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Removal of pikeperch (*Stizostedion lucioperca*) from a British Canal as a management technique to reduce impact on prey fish populations

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Pikeperch in a British canal have been depleted for a period of 16 years in an attempt to reduce their abundance. For the first 11 years, the intensity of removal was low but was then increased. Initially, two dominant cohorts followed each other with a gap of four years. After intensifying removal, there have been no further dominant cohorts. Total pikeperch biomass did not decrease after the change in removal rate, but numbers increased and mean length decreased. It is suggested that in this case, removal of pikeperch increased the intensity of predation on prey fish.

1. Introduction

Pikeperch (*Stizostedion lucioperca*) are not indigenous to the UK (Wheeler & Maitland 1973), but following introduction to Eastern England they have now become established in a wide range of stillwaters, rivers and canals across lowland England (Fig. 1). Pikeperch are highly valued sport fish in mainland Europe (Willemson 1983), but not in British waters where the majority of anglers prefer to catch other fish such as the cyprinids, carp (*Cyprinus carpio*), roach (*Rutilus rutilus*) or bream (*Abramis brama*). Associated with the introduction of pikeperch into some waterbodies has been a simultaneous reduction in the numbers of these cyprinids. Since pikeperch were new to the UK and obviously piscivorous, many anglers and some fishery managers attributed such declines in the cyprinid populations to colonisation by the new predator.

Subsequently, the managers of British waters colonised by pikeperch have often tried to reduce pikeperch biomass by removal programmes (the process hereafter referred to as culling) in the hope that this would maintain or restore the abundance of prey fish. Pikeperch culls have been promoted for the management of many colonised waters. However, the lack of long-term data on the outcome of these programmes has prevented the evaluation of their effectiveness.

Pikeperch were first found in a section of the North Oxford Canal (part of the East Midlands Canal network) in 1976 (Hickley 1986) (Fig. 1). Since 1977, this pikeperch population has been culled annually by the Severn Trent Water Authority (later the National Rivers Authority, Severn Trent Region) (Hickley 1986). During the late 1980s anglers alleged that the fish biomass in the North Oxford Canal had decreased as a consequence of the in-

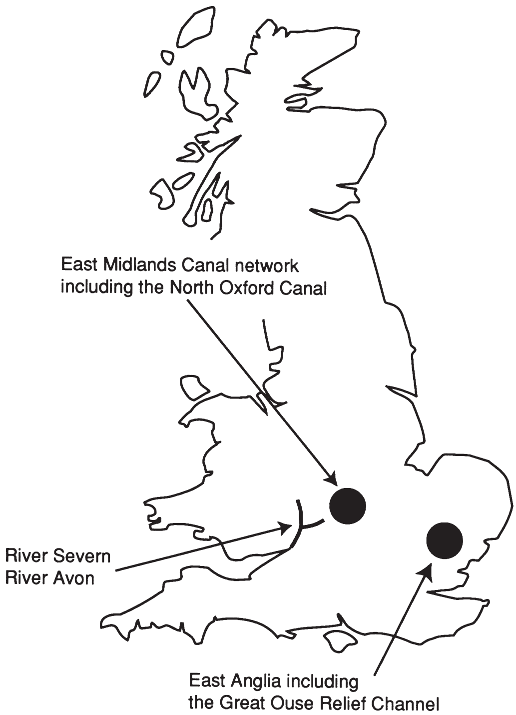

Fig. 1. Geographic location of the areas mentioned in the text.

troduction of pikeperch. Consequently British Waterways, the owners of the canal and managers of the fishery, have also culled the pikeperch since 1988 (Ellis 1994). Quantitative fish population surveys on the North Oxford Canal during 1992 confirmed that the pikeperch-colonised length contained a significantly ($p = < 0.01$) lower biomass of indigenous fish (11.9 g m^{-2}) when compared to the pikeperch-free (23.5 g m^{-2}), but otherwise ecologically similar, adjacent length (Smith *et al.* 1994).

The impact of these culling programmes on pikeperch populations in the North Oxford Canal was investigated using the 16 year data set collected between 1977 and 1992 during the culling operations and supplemented by additional samples collected by the authors in 1992. The implications of changes in pikeperch populations for the populations of their prey fish were assessed by analysis of pikeperch stomach contents obtained in 1992. Growth rates for fish caught in 1992 were compared to those for 1978–1979 and used to estimate predation rates.

2. Methods

The study length comprised a section of the North Oxford Canal between Hillmorton Locks (National Grid Reference SP 538746) and Hawkesbury Junction (National Grid Reference SP 364846). It is one continuous, lock-free body of water and fish are free to move along its length. Immigration and emigration are restricted by navigation locks at each end. This pikeperch-populated section is 26.3 km long, 11 m wide, has a maximum depth of 1.5 m and a water quality high enough to support a good fishery (Table 1). Emergent and submerged vegetation is sparse due to a combination of heavy recreational boat traffic and high water turbidity (Murphy & Eaton 1983).

Pikeperch numbers and sizes (forklength FL), together with effort (area fished) for two culling programmes using similar electric fishing equipment (described in Hickley & Starkie (1985)) were obtained from National Rivers Authority, Severn Trent Region and British Waterways for the period 1977–1992. On each occasion total weight of catch was either recorded or reconstructed from the length frequency data using the following weight — forklength equation derived from pikeperch caught from the North Oxford Canal in 1992 (eq. 1):

$$\mathrm{Log}_{10}Wt = -4.88 + 2.97\mathrm{Log}_{10}FL \quad (1)$$
$$p = < 0.01,\ r^2 = 0.97,\ n = 80.$$

Catch per unit effort (*CPUE*) was expressed in numbers ($CPUE_{nos}$) as pikeperch caught km^{-1} of canal, or wet weight ($CPUE_{wt}$) of pikeperch as kg km^{-1}. *CPUE* results were pooled for each growing season, which consisted of the period from summer (June) to the subsequent spring (March). Fisher (unpublished data), estimated the efficiency of the electric fishing gear used by British Waterways and by employing a depletion method, found that pikeperch > 160 mm *FL* (i.e. aged II or older) were caught with an efficiency of 40%. This is supported by preliminary results from current investigations by the present authors, using the same equipment. In September 1992, 6 sites on the North Oxford Canal were netted to assess numbers of small (< 160 mm *FL*) pikeperch (Smith *et al.* 1994).

Table 1. Summary statistics for 20 water samples obtained from the North Oxford Canal for the period 6 April 88 to 15 October 92. Data supplied from the National Rivers Authority (Severn Trent Region).

	mean	*s.e.m.*
Dissolved oxygen (mg l^{-1})	11.30	0.30
B.O.D. (mg l^{-1})	2.17	0.48
Ammonia (mg l^{-1})	0.06	0.01
Suspended solids (mg l^{-1})	24.20	4.30
pH	8.00	0.10
Conductivity (µS cm^{-2})	735	22

s.e.m. – standard error of the mean
Samples taken at Newbold (National Grid Reference SP 494 773)

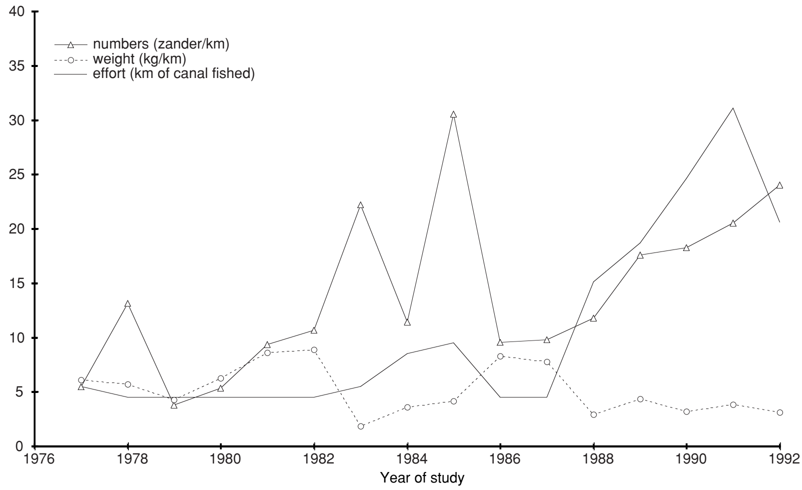

Fig. 2. Relationship between Catch Per Unit Effort (*CPUE*) for pikeperch numbers (pikeperch km^{-1}), pikeperch weight (kg km^{-1}) and effort applied (km of canal fished). Data from the North Oxford Canal (1977–1992).

The size structure of the catch was analysed for each growing season. Mean weights for each growing season were also calculated.

Pikeperch age was determined from scales, a technique found to be satisfactory by Fickling (1982), Willemson (1983) and others. The numbers of each age class for the 1992 population were calculated from an age-length key (Table 2). Total mortality was calculated from a smoothed catch curve analysis (Ricker 1975), based on population density estimated from electric fishing and netting data (Table 3). The estimates of fishing mortality were based on the efficiency of the gear and do not include mortality from any other sources such as recreational angling.

The stomach contents of 114 pikeperch collected by electric fishing in March 1992 were examined. Prey items were identified to species level where possible. Identification of prey fish remains was aided by examination of pharyngeal teeth and the pre-digested forklength of these fish were estimated using formulae provided by Fickling (1982).

3. Results

3.1. Catch and effort

Trends for effort, $CPUE_{wt}$ and $CPUE_{nos}$ are given in Fig. 2. Effort remained uniform and relatively low between 1977–1987 and from 1988 it increased. $CPUE_{nos}$ varied, but increased for the periods 1979–1985 and 1986–1992. $CPUE_{wt}$ increased for the periods 1979–1982 and fluctuated with no obvious trend for the period 1983–1992.

At low fishing intensity (< 10 km of canal fished per year) the *CPUE*s were variable (Fig. 2). As effort increased, regression analyses indicated a significant, but weak relationship between $CPUE_{nos}$ and effort (eq. 2):

$$CPUE_{nos} = 8.97 + 0.47 Effort \quad (2)$$
$$p = 0.04,\ r^2 = 0.29,\ df = 15.$$

The relationship between $CPUE_{wt}$ and effort was not significant (eq. 3):

$$CPUE_{wt} = 5.88 + 0.44 Effort \quad (3)$$
$$p = 0.62,\ r^2 = 0.02\ df = 15.$$

3.2. Removal intensity and size-structure of the caught pikeperch

Fig. 3 illustrates the mean weight and modal length of pikeperch for the period 1977–1992. Both modal length and mean weight increase for the periods 1979–1982 and 1983–1987, but not in the subsequent period 1988–1992. For the period 1988–1992, the modal length and mean weight fluctuate but did not exhibit any obvious trend.

3.3. Growth and mortality

There are no 'standard growth curves' (such as published for other species by Hickley and Dexter

Table 2. Age for length key for the 1992 pikeperch population of the North Oxford Canal.

Age class	*FL* range (mm)	Mean (mm)
I	< 180	120
II	180–275	227
III	280–375	327
IV	380–475	427
V	480–560	520

(1979)) so growth has been compared with some example data from Continental Europe. The growth of pikeperch in the North Oxford Canal is intermediate when compared to two European populations (Deelder & Willemson 1964) and there is little difference for the two periods of study (Table 3). The L_∞ for the two North Oxford Canal populations decreased from 1 751 mm in 1978–1979 to 1 189 mm in 1992 compared with 1 168 mm and 925 mm for the European populations.

The instantaneous mortality coefficient of the 1992 population was calculated by the regression of ln year class abundance against age. The value attained for the slope (1.22) is equivalent to a survival rate ($S = e^{-z}$) of 30% per annum (eq. 4):

$$\ln abundance = 5.08 - 1.22 Age \quad (4)$$
$$p = < 0.001,\ r^2 = 0.96,\ df = 4.$$

For the period 1977–1987, < 10 km of canal was culled representing < 38.0% of the entire canal being fished. Assuming the removal efficiency to be 40% for pikeperch > 160 mm then the fishing intensity equalled 40% × < 38% = < 15.2%. For the period 1988–1992, the intensity was approximately 20 km of canal, representing 30.4% of pikeperch > 160 mm being removed. Total annual mortality from the catch curve analysis for this period was 70%.

3.4. Pikeperch feeding

The stomach contents for each age group of pikeperch are given in Table 4. The majority of prey items were fish, although invertebrates e.g. *Asellus aquaticus* and *Lumbricus terrestris* were present in 10.5% of the stomachs. As the age of pikeperch increased, the proportion of roach decreased and the proportion of bullheads increased. Pikeperch < 120 mm *FL* were found in pikeperch aged II and III. The mean length of prey increased with the age of the pikeperch.

4. Discussion

Pikeperch has a preferred biotope of relatively warm, productive waters which are still or slow moving and have a high turbidity (Deelder & Willemson 1964). They can also breed in areas that have no macrophytes, heavy siltation and low dissolved oxygen concentration (Marshall 1977). A self-sustaining population of pikeperch has developed in the North Oxford Canal since 1976, despite considerable efforts to stop this by programmes of culling. This certainly indicates that the environmental conditions in the canal are suitable for all life stages of pikeperch.

Table 3. Abundance and growth rates of pikeperch in the North Oxford Canal.

	Age group of pikeperch I	II	III	IV	V
***CPUE*$_{nos}$ (pikeperch km^{-1})**					
Netting results	62.9	8.6	1.4	0	0
Electrofishing results	3.2	8.3	3.6	2.0	0.3
1992 data					
Pikeperch ha^{-1}	57.2	18.9	8.2	4.6	0.7
Smoothed pikeperch ha^{-1}	65.6	22.0	7.4	2.5	0.8
Mean forklength (mm)	119	231	330	432	500
s.e.m.	11.9	6.8	6.2	19.0	–
n	4	18	15	3	1
Mean weight (g)	19	135	391	869	1 343
Pikeperch (kg ha^{-1})	1.25	2.97	2.89	2.16	1.12
1978–9 data					
Mean forklength (mm)	100	198	301	358	445
s.e.m.	16	33	99	13	8
n	3	5	3	7	8

s.e.m. — standard error of the mean.
Assuming that netting was 100% efficient for pikeperch < 160 mm, electric fishing caught these with an efficiency of 12.7%.

Fig. 3. Modal length and mean weight for pikeperch caugh from the North Oxford Canal (1977–1992).

The data in this study are provided from fish caught in removal programmes using electric fishing methods. Using the results from such operations has a number of limitations. Electric fishing is size-selective (Borgstrom & Skaala 1993, Table 3) and the actual catch-efficiency may have varied from year to year depending on weather conditions. Further problems may have been introduced to the data if culling activities were focussed by the operatives on areas with perceived aggregations of pikeperch. Despite these limitations, useful information can be derived from an analysis of the catch data.

4.1. Abundance, growth rate and mortality of pikeperch in the North Oxford Canal

Dominant cohorts passed through the pikeperch populations of the canal during the periods 1979–1982 and 1983–1987. This was evident in the fluctuations in modal size and mean weight (Fig. 3). A strong year class of young pikeperch was only produced when large pikeperch (> 375) mm *FL* were low in abundance. For the period 1989–1992, when removal intensity was high, there were few of these large pikeperch and many young pikeperch appear to have survived. As the fishing method used to remove pikeperch during culling is strongly size-selective, a high intensity of culling may eventually produce a reduction in modal length and mean weight in the population. In 1992, with relatively high levels of mortality due to culling, the numbers of pikeperch in very small size classes were high but biomass was dominated by fish aged II–IV (Table 3). This is a notable contrast with the period 1979–1987.

Trends in abundance of pikeperch in the study area were followed using *CPUE* data and analysed by regressing *CPUE* as a function of effort (eqs. 2 and 3). The use of arithmetic regression for this type of data has been criticised (Ricker 1975), but if applied suggest that pikeperch numbers increased with application of greater effort. Thus it is possible that removal of circa 30% of pikeperch > 160 mm *FL* brought about an increase in numbers. There is no significant effect of effort on $CPUE_{wt,}$ suggesting that biomass is independent of culling intensity.

The data on pikeperch growth presented in Table 3 are based on a fairly small sample size of fish and conclusions therefore need to be cautious. There are no average growth curves for British pikeperch, but the North Oxford Canal populations have been

Table 4. Stomach contents of pikeperch caught in 1992 from the North Oxford Canal.

Age class of pikeperch	I	II	III	IV
Stomachs examined (*n*)	15	29	34	17
Stomachs empty (*n*)	3	4	9	3
Prey type				
Unidentified fish	3	6	18	4
Roach (*Rutilus rutilus*)	3	16	6	1
Bullhead (*Cottus gobio*)	0	5	11	17
Pikeperch (*Stizostedion lucioperca)*	0	2	1	0
Perch (*Perca fluviatilis*)	0	0	0	1
Lumbricus terrestris	0	1	3	1
Asellus aquaticus	3	2	1	0
Mean length of prey				
Fish (mm)	34	49	49	68

compared to two European populations used as examples of fast and slow growth by Deelder and Willemson (1964).The mean length for age of pikeperch in the North Oxford Canal is intermediate and there is little difference between the two periods of study (Table 3). However, the L_∞ for the two canal populations has decreased from 1 751 mm in 1978–1979 to 1 189 mm in 1992.

Mortality was calculated from the estimates of abundance of each age class (catch curves), obtained for age groups II–V by electrofishing and for age group I by netting. Despite the uncertainties involved, a similar value was obtained to those from various European waters (Table 5). It should be noted, however, that the nature of the fishing mortality in European waters will be different from that in British waters because of the considerable harvest of fish taken by Continental anglers. In the UK, the fishing mortality in the absence of culling programmes is probably quite low because few recreational anglers target pikeperch or remove them for eating.

4.2. Pikeperch feeding and potential impact on prey fish

The impact that a population of pikeperch will have on the prey fish populations will be determined by the number and type of prey fish eaten. As ration is influenced by temperature, individual pikeperch size and growth rate (Elliott 1976, Willemson 1983), the number and type of prey eaten for a given temperature range will be affected not only by the total biomass of pikeperch present in a waterbody but also by the population size-structure of the predator (Popova 1978). In exploited fish populations, where large fish are removed in a size-selective manner, the remaining fish population often shows a reduction in mean size, a density-dependent increase in growth rate and a reduction in age of maturity (Bagenal 1977, Biro 1985, Weatherley 1987). Consequently the removal intensity achieved during the culling programme may affect the size-structure of the remaining pikeperch population. This in turn has implications for the number and type of prey fish removed from the fishery by subsequent pikeperch piscivory. This was investigated by a diet study.

Table 5. Percent annual total, natural and fishing mortality for various populations of pikeperch.

Location	Mortality	Natural	Fishing	
Suokumaanjarvi	0.70	0.20	0.50	(1)
Aland (brackish)	0.58	0.39	0.19	(1)
Helsinki	0.30	0.25	0.05	(1)
L. Balaton (1973–75)	0.65	0.24	0.41	(2)
Balaton (1984–85)	0.3–0.7	0.1–0.2	0.2–0.5	(2)
North Oxford Canal (1992)	0.70	0.40	0.30	(3)

Author: — (1) Lind (1977), (2) — Biro (1985), (3) — present study.

Young pikeperch feed initially on zooplankton and become piscivorous at 50–100 mm (Collette *et al.* 1977) though they may eat invertebrates if prey fish are scarce or invertebrates large or numerous (Popova & Sytina 1977). Pikeperch are opportunistic piscivores (Marshall 1977) with the annual feeding patterns closely linked to seasonal abundance of food (Popova & Sytina 1977, Popova 1978). Pikeperch eat small fish (< 100 mm) and for a given availability of prey, both the size and species of prey varies as pikeperch increase in size (Popova 1978, Willemson 1983). This implies that the nature of the impact on prey fish populations will be strongly influenced by the size composition of the pikeperch population.

The diet results obtained from the North Oxford Canal population (Table 4) reflect the general findings of other UK workers (Fickling 1982, Kell 1985) even though they are based on a small sample obtained from just a single season. The pikeperch stomachs examined in this study mainly contained fish less than 80 mm *FL* (roach and bullhead with a low number of aged I pikeperch), or, in a few cases, invertebrates (usually either *Asellus aquaticus*, which is abundant in the canal or the large *Lumbricus terrestris*) (Table 4). As pikeperch size increases, the composition of prey changes, with small pikeperch (aged I) consuming roach and *Asellus*. At the same time, roach decrease in importance whilst bullhead increase and the mean length of prey also increases. This suggests that not only the species eaten by pikeperch, but also the size range is dependant on pikeperch size.

4.3. Population regulation of pikeperch in the North Oxford Canal

The abundance of fish in any water is dependant on the difference between natality and mortality (Weatherley & Gill 1987). A high juvenile mortality in a large predatory fish is commonly associated with cannibalism (Lind 1977, Popova & Sytina 1977, LeCren 1987, Van Densen & Grimm 1988) or size-dependant winter mortality (Buijse & Houthuijzen 1992). Barthelmes (1988) found that in all thorough investigations of pikeperch populations, cannibalism was observed, though its importance is increased when there are high numbers of large pikeperch and few alternative prey (Loadman *et al.* 1986). Slow growth of juvenile pikeperch caused by cool temperatures and low food availability increases the risk of winter mortality and predation (Van Densen & Grimm 1988) The likelihood of slow growth may be increased by large numbers of juvenile conspecifics, few invertebrate prey and failure to switch to piscivory (Buijse & Houthuijzen 1992). Other factors such as temperature regime, habitat, nutrient status and intensity of fishing determine the relative importance of these factors and can lead to the wide variations in recruitment commonly observed in European populations (Bagenal 1977, Willemson 1977, Willemson 1983, Van Densen & Grimm 1988).

In this study, although only 2.6% of examined pikeperch had eaten conspecifics (Table 4) small individuals (aged I) were found to be eaten by pikeperch aged II and III. As the biomass of pike in the North Oxford Canal is low (Smith *et al.* 1994) and there are few avian and mammalian piscivores of pikeperch, cannibalism, mainly of age group I fish, may be a factor regulating overall abundance of pikeperch (Ricker 1954, Polis 1981, Willemson 1983, Biro 1985). The data presented here on abundance, intensity of removal and diet lead to the hypothesis that at low removal intensity (circa 15% of pikeperch *FL* > 160 mm per year), the pikeperch population in this canal is regulated by cannibalism. Then as removal intensity increases to circa 30% decreasing numbers of larger pikeperch, the intensity of cannibalism is reduced and relatively higher numbers of young will survive. This type of effect may occur in other piscivorous fish species e.g. pike (*Esox lucius)* (LeCren 1987), Arctic Char (*Salvelinus alpinus*) (Amundsen *et al.* 1993), perch (Thorpe 1977) and walleye (*Stizostedion vitreum*) (Reid & Momot 1985).

4.4. Management implications

The North Oxford Canal fishery is based on recreational angling, predominantly for cyprinids and as pikeperch may reduce cyprinid biomass (Smith *et al.* 1994), management action in the form of culling is potentially useful to protect the fishery and to assure anglers that pikeperch populations are being controlled. The data presented here provide an insight into the effects of two differing intensities of culling, applied to the same area but at different times. Unfortunately, the effects of culling may be masked by the natural development of the population following colonisation. Culling intensity was comparatively low during 1977–1987, (< 15% of the > 160 mm *FL* pikeperch present). During this period, the pikeperch population consisted of two strong cohorts separated by periods of poor reproductive success. Culling intensity was increased in 1988 (circa 30% average for 1988–1992) and subsequently the dominance of single cohorts was reduced and some successful reproduction occurred each year.

The implication of these findings is that the intensity of pikeperch culling can change the size distribution of the pikeperch population. Because of the strong, size-selective nature of pikeperch predation on cyprinids, this will affect the intensity and nature of the impact on prey fish stocks. A further implication is that culling of an intensity sufficient to reduce the number of large pikeperch, could increase the number of small pikeperch surviving to subsequent years. Whilst this has been demonstrated to have occurred in the North Oxford Canal under one particular set of circumstances, it is not known how general this effect will be. The impact that different culling intensities will have on pikeperch communities and the implications for the abundance of prey fish remains to be fully evaluated and will require a detailed investigation of pikeperch feeding in relation to population structure, habitat, season and prey availability.

Against this background, the use of electrofishing, which has a relatively low overall efficiency in combination with a very low efficiency for small pikeperch, presents problems for the design of successful removal programmes. The culling of all pikeperch from this canal would be technically difficult, present problems and may not present a cost effective option.

5. Conclusions

1. A self-sustaining population of pikeperch has become established in a section of the North Oxford Canal.

2. Differences in culling int ensity were associated with changes in the size structure of the pike-perch population. At low culling intensity, the pikeperch population was dominated by sequential, dominant cohorts persisting for a period of approximately 5 years.
3. Intensive size selective culling removes large pikeperch, disrupts the domination by a single year class and may produce a population consisting of many young pikeperch.
4. The impact that pikeperch have on prey populations will depend on abundance and size structure of the pikeperch population, both of which may be influenced by the intensity of culling.

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