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Rehabilitation of lakes for fish and fisheries in Europe — a review

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Introduction

Ecological conditions in European fresh waters have drastically changed due to human activities. In most cases environmental changes have harmed fish populations and the quality of fisheries. The general trend has been an increase in cyprinid fish species and a decrease in salmonid and anadromous fishes. In addition, overexploitation is a major problem in the case of many commercially valuable species, especially those that spawn at high age and large size.

Different environmental changes affect fish assemblages differently. However, in most cases the fish population structure and quality of the fishery have deteriorated and this has given reason to rehabilitate lakes. The basis for rehabilitation in each case is the present quality of the environment. The most important environmental changes are caused by eutrophication and pollution from municipal, industrial and agricultural sources, regulation of lake levels, lake acidification, heavy metals and other harmful substances, land and water use, introduction of new species, and fisheries. Effects of these on fish communities are in many respects different but some general phenomena can be found, such as deminished species diversity, dominance of smaller and short-living species and increased share of opportunistic species.

Rehabilitation of a lake can be defined as the action of restoring a lake towards a previous condition or status (Bradshaw 1996). This means that the rehabilitated status is not expected to be the same as it had been before environmental changes.

Numerous strategies have been adopted to mitigate or rehabilitate the impacts of environmental deterioration. The future management of fish resources in inland waters will involve seven major strategies, and these depend on the demands to be placed on the resources and the socio-economic priorities associated with them. These are (according to Bradshaw 1996, and Cowx and Welcomme 1998):

Do nothing: This is the most frequently used strategy and may lead to the highly modified situation in which many lakes and reservoirs find themselves today.

Protection: Protecting lakes that have not yet been strongly affected by human impacts. In most cases the goal of protection is to protect waters and the environment, not fish and fish populations. In undamaged environments fish populations can reproduce and form self-sustaining populations.

Rehabilitation: The restoration of modified waters or fish populations in situations where the

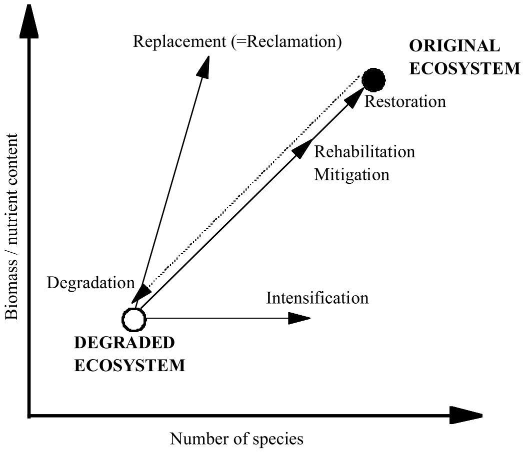

Fig. 1. The different options of remediation (modified from Bradshaw 1987).

pressures which caused modification have eased or where the technology can be introduced to reduce stresses. In rehabilitation the original state of the ecosystem is not always reached but considerable reclamation may occur.

Mitigation: Mitigation is one of the most common methods of fishery management because many of the changes in lakes are irreversible. Mitigation attempts include creation of artificial habitats, or the stocking of fish which have no alternative way to reproduce.

Intensification: Methods to intensify fish production include introduction and stocking with desired species, elimination of unwanted species and physical modification of the environment.

Remediation: Remediation is improve the quality of the lake. The emphasis is on the process rather than on the endpoint reached.

Reclamation: Reclamation is defined as to bring back to a proper state. It does not mean to return to the original state but rather to a better one.

Management procedures may be applied to ecosystems, habitats, communities, species, water quality etc. However, the central target of rehabilitation is the ecosystem which covers both biological and non-biological elements (Fig. 1).

Lakes in Europe

In Europe there are more than 500 000 lakes larger than one hectare. From these 89%–90% have a surface area between 1 and 10 ha, and about 16 000 have a surface area exceeding 1 km^2 (Kristensen and Hansen 1994). Lakes exhibit great variety with regard to depth, morphometry, trophic status and biology. The diversity of habitats makes the fisheries management of this group of water bodies very challenging.

The majority of natural lakes in northern and central Europe are of glacial origin (i.e. 9 000–16 000 years old). The ice sheet covered all of northern Europe. In central and southern Europe the ice sheet was restricted to the mountain areas. Most natural lakes lie in the areas affected by the ice-sheet. Areas that were not affected by the glacial period have only few natural lakes. In these areas man-made lakes are more frequent than natural ones (Kristensen and Hansen 1994).

At present, European lakes are used by man for purposes such as fisheries, waste disposal, water supply, industrial processes, transportation, irrigation, recreation and hydroelectric power generation. Historically the most dramatic changes occurred with the onset of the Industrial Revolution in the 1700s and thereafter. Another pressure towards lakes was the growing need for cultivated land and in numerous cases lakes were drained or water levels lowered. Processes have accelerated towards the end this century and practically there are no totally natural lakes in all Europe.

Man has also created more than 10 000 reservoirs in Europe. Their total surface area is at present over 100 000 km^2 (Kristensen and Hansen 1994). Reservoirs can in most cases be described as an intermediate habitat type between natural lakes and streams. Artificial lakes differ from natural lakes in both hydrography and biology. Use of reservoirs for fisheries is only part of functions of these lakes. Other uses include hydroelectric power, flood control, navigation, irrigation, power plant cooling, municipal and industrial water supply, and streamflow augmentation.

Fishes of Europe

Maitland (1976) recorded 215 species west of the Urals and Kottelat (1997) 358 species in Europe, exclusive of the former USSR. This difference is mainly due to their different thoughts about the species concept.

No freshwater fish species has spread throughout continental Europe. Banarescu (1989) distinguishes two main areas of distribution of freshwater fish fauna in Europe: central Europe in a broad sense and southern Europe, i.e. the three southern peninsulas. He did not consider northern Europe but there exist several similarities among central European fish fauna.

Environmental changes have often resulted in changes in fish abundance and species composition. Many species have become rare, vulnerable, threatened or extinct in certain parts of their distribution area.

Changes in the status of freshwater fishes can be assessed in the light of their original distribution. During the last glaciation period the northern part of Europe was covered by an ice sheet. The fish fauna south of the ice sheet was composed of cold water tolerant species which lived in refugia in southern Europe beyond the influence of the ice. After the retreat of the ice, freshwater fishes migrated via the sea or via rivers from the southern refugia. It is probable that this natural colonization is still taking place (Evans 1989).

Natural processes have affected fish populations for many thousands of years. However, human activities have accelerated the changing rate and today the European fish fauna faces threats to its existence on an unpredictable scale. The number of threatened fish varies in different studies. Banister and Wheeler (1982) suggested that 4 fish species in the area of EEC were endangered, 8 were vulnerable and 34 were rare, insufficiently known or indeterminate. Lelek (1987) listed approximately 25 endangered and 40 vulnerable species in Europe. The International Union for Conservation of Nature and National Resources (IUCN) in Europe classified 11 freshwater fish species as globally endangered, 6 species vulnerable and 3 species rare. In the Bern Convention 122 species of freshwater fish are included (Kristensen and Hansen 1994).

Habitat requirements of fish

The ecology of a lake depends primarily on whether the lake is deep or shallow, large or small, eutrophic or oligotrophic. Lakes have many biological communities, e.g. submerged macrophytes in shallow littoral parts and phytoplankton in pelagic and deep parts. The species and demographic composition of zooplankton, zoobenthos and fish varies between different zones. Littoral areas and wetlands are the most productive ecosystems.

The suitability of a physical environment for a fish species depends mainly on the geological, morphological and hydrological processes which influence the width of littoral and deep habitats and riparian vegetation (Cowx and Welcomme 1998). An important factor is also the quality of the catchment area, which affects the water quality and productivity of lakes.

In its broadest sense, the term habitat defines where a fish species lives without specifying resource availability or use (Cowx and Welcomme 1998). Different ontogenic stages often favour different habitats. Even sedentary species may change their habitat during their life span.

The existence of a fish population in a lake is dependent on suitable spawning, feeding and wintering sites. Fish display migratory patterns between these habitats. In most cases the spawning sites are quite close to the feeding sites. However, to optimize reproduction success, many fish species migrate further away, often to shallow areas or to streams where their spawning grounds are situated. Optimum feeding strategies, avoidance of unfavourable conditions or enhancement of colonization may also be reasons for migrations.

The microhabitat for an individual fish is the site where the fish is at any point in time. This site is influenced by the structural complexity of the lake. Rehabilitation projects that focus on physical habitat and microhabitat must be based on an assessment of habitat connectivity. Depth, substrate and vegetation all appear to be important in the use of microhabitats by fish. Lakes in a natural condition tend to support more diverse fish communities and remain more stable throughout the seasons than the lower-diversity communities of modified lakes. However, habitat structure is not the only component affecting the species composition of the fish living in a lake or reservoir but also has a major effect on the age structure of fish populations (Cowx and Welcomme 1998).

Habitat requirements of fish form the basis in maintaining or rehabilitating lakes for fish bio-

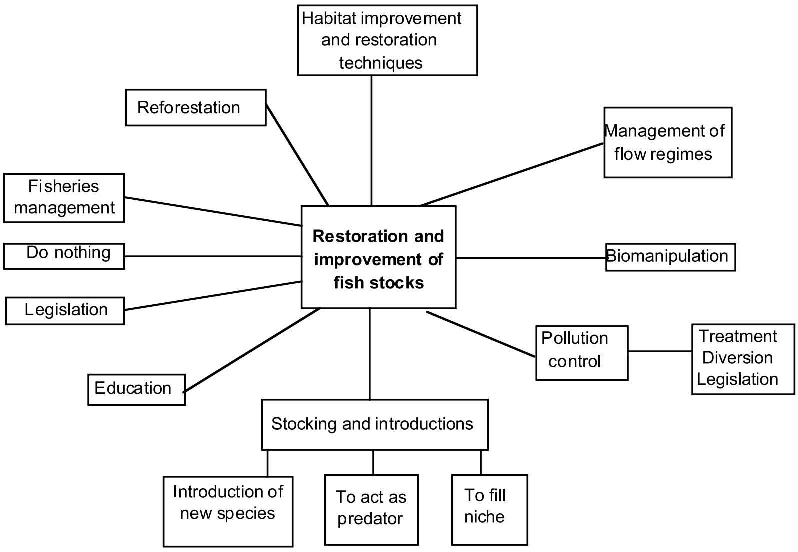

Fig. 2. Techniques for rehabilitation of inland fisheries (redrawn from Cowx 1994a).

diversity. In general, habitat requirements are satisfied by complex habitat structure. There are differences between the habitat requirements of different fish species and of ontogenetic stages. Therefore, a need to understand the species-specific requirements form an essential starting point of a rehabilitation process.

Methods used in lake and reservoir rehabilitation

Many methods have been used in rehabilitation and management of lakes to improve or stabilize the status of the fisheries and prevent further decline. These strategies range from the physical creation of new habitats to the complex management of large lakes. Rehabilitation techniques are given in Fig. 2.

Before rehabilitation, objectives must be defined with respect to the current factors limiting fish stocks. This includes assessment of the position and relationships of fish communities and status of fish community under pre-rehabilitated conditions.

There is a close relationship between ecological understanding and successful restoration. Bradshaw (1987) stresses that "any attempt to reconstruct an ecosystem is a test of our knowledge of the ecosystem and will reveal any deficiences in our theoretical knowledge. It is easy enough to take an ecosystem to bits and think that all the significant attributes have been identified. It is only when attempts are made to put it together again that it can be seen whether the bits have been identified correctly. We can learn from our failures."

Rehabilitation practices may include the regulation of a fishery, food web manipulations, fish stocking, fish introductions, predator control and habitat management through artificial spawning areas, blocking access to inflows, blocking of outflows, removal of barriers, liming, controlling vegetation, raising of the water level, addition of fertilizers and introduction of prey species.

Regulation of a fishery

The possibilities to affect fish populations through fishing regulations are numerous. However, the general aim is to prevent overfishing, and this in most cases requires reduction of fishing effort and in many cases fishing gear restrictions, licence restrictions, catch quotas and closed seasons. These regulations, may however, give rise to many problems due to opposite socio-economic consequences.

Interyear variation in catches is mainly caused by variation in recruitment. The aim of rehabilitation is in many cases to stabilize this variability. Two policies have been used to achieve this goal: constant catch quota or constant fishing effort. The former reduces the variability of catches whereas the latter agrees better with sustainable management and reduces the risk of overexploitation. Buijse *et al*. (1994) developed a model to link the variation in the yield to variations in recruitment and the exploitation pattern. The model revealed that the stabilizing effect of a reduced fishing effort is higher when a stock is effectively exploited. i.e. when the yield comprises fewer age groups (see also Beddington and May 1977).

In practice, the possibilities for stabilizing yield by managing with an effort policy is rather limited due to the large variations in recruitment and uncertainties in predicting future yields. Management strategy may be hindered also by year-to-year variability in the yields, which makes it difficult to demonstrate the possible benefits of rehabilitation operations. Therefore, fishery scientists should inform fishermen about the expectations with respect to exploitation of natural resources (Loftus 1987).

Food web manipulation

As a method to rehabilitate fisheries people have manipulated the composition and abundance of fish populations and thus influenced trophic interactions between fishes and other organisms (McQueen 1990, Shapiro 1990). In food web manipulation the purpose is usually water quality management and it is often based on two assumptions; piscivorous fish control planktivorous fish which have a negative influence on herbivorous zooplankton or benthivorous fish recycle bottom material by releasing deposited nutrients and through excretion and egestion (Hosper 1997). Dense fish populations may also inhibit the growth of macrophytes through reducing the clarity of water (Meijer *et al*. 1990).

In eutrophic lakes the balance of fish assemblages is disturbed and predators are not able to control the increase of cyprinid fish populations. Mass removal of cyprinid fishes has therefore been used in several lakes to balance the predator-prey relationship. Fishing can be considered as a selective predation (Urho 1994). Selective removal of planktivorous and benthivorous fishes by both man and piscivorous fishes affects species composition and biomass of prey fishes and hence the species composition and biomass of phytoplankton and zooplankton (Tátrai and Istvánovics 1986). The ultimate goal of food web manipulation is usually to diminish phytoplankton biomass which may be harmful and often toxic.

Simultaneously, it is possible to enhance the structure of fish populations. In eutrophic lakes the function of food webs can be manipulated in two ways; by decreasing external nutrient loading or by decreasing the internal loading through reduction in the density of planktivorous fishes which in turn increases grazing on phytoplankton by zooplankton (Carpenter *et al*. 1985). There are many examples how removal of piscivores has affected the abundance of organisms belonging to lower trophic levels, and this has affected water quality (Horppila 1994, Horppila *et al*. 1998, Sarvala *et al*. 1998).

Stockings and introductions

Stockings, introductions and transfers of fish are generally used in the management of lakes and reservoirs. However, stocking programmes are seldom based on well-defined objectives, or on prior appraisal of the likelihood of the success of the exercise (Cowx 1994b). In spite of this, billions of fish are stocked annually into European fresh waters.

Stockings have many consequences in lakes and reservoirs. They can result in the loss of genetic integrity, changes in ecological balance and shifts in community structure. Proposals for stocking or introduction of a new species should therefore be based on clearly defined objectives and throughout pre-operational assessment of the ecosystem (Cowx and Welcomme 1998).

In compensation stockings native fish species are stocked to compensate for negative human impact on the environment. In most cases it concerns the lack of a critical habitat such as a spawning site or substrate, or an obstacle to migration such as a dam for anadromous species. The degree to which the fishery is dependent on stocking depends on the extent of modification to the ecosystem, and can range from total, where the native stock would disappear without support, to partial, where the stock would be drastically reduced. A special case of compensation stocking is to maintain exotic species that do not naturally breed in the recipient water. This strategy is particularly favoured in situations where it is not thought desirable to introduce a permanent new element to the fauna and where stocks of the species would eventually die out without new material being added.

The goal of maintainance stocking is to compensate for recruitment overfishing. A great number of fish stocks are so systematically overfished that reproduction of exploited populations is impeded. Stocking should be carried out to support these species.

Enhancement stocking aims to maintain the fisheries productivity at the highest potential level. Thus, enhancement stocking seeks to direct the yield from the lakes towards a certain number of species which are valuable. lt is significant both in commercial fisheries, where the total catch of the preferred species is the main criterion, and in recreational fisheries the aim is to influence the composition of the fish population towards those species and size categories which are attractive to anglers.

Species threatened with extinction can be retained by conservation stocking. This stocking purpose has many similarities to mitigation stocking but is usually more preservationist in its intent. Stocking may take place in habitat refugia or other areas not subject to the endangering threat but often the species has to be maintained in areas where the threat still exists through continual inputs of new material from fish hatcheries.

Stocking is the most common way for introducing new species into a waterbody. Many recreational fisheries introduce new species to improve the variety available to the fisherman or to introduce species of particular sporting value. Similarly commercial fisheries may benefit from new additions that are more resistant to fishing pressure or have greater market value.

In some areas there are impoverished fish faunas that do not fully use the trophic and spatial resources available. This can arise in some natural waters but more commonly the need for such introductions arises as a consequence of human activities. Thus where environments have changed native species are not always capable to fully colonising them.

From the point of view of a fisheries managers, the ultimate goal of stocking is to increase fish catch, value of catch or fishing. Managers wish that stocked fishes survive and grow large enough to be caught. In ideal conditions stocked fish should have much food and no predators and competitors. Competition for food and space is always highest between individuals belonging to the same species. Thus stocking increases competition if same species already exists in a lake.

Concluding remarks

The quality of fish populations and fishing in a lake depends on a variety of factors, many of which are independent of the fishery or even independent of the aquatic system. Pressures on lakes from domestic, industrial and agricultural uses has deteriorated most lake fish communities in Europe and given reason for rehabilitation. It is not easy to find and maintain a balance between the requirements of fisheries and other forms of water use. The changes undergone by fish communities involve a displacement of the community towards the smaller, faster growing but shorter living species while the more appreciated fish species are usually those larger, slower growing ones which disappear early in the process. Fishery managers have in this situation a variety of methods to manipulate lakes and fish stocks. Selection of the right method is the starting point of a successful rehabilitation process.

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Fish tumor pathology and aromatic hydrocarbon pollution in a Great Lakes estuary. In Hydrocarbons in the Aquatic Environment (ed. Gan, B. K. A. & McKay, D), pp. 559â€“65.Â Review on the effects of pollution on marine fish life and fisheries in the North Sea. Zeitschrift fÃ¼r angewandte Ichthyologie 3, 97â€“118. Dethlefsen, V., Watermann, B. & Hoppenheit, M. (1984). MoE publication type. A2 Review article in a scientific journal.Â In: Boreal Environment Research, Vol. 4, No. 2, 1999, p. 137-143. Research output: Contribution to journal â€º Review Article â€º Scientific â€º peer-review. Ty - jour. T1 - Rehabilitation of lakes for fish and fisheries in Europe. T2 - a review. AU - Lehtonen, Hannu. PY - 1999. The environmental impact of fishing includes issues such as the availability of fish, overfishing, fisheries, and fisheries management; as well as the impact of industrial fishing on other elements of the environment, such as by-catch. These issues are part of marine conservation, and are addressed in fisheries science programs. According to a 2019 FAO report, global production of fish, crustaceans, molluscs and other aquatic animals has continued to grow and reached 172.6 million tonnes in 2017, with Sport fishing, swimming, and boating are highly popular pastimes, and lake-front property has a high economic value.Â Lake restoration is a relatively recent activity. Historically, the term restoration has been applied broadly in lake management to an array of actions aimed at improving lake conditions for designated human uses (e.g., contact recreation, fishing, water supply). Return of a lake to its pristine condition has not been an explicit goal of most lake restoration projects, although these actions often improve some aspects of a lake's ecological attributes. As such, most so-called lake restoration projects are actually rehabilitation efforts (in the sense of the definitions in Chapter 1), and Floodplain wetlands, lakes, and other aquatic habitat support large fisheries and aquaculture operations in many parts of the world (Welcomme, 1985; Thompson and Hossain, 1998; Hoggarth et al., 1999; Ghosh and Ponniah, 2001; Welcomme and Petr, 2004a,b). The channelization of rivers for industrial, urban, agricultural, and other human uses has lead to a decline in fish production in many floodplain areas.Â This problem is common to many stream channels in Europe, North America, and throughout the world.Â Rapid colonization is not altogether surprising given that many freshwater fish species are entirely or partially dependent uponÂ For example, in a review of Danish stream rehabilitation, Iversen et al.