MARKING ONE-SUMMER-OLD WHITEFISH WITH FLUORESCENT PIGMENT SPRAYING METHOD AND RESULTS OF WHITEFISH STOCKINGS IN THE GULF OF BOTHNIA

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Abstract

Anadromous whitefish is one of the most important fish species in the Finnish coastal fisheries in the Gulf of Bothnia. To compensate the lost reproduction due to river damming and to support the fisheries, several million one-summer old whitefish are released yearly into the Gulf of Bothnia. Since there are naturally reproducing whitefish in the Gulf as well, and the wild and stocked fish can not be separated in the catch, stocking impact can only be estimated by marking the stocked fish.

Due to the small size and large number of released whitefish, the scattered fishery and large area where the whitefish migrate, most of the traditionally used fish marking methods were either unsuitable (e.g. Carlin-tags) or proved to be too expensive (e.g. coded wire tags). Fluorescent pigment spraying method offered a fast and cost-effective method to mass-mark young fish. However, the results are not always satisfactory due to low long-time retention of the marks in some species. The method has to be tested and proper marking conditions and methods determined for each species.

This thesis is based on work that was accomplished while developing the fluorescent pigment spraying method for marking one-summer old whitefish fingerlings, and it draws together the results of mass-marking whitefish fingerlings that were released in the Gulf of Bothnia.

Fluorescent pigment spraying method is suitable for one-summer old whitefish larger than 8 cm total length. The water temperature during the marking should not exceed 10^{o} C. Suitable spraying pressure is 6 bars measured in the compressor outlet, and the distance of the spraying gun nozzle should be ca 20 cm from the fish. Under such conditions, the marking results in long-term retention of the mark with low or no mortality. The stress level of the fish (measured as muscle water content) rises during the marking procedure, but if the fish are allowed to recover after marking, the overall stress level remains within the limits observed in normal fish handling during the capture-loading-transport-stocking procedure.

The marked whitefish fingerling are released into the sea at larger size and later in the season than the wild whitefish. Surprisingly, the stocked individuals migrate to the southern feeding grounds in a similar pattern to the wild ones. The catch produced by whitefish stocking in the Gulf of Bothnia is comparable to results reported elsewhere in Finland. The releases in the southern Bothnian Bay result in a larger catch than those made in the northern Bothnian Bay. The size of the released fingerlings seems to have some effect on survival of the fish during the first winter in the sea. However, when the different marking lots are compared, the mean size of the fingerlings is not related to stocking success.

Original publications

This thesis is based on the following papers, which are referred to in the text by the Roman numerals:

I: Friman, T. & Leskelä, A. 1998. Spray marking one-summer-old coregonid fish with fluorescent pigment. In: Eckmann, R., Appenzeller, A. & Rösch, R. (eds.): Arch. Hydrobiol. spec. Issues Advanc. Limnol 50: 471-477.

II: Leskelä, A., Friman, T. & Hudd, R. 1998. Stress response of whitefish fingerlings marked with the fluorescent pigment spraying method. In: Eckmann, R., Appenzeller, A. & Rösch, R. (eds.): Arch. Hydrobiol. spec. Issues Advanc. Limnol 50: 479-485.

III: Leskelä, A. 1999: Prolonged retention of fluorescent pigment spray marks in European whitefish, *Coregonus lavaretus* (L.). Fisheries Management and Ecology 1999, 6:1-3.

IV: Leskelä, A., Jokikokko, E. & Huhmarniemi, A. 2002. Sea migration patterns of stocked anadromous European whitefish (*Coregonus lavaretus* L.) fingerlings. Arch. Hydrobiol. Spec. Issues Advanc. Limnol 57: 119-128.

V: Jokikokko, E, Leskelä, A. & Huhmarniemi, A. 2002. The effect of stocking size on the first winter survival of whitefish, *Coregonus lavaretus* (L) , in the Gulf of Bothnia, Baltic Sea. Fisheries Management and Ecology 2002, 9: 79-85.

VI: Leskelä, A., Jokikokko, E., Huhmarniemi, A., Siira, A. & Savolainen, H. 2004: Stocking results of spray marked one-summer old anadromous European whitefish in the Gulf of Bothnia. Ann. Zool. Fennici 41: 171-179.

Author's contribution to the above named papers:

	I	II	III	IV	V	VI
Original idea	TF	AL RH TF	AL	AL	EJ AL AH	AL EJ AH
Design and methods used	TF AL	AL	AL	AL EJ AH	EJ AL AH	AL
Data collecting and processing	TF AL	AL TF	AL	AL EJ AH	EJ AL AH	AL EJ AH AS HS
Manuscript preparation	AL TF	AL	AL	AL	EJ AL AH	AL EJ

Introduction

Gulf of Bothnia

Gulf of Bothnia is the northernmost part of the Baltic Sea. As a 500 km long bay it separates Finland and Sweden, reaching from the Archipelago Sea in the south to the Bothnian Bay in the north (Fig. 1). There is a clear north-south gradient in two for the aquatic animals essential characteristics, salinity and temperature (Leppäkoski and Bonsdorff 1989). Several large rivers bring fresh water into the Gulf while shallow areas in the Archipelago Sea and in the Northern Quark retard saline water inflow from the Baltic proper. As a result, the water in the Gulf has low salinity when compared to the brackish water in other parts of the Baltic Sea. In the southern parts, or the Archipelago Sea, salinity of the surface water is 6-8 ppm, whereas in the northernmost parts of the Bothnian Bay it is only 2-4 ppm.

The biotic community of the Gulf reflects the low salinity, with kelp (*Laminaria digitata* Huds.) found only in the Northern Quark area and southwards. Many fresh water fish species are abundant through the nearshore waters of the entire Gulf. Freshwater species which tolerate only low salinity, for example vendace (*Coregonus albula*) are common in the northernmost parts of the Gulf, but in the middle and southern parts they are mainly found in the estuaries of larger rivers. Such species as stone loach (*Neomacheilus barbatulus*) and blue bream (*Abramis ballerus*), are not found in the Gulf at all, although they are abundant in the adjacent fresh waterbodies. Of the most common marine fish species, Baltic herring (*Clupea harengus*) are commonly found in all parts of the Gulf, whereas sprat (*Sprattus sprattus*), cod (*Gadus morhua*) and flounder (*Platichthys flesus*) are rare in the northern parts but become more common in the southern parts and support professional fisheries in the southern parts of the Gulf and Archipelago Sea.

The northern location of the Gulf leads to strong seasonality – warm, productive summer is followed by cold, dark and unproductive winter. In the summer the surface water temperature may exceed 20^{o} C, while in the winter ice is common. Bothnian Sea and Archipelago Sea do not freeze consistently, but Bothnian Bay and Northern Quark are ice-covered every year, and in the northernmost parts the ice winter may last for six months.

The fishery in the Gulf of Bothnia concentrates on a few species. Most important is Baltic herring, which is fished mainly by trawling in the Bothnian Sea. Sprat is caught in the southern part of the Gulf of Bothnia as a bycatch in herring trawl fisheries. Whitefish is the second most important commercial species in the Gulf of Bothnia, when the value of the catch is considered. Catch consists of both anadromous and sea-spawning whitefish forms. The Atlantic salmon (*Salmo salar*) fishery is an important part of the coastal fishery in the Gulf of Bothnia, as a major part of both wild and stocked salmon in the Baltic originates to Bothnian Bay. Significant catches of several freshwater species like pike-perch (*Stizostodeon lucioperca*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and vendace (*Coregonus albula*) support the coastal fisheries of the Gulf. At present, cod and flatfish fisheries in the Gulf of Bothnia are of minor importance.

Anadromous whitefish in the Gulf of Bothnia

Whitefish (*Coregonus lavaretus* (L.)) is one of the most important fish species both in the commercial and the recreational fisheries in the Gulf of Bothnia. Although marine catches are significantly lower than in the 1990's, the total annual catch from the Baltic Sea in recent years has exceeded 1000 tonnes. In the Baltic most of the catch is taken by professional fishermen, and the primary fishing area is the Gulf of Bothnia. There exists two sympatric whitefish forms in the Gulf of Bothnia, a river-spawning and a sea-spawning form. The river-spawning form, often referred to as "anadromous whitefish" or "migratory whitefish", makes long feeding migrations from the spawning rivers to feeding areas in the southern parts of the Gulf, and returns to river to spawn after reaching sexual maturity (Lehtonen & Himberg 1992). Due to the feeding migration, anadromous whitefish grows faster and reaches a larger size at maturity than local, sea-spawning whitefish in the most parts of the Gulf (Lehtonen 1981). In the southern part of the Gulf, however, growth of the two forms is almost equal. The length of the feeding migration depends on the latitude of the spawning river, the northern populations making longer feeding migrations than the southern populations (Lehtonen and Himberg 1992). Like many other anadromous fish species, river-spawning whitefish have a homing behaviour, where mature whitefish return to the river in which they had been reared (Petersson 1966, Lind and Kaukoranta 1974, Huusko and Grotnes 1988).

The two whitefish forms are not separated in the catch statistics or fish markets. However, several fishing methods target one or the other of the whitefish forms. For example, fisheries with trapnets and anchored or drifting surface nets target anadromous whitefish on their spawning migration, and sea-spawning whitefish is caught typically during spawning season with dense-meshed bottom gillnets.

Traditionally, large whitefish are considered a highly valued, delicious fish, and the commercial price rises with the size. In the Finnish commercial catch, whitefish are sorted according to gutted weight in four size categories. The categories and fishermen prices per kg of gutted fish in 2004 (Anon 2005b) were:

I	more than 800 g	4,51 e
II	400 – 800 g	3,68 e
III	250 – 400 g	2,90 e
IV	less than 250 g	1,73 e

The most important gear in the Gulf of Bothnia whitefish fisheries is bottom gillnet. Gillnets are used to catch both whitefish forms throughout the Gulf. The percentage of the two forms in the catch depends on mesh size, time of the year and fishing area. In professional fisheries bottom gillnets comprised 80 % of the catch in 2004 (Anon 2005a). In most parts of the Gulf of Bothnia, mesh size of the bottom gillnets is not regulated. The main part of the bottom gillnet catch in Finnish professional fisheries is caught with mesh-size of 36 to 45 mm (bar length). As a consequence of relatively dense nets and high fishing effort, the average whitefish size at catch is relatively small. In the fish price statistics 2004 (Anon 2005b), 52 % of the whitefish included in statistics belonged to size categories III and IV, and 4 % in the category I.

The second important whitefish fishing gear is trapnet, which accounted for 16 % of the catches in 2004 (Anon 2005). Trapnets are mainly used to catch sexually maturing river-spawning whitefish that is migrating northwards. The usual fish-bag mesh-size in the trapnets is 35 mm bar length, which means that practically all sexually mature whitefish are large enough to be caught with trapnets. Although trapnets are used in all parts of the Gulf of Bothnia, the most important trapnet fishing areas are located in the northern parts of the Gulf of Bothnia, from Northern Quark northwards.

The recreational whitefish fisheries in the Gulf of Bothnia are characterized by common use of passive gears. The share of rod and line fisheries is very low in the recreational whitefish fisheries - almost 90 % of the recreational catch was caught with gillnets in 2002 (Anon 2004a).

Young whitefish are also target to a bycatch fishery from their first autumn onwards. They are caught in the trawl and trapnet fishery which target Baltic herring and vendace (*Coregonus albula*) in the Bothnian Bay. The amount of whitefish in the bycatch varies a lot depending on the season and fishing area. It was estimated that 74 tonnes of whitefish, of which 15 % was anadromous whitefish, were caught annually in herring and vendace trawl fisheries in late 1980's (Leskelä and Lehtonen 1992). Recently the trawl fishery as well as the status of the whitefish stocks has changed significantly. No new estimates on the bycatches in trawl fishery are available.

Whitefish fingerling production

In Finland, one-summer old fingerlings of several fish species are reared in natural food ponds. The annual production of one-summer old whitefish in the ponds has been above 20 million fingerlings / year in recent years. Fingerlings are stocked both in the Baltic Sea and in the inland lakes.

The natural food pond method may be characterized as semi-intensive. Rearing ponds are either man-made or they are small natural lakes and ponds. The shape of the pond is deepened so that it can be drained, with a regulating dam built at the end of the drainage. The size of the ponds varies from less than one hectare to some hundreds of hectares. Most of the ponds are located in the middle and northern Finland.

During the winter the ponds are drained and freeze through killing remaining fish and predatory insects. At times, some fish are able to overwinter in some part of the pond. During winter or spring, ponds are often treated with lime or fertilizer to enhance plankton production.

In the spring, the regulating structure is closed and the pond is filled with water. Newly hatched whitefish larvae are brought to the pond soon after it has been filled. In shallow ponds, the water starts to warm rapidly and production starts. Since there are no other fish in the ponds and only a sparse population of predatory insects, most of the plankton production is available for the whitefish larvae. Growth rate during the summer months depends on the productivity of the pond and density of the fish population, at the end of the first summer the mean total length of the fingerlings is typically 9-12 cm. In a dense population the mean length may be as low as 7 cm, whereas in sparse population fingerlings are able to reach a total length of 15 cm or more within one summer. The survival from newly hatched larvae to one-summer old fingerling is variable but a 50 % survival is considered to be a satisfactory result.

The semi-intensive nature of the natural food pond production becomes evident in the latter part of the summer. At the end of the summer the production of the pond starts to decrease as the days became shorter, temperature decreases and most of the nutrients in the water are consumed. At the same time, the biomass of the whitefish fingerlings is at largest. The survival and growth of the larvae varies and it is difficult to estimate the number or biomass of fish present in the pond at the end of the growing season. Rearing ponds can not be drained until water temperature reaches 10 ^{o}C. If the whitefish population is dense, warm autumns may have a detrimental effect on fingerling condition due to decreased amount of food in the pond. Thus the weather conditions during the summer and autumn have a major, uncontrollable effect on the amount and quality of the fingerlings produced.

During draining the whitefish are captured either with small pound-nets from the pond or with capturing device in the outlet of the pond. After the fingerlings are captured, the regulating dam is opened and rest of the water is let out of the pond, leaving it empty until next spring.

Anadromous whitefish stocking in the Gulf of Bothnia.

In the Finnish side of the Gulf of Bothnia, most of the rivers are dammed for hydroelectrical purposes. In many of the rivers, the lowest power-plant is built close to the river mouth, and successive power-plants from the river-mouth upstream have changed the river habitat to a series of regulated reservoirs. In many of the rivers, water quality has been deteriorating and clearing, ditching and draining have caused loss of spawning and nursery habitats. As a consequence the anadromous fish populations have suffered habitat deterioration, with whitefish being no exeption. It has been estimated, that naturally reproducing whitefish populations inhabited more than 30 rivers along the Gulf of Bothnia (Böhling and Juntunen 1999). At present, natural reproduction exists in more than 10 rivers, but in many of them the whitefish populations are supported with stockings.

The loss of natural reproduction created a need to maintain the fisheries and fish stocks with compensatory stockings. As a rule, stocking obligations are ordered in water court decisions as a part of the permission to execute water power project. For example, the water power production in river Kemijoki, the largest river in Finland, is allowed under an obligation to release 3,1 million one-summer old whitefish, 615 000 salmon smolts and 90 000 at least 18 cm long sea trouts in the sea area (Huttula et al. 2002).

Anadromous whitefish, a fast-growing and highly valued species that is easy to maintain and produce in rearing facilities, is also used to compensate other environmental damages. On the coast of Gulf of Bothnia, it is used to compensate effects of industrial effluents or population centre sewages, even if the damage is caused to local, non-migratory fish populations. Some anadromous whitefish are stocked by private interests like water owners' or fishermen organizations.

Altogether, the annual number of one-summer old anadromous whitefish released in the Gulf of Bothnia reaches 7-10 million fingerlings. The main portion of those are stocked in the northern parts of the Gulf, to the northern Bothnian Bay. An additional 40-60 million newly hatched larvae are stocked every year. The most important rivers with natural reproduction of the anadromous whitefish are located in the northern Bothnian Bay. Thus the anadromous whitefish stock in the Gulf of Bothnia consists of fish from three different origins: fish stocked as one-summer old, fish stocked as larvae and fish that result from the natural reproduction. In my thesis I concentrate on the part of the stock that originates from the one-summer old fingerlings stocked in the Bothnian Bay.

Fish tagging and marking as a tool in whitefish studies

Fish marking is one of the most common methods in estimating the stocking success of fish. Only in cases, where an exotic species or subspecies is introduced into a waterbody, it is possible to evaluate stocking success without marking or tagging at least a part of the stocked individuals. Mark-recapture studies often include several sources of error (e.g. Youngs and Robson 1978). The most important conditions for the estimation of stocking success with e.g. Petersen-estimates are (according to Ricker 1975):

- Natural mortality and catchability of the marked and unmarked fish are the same
- Tags are not lost
- Marked and unmarked fish are randomly mixed with each other
- All marks in catch sample are found and reported
- Recruitment, immigration and emigration during recapture phase is insignificant

For calculating a reliable estimate of the catch produced by stocked fingerlings, the following conditions presented by Geiger (1990) shoud be fulfilled as well.

- number of marked and unmarked stocked fish are known.
- The marked fish are randomly chosen from the stocked fish
- There is reliable data on total catches and number of checked fish
- The samples for mark detection are randomly chosen from the total catch

Characteristics of the ideal tag or mark are according to Lucas and Baras (2001, modified from Nielsen 1992).

- No risk of alteration during storage
- Easy and fast application, requiring no anaesthesia or specialized equipment
- High tagging/marking rate
- Minimum bulk and size, applicable to fish of all sizes
- Enabling individual identification
- Low cost
- 100 % retention

- No alteration or fouling of tag material
- No effect on health, physiology, behaviour, performance and fitness of tagged fish
- No influence on the probability that the fish be prayed upon or captured by fishing or sampling gears
- No effect on fish appearance or saleability
- No need of specialised equipment of training for detection and identification
- No risk of confusion while identifying tag presence or code
- Requires no handling for post-tagging identification
- Can be detected and identified at any distance and at any time
- Should be relayed to the fish progeny

Unfortunately, there is no such thing as an ideal tag or mark available at present, and the conditions for an unbiased mark-recapture study are only seldom perfectly fulfilled. For example, when studies of stocking success are in question, marking arrangements inevitably lead to some extra handling of fish, which increases the stress level and may cause injuries. Several individual and group marking methods have been used to mark one-summer old, reared whitefish. In many of the taggings and markings, the purpose of the projects have been to estimate the stocking success or compare the relative stocking success of groups with different characteristics. Subsequently, studies have shed light on migration patterns and validity of age estimation techniques as well (e.g Salojärvi 1992b).

Carlin-type external marks either with one or two attachment strings, plastic band marks and Lea marks have been tried in whitefish tagging. Although external tags have given valuable information on whereabouts of the adult or young whitefish (e.g. Lehtonen & Himberg 1992) they have not proven to be successful in tagging one-summer old whitefish (FGFRI, unpublished). One-summer old whitefish are too small and fragile for that type of tags. In tests conducted, the main part of the recaptures have been received in the autumn following the stocking, and very few recaptures have been made after the first winter in the sea, which suggests that fish with external tags had high mortality within the first year after stocking.

Fin-clipping offered the most suitable and cost-effective method to evaluate whitefish stocking success in the early days of whitefish stocking in Finland. Partly removed fins regenerate (McNeil & Crossman 1979, Churchill 1963), which may have been a source of error in the fin-clipping studies. The number of different codes in fin-clipping is, of course, rather limited, and removal of more than one fin may increase mortality (Nielsen 1992, Mears and Hatch 1976). In Finland, fin-clipping has been utilized e.g. by Lehtimäki (1984) in a study where he compared survival of different size-groups of stocked whitefish in small lakes and Salojärvi (1988) when he compared the catch created by two stocking densities in Lake Peranka. Scars created by burning iron, laser-beam, cold burning or chemical burning offer methods to mark small fish for lifetime. Of those mentioned, burning with hot iron have been tested and found suitable for one-summer old whitefish (Saura 1993).

Coded wire tags (CWT) (Jefferts et al. 1963) have been perhaps the most common method in marking one-summer old whitefish in Finland. CWT have been used both in Finnish lakes and the Gulf of Bothnia, although in the latter the large size of the study area, long migrations of the whitefish and scattered recaptures resulted in low cost-effectiveness of the method. CWT do not affect on fish growth, mortality, behaviour or catchability (Nielsen 1992), and retention of the tags is usually acceptable if suitable mould is used (Bergman et al. 1968, Blankenship 1981, Ostergaard 1982). In Finland CWT-tags have been successfully used to estimate the catch obtained by releasing whitefish fingerlings (e.g. Salojärvi 1992, Salonen 1998). The large number of different codes allows comparing several groups of stocked whitefish, and in recent years individually coded CWT-tags have been applied in whitefish studies as well (Niva, unpublished). The use of individual tagging instead of group marking leads to a highly improved accuracy of the studies and offers a possibility to more complex experiment designs.

Fluorescent pigment marking

The use of fluorescent pigment spraying in fish marking was first invented by Jackson (1959). In 1960's, the method was widely used in mass marking of Pacific salmonids (Phinney 1967, Phinney and Matthews 1969, 1973). Later on, the method has been used on Atlantic salmon and trout and on several other species as well (Andrews 1972, Rinne and Deacon 1973, Engelhardt 1977, Pierson and Bayne 1983, Strange and Kennedy 1984). The main advantage of the fluorescent pigment marking method is fast marking of large amounts of fish. Fish are not anaesthetized and they are not handled individually. Typically the method has been used in situations, where large amount of relatively small fish has been released (Babey 1983, Nielson 1990).

The method has been found to be applicable on largemouth bass (retention at least 9 moths) (Engelhardt 1977), rainbow trout (*Oncorhynchus mykiss*) (retention at least five years) (Wiltzius and Smith 1976, Evenson and Ewing 1985), cutthroat trout (*Salmo clarki*)(Nielson 1990) and channel catfish (*Ictalurus punctatus*) (Pierson and Bayne 1983). There is also several species, which can not be marked with fluorescent pigment spraying method, like brook stickleback (*Culaea inconstans*) (Moodie and Salfert 1982), silver carp (*Hypophtalmichtys molitrix*) (Pierson and Bayne 1983), burbot (*Lota lota*) and Arctic charr (*Salvelinus alpinus*) (I). For several species, a fish smaller than a specific limit length cannot be successfully marked. The minimum size is apparently connected to development of the scales, as retention in the young, scaleless fry is poor (Phinney et al. 1967, Andrews 1972, Strange and Kennedy 1982).

If species-specific size-limits, suitable marking pressure and other factors have been used, the mortality caused by fluorescent pigment marking has been generally only some per cents (Andrews 1972, Engelhardt 1977, Strange and Kennedy 1982, I). It is recommended, that marking should be carried out in cold water. Holland-Bartels et al. (1989) noticed that mortality due to capture, handling and marking was directly proportional to water temperature in 10 – 20^{o} C, although the level of mortality varied between species. Under long-term tests, no detrimental effects of the marking have been observed (Andrews 1972). In the test made by Phinney and Matthews (1969), it was found that predators do not select marked individuals.

Why to use fluorescent pigment method in estimating the Gulf of Bothnia whitefish stocking results?

Economics were the primary reason to start trials with fluorescent pigment spraying as a marking method for the whitefish fingerlings released in the Gulf of Bothnia. Due to large number of (both wild and stocked - in an unknown ratio) whitefish captured in the Gulf of Bothnia, the large study area and very dispersed fishery, we had to mark considerable number of whitefish fingerlings. Such numbers could not be marked with individual tags, and even many of the group marking methods proved to be too expensive for such a project. Furthermore, the circumstances in Finnish pond culture do not allow for a long marking period. As a rule, the whitefish fingerlings are not collected from the ponds before the water temperature in the autumn reaches 10 °C. Especially in the northern Finland, autumn may turn to winter very rapidly, and shallow ponds start to freeze, leaving a limited time window for capturing, collecting, loading and transport of the fingerlings. If we were to mark remarkable amounts of whitefish, we had to do it fast and cause only minimal delay to stocking routines of fish-farmers.

The objectives of this thesis

The objectives of this thesis were to:

1. Find out if fluorescent pigment spray marking of one-summer old whitefish offers a suitable method, which can be applied in a large-scale study.

2. Study the whereabouts of one-summer old stocked anadromous whitefish fingerlings between stocking and their appearance to the whitefish catches. Of special interest was the question of southward migration of young whitefish after stocking – when does it occur and how far to the south it reaches.

3. Estimate the importance of the large-scale compensatory stockings for the Gulf of Bothnia whitefish fishery. Catch productivity of the stockings was one of the primary interests, but we were also interested in studying how the present fishing pattern in the Gulf of Bothnia relates to the growth and migrations of the stocked whitefish.

All these questions were important due to the of large compensatory whitefish stocking programs in the Bothnian Bay. The purpose of the stockings is to compensate for the damages caused to whitefish and other fish populations and fisheries by hydro-electric projects and other activities. The compensatory whitefish stocking programs have been ongoing since 1970's or early 1980's, but no scientific evaluation of the results has been made due to lack of suitable marking method at considerable expenses.

Materials and Methods

Catch statistics

Professional fisheries

The base of the statistics is the catch notifications submitted by the fishermen. Until 1995, the catch notifications were collected by Finnish Game and Fisheries Research Institute. Since that, data have been collected by local Finnish authorities, the fishery units of the employment and economic development centres. The data obtained from the fishermen is at the disposal of the Finnish Game and Fisheries Research Institute for statistical purposes.

The response of the fishermen is high. Non-response in over 10-meter long vessels was 0 % and in smaller vessels 15 % in 2004 (Anon 2005a). The bias resulting from non-response is rectified by stratum-specific coefficients, where area and fishermans income classification are used as strata. The high response rate results in narrow confidence limits of the estimates. However, the magnitude of under-reporting of by-catch and discards was not estimated in the statistics. This may lead to an underestimate of whitefish catch in recent years, as an increasing part of whitefish catch has been discarded due to seal damages (Kreivi *et al*., 2002; Kauppinen *et al*., 2005).

Latest major change related to catch statistics occurred in 1995, when Finland joined EU and completion of the catch notification forms and registration as a commercial fishermen became obligatory for marine fishermen. In the calculation of the catch produced by the stocked and marked whitefish (VI), commercial fishery statistics and data from catch notifications for the years 1999, 2000, 2001 was used (Anon 2000a, Anon 2001, Anon 2002a). During those years, the methods for collecting and processing the data from commercial fishermen remained similar.

Recreational fisheries

Fishing is one of the most common leisure time activities in Finland. In 2002, 48 % of Finnish men and 27 % of women took part in the recreational fishery (Anon 2004a). Catch statistics for the non-professional fishermen are collected by the Finnish Game and Fisheries Research Institute with a questionnaire, which is normally carried out every second year. Questionnaire is sent to a sample of the population which is drawn from the population register maintained by the Population Registration Centre.

In the Finnish fisheries, herring, sprat, salmon and cod are typically caught mainly by professional fishermen, whereas all other species are caught equally or more by recreational fishery (Anon 2004a, Anon. 2005). The catch of whitefish in the Gulf of Bothnia by recreational fishermen is remarkable. In the year 2002, which is the latest estimate available, the catch of the recreational fishermen was estimated to be 335 tonnes (Anon 2004a), over 30 % of the total whitefish catch in the Gulf of Bothnia that year. Approximately 90 % of the recreational whitefish catch in the Finland is caught with gill-nets (Anon 2002b, 2004a).

In the calculation of the catch produced by the stocked and marked whitefish (VI), recreational fishing statistics from the years 1998 and 2000 were used (Anon 2000b, 2002b). In both years, sampling was targeted to persons aged 18-74 years, and stratified sampling (according to geographic area and both type and location of the persons' municipality of residence) was used. Sample size (number of the household-dwelling units to whom the query was sent) was 4000 in 1998 and 6012 in 2000.

Determining marking technique for one-summer old whitefish

Tuning the apparatus

The fluorescent pigment marking method was first introduced by Jackson (1959) as a method to mark Pacific salmonids. Experiments of the method in Finland were started in 1993 (I). On the basis of several papers (*e.g.* Phinney *et al.*1967, Phinney & Matthews 1973, Strange & Kennedy 1982, Nielsen 1990), fluorescent pigment spraying offers a cost-effective method to mark large amounts of small fish, and would be a suitable method to study results of the large stocking programs in Finland. Most of the earlier work had been made with Pacific and Atlantic salmonids and cyprinid species, and no previous efforts had been made to apply the method to coregonids.

The marking equipment for the first experiments was based on the above named papers, but it was further developed after own early experience (I). Main difference compared to the most other studies where fluorescent pigment marking method has been used was that we applied the use of water-pigment mixture instead of using dry pigment powder. The idea of mixing pigment with water prior to spraying was described in a progress summary given by Silva and Gosine (1992).

The most important factors affecting the quality of the fluorescent pigment marks are fish species, size at marking, water temperature, spraying pressure and pigment used. An unsuccessful combination of those factors may lead either to high mortality after marking or inadequate retention of the marks. As recommended by Rinne & Deacon (1973) the technique should be tested and suitable values defined for each species separately. In the first experiments we used both vendace (*Coregonus albula*) and European whitefish (*C. lavaretus*). In the early tests, we varied the application pressure (5-8 bar) and used different granule size of the pigment (< 63 µm and > 63µm). The mean length of the fish varied between the experiments (75 mm - 121 mm) and the water temperature varied between 1,4°C - 12,5°C.

Stress caused by marking

Although adult whitefish have been successfully marked with external tags (e.g. Ahlbäck 1964, Petersson 1966, Sormunen 1968, Lind and Kaukoranta 1974, Huusko and Grotnes 1988), the attempts to mark one-summer old whitefish with external tags have resulted in less than encouraging results. In the trials run, external taggings of one-summer old anadromous whitefish in the Gulf of Bothnia resulted to few recaptures which were mostly made close to releasing site within few months after release (FGFRI unpublished data). The reason is probably the small size of the one-summer old whitefish and their sensitivity for handling. Whitefish fingerlings do tolerate the handling resulting from marking with coded wire tags (Salojärvi 1992, Salonen 1998). Also fin-clipping and burning (Salojärvi 1988, Saura 1993) has been used to mark one-summer old whitefish with acceptable results.

The procedure of spray marking differs from other marking methods. Fish are not anaesthetized and they are marked as a group, not individually. In the initial marking experiments, both the immediate and long-term mortality after marking were low when spraying pressure, water temperature and fish size were within appropriate limits (I). However, when marking the millions of fingerlings to be released in the Gulf of Bothnia, our marking routines often differed from those in the first experiments. We had to link the marking procedure to capture, collecting, loading and transport practices and time-tables of the fish-farmers. The practices varied between the farmers, and we had to adapt the marking procedure when moving from one location to another (II). Sometimes, we were not able to allow the fingerlings enough recovery time between the marking and loading, transport and stocking. The temperature and the quality of the pond water as well as the transport water varied. Fingerling condition, size and possibly health varied between ponds as well.

To evaluate the effect of stress caused by marking to stress caused by all other handling of the fingerlings, we decided to monitor 1) stress level of the fingerlings (measured as carcass water content) in different phases of the collecting-marking-loading-transport-stocking-procedure and 2) mortality of the stocked fingerlings in net-cages within a 7-day period post-stocking. The measurements were made in several farming ponds, thus the different fingerling groups varied in size and were exposed to slightly different handling routines. The measurements were made in both marked and unmarked groups of fingerlings.

The use of carcass water content as a stress indicator was based on the effect of stress on the osmotic and ionic regulation of fish (Eddy 1981). In stressed fish, water permeability of the gills increases (Pic *et al.* 1974), which in fresh water environments leads to a rise in the water content of fish (Mazeaud *et al.* 1977). To measure the stress level of the fingerlings, we took tissue samples and analyzed the carcass water content of the fish (II). The carcass water content was used as a stress indicator because it offered a simple and fast method which was applicable in field conditions.

Long-time retention of the marks

The retention time of the fluorescent pigment marks has been observed to depend on (at least) the fish species (Rinne and Deacon 1973, Pierson and Bayne 1983), the size at marking (Strange and Kennedy 1982), the spraying pressure (Andrews 1972) and the granule size of the pigment used (Strange and Kennedy 1982). As there have been differences in the observed retention time between species, it is recommended that the retention should be evaluated separately for each species (Rinne & Deacon 1973).

To study the long-term retention of the spray marks in whitefish we collected samples of the fish marked in 1993 and reared for four years after marking (III). One group was kept in a small lake in northern Finland where it lived on natural food, and the other lot was kept in net cages in the Gulf of Finland and fed with commercial trout feed. The last sample was taken from the both groups four years after marking. At that time all of the studied fish were sexually mature. The fish in the lake had reached a mean size of 291 mm and those in the net cage 449 mm. The mark retention was determined by taking a sample of the whitefish and checking them in a dark room using an ultraviolet lamp.

Mark-recapture study of the stocked, one-summer old anadromous whitefish in the Gulf of Bothnia

Marking and release

The large-scale mark-recapture study of stocked anadromous whitefish in the Gulf of Bothnia started in 1995. Fingerlings were released in 1995-1996 in the Southern Bothnian Bay and in 1996-1998 in the northern Bothnian Bay (Fig. 1, Table 1). The fish were marked either in the ponds after collecting them before transport or at the stocking site, where the fingerlings were unloaded to net cages. The quidelines for whitefish marking obtained in the small-scale experiments (I) were followed as strictly as possible, and the stress and mortality caused by handling and marking were evaluated (II). The principle of the marking equipment was similar to the one described in (I) in all mass markings in the Gulf of Bothnia, although some improvements to collect excess pigment after marking were made.

Three colours produced by Swada Ltd, London, UK, were used in the marking: lunar yellow (LMP27), tellar green (LMP8), and flame orange (LMP4). When examining the adult fish we found out that green and yellow colour could not be separated and some groups originally treated as separable had to be combined. In Table 1 and later on in this thesis, both LMP27 and LMP8 pigments are simply referred to as yellow. Also combinations of orange+yellow and orange+green colours was used. As the same colours were used in successive years, fish age and pigment colour together formed the mark.

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 (According to Fig 1)
1995	Yellow	320 000	106.8 (18.7)	A
1995	Orange	190 000	99.0 (9.9)	C
1995	Yellow + orange	175 000	105.2 (8.8)	A and B
1996	Yellow yellow	395 000 1 320 000	99.4 (8.6) 99.6 (3.64)	A and B 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

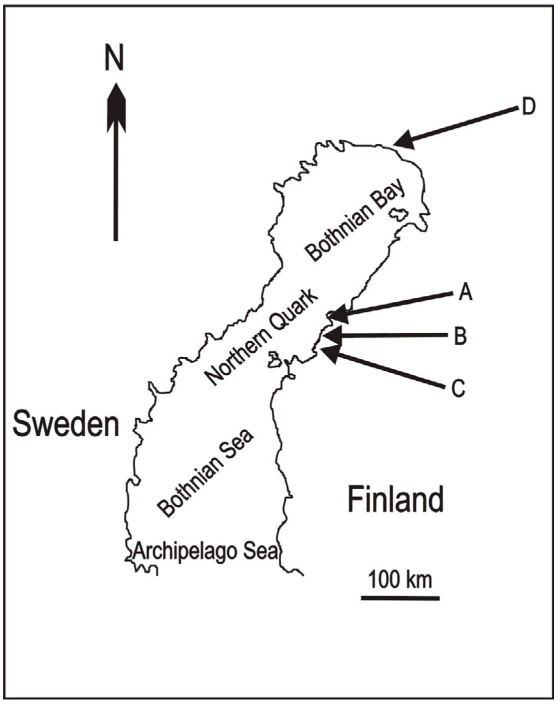


Fig 1. A map of the Gulf of Bothnia showing the stocking places in the southern (A-C) and northern (D) Bothnian Bay.

Sampling for marked whitefish

It takes several years before the stocked whitefish reach a fishable size and recruit to whitefish fisheries. However, young whitefish are a common bycatch in the Baltic herring fisheries (Leskelä & Lehtonen 1992). Baltic herring fishery takes place from the northernmost Bothnian Bay to the Archipelago Sea, but the intensity of the fishing as well as the proportion of the bycatch, including whitefish, varies considerably. In the Northern Quark and southwards we were able to create a net of herring trapnet fishermen, who collected whitefish from their catches and kept them frozen for future analysis. In the Bothnian Bay, where whitefish is a more common bycatch, we were also able to collect young whitefish directly from the Baltic herring catches in fish harbours. The sampling from the Baltic herring fishery allowed us to obtain information of the growth and migrations of the whitefish before they entered whitefish fishery (IV, V).

Catches of the whitefish fishery were sampled from 1999 onwards (VI), although few whitefish released in 1995 were observed in the commercial whitefish catch already in 1998 (V). The whitefish fishery in the Gulf of Bothnia is a typical small-scale coastal fishery, where several hundreds of fishermen actively take part and catch is landed in numerous fishharbours or fishermen's own home piers. The primary gear in the Gulf of Bothnia whitefish fishery are bottom gill nets and trap nets, which together take up to 90 % of the annual catch. The fishery, especially with trapnets, follows a clear seasonal pattern, which helped us to target our sampling efforts to the main seasons and fishing areas.

Sampling was done in the fish harbours or in the stores of wholesale purchasers, or alternatively a fish sample was purchased and brought to laboratory. Marks were detected in dark room whenever it was possible. In most cases, a dark room was available in the cold storage at the fish harbour. If the marked fish could be bought, they were measured and aged in laboratory using burned or dyed otoliths together with scales and operculums. If the fish could not be bought, they were measured in the fish harbour and scales from between the ventral fins were used in ageing. A part of the mark observation was made by chosen fishermen, who were trained to detect the marks. In those cases, all the marked fish found by fishermen were later checked by Finnish Game and Fisheries Research Institutes staff.

First-year survival, migration, growth and catch estimates

To study the effect of stocking length on the survival over the first winter in the sea we used the fish that were captured in 1995-1999 in the Baltic herring fisheries. We used the scales to back-calculate the length of those fish as 1-year old and compared that to the mean length at stocking (IV). As the fish were stocked in the late autumn it was assumed that there would be no growth in the sea before formation of the first year-ring. The assumption was that if the size of the stocked fish had an effect on survival, the smallest fish would die during the first winter and the back-calculated mean length of the recaptured fish as 1-yr old would be greater than that of the mean length at stocking.

The samples from Baltic herring fisheries by-catch were also used to study the migration of the young whitefish. Before our studies, the knowledge of the migrations of the anadromous whitefish in the Gulf of Bothnia was based on observations made by external taggings. Adult or subadult specimens of migratory whitefish had been marked both in the spawning rivers and in the feeding grounds in the southern parts of the Gulf of Bothnia. It was evident that anadromous whitefish perform long migrations (Lehtonen and Himberg 1992), and repeated captures of an individual whitefish in the same river (Huusko and Grotness 1988) suggested that whitefish have homing behaviour. Since the external tags were not suitable for tagging one-summer old whitefish, the migration of one-summer old whitefish after release (or after leaving its home river) until recruitment to fishery was not known.

Our observations on the migration of young whitefish were based on the sampling of Baltic herring trap-net and trawl fisheries bycatch (V). Sampling on herring fisheries caused some limitations on the areas and seasons where samples were available. Our sampling covered the herring fishery throughout the Gulf from the Bothnian Bay to the Archipelago Sea, but more samples were obtained from the northern areas than the southern ones (Table 2).

Table 2. Samples collected in the different areas of the Gulf of Bothnia. n1= number of samples, n2=number of sampled fish, n3=number of marked fish recaptured in the areas.

	Bothnian Bay			Northern Quark			Bothnian Sea		
Year	n1	n2	n3	n1	n2	n3	n1	n2	n3
1995				44	306	42			
1996	3	153	1	97	2 332	157	2		
1997	211	35 403	472	109	1 825	127	3 1	282	7
1998	141	22 045	289	22	1 010	18	92	1 158	56
1999	62	7 932	64				6	137	14

The samples collected from whitefish fisheries were used to study the adult (spawning) migration, growth and maturation and catch productivity of the stocked whitefish (VI). On the basis of the samples it was also possible to evaluate the exploitation pattern of the present fishery, geographic distribution of the catch and possible needs for whitefish fishery management.

Primary fishing gears and seasons of professional whitefish fishery were included in the sampling. Recreational fisheries were not sampled. Since the main gear in the non-professional fisheries is bottom gill-net, the recreational fishery was treated like the professional bottom gill-net fishery when calculating the catch estimates.

Estimates of the catch produced by released 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 proportion of marked fish in the whole catch of the gear, area and year in question.

Results and Discussion

Applying the fluorescent pigment marking method for the one-summer old whitefish

When applying fluorescent pigment marking method, several factors affect mortality, mark quality and mark retention. The most important are spraying pressure, fish species, fish size and type of pigment (Phinney *et al.* 1967, Hennick & Tyler 1970, Andrews 1972, Holland-Bartels *et al.* 1989).

In salmonid marking, spraying pressure of close to 8 bars is considered suitable (e.g. Strange and Kennedy 1982). In whitefish, however, we found that such a high pressure led to high mortality, especially in water temperatures close to 10^o C (I). In our tests we found that a pressure of 6 bars was tolerated by whitefish in all tested temperatures (I), and it still produced a mark that was clearly visible with good retention (I, III). The pressure is measured at the outlet of the compressor. It should be noted that the pressure at fish or the momentum of the pigment granules when they hit the fish depends on the type of the spraying gun and the distance of the spraying nozzle from the fish as well. When testing or using fluorescent pigment spraying method, the distance between fish and the spraying nozzle as well as spraying gun type are standardized. In our studies the distance between spraying nozzle and fish was determined by the construction of the marking craddle to approximately 20 cm and the same type of spraying gun was used through the study (I).

Water temperatures near 10^o C were connected to high mortality of fingerlings in our experiments (I). Whitefish are known to be sensitive to handling in high temperatures, and it is recommended to start emptying the rearing ponds only after water temperature have cooled to 10^o C (Anon 2003, 2004). Holland-Bartels *et al.* (1989) also found that mortality depended on temperature when field-collected fish were marked with fluorescent pigment spraying.

In the cases where fish size has been observed to effect the marking result, an acceptable mark quality has been obtained when the fish is above certain threshold size (Strange and Kennedy 1982, White 1976). There has also been a common observation that bigger fish result in better mark retention (Nielson 1990). We recommend marking whitefish larger than 80 mm total length. Small whitefish are more sensitive to all kinds of handling, and tend to loose scales easily. High mortality was observed in some cases when marking small whitefish (I). Finnish stocking recommendations dictate a mean size for one-summer old whitefish to be stocked at 100 mm (Anon 2004b, Salminen & Böhling 2002).

Unlike Strange and Kennedy (1982), we did not find that granule size of the pigment had any effect on the mark quality or retention in whitefish (I, III). The pigment fractions tested by us (above and below 63 µm) were both within the 20 – 350 µm limit recommended by Strange and Kennedy (1982).

The values we recommended in (I) for marking whitefish with LMP-series pigments were: 1. spraying pressure 6 bars, 2. water temperature below 10^o C and 3. fish size above 80 mm. In whitefish these recommendations resulted in marks of good quality, low marking mortality and acceptable stress effect (I, II, III)

Stress caused by marking

The Finnish method of producing one-summer old whitefish in natural food ponds includes a minimal amount of handling the fingerlings during rearing. However, at the end of the rearing season, when the ponds are emptied, the fingerlings must be captured from the pond, collected and loaded into tanks for transport. The stress caused to fingerlings due handling varies due to different capture and collecting methods and working practices. The mortality of whitefish fingerlings connected to emptying the ponds and releasing fingerlings is usually low, but no studies exist on the sress level of the fingerlings.

We used the carcass water content of the whitefish to measure the stress level of the fish. It is a rough method and does not reflect small changes as well as, for example, using of plasma cortisol and plasma glucose levels (Staurnes *et al.* 1994). The use of other, more sensitive physiological stress indicators, like plasma glucose and cortisol levels or blood lactic acid level (Wedemeyer and McLeay 1981), may have resulted in well-defined results. However, our choice of method was dictated by the primitive sampling conditions and personnel available.

When the water content was compared before and after marking, there was a statistically significant difference in two out of six marking lots (II). In both cases, the marked fish had higher carcass water content indicating that the marking had caused stress. In other groups, the water content was probably elevated before marking due to collecting method that did not allow the fish to recover from the stress initiated by the capture.

When a group of fingerlings was followed throught the capture-marking-loading-transport-stocking-procedure, it was evident that marking elevated the carcass water content and stress level of the fish, but during the later phases of the procedure, the differences between marked and unmarked fish equalized (II). The control groups held in net cages at the coast, showed low post-stocking mortality (highest observed 3,04 %) both in marked and unmarked groups.

Long time retention

Two groups of marked fish were held up to four years after marking, one in a small lake and the other in a net cage. In both groups of fish marks could be detected in all but one specimen examined, indicating excellent retention of the pigment in whitefish marked according to quidelines given in (I). Results on long-time retention of fluorescent pigment marks have been variable and not always good. (Phinney & Mathews 1973, Pierson & Bayne 1983, Strange & Kennedy 1982, 1984). Ware (1968) suggested that fast growing individuals might have poorer mark retention than slowly growing ones. In our study mark retention was good in both the fast (net cage, artificial food) and slower growing (lake in northern Finland) group of fish. Nielson (1990) found that in cutthroat trout (*Salmo clarki*) it was more difficult to detect marks in spawning specimens, since the fish skin changed and its colour darkened in spawning time. The group B whitefish sampled in 1997 were captured near spawning, but the marks were still clearly visible, probably because whitefish show only minor skin changes at spawning.

Mark-recapture study of the stocked, one-summer old anadromous whitefish in the Gulf of Bothnia

First year survival

In the northern Bothnian Bay, most of the released whitefish fingerlings are smaller than naturally reproduced whitefish at the same age (Ikonen et al. 1985, Jokikokko 1985). It has been argued that the released fingerlings either starve to death during winter or are consumed by predatory fish due to their small size. It has been observed that the size of the fingerlings in the autumn is correlated to their survival through the first winter (Shuter & Post 1990, Johnson & Evans 1991, Buijse & Houthuijzen 1992, Conover 1992). Experiments with several species have shown that the catch produced by stocked fish has been positively related to the size of stocked fish (Salminen 2000, Lundqvist *et al*., 1994, Skilbrei *et al*., 1994, Jonsson *et al*., 1994, Vehanen *et al*. 1993, Hyvärinen and Vehanen 2003, Ruuhijärvi *et al*. 2001). Size-related predation may cause high mortality during the first weeks after release. In a telemetry study, Hyvärinen and Vehanen (2004) observed that pikes ate 50 % of the released age-3 brown trout within two weeks after release, whereas only 5 % of the larger age-4 trout were eaten. Lehtimäki (1984) found that recapture rate of whitefish increased substantially with increasing stocking size in small lakes. There is also evidence that in the case of whitefish the size of the released fingerlings does not necessarily play such a significant role (Salojärvi 1991, 1992a, 1992b, Salo 2003).

In our study, large fingerlings survived better through their first winter in the sea than the small ones in four of the five stocking groups studied (IV). The differences, although statistically significant, were small. Within the length range of fingerlings stocked, there was no threshold length under which 100 % winter mortality was expected. The back-calculation method used contains some potential sources of error (Francis 1990). According to Pierce *et al.* (1996) back-calculated length at age-1 is often smaller than the actual length, and this may have been the case in our study as well.

Salo (2003) studied the first-year survival of whitefish in small lakes in nothern Finland. He reported that only in a lake with a dense perch population was the survival of the whitefish through the first winter size-dependent. The relatively small size of the fingerlings stocked to the Gulf of Bothnia and their slow migration to south along shallow coastal waters (V), may make them vulnerable for predation. Pike, burbot and perch are all common species in the Gulf of Bothnia, and predation by those species may be the reason for the observed poor survival of the small fingerlings.

Migrations

The anadromous whitefish stocks from the Bothnian Bay are known to extend their feeding migration to the Bothnian Sea and Archipelago Sea (Lehtonen & Himberg 1992). In the wild, the larvae descend from the spawning river either soon after hatching or later during the summer (Leskelä *et al*. 1991, Lehtonen *et al* 1992,) and disperse into the shallow areas in the estuary, coast and archipelago. The exact timing of the southward migration of the wild anadromous whitefish is not known, but they may start their migration earlier than the stocked ones, which normally are released into the sea in the late September or October. Southward migration of the fingerlings is a prerequisite for the fast growth of the anadromous whitefish, and if stocking is to be successful, the rearing and stocking practices must be such that the fingerlings do migrate to south.

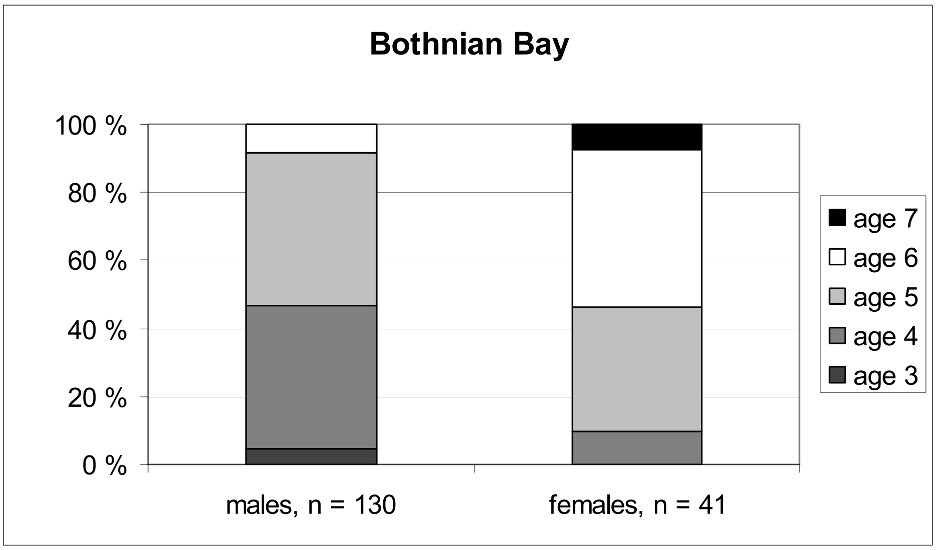
Whitefish from the both stocking areas, in the northern and southern Bothnian Bay, migrated southward to the Bothnian Sea and some of them even to the Archipelago Sea (V, VI). The timing of the migration varied greatly between individual fishes, as a part of them started southward immediately after stocking whereas others stayed near the stocking site for nearly one year in the southern Bothnian Bay and almost two years in the northern Bothnian Bay (V). The longer migration and lingering start of migration in the northern Bothnian Bay slows down the growth of the fish released in the north. The question if the current rearing and release practices affects the onset of the migration remains to be answered, since there are no observations on the onset of migration in wild whitefish. After spending several years in the feeding areas, the stocked whitefish reached maturity and started spawning migration back to north (VI).

Growth, maturity and catch estimate

By the end of the year 2002, a total of 2557 marked whitefish had been recovered among 85 569 sampled whitefish (VI). The percentage of marked individuals varied from 7 % to 0.5 % depending on the gear, area and season. Trap nets, which catch mainly anadromous whitefish, had higher percentage of marked fish than gillnets, which catch both whitefish forms.

Youngest individuals in the commercial whitefish catch were caught with bottom gillnets in the latter part of their third summer in the sea (VI). At that age, they had reached a mean length of 330-340 mm and a mean weight of slightly above 300 g (VI). The growth of the whitefish was stable and relatively fast through the study period. The oldest marked fish had reached an age of 7 years and mean weight of close to 1000 g .

Males reached maturity earlier than females (VI). In the Northern Bothnian Bay, male spawners were age 4+ to 5+, whereas the female spawners were mainly age 5+ to 6+. In the southern Bothnian Bay, male spawners were mainly age 4+, whereas females were 4+ to 5+ (Fig 2). Also within an age group, mature females were larger than mature males (VI).



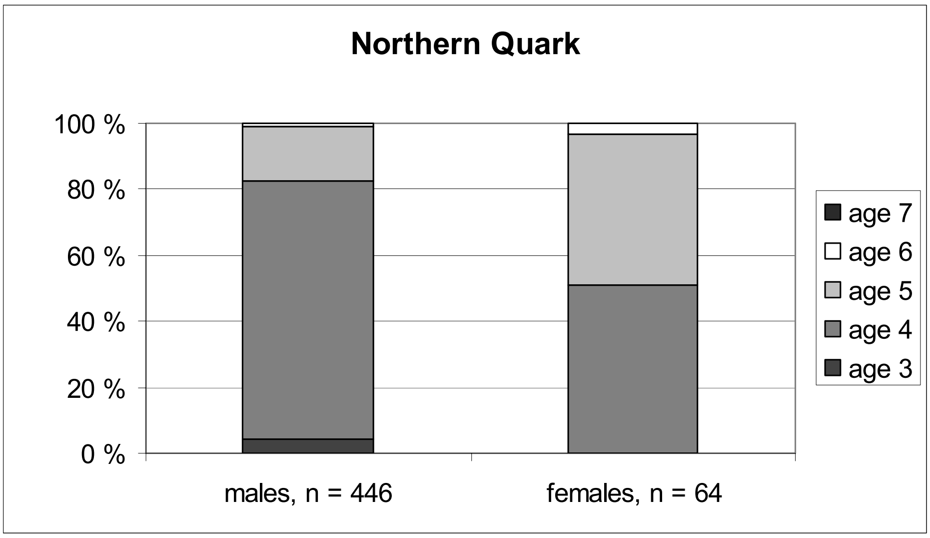


Fig. 2. Proportion of age-groups in the mature marked whitefish caught during spawning migration in the Bothnian Bay (above) and Northern Quark (below).

Mortality of whitefish after recruitment to fisheries is high. Whitefish are fished effectively both in their feeding areas and during the spawning migration (Lehtonen and Jokikokko 1999, Aronsuu and Huhmarniemi 2004). The combination of effective fishing and small size at recruitment to fisheries has led to growth overfishing. Our studies showed that most of the recaptured whitefish were caught before their first spawning (VI). As a consequence of the present fishing practices the sex ratio in the spawning population is altered. Because females have to reach an older age and larger size before maturity, they are targeted by bottom gill net fisheries in the feeding areas for longer time than males. Among the marked fish sampled from trap nets, gill nets and in river fisheries, where catch consists almost exclusively of mature fish during spawning migration, the predominance of males was significant (Fig 2, VI).

The estimated catch produced (until the end of 2002) by whitefish stocked in 1995 and 1996 was from 44.4 kg to 90.1 kg / 1000 stocked whitefish depending on the stocking group (VI). The estimate was lowest for the "mixed" group that consisted of whitefish stocked both in northern Bothnian Bay (77 % of the group) and southern Bothnian Bay (23 % of the group). The groups released in northern Bothnian Bay in 1997 and 1998 produced relatively low catches during the first years which they were targeted by professional fisheries, which suggested that the catch yielded by them would be even lower than that of the mixed group in 1996.

Compared with results reported elsewhere, the large Gulf of Bothnia stocking programs resulted in a catch which might be characterized as typical. In Finnish lakes stocking results vary from 2 to 250 kg / 1000 one-summer old fingerlings with the mean of 55-60 kg (Salojärvi 1992). In the Gulf of Finland, a catch of up to 200 kg / 1000 one-summer old fingerlings has been obtained (Raitaniemi *et al.* 1996).

Our study could have included some typical mark-recapture study errors, which lead to an underestimate of the catch produced by marked fish (Youngs and Robson 1978). All of the fish may not be marked, some of them may lose the marks or some of the marks remain unobserved when checking the samples. The quality and retention of the fluorescent pigment marks in whitefish was studied (I and III) and found to be satisfactory. The stress caused by marking, although moderate (II), may increase the mortality of the marked fish. Our sampling proved that marked fish were caught both in river fisheries and as a by-catch in herring fisheries. The amount of such catches was neither estimated nor included in the yield estimates as there were no reliable statistics on total catch in river or by-catch fisheries. These errors may have affected the catch estimates, and the estimates presented in (VI) are minimum values. The conclusions made on the basis of the studies remain the same even if we consider the catch estimates biased downwards.

Conclusions

1. Fluorescent pigment marking method offers a suitable method to mark large numbers of one-summer old whitefish fingerlings to study their migration, growth and catch production. Even though the method is not applicaple to all species in long-term studies,

in whitefish it results in marks of good quality. Both marking mortality and stress to fish remain at acceptable levels if the work is done according to guidelines given in (**I**).

2. Stocked fingerlings show a typical southward migration pattern although they arrive to the sea in different time and manner than wild born fingerlings. The onset of migration varies between the individual fish of the same marking lot, and it may be retarded compared to wild whitefish fingerlings. After reaching maturity, the stocked whitefish migrate back to north to spawn.

3. Whitefish stocking in the northern Bothnian Bay resulted in less catch than stocking in the southern Bothnian Bay. One of the reasons was more time-consuming migration to southern feeding areas and later onset of southward migration, which resulted in slow growth and increased the risk of predation. Another reason was higher by-catch mortality, as whitefish by-catches in the northern Bothnian Bay are higher than in the southern areas.

4. The size of the stocked fingerlings had an effect on the survival through the first winter in the sea with large fingerlings surviving better than small ones. When comparing the stocking success between the marked groups, there was no relation between the mean length of the stocked fish and the catch obtained. Within the narrow size range studied here, other factors affected the stocking result more than the mean size of the released group.

5. It is possible to increase whitefish catches by stocking one-summer old fingerlings. Whether this is the most beneficial way to increase whitefish catches and how the catch level otherwise might be increased, remains to be studied. Stocking result varies significantly between different marking lots, even when fingerlings of approximately same size are stocked in areas close to each other or in the same area in two consecutive years.

6. With the present fishery, growth potential of the stocked whitefish is not fully utilized, and a management scheme that would increase the fish size at recruitment to fishery would increase the stocking result.

Acknowledgements

I wish to thank the former Director General Kare Turtiainen and Research Directors Petri Suuronen and Eero Aro in the Finnish Game and Fisheries Research Institute for their support and encouragement, and for giving me the possibility to devote my time and effort for this work. A special thank goes to Professor Hannu Lehtonen, with whom I have been studying the Gulf of Bothnia whitefish since I was a newly recruited student.

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Research Station, was open-minded enough to throw himself into the project in spite of the question marks hanging in the air around it.

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