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The impact of Cormorant predation on Atlantic salmon and Sea trout smolt survival

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The downstream migration of anadromous salmonid smolts is a critical phase often associated with high mortality due to predation by fish, mammals and birds (Aarestrup, Jepsen, Rasmussen & Økland, 1999; Handeland, Järvi, Fernö & Stefansson, 1996; Jepsen, Holthe & Økland, 2006; Jepsen, Pedersen & Thorstad, 2000). This predation can be a significant source of mortality for salmon, *Salmo salar* L., smolts (Ibbotson, Beaumont & Pinder, 2011; Jepsen, Aarestrup, Økland & Rasmussen, 1998; Koed, Baktoft & Bak, 2006; Schwinn, Aarestrup, Baktoft & Koed, 2017). Cormorants (*Phalacrocorax* spp.) are frequent predators of fish in European fresh waters (Čech, Čech, Kubečka, Prchalová & Draštík, 2008; Jepsen, Ravn & Pedersen, 2018; Keller, 1995; Klenke et al., 2012; Skov et al., 2013; Steffens, 2010), and may also impact fish populations in coastal areas (Hansson et al., 2017; Jepsen, Sonnesen, Klenke & Bregnballe, 2010). Some studies have found little effect of cormorant predation on wild fish populations in rivers or lakes (Boström, Lunneryd, Karlsson & Ragnarsson, 2009; Engström, 2001; Frechette et al., 2012; Kumadaa, Arimaa, Tsuboib, Ashizawab & Fujioka, 2013; Leopold, van Damme & van der Veer, 1998; Suter, 1995), whilst others have shown that cormorant predation influences fish populations (Jepsen et al., 2010; Klenke et al., 2012; Koed et al., 2006; Rudstam et al., 2004; Skov et al., 2013; Steinmetz, Kohler & Soluk, 2003). Several studies have described cormorant predation on salmon populations (Warke & Day, 1995; : Blackwell, Krohn, Dube & Godin, 1997; Dieperink, Bak, Pedersen, Pedersen & Pedersen, 2002; Koed et al., 2006; Boström et al., 2009; Kennedy & Greer, 1988; Harris, Calladine, Wernham & Park, 2008): a few found low impact (Boström et al., 2009; Lyach & Čech, 2017); whereas others have suggested that wild salmon populations may be threatened by cormorants (Jepsen et al., 2010; Koed et al., 2006). It is important to note that once a trout or a salmon reaches smolt age, density-dependent mortality does not play a role anymore, meaning that, for example, a 40% decrease in the smolt number will result in a 40% reduction of the spawning population. The aim of this note is to present information on Danish studies on smolt predation to elucidate the impact of cormorant predation.

In Denmark, the breeding population of great cormorant, *Phalacrocorax carbo sinensis* (L.) increased from less than 2,000 breeding pairs in 1980 to over 40,000 pairs in the late 1990s. Breeding cormorants are counted annually, and the number has decreased to approximately 30,000 pairs over a total area of 44,000 km^2 (i.e. the total area of Denmark), representing a density between 0.5–5.6 bird/km^2 (highest number in the autumn, lowest in mid-winter). Colonies are distributed throughout the country, and most salmon and sea trout rivers and coastal areas are within 25 km of a colony. In the Skjern estuary, where most studies were performed, there are 1,200–2,500 breeding pairs. In Lake Hald, there is a breeding colony of 300–600 pairs. In the Mariager Fjord, there is a colony of 200–300 pairs, and in Horsens Fjord there was a large colony of 2,000–4,000 nests at the time of the studies.

In the studies presented here, wild trout, *Salmo trutta* L., and salmon smolts were captured in screened traps, rotary screw traps or fyke nets in the lower reaches of rivers or by electrofishing in shallow areas (upper reaches). Hatchery fish, either stocked at 6 months or 1-year-old (marked by fin clipping and coded wire tagging) were caught by the traps or electrofishing, but in some cases hatchery smolts were directly tagged and released. The studies presented here have been based on: (a) radio-telemetry, where tagged fish were followed through their river migration and tags recovered/recorded in cormorant colonies; (b) acoustic telemetry, where smolts are tagged and followed via hydrophone arrays from the river to sea entry; (c) PIT-tagging, where cormorant colonies are subsequently (post-smolt run) scanned for PIT tags; and (d) analyses of cormorant pellets for salmon otoliths or coded wire tags to estimate the number of smolts eaten. These analyses were combined with weekly counts of birds to calculate the total number of individual fish eaten in each weekly interval. Details of the methods are published in the cited papers and reports (Table 1) and will not be discussed in detail here. It is important to note, however, that the most direct measure of cormorant predation comes from radio-telemetry, where the cause of death is directly revealed. For example, if 35 of 79 tags are found in a cormorant colony it is safe to conclude that 44% of the tagged fish were eaten by cormorants. The true number could be higher (but not lower) because cormorants could have regurgitated eaten tags elsewhere (outside the range of the receivers), gulls could possibly have eaten and removed pellets, or the tags could

TABLE 1 List of studies summarising estimates of predation by cormorants (*Phalacrocorax carbo sinensis*) on Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) smolts in Danish waters from 1997-2017

Year	Number tagged	Species and origin	Estimated mortality caused by cormorants (%)	Method	Source	Location
1997	50	Wild trout	55	Radio-telemetry	Dieperink, Pedersen & Pedersen (2001);	Estuary (Horsens)
1997	50	Hatchery trout	67	Radio-telemetry	Dieperink et al. (2001);	Estuary (Horsens)
2000	17	Wild trout	24	Radio-telemetry	Dieperink et al. (2002);	Lower river/ estuary (Skjern)
2000	51	Wild salmon	48	Radio-telemetry	Dieperink et al. (2002);	Lower river/ estuary (Skjern)
2002	51	Salmon (mix)	40	Radio-telemetry	Baktoft (2003);	Lower river/ estuary (Storaa)
2003	64,500	Hatchery salmon	23	CW-tagging	Jepsen et al. (2010);	Lower river/ estuary (Skjern)
2003	-	Salmon (mix)	> 60[a]	Pellet analyses	Sonnesen (2007);	Lower river/ estuary (Skjern)
2005	10,000	Hatchery salmon	31	CW-tagging	Jepsen et al. (2010);	Lower river/ estuary (Skjern)
2005	58	Salmon (mix)	53[b]	Acoustic telemetry	Koed et al. (2006);	Lower river/ estuary (Skjern)
2005	42	Trout (mix)	88[b]	Acoustic telemetry	Koed et al. (2006);	Lower river/ estuary (Skjern)
2007	69	Salmon (mix)	60[b]	Acoustic telemetry	Baktoft & Koed (2008);	Lower river/ estuary (Skjern)
2007	30	Wild trout	61[b]	Acoustic telemetry	Baktoft & Koed (2008);	Lower river/ estuary (Skjern)
2008	4,363	Wild trout	45[c]	PIT-tagging	Jepsen, Skov, Pedersen & Bregnballe (2014);	Fjord (Mariager)
2009	1,038	Hatchery salmon	79[c]	PIT-tagging	K. Aarestrup, unpublished	Fjord (Mariager)
2009	20	Wild trout	41	Radio-telemetry	Boel (2012);	Lake Hald
2009	5,009	Wild trout	42[c]	PIT-tagging	Jepsen et al. (2014);	Fjord (Mariager)
2008-2010	3,602	Wild trout	42[c]	PIT-tagging	Boel (2012);	Lake Hald
2010	5,900	Hatchery trout	72[c]	PIT-tagging	Thomsen (2013);	Coast (Fynen)
2014	1,400	Wild trout	22[c]	PIT-tagging	Jepsen et al. (2014);	Coast (Fynen)
2016	74	Salmon (mix)	42	Radio-telemetry	N. Jepsen, unpublished	Lower river/ estuary (Skjern)
2016	54	Wild salmon	48[b]	Acoustic telemetry	Flávio, Aarestrup, Jepsen & Koed (2018);	Lower river/ estuary (Skjern)
2017	75	Wild salmon	48	Radio-telemetry	Unpublished	Lower river/ estuary (Skjern)
2017	215	Wild salmon	56[b]	Acoustic telemetry	Flávio et al. (2018)	Lower river/ estuary (Skjern)

[a]Recovery of otoliths gave an estimate of 33,000 salmon eaten, based on weekly counts of birds. The total smolt number from Skjern River was estimated to be 50,000. [b]Survival of smolts through the estuary, other sources of mortality than cormorant predation could be relevant. [c]The proportion of tags recovered is divided by 0.4; assuming a 40% scanning/recovery efficiency (see text).

have been deposited at the water's edge where even very shallow saltwater attenuates the signals. The other methods used required some basic assumptions, for example about scanning efficiency for PIT tags (the proportion of the tags eaten, found in a given colony) or about the cause of loss for acoustic tags. The studies using acoustic telemetry are the most likely to overestimate predation because the cause of the observed mortality/loss is not documented. The figures included in Table 1 are from acoustic telemetry performed in Skjern River/estuary where the studies from 2017 to 2018 showed that cormorant predation accounted for 80%–90% of the total loss. Predation from pike, *Esox lucius* L., in the river is the second highest cause of loss. Thus, it is relatively safe to assume that most of the documented smolt loss in the lower Skjern River/estuary is caused by cormorant predation.

For recovery of PIT tags, Boel (2012) investigated the efficiency of ground scanning for PIT tags under the cormorant breeding colony in Lake Hald and evaluated this in combination with radiotelemetry. He found that 40% of the tags actually taken by cormorants were found in a colony by scanning (further described in Skov et al., 2013; Jepsen et al., 2018). Thus, this proportion takes into account the number of PIT tags regurgitated outside the colony as well as undetected tags in the colony (see also Frechette et al., 2012). The overall question of whether capture, handling and tagging of smolts increase the probability of being eaten by a cormorant is relevant, but hard to resolve (see Jepsen, Christoffersen & Munksgaard, 2008). However, since a range of different methods provided similar predation estimates suggests that this was not a major problem in these studies.

The results in Table 1 were obtained over 20 years in five rivers (Skjern, Storaa, Villestrup, Geels, Bygholm) and one lake (Hald). Lake Hald has two tributaries with populations of migrating brown trout. The trout from the tributaries smoltify and migrate out of the lake during spring. In all 24 individual studies, cormorant predation was consistently found to be over 20%, with a mean of 47%. Migrating smolts are a very time-limited resource, only available for coastal predators during a few weeks. Thus, environmental factors like flow, turbidity, wind and temperature may play an important role in determining the risk of predation for the smolts (Schwinn et al., 2017). Considering this, the variation between 23% and 88% in estimated predation from cormorants is modest across species, years and systems, leading to the conclusion that cormorant predation on smolts generally is an important factor in lowland rivers. This should be taken into account in areas where cormorants are abundant before calculating return rates and applying population models for salmon and trout populations. Furthermore, the increasing body of documentation on the effects of predation must be considered in efforts to restore or improve declining salmon and sea trout stocks. In the last decades a general decrease has been observed in Atlantic salmon stocks, which has been associated with unfavourable ocean conditions (ICES, 2014; Mills, Pershing, Sheehan & Mountain, 2013), but also with problems in fresh water (Friedland et al., 2009; Gibson, 2017). If an increase in predator density has led to a general decrease in return rates (i.e. due to increased predation of parr in rivers, smolts in lower rivers and estuaries and adult returning fish in coast/estuaries), this may contribute, in part, to a viable explanation for the general decrease in salmon stocks. There are still much to be gained by improving smolt production and survival in rivers. Irrespective of how difficult predator control may be, it is certainly more manageable than climate change and general ocean conditions, and should be considered as an option to protect declining salmon populations.

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