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Stocking results of spray-marked one-summer old anadromous European whitefish in the Gulf of Bothnia

Ari Leskelä[1], Erkki Jokikokko[2], Alpo Huhmarniemi[3], Antti Siira[3] & Heikki Savolainen[1]

[1)] *FGFRI, Quark Fisheries Research Station, Korsholmanpuistikko 16, FIN-65100 Vaasa, Finland*
[2)] *FGFRI, Bothnian Bay Fisheries Research Station, Jenssintie 2, FIN-95200 Simo, Finland*
[3)] *FGFRI, Oulu Game and Fisheries Research, Tutkijantie 2 A, FIN-90570 Oulu, Finland*

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About 6 million one-summer-old, fluorescent pigment marked whitefish were released in the northern and central parts of the Gulf of Bothnia in 1995–1998. Growth and dispersal of the stocked fish were followed by detecting and recording marked whitefish in samples from the professional fisheries catch during 1999–2002. The yield produced by stocked fish was estimated by assuming that the proportion of the marked fish in the total catch was the same as in the samples. The total yield from the stockings in 1995 was estimated to be 55–90 kg/1000 released fingerlings. A better result from the stockings could be achieved by increasing the recruitment size in the fishery. Even for the 1995 stockings, a few of the released fish were probably still migrating in the sea at the end of the study period, although the main part had already been caught. For fish released in 1996 or later, no exact estimates of total yield can be given, as a considerable part of the catch was still to come. The estimates from the preliminary re-catches, however, suggest that the stockings in northern parts produce lower catches than stockings in central parts of the Gulf of Bothnia.

Introduction

European whitefish (*Coregonus lavaretus* (L.)) is one of the most important fish species in the professional and recreational fisheries in the Gulf of Bothnia. Two whitefish forms, whose life histories differ from each other are represented: a river-spawning, anadromous form and a sea-spawning form. Anadromous whitefish migrates to southern feeding areas and grows fast, whereas the sea-spawning form lives more stationary in the sea and reproduces there (Lehtonen & Himberg 1992). Especially in the Bothnian Bay, the sea-spawning form grows more slowly than the anadromous one (e.g. Lehtonen 1981). Due to the differences in the growth rate in the north and small population sizes of the sea-spawning stocks in the south, the anadromous form is nowadays most important to the fisheries.

Most stocks of the anadromous whitefish have suffered due to the construction of hydropower dams and other human activities in the spawning rivers. To compensate these negative effects and to increase catches, both one-summer-old and newly hatched anadromous whitefish are commonly stocked. The stocking numbers in the Gulf of Bothnia have been relatively stable in recent years: 6–8 million one-summer old fingerlings and about 60 million newly hatched whitefish per year. In spite of habitat loss and degradation, anadromous whitefish still reproduces naturally in many of the rivers running into the Gulf of Bothnia. In some rivers, the stocks are still strong and maintain river fisheries, whereas in others they are nearly extinct. Even in most of the rivers with natural reproduction the stocks are supported with stockings.

In spite of the large stocking programmes, the whitefish catch in the Gulf of Bothia has been decreasing since 1998, and was in 2002 at its lowest level since 1985. Fishing effort has risen from the 1980s to the 1990s and there has been a trend towards smaller mesh sizes. There are evident signs of overfishing, and the intensive fishing has been concluded also to have effects on the population structure of the spawning stock (Lehtonen & Jokikokko 2002). However, in the Gulf of Bothnia it is unclear how the sea fishery targets the anadromous whitefish stocks, as the catch consists of both anadromous and sea-spawning whitefish. Information on exploitation patterns obtained through marking is, therefore, needed before managers and fishermen from various regions can reach a compromise on whether, where, when and how the fishery should be regulated.

The results of the stocking programmes have been questioned as well. The size of the stocked fingerlings is smaller than that of one-summer-old whitefish in the nature (Jokikokko *et al.* 2002), and there have been doubts about whether they survive after stocking. Especially in the northern Bothnian Bay the fishermen's opinion is that at present the compensatory programmes are not working and the damage caused by hydro-power plants and industrial activity is not fully compensated through stocking. Although there are reports of positive impacts of whitefish stockings in inland waters (Klein 1988, Rasmussen 1988, Salojärvi 1992), the effects of the large-scale stocking programs in the Gulf of Bothnia are poorly known. Due to differences in the ecology, chemistry and morphometry, the stocking results in large brackish-water basins may differ from that obtained in lakes. In the Gulf of Finland, whitefish stocking has been estimated to produce a catch of 100–250 kg/1000 stocked fingerlings (Raitaniemi *et al*. 1996, Saura & Mikkola 1996), a figure well above the results usually obtained in lakes.

The main difficulty in estimating the stocking results in the Gulf of Bothnia is that natural and stocked whitefish cannot be separated from each other on the basis of external characters. Several methods for separating wild and stocked fish have been evaluated (e.g. Schwarzberg *et al.* 1993), but it was only when the fluorescent pigment spraying method was found to be suitable, that it was realistic to carry out a large marking program in the Gulf of Bothnia. After some preliminary trials, a large-scale marking program was started in 1995 and continued until 1998. During this period, altogether approximately 6 million one-summer-old anadromous whitefish were marked before stocking.

As the catches have decreased, there has been an increasing demand either to change the current stocking practises or to start regulating the whitefish fishery. The aim of this paper is to explore the results of the extensive whitefish markings in the Gulf of Bothnia in order to evaluate the benefits of the prevailing stocking programs and to identify any potential needs to change the current management of the whitefish fishery.

Materials and methods

Marking and stocking

Fluorescent pigment spraying is a group marking method developed by Jackson (1959). It has been used with variable results for several fish species (Phinney & Matthews 1973, Rinne & Deacon 1973, Strange & Kennedy 1982, 1984, Pierson & Bayne 1983). In coregonids, it produces a mark that lasts for several years (Leskelä 1999). The marking procedure used in this study is described in detail by Friman and Leskelä (1998). The marked fish were a part of the whitefish fingerlings used in compensatory stocking programs in the Gulf of Bothnia, produced and stocked by several companies using a routine semi-intensive pond method (Leskelä *et al*. 1998). Marked fingerlings were stocked to three locations close to each other in the southern Bothnian Bay and to one location in the northern Bothnian Bay (Fig. 1.)

Three colours produced by Swada Ltd, London, UK, were used in the marking. The colours are named by the producer as lunar yellow (LMP 27), tellar green (LMP 8) and flame orange (LMP 4). Combinations of orange + yellow and orange + green colours were also used, giving a total of five colour codes. However, during the sampling phase it became evident that the green and yellow colour could not be separated, which reduced the number of colour codes to three. Some groups originally considered as separate thus had to be combined. In 1996, this led to a mixed group, which included whitefish stocked both in the northern and southern Bothnian Bay. In 1995 and 1996 all three colour codes were used in the marking, whereas in 1997 and 1998 only one colour was used each year (Table 1). When the same colour had been used in successive years, the combination of fish age and pigment colour formed a specific mark.

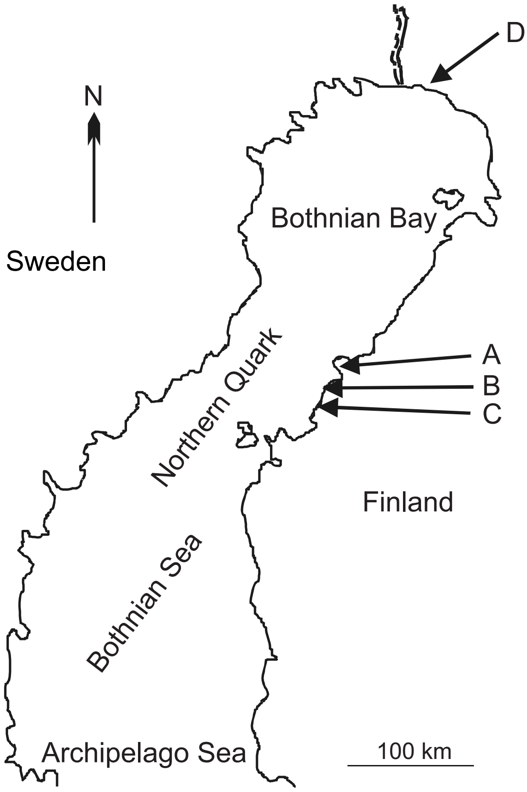

Fig. 1. A map of the Gulf of Bothnia. Stocking places in the southern (A–C) and in the northern (D) Bothnian Bay are shown with arrows.

Sampling and ageing

Whitefish were sampled from the professional fisheries catches from 1999 to 2002. Sampling was targeted on the main gears and main fishing seasons of the professional whitefish fishery (Table 2). The main gears in the Gulf of Bothnia whitefish fishery are bottom nets and trap nets, which together took over 90% of the yearly professional whitefish catch in the years 1999–2002. For the bottom nets, the fishery continues practically round the year with peak seasons in early summer and autumn, whereas trapnets are mainly used during the spawning migration in late summer and early autumn. The sampling

Table 1. Numbers and mean total lengths of the whitefish fingerling groups marked and stocked in the Bothnian Bay. Stocking places are presented in Fig. 1.

	Pigment used	No. of marked fish	Mean total length (S.D.)	Stocking place
1995	Yellow/green	320 000	106.8 (18.7)	A
1995	Orange	190 000	99.0 (9.9)	C
1995	Yellow/green + orange	175 000	105.2 (8.8)	A and B
1996	Yellow	395 000	99.4 (8.6)	A and B
	Green	1 320 000	99.6 (3.64)	D
1996	Orange	360 000	103.4 (7.2)	C
1996	Yellow + orange	140 000	102.0 (5.2)	A
1997	Orange	1 500 000	88.0 (5.10)	D
1998	Yellow	1 400 000	89.7 (4.23)	D

area was selected on the basis of earlier taggings of adult migratory whitefish reviewed by Lehtonen and Himberg (1992) and covered the whole Gulf of Bothnia, including the Archipelago Sea in the south. Sampling of pre-recruit whitefish in the by-catch of Baltic herring fisheries verified that marked fingerlings followed the migration pattern observed in tagged adult whitefish (Leskelä *et al*. 2002). Samples were collected from both the Finnish and Swedish sides of the Gulf, although mainly from the Finnish side.

Sampling from the professional fisheries catch was done either in the fish harbours or in the stores of wholesale purchasers, or a fish sample was bought from fishermen and brought to the laboratory. Marks were detected in a dark room, which in most cases was available in the cold storage rooms of the fish harbours. A single 18 w ultraviolet light tube (OSRAM L 18W/73) was used. Whenever possible, the marked fish were bought and subsequently measured and aged in the laboratory. For those fish, ageing was based on burned or dyed otoliths. If there were difficulties in counting the age rings in the otoliths, also operculum and sometimes scales were studied to assure the interpretation. When the fish could not be bought, they were measured in the fish harbour and scales taken from between the ventral fins were used in ageing. Sampling was partly done by professional fishermen, who were trained to detect the marks. All the marked fish found by fishermen were bought and the marks were verified by research personnel. In Finnish fisheries, whitefish is normally gutted before landing. In such cases, the fish weight was calculated as round weight = 1.08 × gutted weight (Anon 2002a). Information on fish sex was only obtained when we bought ungutted samples from the fishermen.

Non-professional fishermen take almost half of the whitefish catch in the Gulf of Bothnia. However, the non-professional catch is very scattered in time and place. Approximately 35 000 households caught whitefish non-professionally in the Gulf of Bothnia in 2000 (Anon. 2002b). For practical reasons, we were not able to build a sampling program for non-professional catches.

Catch estimates

Estimates of the catch produced by marked whitefish were obtained using the Petersen mark–recapture method (Ricker 1975), based on the assumption that the proportion of marked fish in a random sample is the same as the pro-

Table 2. Number of sampled whitefish and marked whitefish in the samples by year, area and gear. River samples not included. Sampling areas are shown in Fig. 1.

Year	Area	Gear	No. of sampled fish	No. marked in the samples	Marked (%)
1999	Bothnian Sea	Gill net	1322	26	1.97
1999	Northern Quark	Gill net	2270	45	1.98
1999	Northern Quark	Trap net	6644	240	3.61
2000	Archipelago sea	Gill net	2626	79	3.01
2000	Northern Quark and Bothnian Sea	Gill net	564	39	6.91
2000	Northern Quark	Trap net	4722	325	6.89
2000	Bothnian Bay	Trap net and gill net	15689	88	0.56
2001	Archipelago Sea	Gill net	4167	44	1.06
2001	Bothnian Sea	Gill net	2816	76	2.70
2001	Northern Quark	Gill net	2647	66	2.49
2001	Northern Quark	Trap net	8099	504	6.22
2001	Bothnian Bay	Gill net and trap net	12403	344	2.77
2002	Archipelago Sea	Gill net	4298	29	0.67
2002	Bothnian Sea	Gill net	3500	148	4.23
2002	Northern Quark	Gill net	4825	178	3.69
2002	Northern Quark	Trap net	3047	130	4.27
2002	Bothnian Bay	Trap net and gill net	5930	196	3.31

portion of marked fish in the whole catch. The estimation formula was:

$$C_e = (N_m/N_c) \times C,$$

where C_e = estimated catch produced by marked fish, N_m = number of marked fish in a sample, N_c = total number of fish in a sample, and C = total catch obtained from statistics.

Calculations were made separately for each year, area and gear, as the proportion of anadromous whitefish and marked individuals varied among areas and gears. Yearly catches in different areas and with different gears were obtained from the official catch statistics. For professional fisheries, catch statistics were based on the catch notifications made by the fishermen (Anon. 2000a, 2001, 2002a). For the gears which were not sampled, we used a mean proportion of marked fish in bottom gillnets in that area. For non-professional fisheries, catch estimates were available for the years 1998 and 2000 (Anon 2000b, 2002b). For the year 1999 the average of the 1998 and 2000 estimates was used, and for the year 2001 the value from 2000. When calculating the catch of marked fish in non-professional fisheries, the proportion of marked fish in the commercial bottom gillnet catches of the respective area was used. Over 90% of the non-professional whitefish catch in Finland is caught with gillnets (Anon 2000b, 2002b).

Results

Sea migration, growth and maturation

Marked fish were found in the whitefish catch of professional fisheries from the northernmost part of the Bothnian Bay to the Archipelago Sea in the south. Only three marked whitefish were found on the Swedish side among 2676 whitefish checked in 1999–2002. Recruitment to the commercial whitefish fisheries in the Gulf of Bothnia started at the latter part of the third summer in the sea (age 3+). At that age, marked whitefish had reached a mean length of 330–340 mm and mean weight of slightly above 300 g (Fig. 2). Only a few fish at age 3+ were caught with other gears than bottom gill nets. Growth of the stocked fish has been stable and relatively fast through the sampling years, and there were no significant differences in the size at age between the year-classes (Fig. 2).

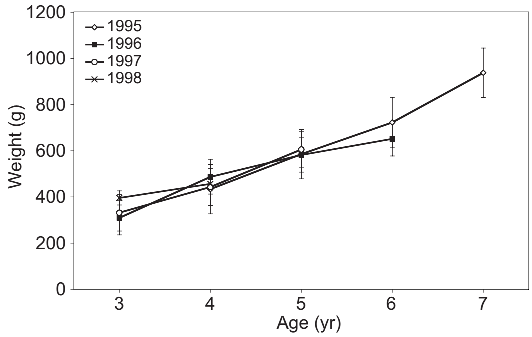

Fig. 2. Mean weights at age for various year-classes of marked anadromous whitefish caught in the professional fisheries. Data on all marking groups are included. Error bars show standard error of the mean.

After reaching maturity, the whitefish started their spawning migration to the north, and mainly mature fish were captured in the trapnet and gillnet fisheries in the Bothnian Bay and Northern Quark. Among the mature fish, only a few specimens of age-group 3+ were observed and those were all males. Females became mature at an older age than males (Fig. 3). Also within an age-group, female spawners were larger than male spawners. The average weight of five-year-old male spawners was 533 g in the Northern Quark and 507 g in the Bothnian Bay. Female spawners of the same age were 657 and 708 g, respectively. The difference between males and females was statistically significant (t-test: $p < 0.01$ in both areas). Males clearly outnumbered the females in the spawning population. In the Bothnian Bay, 24% of the sexed spawners were females and in the Northern Quark only 13% (Fig. 3).

Catch estimates

Catch estimates were calculated separately for all marking groups (Table 3). The catch produced until the end of the year 2002 by the southern Bothnian Bay stocking in 1995 varied from 53.2 to 90.1 kg/1000 fingerlings, depending on the stocking site. The stocking in 1996 had by the end of 2002 produced a catch of

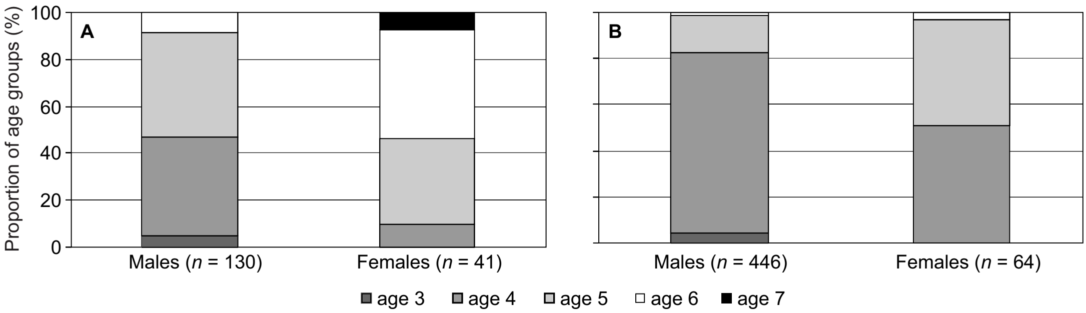

Fig. 3. Proportion of age groups in the marked whitefish caught during the spawning run in (**A**) the Bothnian Bay and in (**B**) the Northern Quark. Data on all marking groups are included.

51.2–79.9 kg/1000 fingerlings for the southern stocking site and 44.4 kg/1000 fingerlings for the group which includes fish stocked at sites in both northern and southern Bothnian Bay. For the stockings in 1997 and 1998, respectively, only 16.4 and 4.6 kg/1000 stocked fingerlings had been caught by the end of 2002, and a considerable part of the catch produced by these stockings is still to be caught during the next years.

The age-structure of the catch produced by marked fish (Fig. 4) demonstrates a high fishing pressure in the Gulf of Bothnia whitefish fisheries. Most of the fish from year-class 1995 were captured at an age of 4+, i.e. the age when the main part of the fish reached a fishable size. Almost all of the yearly fishery takes place before spawning time, so most of the stocked whitefish are caught before their first spawning. This is especially the case for the females, which reach sexual maturity later than the males.

Discussion

Our main conclusion is that at present the growth potential of the stocked whitefish is poorly utilized in the Gulf of Bothnia fisheries. Although the growth of the fish remains steady at least until the age of 7+, the fishery targets them very effectively already at the age of 4+. There is a possibility to increase the catch produced by whitefish stocking in the Gulf of Bothnia by increasing the recruitment size in fisheries. This effect is most easily achieved by regulating mesh sizes of bottom nets, which are used to catch growing whitefish in the feeding areas.

The heavy fishing pressure also leads to a low number of spawners in naturally reproducing stocks. The number of the whitefish spawners ascending the rivers is not estimated in Finland, but the river catch, e.g. in Torniojoki, has decreased and stayed at a low level since

Table 3. Catch estimates (as catch per 1000 stocked fingerlings) for the whitefish fingerlings marked and stocked in the Bothnian Bay. Stocking places are shown in Fig. 1.

Pigment used	Stocking year and place	Catch produced as kg/1000 stocked fingerlings until January 2002				
		1999	2000	2001	2002	Total
Yellow/green	1995 A	31.9	15.1	4.8	1.4	53.2
Orange	1995 C	76.2	4.6	7.2	2.1	90.1
Yellow/green + orange	1995 B	45.3	8.0	3.8	0.2	57.3
Yellow	1996 A and B	1.1	24.3	12.7	6.3	44.4
Green	1996 D					
Orange	1996 C	5.8	40.3	23.8	10.0	79.9
Yellow + orange	1996 A	6.4	20.1	17.3	7.4	51.2
Orange	1997 D	0	3.2	4.9	8.3	16.4
Yellow	1998 D	0	0	0	4.6	4.6

the early 1990s (Lehtonen & Jokikokko 2002). It is possible that one reason behind the sinking catch trends in the Gulf of Bothnia is low natural whitefish production due to lowered spawning stocks.

Compared with results reported for Finnish lakes, the large Gulf of Bothnia stocking programs gave a result which might be characterized as usual. Stocking results in lakes have been very variable: from two to 250 kg/1000 one-summer old fingerlings with the mean of 55–60 kg (Salojärvi 1992). As the Gulf of Bothnia stocking results, even with the present exploitation pattern, are close to the mean presented by Salojärvi (1992), we consider the present stocking practises acceptable. On the other hand, the results of whitefish stocking in the Gulf of Finland are clearly higher than in the Gulf of Bothnia. Compared to the Gulf of Bothnia and most of the Finnish lakes, the Gulf of Finland is warm and eutrophic and natural whitefish stocks are low, which partly explains the good stocking success. Also the fishery in the Gulf of Finland is different from that in the Gulf of Bothnia: whitefish is caught mainly as a by-catch and the recruitment size to the fishery is larger (Raitaniemi *et al.* 1996).

In our data there was no evident link between stocking size and stocking success. Size-dependent mortality has been observed both in stocking experiments and studies of natural young-of-the-year fish in many species (e.g. Champigneulle & Gerdeaux 1992, Buijse & Houthuijzen 1992, Kirjasniemi & Valtonen 1997, Gunn *et al.* 1987, Post & Evans 1989). On the other hand, Salojärvi (1991) found no dependence between stocking size and stocking success of one-summer old whitefish in a Finnish lake. The results of the first winter survival of stocked whitefish by Jokikokko *et al.* (2002) suggest that a relationship exists between stocking size and stocking success in the Gulf of Bothnia as well. However, differences in the mean size of the stocked groups were small in our data, and possible size effects were hidden by differences in condition, health, stress level or other characteristics of the stocked fingerling groups, or differences in stocking places.

Although the catch estimates for stockings in the northern Bothnian Bay are preliminary, they suggest that stocking in this area produces less catch than that in the southern Bothnian Bay. There are several possible reasons for that, and probably more than one of them lie behind the difference. The feeding migration is longer for the northern groups, and they start migration later, which retards their growth (Leskelä *et al.* 2002). The long winter in the north may cause lower survival as well, especially for the small fingerlings. As shown by Leskelä and Lehtonen (1992), young whitefish in the northern Gulf of Bothnia are more vulnerable to the bycatch mortality in the Baltic herring fishery than those in the southern areas.

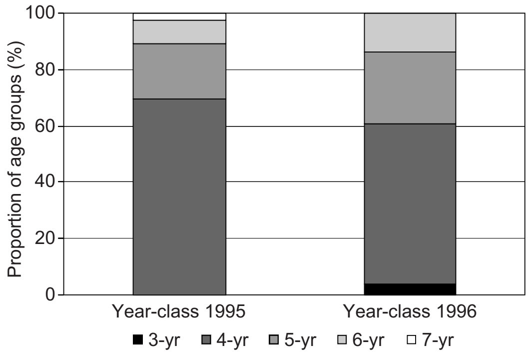

Fig. 4. Proportion of age groups in the catch produced by whitefish marked and stocked in 1995 and 1996. Data on all marking groups are included.

Our study probably included some typical mark–recapture studies' errors which tend to lead to an underestimate of the catch produced by marked fish (e.g. Youngs & Robson 1978). All of the fish may not get the mark, they may lose the marks or marks may remain unobserved. The marking procedure causes stress to the fingerlings, which may reduce their survival after stocking. However, Leskelä *et al.* (1998) showed that the stress caused by the fluorescent pigment spraying method was at the same level as that caused by normal stocking routines. Some choices in our study design biased the catch estimate downward as well. The catch produced by 1995 year-class during 1998 was not estimated, as we had no thorough sampling on commercial fisheries that year. However, probably part of the 1995 marked fish were caught already at an age of 3+, as that was the case for the fingerlings marked one year later. Although several marked whitefish were caught in the spawning rivers, river catch was not estimated due to difficulties in both sampling and estimating total catch from rivers. Neither the whitefish catch obtained as by-catch in herring fisheries was included. The accuracy of the estimates depends also on the reliability of the catch statistics. Unreported catch, if such existed, biased the total catch and estimated stocking yield downwards.

Together all the possible errors may have a remarkable effect on the catch estimates, but they do not change our main conclusion: it is obvious that there is a potential to increase the yield from stocking in the Gulf of Bothnia by regulating the fishery. This would benefit the naturally reproducing whitefish stocks as well.

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