SECTION III

RELEASE OF CAPTIVE-BRED SPECIES: FRESHWATER FISH

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General aspects

Introductions of freshwater fish from captivity into the wild can be either accidental through escapes from rearing areas and ornamental ponds, or deliberate for the initiation or the alleged enhancement of stocks. Such introductions must be seen against a background of general concern over the loss of genetic material in wild populations. There is strong evidence for genotypic differences between populations of the same species, e.g. for stocks of brown trout, Salmo trutta L., (Elliott, 1989; Ferguson, 1989), Atlantic salmon, Salmo salar L., (Youngson, Martin, Jordan & Verspoor, 1989) and Arctic charr, Salvelinus alpinus (L.), (Partington & Mills, 1988). Such 'gene-pools' are important sources of material, not only for aquaculture, but also for restocking restored habitats that once contained fish populations (see also Ryman, 1981; Nelson & Soule, 1987).

The genotypic differences between populations also have important implications for the management of fish stocks. Whenever possible, deliberate stocking should be performed with fish reared from the indigenous population because the latter should always contain the optimum genotypes for a particular set of local environmental and biological conditions. Hatchery strains will rarely be appropriate for restocking because their genetic diversity is usually greatly reduced. For example, Gyllensten & Wilson (1987) found that Swedish captive bred stocks of brown trout retained an average of only 25% of the mitochondrial DNA variability of the natural populations. If such fish escape into the wild and breed with wild fish, adulteration of the optimum genotypes in the latter could result. Such interbreeding can occur not only between different stocks of the same species but also between species. A wide variety of hybrids has been recorded from continental Europe and those known to occur already in the British Isles are listed in Table 1. Such hybridization increases the range of effects in releasing a captive bred fish into the wild.

Species introduced to the British Isles

At least 17 species have been introduced into the British Isles and information on their origin and success is summarised in Table 2 (based on Maitland, 1972, 1987; Wheeler, 1974; Wheeler & Maitland, 1973). Two of these species (Humpback salmon, Grass carp) have apparently never become established, six species (Channel catfish, Guppy, Largemouth bass, Pumpkinseed, Rock Bass, Tilapia) have only one or two self-sustaining populations, three species (American brook trout, Bitterling, Wels) have several self-sustaining populations and five (Common carp, Crucian carp, Goldfish, Orfe and Zander) have been at least fairly successful and are now widely distributed. The remaining species is the rainbow trout. There have been widespread introductions and escapes throughout most of the British Isles yet there are remarkably few reports of self-sustaining populations.

The two carps and the goldfish have been established in the wild for so long that they could be regarded as part of the British fauna. New varieties of these species are however being introduced for ornamental purposes and these could obviously breed with existing stocks. There is apparently little information on the effects of this interbreeding. It should be noted that two of the introduced species, American brook trout and Orfe, are already known to hybridize with native species (Table 1).

It is important to recognise that even in the absence of hybridization, the establishment of alien species in the wild may well exert selective pressures on native species with which they interact. An obvious example is the spread of the Zander, a highly effective piscivore. This is very likely to exert strong selective pressure in favour of heritable anti-predator behaviours amongst the affected prey communities.

Although Atlantic salmon and brown trout are native to the British Isles, foreign stocks have been introduced for aquaculture. There is an additional problem with these species. There are now large captive stocks that have different genotypes to the wild stocks and any releases could have serious implications for the latter. For this reason, these two species will be discussed in separate sections.

Transgenics

There are special problems of gene transfer with transgenics that are deliberately or accidentally released to the wild, especially if breeding with wild stocks could occur. For example, novel genes have been introduced to rainbow trout to enhance their growth, and the production of transgenic rainbow trout is now a feasible proposition (Penman & Maclean, 1987). It may soon be possible to isolate genes that confer resistance to a particular disease or parasite in one fish species and transfer them into a susceptible species. The future development and escape of transgenic S.trutta, or other genetically altered native species, could result in marked changes in the genotypes of our native stocks. Indeed, the whole aquatic community could be affected through the 'cascading effect' of changes in the biology of an important component of an aquatic ecosystem.

Disease

Although the role of captive-bred fish in transmitting disease to wild stocks does not fall directly within the scope of this review, it is important to realise that this process will itself have an inevitable genetic impact on wild populations. In many cases, this will involve exposure to new selection pressures, favouring individuals best able to withstand the disease or parasite. However in some cases, the entire locally adapted wild population may be threatened. For example, the monogenean skin parasite, Gyrodactylis salaris, was introduced to Norwegian salmon farms from resistant Swedish stock. Its spread to wild populations in Norwegian rivers has resulted in the mass death of juvenile salmon (parr). The only known method of eradication involves the poisoning of all the fish in an entire river system, followed by restocking (Mills, 1989).

Atlantic salmon, Salmo salar L.

Introduction

This species was formerly widely-distributed in Northwest Europe and Eastern North America. It was subject to fishing pressure but, since the industrial revolution, stocks have declined or become extinct. This process has accelerated in recent times (Maitland, 1986,1989). Although salmon became extinct in many British rivers, more recent reductions in pollution have led to restocking and the successful initiation of a few new stocks.

For at least the last 100 years, salmon have been reared in hatcheries and the young fish have been introduced to the wild to augment smolt production (smolts are the life stage that migrates from fresh water to the sea). Traditionally the hatchery eggs were obtained from local fish in the wild and the hatchery progeny were released into the local population. More rarely, progeny of non-native fish were released in an attempt to impart some desired characteristic to the stock. Few adult fish were used each year to supply the hatchery eggs and on release, the hatchery fish had to compete with wild progeny that were usually more numerous. Few salmon survive to the smolt stage and only a small number of adults have to return to the natal river to ensure that the juvenile carrying capacity is attained (Buck & Hay, 1984). This pattern of rearing in hacheries and release has changed markedly in recent years with the rapid growth of the commercial culture of the Atlantic salmon, especially in Scotland. In 1988, 21*10^6 smolts were produced for sea-water culture in Scotland (DAFS, 1988) and this value exceeds the average annual production of wild salmon in Scotland (Youngson et al. 1989).

Genetic variations in salmon

Cultured salmon are often kept in captivity for their entire life cycle and for successive generations. Individual strains of salmon are now established in captivity and artificial selection, both deliberate and inadvertent, has produced directional, stable genetic change. One result of this selection is that the genetic variability of Atlantic salmon in culture is usually lower than in wild fish (Vuorinen, 1982; Cross & King, 1983; Stahl, 1983; Verspoor, 1988a). This reduced genetic variability can produce reductions both in individual performance and in the ability of salmon to respond to new selection pressures (Ryman, 1970; Kanis, Refstie & Gjedrem, 1976; Johansson, 1981; Allendorf & Ryman, 1987).

Interpopulation variability in the genotype of Atlantic salmon is considerable (Stahl, 1981, 1983, 1987; Verspoor, 1988), probably because of the homing behaviour of the adults to their natal streams (Saunders, 1981; Thorpe & Mitchell, 1981). Genetic differences can also occur between young salmon living in different parts of the same river (Stahl, 1987). One of the most detailed studies of genetic variation in cultured salmon is that on twelve strains in Scotland (Youngson et al., 1989). Eight strains were derived from Scottish stocks and four from Norwegian stocks. All strains, except one, had been reared in captivity for at least four generations. Genetic differences were found between the strains and they differed overall from diverse samples of wild Scottish salmon. For nine of the strains, the source population was identified and it was found that the farmed strains differed genetically from these source populations.

The evidence suggests that selective pressure has been acting consistently on the captive strains or on the source population, over the period since the strains were established. Although significant between-year variability in genetic structure was found in a wild population over five brood years, no consistent directional change with time was evident. The limited amount of evidence suggests that selection pressure on the captive strains is chiefly responsible for the dicrepancy between wild and farmed stocks.

Effects of releases of captive bred salmon

The genotypes of salmon populations were probably little affected by traditional methods of rearing young salmon from eggs taken from wild parents and then releasing the progeny into the wild, usually into their parental stream. With the recent growth of the commercial culture of Atlantic salmon, it can no longer be assumed that the effects of releases are negligible. Cultured salmon are now kept in captivity to a much greater age than previously and the release of older fish with a higher probability of survival could affect the composition of spawning stocks in the wild.

It has been shown that the genetic variability of farmed salmon is usually lower than that of wild stocks. If these captive fish are released and survive to spawn, their progeny and the progeny of crosses with wild fish could have a reduced capacity to survive in the wild. This could lead to a reduction in wild stocks.

It has been shown that the genetic constitution of wild salmon varies between populations which are isolated from each other geographically in a manner which is reinforced by the high degree of fidelity with which adults home to the rivers which they occupied as juveniles. It is likely that local genotypes will have resulted from the particular selective pressures acting in their environment in such a manner as to make them uniquely adapted to their local environment. If captive fish derived from diverse sources are released, then adulteration of the optimum genotypes of the wild stocks of salmon could occur, with the possible disruption of their homing instinct. It is notable that captive strains in Britain are derived not only from British stocks but also from overseas, especially from Norway. Fortunately there is some evidence that survival rates are lower for released fish, either reared in captivity or taken from another river, than for salmon released into their natal river (Ritter, 1975; Jessop, 1976; Isaksson, Rasch & Poe, 1978).

Ideally, strenuous efforts should be made to ensue that captive salmon do not escape into the wild. Unfortunately, such efforts appear to be unsuccessful and there are increasing records of escapes, sometimes involving large numbers of fish, e.g. 90,000 salmon escaped when a ship collided with cages, 185,000 escaped from one farm during a storm, $1.6*10^6$ fry escaped from a hatchery into a small Scottish stream (Maitland, 1989). One possible solution would be to rear sterile salmon. Triploid salmon are theoretically sterile and also appear to have a low survival rate in the wild. Nonetheless, some triploid males do mature, albeit with low fertilities. If such males did escape to breed with wild females, they could still affect wild stocks of salmon.

Ranching

In some areas, for example Iceland, there has been a great increase in the release of young captive bred salmon from areas where natural spawning is no longer, or never has been, possible. The goal is to fully utilize the carrying capacity of the marine environment to produce adults which can be harvested at or near the the point of release on their return spawning migration. To safeguard the genetic integrity of wild stocks, it is clearly desirable that ranching stations should only operate in areas distant from significant salmon -producing river systems to minimize the degree of straying (Isaksson, 1988).

Brown trout, *Salmo trutta* L.

Introduction

This species occurs throughout most of Europe and has been successfully introduced into at least 24 other countries and all the remaining continents bar Antarctica (Elliott, 1989). Trout migrate to the sea from some populations but spawning is always in fresh water, usually in rivers and streams but occasionally in lakes. Human activity has led to the extinction of many natural trout populations through the pollution of rivers and reductions in pH due to the effects of acid rain. Other human activities such as impoundment, river transfer, drainage works, land improvement, afforestation and deforestation can all affect trout populations via changes in flow regime (and related effects such as sedimentation of the spawning gravels), temperature regime and water chemistry (Crisp, 1989). The numbers of trout in other natural populations can also be affected by angling pressure, by the introduction of competing species and by the introduction of captive bred stock.

Trout populations can be placed in three general categories:

a) Natural populations. Waters with no history of stocking with hatchery-reared trout.

b) Semi-natural populations. Natural recruitment is important but there is supplemental stocking with hatchery-reared trout to increase the availability of fish to anglers. Waters not normally subject to stocking but subject to large 'one off' introductions in the aftermath of pollution incidents.

c) Artificially-maintained populations. Waters where natural recruitment is either absent or virtually so. This is typically true of lowland reservoirs and lakes that are maintained as 'put and take' fisheries but also applies to some flowing waters where natural reproduction is no longer possible

Genetic variations in trout

Excluding hatchery stocks, published information is available on the electrophoretic study of protein variation in samples of trout from 412 geographically discrete sites in 116 separate drainages (Ferguson, 1989). These studies show that the trout is naturally subdivided into a large number of reproductively isolated and genetically distinct populations, both within and between drainages. Of 70 gene loci examined, the species shows polmorphism at 38 (54%), making it one of the most polymorphic vertebrate species known (Ferguson, 1989). The mean heterozygosity (Nei, 1975) is twice that recorded for the Atlantic salmon and the maximum genetic distance between trout populations (0.15) is almost half as great as the equivalent genetic distance between trout and salmon (0.33). It is particularly important to recognise that individual trout populations contain only a part of the genetic variability of the species. In British and Irish rivers an average population contained only 67% of the genetic variability present in this area (Fleming, 1983). On a wider scale an individual trout population will contain, on average, under a third of the total genetic diversity of the species (Ferguson, 1989). In a notable example of this diversity, Lough Melvin in north-west Ireland contains three brown trout stocks. Each is clearly distinct in terms of allele frequencies, morphometric and meristic characters, spawning sites, growth rates, longevity and diet (Ferguson, 1986).

Effects of releases of captive bred trout

Over a 15 year period, $4.8*10^6$ trout fingerlings and $3.0*10^6$ eggs, bred from broodstock of various non-native origins, were introduced into the Erne-Macnean drainage (Taggart & Ferguson, 1986). This system in north-west Ireland contained the most genetically distinct group of brown trout out of 116 British and Irish populations and might be one of the few remaining locations of a distinct 'ancestral' race of brown trout (Ferguson & Fleming, 1983). The proportions of a marker allele, rare in the native populations but common in the broodstock, were assessed in 10 stocked rivers in the Erne-Macnean system (Taggart & Ferguson, 1986). The genetic contribution of the non-native fish ranged from 19-91%. The introduced genetic component persisted when stocking ceased, and the distribution of the alleles indicated that there was a single, randomly mating population. This provides clear evidence of introgression between the native and non-native strains.

Trout planted directly into Irish lakes, rather than into the spawning rivers, showed a much reduced tendency to run up rivers to spawn, probably due to a lack of imprinting to a natal stream. Electrophoretic studies confirmed that even where lakes were dominated by stocked fish, they made little contribution to the spawning stock, shedding their reproductive products in the lakes (O'Grady, 1984). However it is important that even a very small degree or introgression might be sufficient to engender the collapse of the genetic segregation between sympatric or neighbouring stocks. In the case of Lough Melvin, the replacement of three specialised stocks by a single homogeneous one would almost certainly lead to a lower overall trout biomass in the lake.

Hatchery trout of various origins were stocked into the River Skelleftealven drainage in northern Sweden to compensate for the effects of dam and reservoir construction. Genetic studies strongly suggest that stocking has caused a breakdown of previously existing barriers to reproduction between native populations in the drainage. The resulting interbreeding between previously genetically distinct populations was probably responsible for their loss (Ryman, 1980).

Hybridization between Atlantic salmon and trout produces fertile offspring but is rare in both Britain (Solomon & Child, 1978) and Scandinavia (Stahl, 1981,1983). However in Newfoundland the introduction of trout has resulted in widespread hybridization between anadromous and resident forms of both species (Verspoor, 1988b). Similar high rates of hybridization (up to 7.7%) were observed in Spanish rivers with a long history of stocking with foreign salmon ova and fry (Garcia de Leaniz & Verspoor, 1989). These results suggest that the introduction of captive bred fish may lead to the breakdown of the strong genetic segregation that normally occurs between sympatric stocks of trout and Atlantic salmon.

Conclusions

1. The presumption should always be against the deliberate stocking of viable natural populations. Alternatives such as increasing access to spawning sites and reductions in fishing pressure must always be considered first. For example a policy of catch and return is successfully operated for many resident salmonid populations in North America and is widely applied to non-salmonid species within the British Isles.

2. Sufficient populations should be identified and legally protected against stocking to maintain the remaining genetic diversity of brown trout and salmon in the British Isles. This is important both in terms of the conservation of the species and for the supply of genotypes for aquaculture, and is within the scope of existing electrophoretic techniques.

3. Deliberate stocking of semi-natural populations should always be performed with fish reared from the indigenous population because they should contain the optimum genotypes for the local environment.

4. Deliberate stocking should be performed with juveniles reared from wild parents because after two generations the presumption must be that a domesticated strain with a reduced genetic variability has been created. The potential reduction in genetic variability also makes it particularly unwise to rear juveniles from only a small number of parent fish.

5. Surplus fish from aquacultural installations should never be released into natural or semi-natural populations unless they meet the criteria outlined in 3. and 4. above.

6. Much greater efforts must be made to prevent the escape of fish from aquacultural installations which, ideally, should be excluded from areas which contain those stocks selected for protection.

7. The rearing and stocking of sterile fish should be strongly encouraged.

Table 1. Freshwater fish: natural hybrids known to occur in the British Isles

(Trout)	_Salmo trutta_	x	_Salvelinus fontinalis_ (American Brook Trout)
(Carp)	_Cyprinus carpio_	x	_Carassius carassius_ (Crucian carp)
(Bream)	_Abramis brama_	x	_Leuciscus idus_ (Orfe)
	Abramis brama	x	_Scardinius erythrophthalmus_ (Rudd)
(Roach)	_Rutilus rutilus_	x	_S. erythrophthalmus_
	Rutilus rutilus	x	_Abramis brama_
	Rutilus rutilus	x	_Alburnus alburnus_ (Bleak)
(Chub)	_Leuciscus cephalus_	x	_Alburnus alburnus_
(Dace)	_Leuciscus leuciscus_	x	_Alburnus alburnus_
	Leuciscus leuciscus	x	_S. erythrophthalmus_

Table 2. Species of freshwater fish introduced into the British Isles

Order: Isospondyli
Family: Salmonidae

Oncorhynchus mykiss (formerly Salmo gairdneri Richardson)(Rainbow trout): native of west-coast of North America, many introductions but probably only five self-sustaining populations.

Oncorhynchus gorbuscha (Walbaum)(Humpback salmon): native of west-coast of North America, few introductions and rare, no known self-sustaining populations.

Salvelinus fontinalis (Mitchill)(American brook trout or speckled charr): native of North America, several introductions and possibly some self-sustaining populations.

Order: Ostariophysi
Family: Cyprinidae

Cyprinus carpio L.(Common carp): native of central Asia, now widely distributed and self-sustaining in central and southern England.

Carassius carassius (L.)(Crucian carp): native of eastern and central Europe, now widely distributed and self-sustaining in central and southern England.

Carassius auratus (L.)(Goldfish): native of eastern Asia, self-sustaining populations not numerous and found chiefly in England.

Rhodeus sericeus (Bloch)(Bitterling): native of middle Europe from France to Caspian, only four or five self-sustaining populations.

Leuciscus idus (L.)(Orfe): native of eastern Europe and western Europe, only about fifteen self-sustaining populations.

Ctenopharyngodon idella Cuv. & Val. (Grass Carp): native of China, introduced several times but no known self-sustaining populations.

Family: Siluridae

Silurus glanis L. (Wels or European catfish): native of central and eastern Europe, introduced several times but only four or five self-sustaining populations.

Ictalurus punctatus (Rafinesque)(Channel catfish): native of North America, possibly two self-sustaining populations.

Table 2. Species of freshwater fish introduced into the British Isles (cont)

Family: Poecilidae

<u>Poecilia reticulata</u> (Peters)(Guppy): native of northeastern part of South America, possibly two self-sustaining populations.

Order: Percomorphi
Family: Centrarchidae

<u>Micropterus salmoides</u> (Lacépède)(Largemouth bass): native of North America, possibly two self-sustaining populations.

<u>Lepomis gibbosus</u> L.(Pumpkinseed): native of North America, possibly two self-sustaining populations.

<u>Ambloplites rupestris</u> (Rafinesque-Schmaltz)(Rock bass): native of North America, only one self-sustaining population known and now possibly extinct.

Family: Percidae

<u>Stizostedion lucioperca</u> (L.)(Pike-perch or zander): native of Europe from Netherlands to Caspian; several self-sustaining populations in eastern and central England.

Family: Cichlidae

<u>Tilapia zillii</u> (Gervais)(Tilapia): native of Africa, only one self-sustaining population.