch data to trace the influence of climate on fish populations: examples from the White and Barents Sea fisheries in the 17th and 18th centuries. *ICES J. Mar. Sci. 62: 1426–1435.*

Larinier M. 1998: Upstream and downstream fish passage experience in France. *Fish Migration and Fish Bypasses: 127–145.*

Larinier M. 2008: Fish passage experience at small-scale hydro-electric power plants in France. *Hydrobiologia 609: 97–108.*

Leopold M.F., Van Damme C.J.G. & Van der Veer H.W. 1998: Diet of cormorants and the impact of cormorant predation on juvenile flatfish in the Dutch Wadden Sea. *J. Sea Res. 40: 93–107.*

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

Mather M.E. 1998: The role of context-specific predation in understanding patterns exhibited by anadromous salmon. *Can. J. Fish. Aquat. Sci. 55: 232–246.*

Maynard D.J., Flagg T.A. & Mahnken C.V.W. 1994: A review of semi natural culture strategies for enhancing the post release survival of anadromous salmonids. *Am. Fish. Soc. Symp. 15: 307–314.*

McCormick S.D., Hansen L.P., Quinn T.P. & Saunders R.L. 1998: Movement, migration, and smolting of Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci. 55: 77–92.*

McMenemy J.R. 1995: Survival of Atlantic salmon fry stocked at low density in the West River, Vermont. *N. Am. J. Fish. Manag. 15: 366–374.*

Menzel H.J. & Schwevers U. 2012: General conditions for building Europe's biggest fish pass at the Northern Riverbank at the Weir Geesthacht. *Wasserwirtschaft 102: 12–17.*

North Atlantic Salmon Conservation Organisation 2017: Annual progress report on actions taken under the implementation. *Plan for the Calendar Year 2016: 1–8.*

Parrish D.L., Behnke R.J., Gephard S.R. et al. 1998: Why are not there more Atlantic salmon (*Salmo salar*)? *Can. J. Fish. Aquat. Sci. 51: 281–287.*

Platteeuw M. & Van Eerden M. 1995: Time and energy constraints of fishing behaviour in breeding cormorants *Phalacrocorax carbo sinensis* at Lake Ijsselmeer, the Netherlands. *Ardea 83: 223–234.*

Prchalová M., Horký P., Slavík O. et al. 2011: Fish occurrence in the fishpass on the lowland section of the River Elbe, Czech Republic, with respect to water temperature, water flow and fish size. *Folia Zool. 60: 104–114.*

Prevost E., Chadwick E.M.P. & Claytor R.R. 1992: Influence of size, winter duration and density on sexual-maturation of Atlantic salmon (*Salmo-salar*) juveniles in Little Codroy River (Southwest Newfoundland). *J. Fish Biol. 41: 1013–1019.*

Rosengren M., Kvingedal E., Naslund J. et al. 2017: Born to be wild: of rearing density and environmental enrichment on stress, welfare, and smolt migration in hatchery-reared Atlantic salmon. *Can. J. Fish. Aquat. Sci. 74: 396–405.*

Salvanes A.G.V. 2017: Are antipredator behaviours of hatchery *Salmo salar* juveniles similar to wild juveniles? *J. Fish Biol .90: 1785–1796.*

Suter W. 1995: The effect of predation by wintering cormorants *Phalacrocorx carbo* on grayling *Thymallus thymallus* and trout (Salmonidae) populations – 2 case studies from Swiss Rivers. *J. Appl. Ecol. 32: 29–46.*

Suter W. 1997: Roach rules: shoaling fish are a constant factor in the diet of cormorants *Phalacrocorax carbo* in Switzerland. *Ardea 85: 9–27.*

Thorstad E.B., Okland F., Aarestrup K. & Heggberget T.G. 2008: Factors affecting the within-river spawning migration of Atlantic salmon, with emphasis on human impacts. *Rev. Fish. Biol. Fisher. 18: 345–371.*

Valová Z., Janáč M., Svanyga J. & Jurajda P. 2014: Structure of 0+ juvenile fish assemblages in the modified upper stretch of the River Elbe, Czech Republic. *Czech J. Anim. Sci. 59: 35–44.*

Warke G.M.A. & Day K.R. 1995: Changes in abundance of cyprinid and percid prey affect rate of predation by cormorants *Phalacrocorax carbo carbo* on salmon *Salmo salar* smolt in Northern-Ireland. *Ardea 83: 157–166.*

Weatherley N.S., Jenkins M.J., Evans D.M. et al. 1995: Options for liming rivers to ameliorate acidity – A UK perspective. *Water Air Soil Pollut. 85: 1009–1014.*

Wolter C. 2015: Historic catches, abundance, and decline of Atlantic salmon *Salmo salar* in the River Elbe. *Aquat. Sci. 77: 367–380.*

Zahn S., Thiel U., Wolf R. & Kohlmann K. 2009: Protection and development of the aquatic resources of the Brandenburg waters. Subproject salmon in Brandenburg. *Projektreport for years 2006-2008, Institut für Binnenfischerei e. V. (ifB), Potsdam-Sacrow. (in German with English summary)*