**Diploma Thesis**

# Rearing and Stocking of Brown Trout, *Salmo trutta L.*:

## Literature Review and Survey of Austrian Fish Farmers within the Frame of the Project-Initiative TROUTCHECK

**Author**

Kurt Pinter

Department of Water, Atmosphere and Environment
Institute of Hydrobiology and Aquatic Ecosystem Management
University of Natural Resources and Applied Life Sciences, Vienna

Under Supervision of:
O. Univ. Prof. Dr. Mathias Jungwirth
Dipl.-Ing. Günther Unfer

and

Environment, Society and Design Division
Environmental Management Group
Lincoln University, Te Whare Wanaka O Aoraki, Christchurch, New Zealand

Under supervision of:
Prof. Dr. Ken Hughey

Vienna, September 2008

## Acknowledgement

In the first place I would like to thank my mother for many years of support. You made it possible for me to study and to achieve an academic degree.

Thanks to Moni for believing in me, for your love, and for your support in achieving this diploma.

Thanks to Gü for the supervision of my diploma thesis. I really enjoyed writing this diploma thesis under your supervision - thanks for your scientific input, for motivating me, and for a great time.

Thanks to Ken Hughey for accepting to do the co-supervision and for the important and helpful comments.

Thanks to Erwin Lautsch for the assistance in questionnaire design and analysis.

Thanks to Flo for sharing great years of joint studying.

Thanks to all the employees of the Institute of Hydrobiology and Aquatic Ecosystem Management for the integration into running projects and for a great time.

Thanks to all the interviewees who participated in this study.

# Abstract

The present study was carried out within the frame of the project-initiative TROUTCHECK which aims at the renaturation of native brown trout, *Salmo trutta* L., populations in Austria. Austrian brown trout populations are under threat from a variety of anthropogenic interferences. Beside the loss of habitat through river-regulation, hydroelectric power-plants, etc. stocking of propagated brown trout into wild populations increasingly raises concerns among fishery managers as well as conservation biologists.

A literature review on the current knowledge about the implications of stocking as well as on the negative effects of hatchery production shows that the main concerns relate to physiological, behavioural and genetic alterations of artificially produced fish. A loss of genetic integrity, overall fitness and lowered productivity of wild populations are the main endangerments for wild brown trout populations. It becomes evident that significant improvements are necessary. Rethinking the ways of rearing as well as sustainable fisheries management strategies are urgently demanded. According to a variety of scientific studies it shows that some semi-natural rearing strategies have already been tested positively. However, next to these achievements in the area of hatchery rearing, major gaps of knowledge have been identified which highlight the need for subsequent studies.

To gain an insight into the situation of propagated brown trout in Austria a survey of 26 fish farmers from the federal states Lower Austria, Styria, and Upper Austria has been conducted. In particular, analyses of the rearing practices and the social networks of relevant fish farmers have been undertaken. According to the findings, it becomes evident that Austrian wild brown trout populations face severe ecological impacts by stocking of hatchery trout. The main threats derive from the introduction of allochthonous brown trout strains, reduced genetic diversity within the stocked strains, and assumedly high rates of domestication in hatchery fish. The willingness of the interviewed fish farmers to change their rearing methods towards ecological sound methods is limited. Based on the statements of the aquaculture operators, it can be concluded that, among other, this lack of willingness refers to the fact that the farmers do not see the need to apply changes. Potential starting points for the implementation of sound rearing and management practices have been identified and are provided in the study.

# 1. Introduction

## *1.1 Background of the Study*

> *"Stocking refers to the repeated injection of fish into an ecosystem in which a population of that species already exists from one external to it, i.e., a stocked species may be either already native to the recipient water body or exotic to it but previously introduced."* (Cowx 1998)

In Austria, as in many other countries, brown trout, *Salmo trutta* L., is economically one of the most important fish species. This importance is mainly based on its popularity as a sport fish. Due to increasing pressure on the wild living populations through sport fishing as well as many other anthropogenic interferences, stocking of fish has become a widespread fisheries management tool for supplementation of exploited stocks. Despite national regulations and codes of practice, a variety of potential ecological problems are associated with stocking of fish. Ecological imbalance in stocked rivers, change in community structure as well as a loss of genetic integrity broadly defines these ecological consequences (Cowx 1998).

Intermixing fish from the same species but originating from different strains constitutes a common method for the supplementation of trout in Austria. Even non-domestic brown trout lineages from other European regions have been introduced into Austrian hatcheries and into Austrian rivers. The introduction of external strains, though, demonstrably led to genetic as well as phenotypic alterations of former endemic populations.

Next to the introduction of allochthonous brown trout strains, further ecological problems are related to the release of artificially produced fish. Apparently a variety of genetic, phenotypic as well as behavioural alterations of hatchery reared fish have been observed and, in succession, traced back to artificial rearing conditions lacking any resemblance with natural habitats.

According to these deficiencies of hatchery production and contrary to popular belief, stocking of brown trout does not necessarily improve the stocks. Instead of compensating for existing grievances, the release of artificially produced brown trout into wild populations causes increasing concern among fishery managers and conservation biologists.

As a consequence, the project-initiative TROUTCHECK was founded by the Institute of Hydrobiology and Aquatic Ecosystem Management of the University of Natural Resources and Applied Life Sciences, Vienna and the Institute of Zoology of the University of Graz. The main aim of this project-initiative is to implement measures for the renaturation of native brown trout populations of Austria, thus aiming to avoid further degradation and to improve the condition of remaining domestic brown trout populations. In particular, native populations will be identified and semi-natural rearing practices evaluated. Finally, management concepts for ecologically and economically sound supplementation of wild living populations are reflected. The aims of TROUTCHECK are subdivided into four different modules (cf. Chapter 4.1). This study was carried out within the frame of module three which aims to develop and implement sound rearing practices, renaturation measures, and management strategies for stocking purposes.

## *1.2 Aims of the Study*

Sound management practices for future supplementation of wild brown trout populations require adequate and well defined goals as well as comprehensive background knowledge about the current situation of rearing and stocking. Therefore, in the first part of this study, the literature review gives insight into the complexity of problems arising from artificial production and stocking of fish. This literature review serves, on the one hand, to provide a better understanding of the issues addressed when surveying fish farmers (part two). On the other hand, an overview of the current knowledge about the negative effects of artificial rearing on physiological, behavioural, and genetic parameters of the reared fish is given.

Since the development of semi-natural rearing practices is one of the main goals for future stock enhancements, special emphasis was also put on reviewing current research examining semi-natural rearing practices. After all, semi-natural rearing strategies are assumed to provide the tools needed to improve the effectiveness of stocking as a management tool and to reduce the ecological impacts of stocked hatchery fish.

The second part of this study aims to provide the necessary background information about recent rearing and stocking practices of brown trout in Austria. Therefore a survey of fish farmers has been conducted in the federal states Lower Austria, Styria, and Upper Austria. The primary objectives of the survey are to get an insight into the stocking-market of brown trout in Austria and to identify quality related perceptions on the part of the interviewed farmers. Furthermore, important players within the social network of fisheries management can be identified. Overall, the perceived information about rearing of brown trout in Austria will help develop management concepts for future rearing and stocking strategies of brown trout.

## *1.3 Structure of the Study*

After a short introduction about operating principles of hatcheries in Austria (Chapter 2.1), Chapter 2.2 then deals with the implications of stocking. In this context, this Chapter also addresses the increasing concerns of fishery scientists about stocking of artificially produced fish and gives a brief review on the related concerns. In succession Then Chapter 2.3 provides a more detailed discussion about the knowledge gained on the deficits of hatchery reared fish. In particular, the effects of artificial rearing environments (see Chapter 2.3.1) as well as the genetic effects of domestication (Chapter 2.3.2) are discussed by means of both physiological and behavioural changes of hatchery reared salmonids.

Chapter 3 considers the current knowledge about semi-natural rearing methods which are assumed to reduce the deficits of artificially produced fish. This review deals separately with perceptions on conditioning physiological changes (see Chapter 3.4) and behavioural changes (see Chapter 3.5).

Chapter 4 presents the aims and the background of the detailed survey of the fish farmers in detail. After describing the applied methodology (see Chapter 5.) the results of the inquiry are presented in Chapter 6. The structure of this presentation complies with the former defined aims of the investigation and is therefore separated into four sections (Chapters 6.1 to 6.4). A discussion of the results is provided in Chapter 7. Finally, Chapter 8 provides a conclusion to the information generated by the thesis research.

# 2. Review of the Problem Area of Stocking Artificially Propagated Fish

This Chapter provides an introduction into the aims and evolving ecological problems, respectively of hatchery rearing and stocking programmes of salmonids. After a brief introduction into the operating principles of hatcheries the background and current developments of stocking programmes are highlighted. Subsequently, physiological and genetic differences between hatchery- and naturally reared salmonids are described. In general, this Chapter should serve for a better understanding of the need of semi-natural rearing practices.

## *2.1 Operating Principles of Hatcheries*

Rearing of salmonids in hatcheries was first developed around three hundred years ago (VOEF 2007) and comprises a high variety of different species from the family of Salmonidae. The primary purposes of hatcheries rearing salmonids are to produce fish for harvest and for stocking. Today's worldwide production of salmonids in aquaculture has been estimated at approximately two million tons per year (FAO 2007). According to STATISTIK AUSTRIA, total production of salmonids in Austria has been about 2.500 tons per year on average over the last few years (STATISTIK AUSTRIA 2007). Separated into branches of production, roughly 82% (2.033t) amount to production of edible fish and about 18% (459t) have been produced for stocking purposes (STATISTIK AUSTRIA 2007). However, these figures appear to underestimate the total production of salmonids in Austria (cf. Chapter 6.1.3).

Rearing methods for both lake (limnophilous) and river (rheophilous) fish of different families are relatively uniform. Usually the fish are bred in artificial environments, ensuring high survival rates as long as the fish stay in the hatchery. The variety of different indoor and outdoor facilities used for captive breeding, comprises stagnant or flowing water ponds, concrete-raceways, flow-through troughs, recirculation systems or diverse types of tanks (Philippart 1995). Adult-fish are usually kept for two years and are either replaced by their own brood or less frequently by wild conspecifics (see also Chapter 6.1.1). Spawning mates are artificially selected by fish farmers whereby spawning is done by stripping eggs and sperm. After fertilization the eggs are incubated in various designated incubators under suitable temperature conditions. During the first weeks after hatching the brood feeds on the yolk sac. After resorption of the yolk sac the fry obtain food supplies which are adapted to the species and its requirements. In general, hatchery fish are fed with pelleted feeds. Fish demand precise husbandry conditions, particularly during the first stages of life. Parameters such as water temperature, renewal rate of water in tanks or ponds, dissolved oxygen or food and feeding are of particular importance and need to be considered for the different life stages and species.

As a matter of economic viability rearing densities in hatcheries are usually relatively high. The duration of individuals held in captivity lasts between a couple of days after fertilisation of eggs and several years. However, the majority of reared fish are released to streams after a captive breeding period between six months and two years (Brown and Day 2002).

## *2.2 Implications of Stocking*

Stocking of fish is a worldwide practice following different purposes. Cowx (1998 in: Apprahamian et al. 2003) defines stocking as “the repeated injection of fish into an ecosystem in which a population of that species already exists from one external to it, i.e., a stocked species may be either already native to the recipient water body or exotic to it but previously introduced”. Nowadays, releasing fish into the wild is very common in the management and conservation of fish populations. Apparently, hatchery reared fish make up large proportions of some fish stocks (Weber and Fausch 2003). A major benefit of stocking fish is, in terms of anadromous fish, a higher efficiency in the production of returning adults or population enhancement of resident (i.e., nonanadromous) fish when compared with natural spawning. However, there are different reasons for stocking fish which have been summarized by Aprahamian et al. (2003) as follows (see also Holzer et al. 2003):

(a) Mitigation: Stocking that is conducted to mitigate lost production due to a water development scheme or activity which cannot be removed. In general, mitigation stocking describes a permanent solution for the maintenance of endangered populations. The actual reasons for fish population decreases (e.g., hydroelectric plants, habitat degradation) remain (Holzer et al. 2003).

(b) Restoration: Stocking which is carried out after the removal or reduction of a factor which has been limiting or preventing natural productions. The aim of restoration stocking is to establish self-sustaining aquatic ecosystems (Holzer et al. 2003). In this case stocking is only of a temporary nature.

(c) Enhancement: Stocking is carried out to supplement an existing stock where the production is less than the water body could potentially sustain. Enhancement stocking can be undertaken to (1) compensate for the effects of adverse natural factors (e.g., flow which can affect spawning success) (2) to stock migratory salmonids above natural barriers and salmonid ranching (3) to compensate for lost production (e.g., due to urbanisation or land use changes) (4) to maintain an artificial fishery. This category comprises the domain within which most of the stocking programmes have been conducted in the past (Holzer et al. 2003). Holzer et al. (2003) further claim that natural variations in fish population densities are not considered when fisheries are stocked; in the field of enhancement stocking for commercial purposes, the only thing that counts is the fisherman's success.

(d) Creation of new fisheries: Stocking which aims to transfer fish into new water bodies or when new species are introduced into existing fisheries. This form of stocking can also be carried out to manipulate aquatic ecosystems (Holzer et al. 2003). In this sense, stocking is accomplished to either (1) increase the amount of prey for predatory fish or (2) to control stocks of certain species via introduction of predatory fish.

(e) Research and development: Stocking which aims to address particular fisheries management issues.

(f) Conservation: Stocking which aims to conserve the stock of fish.

According to Dannewitz et al. (2003) the most frequent forms of stocking activity are for improving the yield for commercial and recreational fisheries, for support of endangered species, and for reintroduction of already locally extinct species. In terms of recreational fisheries, stocking supposedly increases the capital value of the fishery, lures more anglers and promises more desirable and better quality fish (Postle and Moore 1996 in: Aprahamian et al. 2003). These practices though, are rather questionable, and do not correspond to sustainable river management, and conservation purposes, respectively (cf. Holzer et al. 2003). However, releases for fisheries are most commonly adopted because natural productivity of fish populations decrease (e.g., due to habitat degradation, hydroelectric exploitation or over-fishing). In contrast, fishery releases are also conducted in ecosystems which are more or less intact. In these cases stocking is mainly conducted due to a public demand for increased production (Dannewitz et al. 2003). Wiley (2004) further describes scenarios whereby stocking programmes were based upon production capacities of hatcheries rather than upon ecological issues comprising population densities and carrying capacities of aquatic systems. Such practices are, besides inexperience of fishery managers with aquatic systems, the consequence of desired economic performances (e.g., create more fishing, increase fishing-based-tourism) (cf. Wiley 2004). In response to such methods, scientists increasingly put emphasis on the development of sound fisheries management practices. Resource stewardship by fishery managers, encompassing decision making that is "…ecologically sound, economically sensible, and socially acceptable" (Wiley 2004) is gradually more demanded. In other words, already developed, foresighted fisheries management programs (cf. Holzer et al. 2003, Holzer et al. 2004, Wiley et al. 2004) should be implemented to avoid further impacts on aquatic ecosystems by stocking.

Over recent decades stocking of fish has gained more importance for the conservation of threatened species (Vidergar et al. 2003, Hatchery Reform 2004). The need to maintain populations and to save natural populations from extinction via artificial reintroduction has significantly increased since anthropogenic impacts on aquatic ecosystems have increased. Even though stocking of fish is seen as a measure for conservation purposes it encompasses a variety of threats not least from a conservation point of view. One of the major concerns arises from interbreeding of hatchery and wild fish which might cause a reduction in fitness and consequently contributes to the decline of populations (Hindar et al. 1991, Utter et al. 1993, Reisenbichler and Rubin 1999, Waples 1999 in: Aprahamian et al. 2003). The addressed reduction of fitness derives from a series of physiological and behavioural deficits hatchery reared fish exhibit (see Chapter 2.3). Further on, genetic differences of fish from the same species but differing lineages have not yet been considered in stocking programs (Holzer et al. 2004). As a consequence domestic (autochthonous) lineages get crossed with other, less adapted, lineages which are introduced by humans. That implies a change in the genotype of the autochthonous strains, encompassing incalculable outcomes for following generations (Holzer et al. 2004, see also Araguas et al. 2004). Along with these changes in genotype, scientists raise concerns about the genetic variability of hatchery reared and stocked fish compared to natural populations (see Chapter 2.3). Further concerns regarding stocked fish relate to possible impacts on other native species as well as with the introduction of non-indigenous species into aquatic ecosystems.

Finally, scientific findings revealed a need for change in the role of hatcheries in fisheries management. Fisheries management and conservation biologists, seek the long-term viability of self-sustaining fish stocks, even though the methods used by fishery managers and conservationists are often very controversial. Conservation biologists demand improved rearing conditions and soft release methods to reduce environmental impacts of stocked fish.

In contrast, hatchery practices focus on production of high quantities of fish to fulfil fisheries demands (Brown and Day 2002). Consequently, there is a need to develop strategies that fulfil all interests. Initiatives such as the “Puget Sound and Coastal Washington Hatchery Reform Project” state that today’s fish farms are responsible for helping conserve wild fish populations and to maintain sustainable fishery resources by a new era of management strategies (Flagg et al. 2000, Hatchery Reform 2007). Hence, captive breeding and the reintroduction of reared salmonids to the wild is increasingly seen as a means to provide benefits to the maintenance or recovery of naturally spawning populations (Hatchery Reform Project 2007, Philippart 1995, Flagg and Nash 1999, Berejikian and Tezak 2005). Nevertheless stocking still poses threats to the ecological and genetic integrity of wild populations. As a consequence of these threats it becomes necessary to investigate rearing methods, fulfilling the demands of a sound fishery management.

Beyond that, it is widely noted that stocking measures must not be seen as a long-term solution for species protection or population maintenance. Captive breeding is rather seen as a temporary method as long as habitat improvements have not been carried out (Philippart 1995, Snyder et al. 1996, Fleming and Petersson 2001, Dannewitz et al. 2003, Wiley 2003).

## *2.3 Deficits of Hatchery Reared Fish*

The release of captive bred individuals poses a wide range of potential ecological problems, causing serious concerns among fishery biologists (Philippart 1995, Snyder et al. 1996, Einum and Fleming 2001, Brown and Day 2002, Aprahamian et al. 2003, Dannewitz 2003, Holzer et al. 2004). Some of these problems are summarized by Weber and Fausch (2003) who claim that “stocked fish can negatively affect wild fish through genetic contamination, predation, competition, induction of premature migration, mixed-stock exploitation problems, predator attraction, and disease transmission” (cf. White et al 1995 in: Weber and Fausch 2003). In general, scientists place emphasis on the following three concerns:

- Typical hatchery environments cause changes in the phenotype and behaviour of reared fish compared to their wild conspecifics.
- Intensity and course of selection differ between wild and hatchery reared fish.
- Genetic effects of domestication have been determined, meaning that domestication selection is affecting behavioural and morphological traits of salmonids.

As a consequence of these issues a potentially major problem in fishery management becomes evident. Fisheries, conservationists, and related stakeholders face the issue of high mortality of captive bred fish after release (Fraser 1974, Flagg et al. 2000, Maynard et al. 2004); which, in turn, points out the uneconomic aspect of stocking captive bred fish. Maynard et al. (2004) state that inculture survival of hatchery reared salmonids is usually greater than 95%, but these fish suffer very high mortality after release. According to Maynard et al. (2004) postrelease survival rates are less than one percent for the chinook (*Oncorhynchus tshawytscha*) and ten percent for coho salmon (*Oncorhynchus kisutch*). Survival rates up to adulthood of reared and released salmonids are generally estimated at less than five percent (McNeil 1991 in: Brown and Day 2002, Salvanes 2001).

Most of the mortality occurs during the first few days after release (Brown and Day 2002, Flagg et al. 2000). Hence the conclusion can be drawn that hatchery reared fish, deriving from a protected rearing environment, show substantial deficits in dealing with the complex and peril-filled natural environment. These deficits are especially of behavioural as well as of a physiological nature (Fleming et al. 1994, Einum and Fleming 2001, Brown and Day 2002, AQUAWILD 2002), deriving from poor rearing environments and domestication selection (genetic selection). Many studies have been conducted for the purpose of investigating deficits of hatchery reared fish (e.g., Fleming et al. 1994, Einum and Fleming 2001, Fleming and Petersson 2001, Alvarez and Nicieza 2003, Sundström et al. 2003, Sundström et al. 2005). Although the topic has not yet been fully explored, it became clear that environmental and genetic factors cannot be separated (cf. Huntingford 2004). In contrast, observations revealed strong correlations between rearing environments and genetic adaptations.

Recognizing the variety of behavioural and physiological alterations on top of their causes, scientists began to search for solutions. It has been hypothesized that exposing fish to more natural rearing environments on the one hand, and application of more adequate stocking practices on the other hand, could enhance postrelease survival and minimize at least a few of the ecological problems. Several studies have been conducted investigating the efficacy of semi-natural rearing strategies as a tool to improve postrelease survival (e.g., McDonald et al. 1998, Berejikian et al. 2000, Brown et al. 2003, Berejikian and Tezak 2005). Chapter 3. will give a review on the current knowledge of these rearing strategies. Nevertheless, for a better understanding of the purpose of such rearing methods the complexity of environmental and genetic effects on hatchery reared fish should first be discussed.

### 2.3.1 Effects of Artificial Rearing Environments

Artificial rearing environments, compared to nature, are very homogenous and show virtually no resemblance to natural habitats. Characteristics of natural habitats such as varying water velocities, different substrates, and a variety of structures do not exist in traditional rearing environments of hatcheries (e. g., flow-through tanks, raceways, ponds). In addition, water chemistry as well as water temperatures differ between the rearing environments and the environments where the fish get stocked. Inculture feeding regimes, rearing densities and the absence of predators in hatcheries are also conditions that are not comparable with natural environments. As a consequence, artificially produced fish are not familiar with predation, inexperienced with the variety and qualities of natural habitats, not used to differing and turbulent currents, and unproven in searching and capturing natural prey (AQUAWILD 2002, Maynard et al. 2004, Holzer et al. 2004). Accordingly, hatchery fish suffer a variety of physiological and behavioural deficits which seriously impede their ability to survive in the wild.

#### 2.3.1.1 Phenotypical Changes

High phenotypical plasticity of fish is the reason for considerable adaptations of the individual’s phenotypes by the rearing environment (Fleming and Petersson 2001). Weber and Fausch (2003) further assume that phenotypic differences may result from developmental responses to learning and from the lower early-life mortality of hatchery fish (see also Swain et al. 1991, Fleming et al. 1994, Fleming et al. 1997, Olla et a. 1998 in: Weber and Fausch 2003). This means that certain traits that would be selected against in the wild are brought through in hatcheries (Weber and Fausch 2003).

In fact, effects such as increased body depth and decreased head length as well as fin reduction relate to rearing parameters of hatcheries (Fleming et al. 1994, Flagg et al. 2000, Einum and Fleming 2001, Lahnsteiner and Jagsch 2005, Hill et al. 2006). Feeding regimes, for example, are supposed to significantly affect body shapes and sizes. High fish densities, constant water flow as well as mechanical damages, in breeding tanks cause fin erosion (Einum and Fleming 2001, Lahnsteiner and Jagsch 2005). Body shape and fin condition subsequently influence the swimming performance and the manoeuvrability of fish. Einum and Fleming (2001) further conclude that any deviation in morphology affects an individual’s performance which consequently might result in decreased fitness (see also Weber and Fausch 2003).

In addition to morphometric features, hatchery reared fish seem to be less variable in individual characteristics than naturally reared fish. This is assumedly caused by the homogeneity of hatchery environments (Taylor 1986). In nature, salmonids rear in a complex lighted environment of shade, sunlight filtering riparian vegetation and different lighted gravel substrate. Therefore, in natural environments fish possess well developed cryptic coloration and body camouflage; a development which is likely to serve as protection from predation (cf. Donnelly and Whoriskey 1991 in: Weber and Fausch 2003). Accordingly, monochrome rearing environments are responsible for decreased camouflage (crypsis) of hatchery fish released into stream environments. Thus it appears that hatchery produced fish are more vulnerable to predation than their wild conspecifics (Maynard et al. 1996).

#### 2.3.1.2 Behavioural Changes

As already mentioned, the relevance of rearing environments is also reflected in its impact on a variety of behavioural traits. According to Flagg et al. (2000) social divergences of artificially reared fish may begin as early as the incubation stage. In this early life-stage aberrant behaviours are caused by the lack of substrate and high light levels. Beyond that, subsequent rearing conditions also promote influences of behavioural traits. The following sections deal with behavioural changes in the context of:

(I) Aggression
(II) Feeding Behaviour
(III) Antipredator Behaviour.

**(I) Aggression**

In comparison to wild fish, hatchery reared fish differ in levels of aggression although it appears that the results of studies conducted on this topic are very controversial. According to Einum and Fleming (2001), a comparison of studies on altered aggressiveness indicates that in most cases artificial rearing results in an increased amount of aggression (see also Weber and Fausch 2003). This increased aggressiveness of hatchery reared fish was predominantly due to the attributes of rearing environments (e.g., high rearing densities, feeding regimes). To that effect the theory exists that high densities of fish in hatcheries suppress the establishment of social dominance structures which thereby promotes high aggression after release of hatchery fish; a phenomenon related to the absence of social hierarchies in a population of hatchery reared fish (Weber and Fausch 2003). However, in terms of artificial selection (domestication selection), it is not clear whether it effects an increase or decrease of aggression. In contrast to the findings summarized by Einum and

Fleming (2001), studies by AQUAWILD (2002) imply that hatchery environments may reduce aggression of reared brown trout and salmon. Genetic selection, in turn, seems to increase levels of aggression (AQUAWILD 2002). It is further concluded that the effects of hatchery environments on behaviour override the genetic effects (AQUAWILD 2002). Finally, Einum and Fleming (2001) conclude that the reasons for altered aggression are not fully understood. Additional experiments are needed to clarify "…the causal relations between feeding, growth, body size, aggression, and dominance under various selective regimes" (Einum and Fleming 2001). Additionally, Weber and Fausch (2003) highlight differences of levels of aggression at different life stages of fish.

Evidence suggests that compared to wild fish, hatchery fish show differences in agonistic behaviour. Metcalfe et al. (2003) argue that hatchery reared fish do not gain experiences of defending territories which consequently causes the fish to use aggression inappropriately. This further implies that hatchery fish behave differently in aggressive interactions and consequently fail to win territorial contests (Metcalfe et al. 2003). Bachman (1984) note that even when hatchery fish win agonistic contests against wild individuals they abandon their territories and move more often among territories than the wild reared fish (see also Weber and Fausch 2003).

Differentiating agonistic behaviour seems to be a result of rearing densities (Fenderson et al. 1968, Fenderson and Carpenter 1971 in: Flagg et al. 2000). In this context the effects of the early environment also seem to have a particularly crucial impact on the behaviour in later life (Metcalfe et al. 2003). Ultimately, these behavioural deficits are assumed to be the reason for greater movement rates and consequently higher energy costs as well as poorer growth of stocked in comparison to wild fish (Bohlin et al. 2002).

### (II) Feeding Behaviour

Starvation is a key factor for high postrelease mortality in hatchery fish. Several studies on feeding behaviour of artificially reared fish document differences compared to foraging of wild fish (cf. Johnson et al. 1996, Maynard et al. 1996; Elliott 1975, Olla et al. 1998 in Weber and Fausch 2003). These differences are that hatchery fish are not used to natural prey and therefore appear to be non-selective feeders (Flagg et al. 2000). An unfamiliarity with natural prey and its cues leads to feeding on indigestible food (Olla et al. 1996, Flagg et al. 2000). Moreover, rearing in a typical hatchery environment impairs the ability to capture and consume live prey (AQUAWILD 2002). Additionally, hatchery reared fish occupy energetically less efficient foraging sites than naturally reared fish. A lack of adaptation to natural food resources and to their time dependent availability (hatchery fish get used to feeding times) leads to losses of condition after release (Holzer et al. 2004); temporal patterns of feeding behaviour are also associated with genetic effects of domestication (see Chapter 2.3.2). Another very often observed feature is that released fish continue to feed at the surface (cf. Johnson et al. 1996, Flagg et al. 2000, Weber and Fausch 2003). This is a typical habit resulting from the feeding procedure of hatcheries. It is a common practice in hatcheries that (pelleted) food is introduced on the water surface. Not only foraging seems to be affected by this practice. Scientists recognize that hatchery reared fish respond differently to natural habitats than their wild conspecifics. It has been observed that hatchery strains constantly hold higher positions in the water column of natural habitats than wild fish; assumedly a feature induced by former (inculture) feeding behaviour (see also Flagg et al. 2000, Eber et al. 2003). However, not only position selection within a habitat seems to be affected. Within streams newly released hatchery fish primarily use pool environments because of their nearest similarity to artificial rearing environments (e. g., pools, raceways); in contrast, wild reared fish use riffles and pools in streams (Flagg et al. 2000).

### (III) Antipredator Behaviour

Predator avoidance behaviour is another feature affected by the rearing environment (cf. Olla et al. 1996, Brown and Smith 1998, Maynard et al. 2004). Hatchery reared fish usually do not experience exposure to natural enemies. Consequently these fish are unable to become familiar with the visual, acoustic, and chemical cues which are emitted by their natural enemies (Maynard et al. 2004); a matter which results in reduced response to predation risk after releasing fish into the wild (Olla et al. 1996). In other words, hatchery rearing deprives fish of the necessary psycho-sensory stimuli to develop proper anti-predator behaviour (Olla et al. 1996, Brown and Smith 1998, Berejikian et al. 1999; Olla et al. 1998 in: Flagg et al. 2000). Reduced risk taking behaviour as well as lowered fright response to possible predators or larger objects such as humans is another observed feature of cultured fish (cf. Maynard et al. 2001, Weber and Fausch 2003). The issue of surface feeding has already been addressed in the context of altered feeding behaviour (see above). In the context of predation, surface orientation also increases the vulnerability to predators (cf. Vincent 1960, Moyle 1969, Bachman 1984 in: Weber and Fausch 2003). Avian predators (e.g., cormorants, kingfishers) pose a greater risk to hatchery fish than to wild reared fish (cf. Maynard et al. 1996, Weber and Fausch 2003).

Correct behaviour, in case of predation, is of course not the only strategy to counter predation (see also Chapter 1.3.2.1). As already mentioned, rearing environments are also affecting (cryptic) coloration patterns, swimming performance, and manoeuvring abilities which are consequently decisive for counteracting predation. Finally, scientists revealed that stress caused by injury, transport, handling, or physical exercise can also be causative for increased vulnerability to predators (cf. Houston et al. 1971a,b, Miles et al. 1974, Barton et al. 1980, Barton and Peter 1982, Pickering et al. 1982, Carmichael et al. 1984, Woodward and Strange 1984 in: Olla et al. 1996). In particular, stress-induced physiological changes can last between 4-24 hours bringing along reduced behavioural response to predation (Olla et al. 1996).

### 2.3.2 Genetic Effects of Domestication

Interference to natural selection already occurs when hatchery operators select the first generation of fish for artificial breeding. This choice is usually based upon criteria such as early spawn-timing, coloration or growth of the fish (cf. Smith 2004). Hence, certain genetic strains are artificially preferred and promoted. Put another way, genetic variation of a founding brood stock represents a finite sample from the source population. However, when talking about genetic effects of domestication, the literature describes two ways of interferences in natural selection by artificial breeding. First, altered intensity and course of selection appears due to the efficiency of artificial rearing environments. In particular, during early life stages survival of wild fish is endangered by predation, starvation, and strong currents (e. g., in the case of floods). Considering that hatchery fish do not face these threats it is understandable that survival during egg and juvenile stages is significantly higher in a hatchery environment than in the wild. Accordingly, genotypes that potentially are eliminated under natural conditions are artificially conserved (Elliott 1989, Einum and Fleming 2000a, b in: Einum and Fleming 2001).

The second main threat from evolutionary genetics derives from domestication selection. Domestication describes the process of becoming (genetically) adapted to an artificial or human-controlled environment (Hatchery Reform 2004). Domestication selection expresses the impacts of domestication encompassing "…evolutionary changes due to intentional and unintentional artificial selection by humans and random genetic effects (e.g., bottlenecks, founder effects)" (Fleming and Petersson 2001).

The likelihood of genetic changes, in particular, increases when stocks have been cultured over multiple generations (cf. Huntingford 2004). Einum and Fleming (2001) assume that multi-generation hatchery stocks differ even more from wild fish than first-generation stocks where alterations are mainly based upon grievances of the rearing environments. Lynch and

O'Hely (2001) recommend that selective pressures in captive breeding need to be minimized as much as possible, otherwise long-term supplementation programmes might result in genetic transformations which may lead to natural populations that are no longer able to sustain themselves. In other words, domestication results in increased fitness under hatchery conditions but decreased fitness under natural conditions (Hatchery Reform 2004, see also Ford 2002)

The main disadvantageous effects of domestication selection appear to be altered behavioural and physiological traits (Einum and Fleming 2001, AQUAWILD 2002). These two attributes are frequently interrelated as the following paragraphs will show.

#### 2.3.2.1 Physiological Changes

Growth of fish is primarily associated with abundance of food and an individual's energy budget. However, the growth process is also a matter of heritability. Fleming et al. (2002) stresses high heritability for growth of salmonids, pointing out an increased growth rate of 10 – 15 % per generation (obtained in a breeding programme). These results are traced back to certain mechanisms underlying the growth process which is artificially promoted by selection. Thus, domestication selection is for example, encouraging elevated levels of growth hormone in plasma and pituitary as well as higher food conversion efficiency (AQUAWILD 2002, Fleming et al. 2002). In other words, scientific findings indicate that linkages exist between hatchery programmes with favouritism toward fast growing fish and subsequently promotion of associated physiological traits. This observation is supported by findings for hatchery reared fish whereby the body composition is made up of more fat and less protein compared to wild fish (Phillips 1957, Vincent 1960, Blaxter 1975 in: Weber and Fausch 2003); features which potentially affect competitive ability of hatchery reared fish (Weber and Fausch 2003).

Beside these physiological aspects, abnormities such as decreased antipredator response and increased aggression appear to be related with growth patterns. Scientists identified a direct linkage between growth hormone levels and behavioural features where "…growth hormone-treatment reduces heart rate response to predation risk and increases dominance rank in salmonids" (AQUAWILD 2002; see also Woodward and Strange 1987, Salonius and Iwma 1993, Johnsson et al. 2001 in: Weber and Fausch 2003). This alignment of behavioural and physiological features has also been documented with a correlation between the metabolic rate and dominance bearing (cf. AQUAWILD 2002). Ultimately, Weber and Fausch

(2003) reviewed several studies which have demonstrated a morphological homogeneity of hatchery reared fish over a large geographical range; compared to wild fish of the same range (Hjort and Schreck 1982, Taylor 1986, Fleming and Gross 1989 in: Weber and Fausch 2003). Weber and Fausch (2003) conclude that "…rearing practices promote characteristics that are better adapted to hatcheries, which are similar throughout much of the world, than the local conditions that affect survival in the wild."

#### 2.3.2.2 Behavioural Changes

The effects of domestication selection on behavioural traits are manifold. Reduced response to predation as well as differentiated aggression (dominance) and it's correlations to physiological conditions have already been raised. Summarizing it, domestication selection fosters risk prone genotypes and increased aggression levels. These are findings which are expressed in reduced response to predation risk and altered social dominance of hatchery reared fish (AQUAWILD 2002). Aside from these conclusions, further concerns are raised due to behavioural modifications. The following related issues will be discussed:

(I) Feeding behaviour
(II) Breeding success.

**(I) Feeding Behaviour**

Alterations of feeding behaviour have already been discussed in the context of rearing conditions (see Chapter 2.3.1). However, surface feeding is probably not only a matter of adaptation to feeding conditions in hatcheries. Flagg et al (2000) suggest that surface feeding might also be an innate feature (see also Uchida et al. 1989 in: Flagg et al.2000)
Investigations on genetic effects of domestication imply that domestication selection also affects temporal behaviour patterns. One of these temporal patterns is that hatchery selection seems to reduce diurnal as well as seasonal variation in feeding behaviour. Consequently, released hatchery reared fish forage at times "…where energetic returns are low and/or predation risk is elevated" (AQUAWILD 2002). Further coherences of increased aggression and feeding behaviour are noted by Weber and Fausch (2003). In particular, Weber and Fausch (2003) quote several studies where excessive aggression of hatchery reared fish reduced time for feeding and consequently resulted in reduced condition (see also Fenderson et al. 1968, Fenderson and Carpenter 1971, Deverill et al. 1999 in: Weber and Fausch 2003).

### (II) Breeding Success

Breeding success is a function of various factors such as time, body size, attractiveness, competitive ability or egg size. Apparently, breeding success is a subject of behavioural as well as morphological features. Many of these features are demonstrably affected by relaxation of selection pressures in hatchery breeding. For example, hatcheries develop strains with spawning dates different to those of the ancestral stocks. According to Flagg et al. (2000) hatcheries often select for early spawning fish (see also Vincent 1960, Reisenbichler and McIntyre 1977, Fleming et al. 2002 in: Weber and Fausch 2003); an attribute that is subsequently passed on to the next generations which is due to high heritability in spawning time of salmonids (see also Siitonen and Gall 1989, Silverstein 1993, Gharrett and Smoker 1993, Quinn et al. 2000 in: Fleming and Petersson 2001). Early spawning dates, though, display an endangerment for the emerging fry. Emergence might be prior to the highest natural aquatic food abundance, which consequently may cause high mortality rates (Nickelson et al. 1986 in: Flagg et al. 2000). In addition, early emergence could also result in higher susceptibility to predation or catastrophic floods (cf. Braunnas 1995, Seegrist and Gard 1972, Fausch et al. 2001 in: Weber and Fausch 2003).

Further behavioural abnormalities of hatchery fish have been identified. First, the choice of spawning location can be affected by hatchery rearing. Released fish may hesitate to migrate to the regions where the spawning grounds lie (Fleming and Petersson 2001). In this context Holzer et al. (2004) question the importance of a phenomenon called “homing”. Homing describes the nature of fish to return to the spawning grounds of their origin. This behaviour is widely known from anadromous fish species but has also been documented for fish migrating only in fresh water (Holzer et al. 2004). Homing therefore guaranties that fish migrate to adequate spawning grounds and, finally, breed successfully. Holzer et al. (2004) note that the absence of this feature may contribute to an inability of hatchery reared fish to finding and choosing adequate spawning grounds.

Additional abnormalities become evident when hatchery reared fish breed together or rather in competition with wild fish. For female hatchery fish Fleming and Petersson (2001) describe, in comparison to wild conspecifics, lower competitive ability (e.g., delays in onset of breeding, fewer nests), and differentiated behaviour at fertilisation (hatchery fish appear to have their eggs fertilised by several secondary males). Male hatchery fish appear to be less aggressive and less active in courting females during the spawning period (Fleming and Petersson 2001, Hatchery Reform 2004). Another investigation of male breeding behaviour reveals similar levels of aggression between wild and hatchery males, but hatchery fish were involved in prolonged aggressive encounters (Fleming et al. 1997 in: Fleming and Petersson

2001). As a consequence hatchery males showed increased wounding and higher mortality than the wild males.

These behavioural deficits are accompanied or even correlate with morphological and physiological alterations caused by relaxed or altered selective pressures in hatcheries. Fleming and Petersson (2001) note that hatchery reared adults show losses in breeding success caused by altered morphological expressions (see also Flagg et al. 2000). For example Fleming and Petersson (2001) describe the reduction of secondary sexual characters (e. g., the hooked snout, breeding colours) which are important for obtaining access to females. Flagg et al. (2000) further describe that studies observed reduced secondary sexual characters in fish while a disproportionate amount of energy was invested in sperm or egg production. Scientists conclude that it is disadvantageous for reproduction when surpassing amounts of energy are invested into production of sperm or eggs than into traits that are important to achieve mating at all; because mating success is one of the key factors for breeding success. However, it is believed that selection in hatcheries as well as the artificial nature of the breeding process in hatcheries favours those fish that allocate their resources to egg and sperm production rather than into secondary characteristics (Fleming and Petersson 2001). Investigations on egg size reveal that hatchery rearing affects egg size by favouring larger eggs (Heath et al. 2003, Fleming and Petersson 2001). However, is not yet clear what the long term responses to altered egg sizes might be.

## *2.4 Summary*

A variety of investigations demonstrate that artificial culture environments condition salmonids differently than natural rearing does. Cultured fish respond differently in physiological and behavioural traits affecting response to natural food, habitats, conspecifics, and predators. Present culture techniques also change selection regimes which are supposed to result in genetic divergences between naturally and artificially produced fish. These genetic divergences are either of physiological and / or behavioural natures. Due to the scale these differences can take on, Gross (1998) clearly distinguishes between Atlantic salmon (*Salmo salar*) reared in either wild or aquaculture environments. He specifies Atlantic salmon from both rearing treatments as “one species with two biologies” and proposes a classification of the two as separate species (Gross 1998). In other words: “…for hatcheries rearing and releasing salmonids, […] any attribute that detracts from performance in the natural rearing environment may be cause for concern” (Berejikian and Tezak 2005).

Finally, there is little doubt that such differences are responsible for poor survival of hatchery reared fish in the wild. Moreover, released hatchery fish are supposedly lowering population productivity (Petersson et al. 1996) and consequently population abundances of wild fish. Based on the current level of knowledge it becomes clear that significant improvements must be made in hatchery production, to fulfil the aims of sustainable and ecologically sound stocking programs including the protection of already existing (wild) stocks (see also Ford and Myers 2008). Both fisheries managers and conservationists should seek improvements to fish culture methods to produce fish that are morphologically, physiologically, behaviourally, and genetically similar to the wild conspecifics.

In the context of improving culturing methods, scientists investigate semi-natural rearing techniques. The following Chapter provides a review on these methods and the related scientific findings. With regard to the aspired aims of the project initiative TROUTCHECK (see Chapter 4.1), the current knowledge on semi-natural rearing practices will be analysed.

# 3. Review of Semi-Natural Rearing Methods

This Chapter contains a review of studies investigating semi-natural rearing methods, encompassing an overview of the perception of scientists on semi-natural rearing environments as well as on the preliminary findings from rearing experiments. The aim of this review is to summarize and compare the findings that have been made on the topic of semi-natural rearing. Furthermore, findings achieved within the review should serve as a base for comparisons and conclusions related to the rearing approaches of the project initiative TROUTCHECK. In addition, deduced insights will be related to findings obtained by the consultation conducted with hatchery operators.

## *3.1 The Need for Semi-Natural Rearing Methods*

Reintroduction programmes for salmonids face the problems of high postrelease mortality rates, interbreeding of wildly and hatchery reared fish and consequently the decrease in fitness of natural fish populations. Even if the reasons for postrelease mortality are not yet fully understood, there is evidence from research on reintroduction biology that behavioural and physiological conditions are of special importance for the survival of introduced fish (Olney et al. 1994, Clemmons and Buchholz 1997, Brown and Day 2002, see also Chapter 2.2). Proper behaviour for food acquisition and adequate response to predation are just two patterns illustrating the importance of correctly developed traits for survival in the natural environment. Development of behavioural- and physiological traits, though, is demonstrably suppressed by unnatural rearing conditions in hatcheries. Maynard et al. (1995) describe hatchery reared fish as “Groups of fish […] reared in the open, over uniform concrete substrates; conditioned to minimal raceway flow regimes; provided no structure in which to seek refuge from water current, predators, or dominant cohorts; held at high, stress-producing densities; surface fed; and conditioned to approach large, moving objects at the surface” (Maynard et al. 1995 in Flagg et al. 2000, see also Reisenbichler 2004). Reared under these “conventional” rearing conditions, it is no surprise that these fish as a result differ in terms of the mentioned features from their wild conspecifics.

Along with experiences from zoos, research has revealed that the development of behavioural and physiological attributes of higher vertebrates benefit from enhanced rearing conditions (see also Flagg et al. 2000). These observations have led scientists to hypothesize that improvements in rearing conditions for hatchery fish could help reduce the identified deficits and consequently increase postrelease survival. Several investigations have been conducted examining the efficacy of improved rearing strategies.

## *3.2 Definition and Strategies of Semi-Natural Rearing*

Semi-natural rearing strategies in hatchery programmes incorporate a variety of approaches to produce ecologically viable fish. Ecologically viable basically means that the fish are better equipped to cope with the conditions in the wild than those from conventional rearing. In other words, these programmes follow the primary goal of maximising postrelease survival by producing fish that are morphologically, genetically, behaviourally, and physiologically similar to the stocks that are aimed for enhancement (Brown et al. 2003). In order to attain this goal, scientists design and construct “enriched” (semi-natural) rearing habitats. According to Brown et al. (2003), there isn’t any real definition of what constitutes an enriched rearing environment. The current experiments with supplemented rearing habitats include components of natural or artificial substrate (e.g., gravel, sand, cobble substrate), submerged structure (e. g. branches, drift wood, live or plastic plants), and overhead cover (e.g., solid covers or camouflage nets). These attributes are usually added to conventional rearing vessels, such as tanks or raceways, with the aim to provide fish the opportunity to experience environmental complexity prior to release (Maynard et al. 2004). Depending on the research question, the above mentioned structures are applied to investigate, for example, whether fish develop skills such as flight- or hiding behaviour, territorial behaviour, or the development of camouflage coloration. Furthermore, investigations on growth, morphology, fitness, and survival are also conducted using these rearing techniques.

Additional strategies for investigations on semi-natural rearing are applied to examine the teachability of so called “life skills” (Brown and Day 2002). These experiments range from training of proper predator avoidance to stimulation of foraging behaviour. These and other manners require some degree of learning and, according to Brown and Day (2002), can be taught by repeated exposure to correlating stimuli. In this sense, scientists use natural as well as artificial predators to train and investigate the development of antipredator behaviour. Furthermore, the introductions of live prey or live food supplemented diets are used to investigate improvements in hunting ability. Underwater food delivery is examined for encouraging natural foraging behaviour. Another training technique under investigation is the housing of captive reared individuals with more skilled conspecifics. These techniques base on the assumption that social learning plays an important role in the development of behavioural traits (Brown and Day 2002). For the purpose of improving the swimming performances of hatchery reared fish scientists study the effects of different water velocities within the rearing vessels. Different current- and exercise regimes are developed to gain information about adaptations of hatchery reared fish on varying flow. In this context and beyond, experiments are conducted exploring the impacts of different rearing densities.

## *3.3 Methodology*

As already mentioned, a variety of methods have been developed and are currently under investigation to minimize deviations of hatchery reared fish from natural reared individuals and finally to increase postrelease survival. The following sections deal with these methods in detail by reference to the different investigated traits. Depending on the study design, the varying adaptations to the rearing environments are discussed separately. Literature was identified by online research and by library searches. Unless otherwise stated, the conclusions of the authors have been accepted without evaluating the experimental design or the statistical power of the reviewed studies (Weber and Fausch 2003).

## *3.4 Conditioning Physiological Traits*

### 3.4.1 Growth

In the course of examining the efficacy of semi-natural rearing strategies scientists also turned attention onto growth patterns. After all the growth rate of fish constitutes an important parameter "[…] influencing the economic return in both the hatchery and in the wild" (Langton and Wilson 1998). Surveys concerning this matter reach from trials on alevins through to the impact assessment of semi-natural rearing on postrelease growth of salmonids. The following list encompasses the main factors that have been estimated:

- Application of substrate
- Structural enrichment
- Altered rearing densities
- Varying water currents.

Investigations into fry of coho salmon (*Oncorhynchus kisutch*) revealed that semi-natural rearing habitats increase the growth of incubated alevins. In detail, the usage of **covering** and **artificial substrate** in the form of plastic netting has proved to be beneficial for the development of alevins (Fuss and Johnson 1988). These findings are related to the assumption that suboptimal environmental conditions during ontogeny remove energy available for growth and therefore lower the growth rate (Bams 1982 in: Fuss and Johnson 1988). Habitat enrichment, in this context, appears to be advantageous.

However, trials with rainbow trout (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarki*) fingerlings showed that growth can also be negatively affected by the usage of (cobble) substrate (Bosakowski and Wagner 1995 in: Wagner et al. 1996, Wagner et al. 1996). These results are traced back to difficulties with feed intake due to the applied cobble substrate, accordingly food pellets might be more difficult to find within the substrate (Wagner et al. 1996). Conclusively, not every form of substrate seems to be favourable in relation to the growth of fingerlings. However, cobble substrate showed to be advantageous for other traits such as improvement of fin conditions (Wagner et al. 1996) (see also Chapter 3.4.2).

A series of investigations on **semi-natural habitats** in raceways and rectangular tanks have been conducted by Maynard et al. (1996 a, b, d, 2001 a, 2003 a, 2003c in: Maynard et al. 2004). Overall, these studies cover a wide range of experimental conditions applied to chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon. Different types of substrate (e.g., gravel, sand, loose substrate), plastic plant- and conifer structures and overhead cover, for example, camouflage nets or opaque cover have been used. Beside an acclimation approach most of the studies investigated growth, behaviour, morphology, health, and the survival of salmon during the swim up- and the smolt stage. Concerning the growth of chinook salmon Maynard et al. (1996 a, b, c, 2003 a) ascertained that there were slight growth deficits of semi-naturally reared fish when compared with conventionally reared individuals (Maynard et al. 2004). As the results from chinook salmon show, the growth rates of semi-naturally reared coho salmon were similar to that of conventionally reared salmon (Maynard et al. 2003 c in Maynard et al. 2004; Maynard et al. 2004 a). These unequal results are on the one hand, due to slight variations in feeding behaviour of the two species. On the other hand differences in water temperature as well as stress reduction, induced through cover and submerged structure, at coho salmon trials are supposedly responsible for the discrepancy (Maynard et al. 2004 a). Overall, these results suggest that semi-natural rearing habitats neither encourage nor restrain the growth of salmon. Furthermore, salmonids appear to be very sensitive to the (qualitative) properties of their rearing environments.

As already mentioned, the growth of semi-naturally reared salmonids after release is also a matter that has been investigated. Berejikian et al. (2000) examined whether steelhead (*Oncorhynchus mykiss*) juveniles grown in enriched rearing tanks differ from juveniles grown in conventional vessels. Steelhead offspring of a wild population were incubated and then reared in either enriched or conventional circular tanks. Enriched tanks contained in-water structure (tops of Douglas-fir trees), an underwater feeding system, and overhead cover (camouflage netting). After the fish were released into a quasi-natural stream in the presence of mutual competition, growth of fish from enriched rearing treatment was greater than that of conventionally reared fish. These growth differences are suggested to be due to competitive interactions, whereby steelhead from enriched rearing treatment outcompeted fish from conventional rearing environments (Berejikian et al. 2000). This assumption is supported by findings from Sundström et al. (2004) suggesting that the growth of released brown trout (*Salmo trutta*) is predominantly related to the ability of competition and social interaction. These interactions in turn depend on the rearing background. To sum up, the quality of rearing environments appears to affect behavioural traits of salmonids so that interdependent patterns such as growth are subsequently influenced (see also Metcalfe et al. 2003, Sundström et al. 2003; see also Chapter 2.3.1.1).

In contrast to the findings from Berejikian et al. (2000) are the results from Berejikian et al. (2001). In 2001 fry from conventional and enriched hatchery rearing environments were stocked together with naturally reared steelhead fry in the same stream used for the study in 2000 (cf. Berejikian et al. 2000). In this study though, no differences in growth were observed between steelhead fry from conventionally and enriched rearing environments. Similar results were obtained by a comparable study of Riley et al. (2004). However, due to the differing approaches of Berejikian et al. (2001), Riley et al. (2004), and Berejikian et al. (2000) the question arises whether these studies are comparable. After all Berejikian et al. did not include naturally reared steelhead fry in their trial carried out in 2000. Nevertheless, Riley et al. (2004) looked at these studies and subsequently claimed that further research in this area is needed because steelhead fry reared in enriched hatchery environments appear to "[…] have a growth advantage in some situations but not in others." Berejikian et al. (2001) also claim that inconsistency between studies may reflect differential responses of various species to hatchery and natural rearing environments. This assumption was drawn due to contradictory results from studies on the growth of steelhead (Berejikian et al. 2000) and coho salmon (Rhodes and Quinn 1998 in: Berejikian et al. 2001).

**Flow velocities** in rearing raceways or ponds are usually less than 1cm/sec (Maynard et al. 2004) and therefore not comparable with those of natural habitats. In 1986 a study was conducted by Leon, examining the effects of exercise on salmonids. For this purpose, brook trout (*Salvelinus fontinalis*) were reared for 10 weeks in circular tanks with or without exercise (Leon 1986 in: Maynard et al. 2004). According to Maynard et al. (2004) this exercise programme significantly increased the growth of fish. Increased growth is, in this regard, related to an improved food conversion rate due to exercise (Christiansen et al. 1989, 92, Christiansen and Jobling 1990, Nielsen et al. 2000, Azuma 2001 in: Maynard et al. 2004). However, Adams et al. (1995 in: Vehanen et al. 2000) relates improved growth to swimming-induced inhibition of aggressions which has been observed among Arctic charr (*Salvelinus alpinus*). Similar results of increased growth were obtained for chinook salmon with a two-hour a day exercise programme (Maynard et al. 2003 b in: Maynard et al. 2004) and for Atlantic salmon (*Salmon salar*) exposed to different currents (Jørgensen and Jobling 1993 in: McDonald et al. 1997). However, McDonald et al. (1997) conducted a study on the effects of velocities as well as rearing **densities** on Atlantic salmon. He concluded that the effects of density reduction promote the stimulation of growth rather than the effects due to current (McDonald et al. 1997). However, no additional literature is available for further verification of this conclusion. In general though, reduction of rearing densities has been proven to be beneficial for the growth of fish (cf. Soderberg et al. 1993, Wagner et al. 1997). This observation is applied to hatchery- as well as fish raised in the wild (Backiel and Le Cren 1978 in: Ewing and Ewing 1995). Overall, it is important to note that in the context of rearing densities, for most of the above mentioned studies the effects of rearing density can not be separated from the effects of semi-natural rearing habitat (cf. Maynard et al. 2004).

In summary, the available literature on semi-natural rearing strategies and their effects on growth of fish display partly differing results. Overall, proper development of behavioural traits through semi-natural rearing environments as well as the possibility of fish to experience varying current velocities appears to be beneficial for growth of reared salmonids. In this context enhanced development of competitive ability in enriched environments show to promote growth rate. Furthermore, the growth of salmonids is also related to rearing densities, whereby reduced rearing densities may promote better growth. However, apart from differing characteristics of the different species, the quality of semi-natural rearing environments emerges to be a crucial factor for growth related patterns. In this sense, further research is needed to determine under which conditions growth benefits are associated with enriched hatchery rearing (see also Riley et al. 2004).

### 3.4.2 Fin Condition

Fin erosion is one of the most commonly documented morphological changes in hatchery reared fish (Arndt et al. 2001, Berejikian and Tezak 2005). At large, a variety of factors are related to this phenotypical impact. Beside temperature, nutrition, underfeeding, water quality parameters, and microbial infections the most responsible factors appear to be high rearing densities and allied mechanical damages from aggressive interactions (Winfree et al. 1998, Wagner et al. 1997, Barrows et al. 1999 in: Berejikian and Tezak 2005). Thus, fin erosion is attributed to some environmental and some behavioural causes. Considering that fin erosion potentially affects swimming performance and therewith reduces survival in the wild (see also Chapter 3.4.4), scientists carried out trials investigating whether improved rearing methods could eradicate this deficit. The following adaptations to conventional rearing systems have been proved:

- Application of substrate
- Improved water flow systems
- Structural enrichment
- Altered rearing densities.

In general, the use of **substrates** (e.g., gravel) in rearing trials has been verified to improve fin condition (McVicar and White 1982, Bosakowski and Wagner 1994 in: Wagner et al. 1996; Bosakowski and Wagner 1995 in: Maynard et al. 2004; Arndt et al. 2001). Interpretations of correlating study results, though, are not definitive. Research results suggest, for example, that cobble substrate reduces abrasion from rough concrete surfaces in raceways (Bosakowki and Wagner 1994, 1995, Wagner et al. 1996b in: Arndt et al. 2001) and that supplemental prey items living in the gravel as well as physical structures may constitute qualities for fish reared in hatchery environments (Arndt et al. 2001). Admittedly, Arndt et al. (2001) attested that abrasion from rough surfaces may not be a direct cause for decreased fin conditions; which, in turn, challenges the conclusions mentioned above.
However, further ambiguities about the effect as well as about advantages and disadvantages of substrate remain. The significance of algae and aquatic invertebrates growing within the substrate has not yet been evaluated (cf. Arndt et al. 2001) and appears to be controversial. According to Arndt et al. (2001) these organisms contribute to an uptake of additional minerals and nutrients which might positively impact fin condition. This suggestion is supported by investigations showing that supplementation of diets with proteins and minerals improve fin quality (cf. Barrows and Lellis 1999 in: Hatchery Reform 2004). However, Berejikian and Tezak (2005) can eliminate the role of substrate and its relevance for additional nutrition within their study.

Maynard et al. (2004) refer to a study where the addition of natural substrate to rearing tanks caused an increase in the number of Atlantic salmon exhibiting territorial behaviour (cf. Mork et al. 1999 in: Maynard et al. 2004). Accordingly the development of behavioural traits (e.g., aggression, agonistic behaviour, dominance) is broadly related to fin condition (cf. McDonald et al. 1998, Arndt et al. 2001, Berejikian and Tezak 2005). Maynard et al. (2004), though, do not link the development of territorial behaviour and resultant fin conditions. According to that assertion it remains uncontested whether or not distinctive territorial behaviour contributes to better fin condition or not.

Scientists also speculate about the role of bacteria and their abundance under the different rearing conditions (cf. Wagner et al. 1996, Arndt et al. 2001). Arndt et al. (2001), for example, point out that an experiment with **cross-flow** raceways without substrate obtained better results for fin condition than the same experiment including substrate; these results are traced back to a higher abundance of bacteria in the treatment including substrate. However, cross flow systems generally appear to promote a better distribution of fish within the rearing tanks (Ross et al. 1995 in: Arndt et al. 2001). Uniform distribution of fish, in particular, may lead to less aggression and therefore better fin condition (Arndt et al. 2001). In summary, definite conclusions about the usage of substrate are not drawn; in particular the role of substrate for the development of behaviour traits and their effect on fin condition remains unacknowledged.

Experiments with **structurally enriched rearing environments** also obtained positive results in respect of decreasing fin erosion (cf. Berejikian et al. 2001 in: Berjikian and Tezak 2005; Flagg and Maynard 2004). Both fin condition in structurally enriched circular tanks as well as in enriched raceways, have been evaluated. For this purpose circular tanks and raceways have been equipped with submerged tops of fir tress, overhead cover, and underwater feed delivery systems (cf. Berejikian and Tezak 2005, Flagg and Maynard 2004). Fish grown in such tanks or raceways exhibited dorsal fin qualities greater than those of conventionally reared and similar to those of naturally reared fish (Berejikian and Tezak 2005, Flagg et al. 2004). In fact, Berejikian and Tezak (2005) could not determine the relative effects of overhead cover, submerged structure, or underwater feeding on fin condition. However, it is precluded that substrate and consequently supplementary food from invertebrates are causative factors for improved fin condition; in fact this is contradictory to assertions by Arndt et al. (2001). However, visual isolation provided by the submerged structure is believed to reduce the frequency of nip attacks and as a result leads to improved dorsal fin condition (Berejikian and Tezak 2005). This assumption, beside the interpretation of the obtained results, relates to further studies which indicate that structural enrichment can reduce the frequency of aggressive encounters (Mesick et al. 1988 in: Berejikian and Tezak 2005).

Lowering **rearing densities** led to better fin condition in trials with rainbow trout, cutthroat trout, and Atlantic salmon (cf. Mäkinen and Ruohonen 1990 in: Wagner et al. 1997, Wagner et al. 1997, McDonald et al. 1998). According to Wagner et al. (1997) rearing density affected the relative length of the ventral, dorsal, and pectoral fins of cutthroat trout (see also Mäkinen and Ruohonen 1990 in: Wagner et al. 1997 for rainbow trout). In particular, the relative lengths of pectoral fins were significantly affected by the rearing density (Wagner et al. 1997, McDonald et al. 1998). In contrast, findings by Kindshi et al. 1991b and Kindshi and Koby 1994 (in: Wagner et al. 1997) generated opposing results; whereby cutthroat trout as well as rainbow trout showed no difference in fin erosion in comparable final rearing densities than applied in the study by Wagner et al. 1997. Further, Soderberg and Meade (1987) investigated fin erosion of Atlantic salmon and discovered that dorsal fins are more affected by increasing rearing densities than pectoral fins (Wagner et al. 1997). Overall, trials on rearing density and its effect on fin erosion generated controversial results. Nonetheless, Wagner et al. (1997) recommend low rearing densities (below 50 kg/m³) if "…a reduction in pectoral fin erosion is desired" by the fish culturist (see also Mäkinen and Ruohonen 1990 in: Wagner et al. 1997).

Summarizing, a reduction of fin erosion has been achieved by combining conventional rearing methods with natural rearing, encompassing an application of substrate, structural enrichment, improvement of water flow systems, and reduction of rearing densities. Nevertheless, ambiguities remain about the exact reasons for fin erosion as well as about the potential of the different semi-natural rearing-approaches. These ambiguities are also related to the dissimilarity of the various fish species and the way they react adapt to the rearing environment.

### 3.4.3 Skin Colour (Cryptic Camouflage)

Background colour patterns of rearing environments affect the short- and long-term camouflage colouration of salmonids (Maynard et al. 1996). Conventional rearing methods demonstrably produce uniformly and lightly coloured fish which are cryptically mismatched for their release (Flagg and Maynard 2004, see also Chapter 2.3.1.1). In particular, hatchery reared fish have been observed to need over one week of stream residence before they begin with the adaptation of background colours, henceforth providing cryptic camouflage against predators (Flagg and Maynard 2004). Consequently, proper development of skin colours and the ability for cryptic colouration became matters of investigation in semi-natural rearing. Accordingly, the following features have been examined:

- Structural enrichment
- Application of substrate.

Maynard et al. (2004) summarize the results of five studies testing the effects of **structurally enriched raceways**, consisting of gravel embedded in concrete, suspended conifers, and cover through camouflage nets (cf. Maynard et al. 1996 a, d, 2003 a, c in: Maynard et al. 2004, Maynard et al. 1996d). In these studies the coloration of semi-naturally reared coho salmon as well as chinook salmon has been compared with the coloration of conventionally reared conspecifics. In conclusion, the results of all five studies have in common that the skin colour diverged between the two rearing treatments during culture (Maynard et al. 2004). Similar results have also been obtained in additional (comparable) studies between 1992 and 1994 (cf. Maynard et al. 1992, 1994, 1996d). Maynard et al. (2004) conclude that the differences between semi-naturally and conventionally reared fish "…appear to enhance the ability of semi-naturally reared fish to blend into stream and river backgrounds". Correspondingly, Flagg and Maynard (2004) refer to a 25–50 % survival advantage during migration of semi-natural reared fish to external camouflage colour patterns (see also Maynard et al. 1996). In particular, increased crypticity of semi-naturally reared fish reduces their vulnerability to visually hunting predators (e.g., fish, birds, mammals) (Berejikian et al. 1999, Maynard et al. 2004b).

Overall, it appears that rearing with **natural substrates** increases postrelease survival (Berejikian et al. 2001a, Maynard et al. 1996). In particular, it turned out that the more the substrate colours used for hatchery rearing resemble the substrate of released fish, the higher the postrelease survival chances are (Donnelly and Whoriskey 1991 in: Maynard et al. 1996). The importance of substrate for the development of skin colour and cryptic colouration has also been attested in further investigations on coho salmon (cf. Maynard et al. 2003).

In summary, at least for coho- and chinook salmon the described adaptations to conventional rearing methods have been proven to be very advantageous for proper development of skin colour and camouflage patterns. Beside the direct comparison of semi-naturally and conventionally reared fish positive results are also seen in higher survival rates of semi-naturally reared individuals after release.

### 3.4.4 Swimming Performance

Swimming ability is a crucial factor for outmanoeuvring and escaping predators respectively, but also for dealing with turbulent currents or strong effluents. Basically, swimming performance depends on the one hand on fin condition (cf. Chapter 3.4.2) and on the other hand, on stamina. Low and consistent water currents in rearing vessels prevent hatchery fish from experiencing and adapting to manifold flow velocities and currents in natural streams. In other words, the flow environments of hatcheries "…fail to challenge fish to swim as they would in their natural fluvial habitat" (Maynard et al. 2004). Efforts in semi-natural rearing experiments attempt to prepare hatchery fish's stamina using the following method in hatcheries:

- Increased water velocities.

According to Maynard et al. (2004) there is ample evidence that exercising fish in hatcheries through increased velocities improves swimming performance (cf. Leon 1986, Christiansen et al. 1989, 1992, Christiansen and Jobling 1990, Nielsen et al. 2000, Azuma 2001 in: Maynard et al. 2004). Accordingly postrelease survival rates could have been increased, for example, by 50% for brown trout (Creswell and Williams 1983 in: Maynard et al. 2004) or even 62% for chinook salmon (Burrows 1969 in: Maynard et al. 2004). Also in the case of Atlantic salmon, McDonald et al. (1998) could attest increased condition factors as well as increased endurance when fish were reared at higher rearing velocities. However, not all investigations testing exercise programs obtained positive results. Rearing experiments have been carried out finding virtually no changes in condition, endurance (Kiessling et al. 1994 in: McDonald et al. 1989), or postrelease survival (Lagasse et al. 1980, Evenson and Ewing 1993 in: Maynard et al. 2004) between trained and conventionally reared fish.

To sum up, rearing salmonids at higher velocities in comparison to conventional velocities (less than 1 cm/s) has been proven to increase fish condition factors and postrelease survival. Concerning inconsistent study results, Maynard et al. (2004) claim that further research would be necessary to evaluate and refine training protocols.

### 3.4.5 Further Physiological Parameters

It needs to be noted that apart from the topics discussed already, further physiological parameters are under investigation. For example, scientists focus on the effects of different rearing methods on heart rate responses (Sundström et al. 2005), seawater tolerance of anadromous salmonids (Hill et al. 2006) or hormonal balance (Patino et al. 1986). However, not enough literature is available to compare study results of thee parameters.

## *3.5 Conditioning Behavioural Traits*

### 3.5.1 Social Behaviour

Differentiated agonistic behaviour of hatchery reared salmonids compared to their naturally reared conspecifics is a widely publicised subject (Berejikian et al. 1996, Einum and Fleming 2001, AQUAWILD 2002, Weber and Fausch 2003, Sundström et al. 2004). Even so, opinions about the effects of conventional hatchery rearing on aggressive behaviour of salmonids are divided (cf. Chapter 2.3.1.2). Apart from that, it is agreed that behaviourally modified fish from hatcheries can crowd out naturally reared fish through aggressive interactions and increase the levels of aggression in fish populations (Berejikian et al. 1996, 2001). This, in turn, can reduce the overall productivity of fish in the wild (Bachman 1984, Berejikian et al. 2001, Maynard et al. 2004). In the wild, fully-trained social behaviour is decisive in many respects. In this sense, rearing trials attempting to reduce the opportunity of developmental divergences between wild and hatchery produced fish directed attention, along with agonistic behaviour, on context-dependent features such as dominance or territorial manners. Therefore, effects of the following adaptations to conventional rearing methods have been investigated:

- Structural enrichment
- Altered rearing densities
- Application of substrate.

“Behavioral characteristics at any developmental stage result from present and past interactions between an individual’s genotype and external environmental factors” (Berejikian et al. 1996, see also Maynard et al. 1996b). Referring to the environmental effects of hatchery production particular importance is ascribed to the influence of early rearing environments (Metcalfe et al. 2003). Consequently, rearing trials in this area of interest focus on juvenile salmonids. Berejikian et al. (2000), for example, tested whether culturing steelhead fry in **habitat enriched rearing tanks** (using submerged conifers, overhead cover, and underwater feeding) at densities of 10.7 fry/m² affects competitive ability compared to conventionally reared fry. When fish from both rearing environments were tested in both a laboratory flume and a quasi-natural stream, no significant differences in agonistic behaviour were found; even though, steelhead juveniles grown in enriched tanks socially dominated (size-matched) competitors from the conventional rearing tanks (Berejikian et al. 2000). Dominance was measured in maintenance of feeding position, free movement, and superiority towards opponents (cf. Berejikian et al. 2000). Based on the results it is assumed that visual isolation through submerged structures causes improved competitive ability (Berejikian et al. 2000, see also Berejikian and Tezak 2005). This assumption links with Mesick et al. (1988) who attested the role of structure for visual isolation and consequent reduction of aggressive interactions in streams. Additionally, Berejikian et al. (2000) attribute attested improvements in territorial behaviour of steelhead trout from enriched rearing tanks to the underwater feeder inlets which, according to the authors, provided localized and defensible food sources. In summary, Berejikian et al. (2000) argue, that the combination of submerged structures and defensibility of food are the primary causes for improved competitive ability and territoriality of steelhead juveniles. Beside these observations it has been proven that, in the case of Atlantic salmon, application of **natural substrate** can induce increased territoriality (Mork et al. 1999 in: Maynard et al. 2004). However, whether or not the study by Berejikian et al. (2000) produced fish similar to those in the wild remains unacknowledged. Scientists have tried to answer this question in subsequent investigations. Berejikian et al. (2001, 2003) therefore reared steelhead fry in conventionally-, enriched-, and natural environments for consecutive comparisons of the effects of rearing treatments on social behaviour and related differences in competitive ability. The results from the 2000 study have been affirmed whereby dominance rank of steelhead from enriched rearing tanks exceeded dominance of conventionally reared fish; further on, enriched- and naturally reared fish achieved similar ranks of dominance (Berejikian et al. 2001, 2003). Further on, Berejikian et al. (2003) later observed a similarity in the frequency of aggressive attacks (nips, charges, chases) at fish from all rearing environments, however conventionally reared fish showed a significant reduction of threat displays compared to fish from other treatments (Berejikian et al. 2003). Threat displays are supposed to serve as offensive as well as defensive manners, (Keenleyside and Yamamoto 1962 in: Berejikian et al. 2003) whereby such displays reduce the occurrence of injury-prone (aggressive) contests (cf. Berejikian et al. 2003). Generally the results are interpreted as evidence "…that agonistic behaviour may be more natural in enriched rearing environments than in conventional rearing environments" (Berejikian et al. 2003, see also Berejikian et al. 2001). Similarly, Maynard et al. (2004) assert chinook salmon "[…] engage in natural aggressive activity" more often when reared in semi-natural raceways.

In the studies reviewed so far effects of rearing densities have not been investigated so far. However, Riley et al. (2004a) examined aggression and dominance of naturally reared steelhead fry stocked with steelhead fry from conventional and enriched rearing environments at two different **densities**. The rearing densities used in this study come to 0, 9 and 1, 8 fry/m². This study was conducted in an experimental flume in order to prove how the rearing environment on the one hand and different fish densities on the other hand affect behavioural traits. After all, fish from all rearing treatments showed similar levels of aggression, hence, correlated with the results from Berejikian et al. (2001, 2003). However, it became apparent that relative aggressiveness of fish from the differing rearing environments depended on the rearing density rather than on the rearing environment. In particular, the number of aggressive attacks was significantly higher in the high density trials (Riley et al. 2004a). Just as dominance was observed to be density dependent, whereby hatchery reared fry dominated naturally reared fish at high densities while rearing at low densities led to dominated hatchery fry (Riley et al. 2004). Structural differences in the rearing environments had no effect on the behaviour.

Over all, the comparison of investigations on agonistic behaviour in enriched rearing vessels reveals ambiguous results, leaving questions open about the relevance of rearing environments and rearing density. Summarized, no significant differences relating to agonistic behaviour have been found when steelhead juveniles from conventional and enriched rearing were stocked at densities of 10. 7 fry/m² (cf. Berejikian et al. 2000); significant differences in threat displays, though, have been observed when conventionally and enriched reared steelhead fry were stocked with naturally reared steelhead fry at densities of 5.3 fry/m² (cf. Berejikian et al. 2001); additionally Berejikian et al. (2001) noted a significant relationship between body size and aggressiveness when steelhead fry from all three treatments (conventional, enriched, natural) were investigated separately at densities of 4.0 fry/m² (Riley et al 2004a, cf. Berejikian et al. 2001). In particular, during this research aggression of steelhead fry increased with mounting body size in both the enriched and conventionally reared fry but not in naturally reared individuals (Berejikian et al. 2001).

Based on these diverging observations Riley et al. (2004a) challenges the importance of structural enrichment, in contrast to the effect of rearing density. Riley et al. (2004a) do not preclude that methodological differences between the studies (e.g., differing interpretation of behavioural patterns) led to incompatible results. Nevertheless, based on the results obtained by Riley et al. (2004a), whereby the rearing densities played a significant role for behavioural characteristics of steelhead fry (see also Riley et al. 2004b), the authors claim that further research on the issue of rearing density has to be undertaken and that the results may have important implications for stocking practices. Overall, Riley et al. (2004b) note, that rearing density dependent increase of aggression has already been observed for salmonids (cf. Fenderson and Carpenter 1971, Keeley 2000 in Riley et al. 2004b) and other fish species (Jones 1983 in: Riley et al. 2004b).

Retrospectively, some of the aforementioned studies document that enriched hatchery environments may have some effect on the agonistic behaviour. This effect, though, also depends on density, feeding regimes, the presence or absence of predators, and other potential factors (cf. Riley et al. 2004b). Furthermore, the same studies concentrate their investigations on steelhead trout. Research on other species of the family of Salmonidae showed that as well as rearing treatment, species-specific traits (cf. Dickson and MacCrimmon 1982) cause varying achievements at semi-natural rearing attempts. Berejikian et al. (2000) document, that underwater feeding systems promote development of territorial behaviour of steelhead trout. In contrast, this effect could not be shown for coho salmon (cf. Olla 1995, Ryer and Olla 1996 in: Berejikian et al. 2000). Sundström et al. (2003) also highlight varying results from Berejikian et al. (2001) and further rearing trials on coho salmon and Atlantic salmon. Berejikian (et al. 2001) attested that in a feeding situation under semi-natural conditions wild or semi-naturally reared steelhead trout were more likely to become dominant than conventionally reared fish. Conventionally reared coho salmon and Atlantic salmon, in contrast, dominated wild conspecifics under comparable feeding situations (Fenderson et al. 1986, Rhodes and Quinn 1988 in: Sundström et al. 2003). Either context-dependence of aggression or species-specific traits are assumed to generate such inconsistent results (Sundström et al. 2003).

In summary, the modification of conventional rearing practices towards more natural conditions has been proven to reduce behavioural differences between hatchery- and naturally reared salmonids. Particular importance is attributed to the role of rearing densities and food delivery. In particular, rearing densities may be an important determinant of aggression levels whereas localized underwater feeding is, at least for some species, positively affecting territoriality. Overall, importance is also ascribed to structural enrichment of rearing vessels encompassing submerged structures or applied substrate. Structural enrichment though, is seen to be important in combination with further adaptations (cf. Berejikian et al. 2000, Riley et al. 2004b). Along with these observations the experiments affirm the relevance of rearing treatments during early life stages of salmonids. Developmental differences in behaviour between rearing treatments occur after short rearing periods (e.g., 49- to 78-days in: Berejikian et al. 2000). Furthermore, these differences are expected to become more significant after longer rearing periods (Berejikian et al. 2000).

Generally, trials within the scope of social behaviour and its affectation by hatchery rearing highlight that only slight differences between rearing methods may lead to varying study results (cf. Sundström et al 2003). Beside a differing response of the various fish species to manipulations in rearing treatment, this may be an additional factor impeding definite conclusions. Scientists therefore, are partly faced with the problem of insufficient knowledge about behavioural patterns of fish (Sundström et al. 2003) and potential effects of aggression by hatchery fish on natural populations (Maynard et al. 2004).

### 3.5.2 Antipredator Behaviour

Predation is assumed to be a key factor for high postrelease mortality of cultured salmonids (Maynard et al. 1996, Flagg and Maynard 2004). Effective avoidance of predation and proper behavioural response in the event of predation depend on the development of several characteristics of salmonids. Maynard et al. (2004) highlight five attributes: (1) stealth (e.g., cryptic coloration); (2) avoiding habitats that predators use; (3) adopting appropriate behaviour when detecting predators (freezing, hiding, flight, etc.); (4) evolving better swimming and manoeuvring ability than the predators; and (5) outgrowing the predator's gape. Generally speaking, these characteristics are underdeveloped in hatchery reared fish (cf. Chapter 2.3) and consequently a matter of concern in rearing trials. The issue of cryptic coloration in the context of semi-natural rearing has already been discussed in Chapter 3.4.3. Along with these observations as well as efforts to improve stamina and proper habitat use (see Chapters 3.4.4 and 3.5.4) scientists also concentrate their attention on practices conditioning hatchery reared fish to proper antipredator behaviour. Accordingly, research so far, has focused on the following adaptations:

- Exposition to predator stimuli
- Exposition to predators
- Social learning.

Predator recognition and avoidance, respectively rests upon innate- (i.e., genetic) as well as learned traits (Berejikian et al. 1999, Maynard et al. 2004). In rearing experiments aiming to increase antipredator behaviour, advantage is taken of this learning ability. These experiments basically proceed upon the fact that visual, acoustic, and chemical cues from predators are associated with danger (Maynard et al. 2004) and elicit fright response (Smith 1992 in: Berejikian et al. 1999). Earlier investigations, for example, tested electrified models of predators on potential prey by means of electric shocks. In so doing, predator-conditioned chinook- and chum salmon (*Oncorhynchus keta*) (Thompson 1966, Kanayama 1968 in: Maynard et al. 2004) have been reared, exhibiting increased instream survival rates. Thompson (1966) for instance, reduced mortality rates of chinook salmon by up to 50% (cf. Thompson 1966 in: Olla et al. 1996).

Further rearing experiments deal with salmonids ability to identify **chemical cues**. In detail, these investigations refer on the one hand to the ability of fish to recognize and react to chemical alarm signals liberated from attacked and injured conspecifics (Smith 1992 in: Berejikian et al. 1999). On the other hand, some species learn to associate and react to predator odour (Brown and Smith 1998; Magurran 1989, Chivers and Smith 1994, Chivers et al. 1995 in: Berejikian et al. 1999); an ability which is also used for training predator recognition (cf. Brown and Smith 1998, Berjikian et al. 1999). Berejikian et al. (1999) exposed chinook salmon to extracts of conspecifics tissue paired with odour of predatory cutthroat trout. As predicted, Berejikian et al. (1999) demonstrated acquired predator recognition by chinook salmon, whereby the fish primarily treated with paired extracts showed defensive behaviour (i.e., freezing, reduced swimming activity) when predator odour alone was introduced (see also Brown and Smith 1998 in: Berejikian et al. 1999). Interestingly, the experiments by Berejikian et al (1999), but also Thompson (1966) and Kanayama (1968), did not result in differentiated postrelease survival rates of trained and non-trained fish (cf. Berejikian et al. 1999). However, Berejikian et al. (1999) link this missing evidence to study design reasons.

However, as distinct from investigations on chemical predator stimuli, direct **exposure to predators** has been evaluated as a method to increase postrelease survival. This method is based on the assumption that fish can be trained to avoid predators (Fraser 1974). Maynard et al. (2001a) obtained 26% higher postrelease survival when chinook salmon were trained on diverse live predators (predatory birds and fish) compared to untrained chinook salmon. Comparable results have been obtained in studies investigating predator recognition of Sockeye salmon (Ginetz and Larkin 1976 in: Maynard et al. 2004) and coho salmon (Patten 1977 in: Maynard et al. 2004). In general, experiments with live predators obtain better predator response when fish are directly exposed to predation instead of being exposed to caged predators (Javi and Uglem 1993 in Maynard et al. 2004).

Finally, scientists raise the issue of **social learning** in acquisition of predator avoidance behaviours. Regarding this it has been attested that naïve (untrained) salmonids are able to learn predator avoidance from predator-experienced conspecifics (Patten 1977, Suboski et al. 1990 in: Olla et al. 1996). This learning ability signifies that not all individuals need to be conditioned but that the conditioned fish transfer their predator avoidance behaviour to unconditioned individuals (Olla et al. 1996, Brown and Laland 2003).

In summary, it has been shown that postrelease survival can be significantly improved by training fish to display proper antipredator behaviour. The most promising method is that of direct exposure of salmonids to live predators. Nevertheless, scientists claim that predator avoidance strategies are highly species specific (Healey and Reinhardt 1995) and that further investigations should be undertaken in this field (Maynard et al. 2001a). Moreover, additional research is required to develop adequate (i.e., species specific) training protocols (Maynard et al. 2001a, 2004). After all, not all studies carried out in the field of improving predator response developed successful training protocols (cf. Healey and Reinhardt 1995; Berejikian 1996 in Maynard et al. 2004). In general though, it appears that the success of predator avoidance improves as the number of cues and the variety of predators the learner is exposed to increases (Maynard et al. 2001a, Maynard et al. 2004). This is, among others, assumedly due to the ability of fish to clearly distinguish between stimuli of different predators (cf. Maynard et al. 2001).

### 3.5.3 Feeding Behaviour

Beside predation, underdeveloped feeding behaviour appears to be another key factor leading to high postrelease mortality of hatchery reared fish (Hickson and Leith 1996). Poor foraging ability is attributed to various reasons comprising stress, inability to recognize live prey or taste bias against live food (cf. Bachman 1984, Maynard et al. 1996c, Maynard et al. 2004, see also Chapter 2.3). Hickson and Leith (1996) highlight several features that should be considered at hatchery rearing when proper feeding behaviour of fish is anticipated. First, a wide array of different natural (live) prey should be fed so that fish develop foraging flexibility. In detail, hatchery reared fish should get to know the varying visual, textural, and olfactory cues as well as experience how to capture moving prey. Second, for improvement of appropriate territorial feeding and prevention of surface feeding, structural enrichment including subsurface feeders need to be considered. Finally, hatchery feeding has to be adapted to seasonal, lunar, and diel feeding patterns whereby feeds should be delivered in low volumes and at high frequencies preferably randomly positioned. Accordingly, a few studies have been conducted, evaluating the following adaptations to conventional rearing:

- Live food diets
- Structural enrichment

- Underwater feeding.

Full development of the foraging behaviour of fish relies on experience (Brown et al. 2003). Experiments revealed that hatchery reared fish can be conditioned to recognize live prey, however about 15 exposures to the live prey are recommended to become familiar (i.e., recognition and consumption) with it (Paszowiski & Olla 1985, Strademeyer and Thorpe 1987, Reiriz et al. 1998 in: Brown et al. 2003). To illustrate, Maynard et al. (1996a) investigated whether the postrelease foraging ability of chinook salmon could be increased by live food supplemented diets. Apparently, when tested in laboratory aquariums chinook salmon fed with live food, showed more effective foraging on both familiar and unfamiliar prey than conventionally reared salmon. Foraging efficiency (i.e., average handling time), though, was similar for fish from both treatments (Maynard et al. 1996a). Additionally, similar results have been obtained in a subsequent study whereby chinook salmon reared on live food showed more interest for live prey in laboratory tests than conventionally reared salmon; even though, foraging ability on evasive or easy to capture prey was not improved by live food diets (Maynard et al. 2001b). Consequently, foraging ability and foraging efficiency, are expected to be a matter of more natural rearing environments (Maynard et al. 1996a, 1996c) and more complex prey (Maynard et al. 1996a).

Accordingly, Brown et al. (2003) demonstrated, by the example of Atlantic salmon, that structures in rearing environments promote foraging ability. In particular, Brown et al. (2003) reared juvenile Atlantic salmon for three months in enriched tanks (containing river gravel, drift wood, rocks, plastic tubing, live and plastic plants) and fed fish with live prey. The authors proceed on the assumption that both exposure to live prey and rearing in enriched environments improved the ability to forage on novel live prey (Brown et al. 2003). Compared to conventionally reared fish as well as fish reared with only one of the two additional treatment attributes, (structure and live prey) only fish from both the enriched and live prey treatment were able to generalize between different types of live prey. In contrast to live prey diets structural enrichment appeared to be a matter of particular importance. In fact, an independent effect of environmental enrichment, assumedly existing in its role of increasing neural plasticity, improved learning ability and behavioural flexibility (Brown et al. 2003).

In contrast, inconclusive results have been obtained in field trials. In two studies on chinook salmon no significant differences between the two feeding treatments (i.e., pellet diet and live prey diet) could be determined (cf. Maynard et al. 1996c, 2001b). In particular, during both studies most fish, regardless of the rearing treatment had empty stomachs after one week of residency in either marine- or stream enclosures. There were several feasible causes for this occurrence. Firstly, development of taste for food is ascribed to the early life stages of fish (Bryan and Larkin 1972, Ringler 1985, Merna 1986 in: Maynard et al. 1996c). Even though Maynard et al. (1996) reared and analyzed foraging behaviour of chinook salmon which were in their third year of growth. Therefore, empty stomachs of (particularly pellet fed) salmon could result from an already existing lack of taste for natural live foods (Maynard et al. 1996c). Secondly, it has been attested that hatchery reared fish may starve for several weeks after release (Ersbak and Haase 1983, Maynard et al 1996b, Miller 1952, Hochachka 1961, Reimers 1963, Sosiak et al. 1979, Myers 1980, O'Grady 1983, Johnson and Ugedal 1986 in: Maynard 2001b). Therefore, starving could be related to stress provoked by factors such as chemical- or physical differences between rearing- and stocking environments (cf. Maynard et al. 2001b). However, even if the results are not significant it is speculated that live food treatment improved the foraging ability of chinook salmon (Maynard et al. 2001b).

A further approach to producing hatchery fish emulating feeding behaviour of their wild conspecifics is to simulate invertebrate drift patterns by subsurface feeding mechanisms. According to Hickson and Leith (1996) these feeding mechanisms have been positively tested to improve foraging behaviour of various species. Particular importance of these feeding systems is linked to the existence of an adequate current velocity and the food which should be more or less neutrally buoyant to stay in suspension (Hickson and Leith 1996). It is claimed that such systems may provide feeding territories via distributed feed inlets (Hickson and Leith 1996, Maynard et al. 1996d). However, investigations on subsurface feeding systems are mainly tested for their impact on habitat use of hatchery reared fish (see Chapter 3.5.4).

In summary, it has been ascertained that exposure to live prey during rearing periods results in postrelease improvements of foraging success. Furthermore, a combination of the different (semi-natural) rearing strategies (structure, live prey, subsurface feeding) coincide fish not only to recognize but also to handle or to locate prey. These findings come along with the multifaceted development of feeding behaviour whereby "…a complex interaction of habitat selection, availability of prey, inter- and intra-specific competition for forage and cover, innate and acquired feeding rhythms, age of fish, and physiological requirements" play a role (Hickson and Leith 1996). However, as well as the existing perceptions, Maynard et al. (2004) claim that future research is necessary for refinement of the techniques of live food implementation. Moreover, in the sense of improving overall foraging ability particular importance has to be ascribed to a high variety in hatchery diets including feeds of different shape, size, colour, and movement (Paszkowski and Olla 1985 in: Hickson and Leith 1996).

Finally, no literature was available testing the effect on foraging abilities of rearing techniques adapted to seasonal or diurnal feeding patterns.

### 3.5.4 Habitat Use

In comparison to naturally reared fish, a differentiated positioning within the water column of hatchery reared salmonids has been found (cf. Dickson and MacCrimmon 1982, Maynard et al. 1996, Maynard et al. 2004, see also Chapter 2.3.2.1). According to Maynard et al. (2004) surface orientation also has innate components, however, it has been shown that this behaviour is inadvertently conditioned by conventional hatchery (i.e., feeding) treatment. Moreover, hatchery reared fish appear to lack proper usage of available mesohabitats (Maynard et al. 1996b) and microhabitats (i.e., structures) (Flagg et al. 2000) within natural streams. Added together, a series of consequences, hence, endangerments arise from this abnormal behaviour comprising increased energy demand, vulnerability to the force of freshets, and increased predator vulnerability (Dickson and MacCrimmon 1982, Maynard et al. 2004). Moreover, behavioural traits such as territorial defence correlate with habitat preferences of salmonid species (Johnsson et al. 2000) and are consequently influenced by incorrect habitat use. Reinforcement of correct habitat use is attributed to modifications in rearing conditions and is emphasised by scientists (cf. Dickson and MacCrimmon 1982). To date, investigations found for this review tested the following adaptations to rearing environments:

- Structural enrichment
- Subsurface feeding.

Whilst several studies investigated the effects of structural enrichment in rearing vessels, only two were available which focused, among other things, on the benefits of semi-natural rearing for postrelease habitat usage. Berejikian et al. (2000) tested whether steelhead juveniles from structurally enriched rearing tanks (for tank design see Chapter 3.4.1) would differ in their use of woody debris from conventionally reared fish. For this purpose, subsequent to rearing, fish have been observed in a quasi-natural stream channel. Berejikian et al. (2000) found that fish from both rearing treatments used structured or unstructured habitats in the same proportion. According to the authors this outcome could be attributed to the innate habitat preferences of juvenile steelhead which were not affected by the rearing treatment. It remains unacknowledged, whether the fish from the conventional rearing treatment could have learned to use the habitats by watching the more experienced conspecifics. However, it is further assumed that tests on age-1 steelhead, possessing stronger preferences for specific meso- and microhabitats, may develop more distinctive results (Berejikian et al. 2000). Consistent with these findings are those from a similar study by Riley et al. (2004b) who could also verify only a few (nonsignificant) differences in habitat use of steelhead trout from enriched and conventional rearing treatments. Admittedly, both studies have been carried out in the same experimental flumes testing the same species. However, in contrast to the findings mentioned above, Berejikian et al. (1999) stated the assumption in a former study that chinook salmon grown in tanks containing submerged structure and overhead cover may have developed preferences for exactly these structures in the postrelease environment. Interestingly, this assumption is based on results obtained in a natural stream whereby the later (contrary) results by Berejikian et al. (2000) and Riley et al. (2004b) were obtained in laboratory experiments. However, habitat use was not of particular interest during the research by Berejikian et al. in 1999 and therefore has not been further questioned.

A second approach to condition proper habitat use is to apply underwater feed delivery systems that should avoid reinforcement of surface orientation. Maynard et al. (1996d) tested subsurface feeding systems in enriched rearing raceways and compared the behaviour of chinook salmon from those raceways with fish from a conventionally reared (i.e., surface fed) treatment. It has been positively shown that within the water column subsurface fed fish were in deeper water than conventionally reared salmon (cf. Maynard et al. 1999e). Moreover, conventionally reared fish swarmed to the surface even when non-food items (dust particles, etc.) hit the surface; this behaviour has not been observed from chinook salmon which have been fed by the underwater food delivery system (cf. Maynard et al. 1996d).

A subsequent study by Maynard et al. (2001) was solely orientated on subsurface feeding. This means, in comparison to the former study, rearing was carried out without application of structural components. In fact, Maynard et al (2001) found no differences of depth preference between the two feeding treatments. Moreover fish from both treatments showed the same response to unfamiliar objects at the water surface (Maynard et al. 2001). The only observed significant difference between fish from both treatments was the diverging response to humans. In particular, hand fed fish swam to the water surface when humans entered the area, whilst automatic fed fish showed a typical fright response to large objects (i.e., humans, shovels, model of a heron) (Maynard et al. (2001). However, comparing the two studies by Maynard et al (1999, 2001) it remains unquestioned whether the effects of the underwater feeding could be separated from the effects of structural enrichment (cf. Maynard et al. 2004). Apart from that, it also remains unquestioned whether the combination of underwater feeding and structural enrichment account for the positive results obtained in the study conducted in 1999.

In summary, only a few studies were available investigating the effects of semi-natural rearing on postrelease habitat use. Laboratory trials testing the effects of structural enrichment did not show improvements, whereas no literature was available testing effects of semi-naturally reared fish released into natural stream habitats. Also on the matter of underwater food delivery systems no consistent results have been obtained, even though due to differential study designs the question arises whether the results from the observed studies are comparable. Further research would be necessary to test whether improvements of habitat use by semi-natural rearing are achievable. Particular attention, though, should be given to seasonal (Vehanen et al. 2000) and species specific (Dickson and MacCrimmon 1982) preferences of meso- and microhabitats.

Finally, significant results have been obtained with regard to predator vulnerability. In comparison to hand feeding, automatic underwater food delivery systems cause fish to keep their position and to behave properly in case of potential endangerments.

## *3.6 Summary*

In the process of addressing the problem of high postrelease mortality of hatchery reared fish, a variety of semi-natural rearing strategies have been investigated. The majority of the studies considered, therefore, orientated the study design toward the applicability to large scale production settings. Both juvenile and adult salmonids are reared under semi-natural laboratory conditions (i.e., in rearing vessels) to achieve comparison with wild- or conventionally reared fish. Therefore, the majority of the reviewed investigations observed the outcome of rearing differences within adapted laboratory flumes; some investigations studied features of semi-naturally reared fish within natural stream habitats.

Generally then, semi-natural rearing practices can be beneficial for both physiological as well as behavioural traits. Particularly positive results have been obtained in the field of skin colouration and cryptic camouflage but also in terms of improved fin condition. Equally, reduction of rearing densities and predator avoidance training proved to increase survival rates. Decreased rearing densities showed to reduce stress and enable the development of more naturally social behaviour patterns. With regard to recognition of natural enemies the ability of (social) learning takes effect, provoked through direct exposition to endangerments. Moreover, it has been demonstrated that subsurface feeding can contribute to decreased vulnerability to avian predation. Compared to conventional rearing practices some of the applied rearing methods positively affect growth patterns of fish. In this respect increased growth rates might be of particular importance considering the desire of fishery managers and anglers for fast growing fish.

In the course of the investigations it has been found that early exposure to appropriate cues is essential for proper development of behavioural and physiological traits (cf. Berejikian et al. 2000, AQUAWILD 2002, Brown and Day 2002). Basically, early behavioural and physiological imprinting is affiliated to a "strong environmental effect" (AQUAWILD 2002) which, in turn, induces some researchers to recommend stocking of fish as eyed eggs rather than to "…help the fish by rearing them through the early life stages." (Metcalfe et al. 2003, see also AQUAWILD 2002).

However, besides auspicious achievements in the area of semi-natural rearing, noticeable ambiguous results have been obtained in all specific fields of investigation. These differences have various causes. Firstly, only slight differences in the study design encompassing methodological approaches and the interpretation of attributes lead to diverging results. Secondly, particularly in the field of behavioural traits, the various species of the family of Salmonidae show a differing response to semi-natural adaptations in rearing environments. These differences are related to physiological as well as behavioural varieties of the single species. Beyond that, the various species differ in terms of their ecology. Kleiman et al. (1994 in: Brown and Day 2002) claim that for a proper design of natural rearing environments it is crucial "...to have a broad understanding of the biology and ecology of the fish species in question and especially of the environment into which the animals are released." Brown and Day (2002) amplify this remark, pointing out that not only do species specific traits need to be considered but also case specific attributes. In detail, attempts at semi-natural rearing should be adapted to case specific predators or food items which show "…considerable geographical variation even within a catchment" (Brown and Day 2002).

Since the studies on semi-natural rearing focus on the promotion of certain selected traits there appears to be a lack of rearing trials promoting the development of the majority of deficient traits which have been observed in conventionally reared fish; nevertheless the variety of traits are strongly interrelated. However, due to the restricted study designs in laboratories it has been shown that there are limits to the overall findings. After all, alongside correlations of the single traits, proper development is related to a variety of environmental factors; hence, the quality of (semi-natural) rearing environments is a crucial factor. Additionally, Fenderson et al. (1968 in: Berejikian et al. 2000) emphasise that experiments on a laboratory scale may favour certain fish groups (i.e., populations) because of biased adaptations to environmental factors. After all, in 1999 Flagg and Nash (1999) doubted that any hatchery applying conservation strategies were currently capable of using strategies to produce fish with the equivalent genetic resources of a local native stock.

To resolve some of these problems scientists emphasise the need to take the step from laboratory experiments to field experiments (AQUAWILD 2003). Furthermore, the need for more information about local adaptations of populations is stressed (AQUAWILD 2003). Finally, in regard to the reviewed literature the effects of semi-natural rearing on domestication have not been verified. Even though, on the one hand domestication of fish is demonstrably a significant factor for high postrelease mortality. On the other hand, impacts of hatchery reared fish on wild living populations are subjected to domestication. For that reason it would be necessary to incorporate the effects of semi-natural rearing on domestication. Reisenbichler (2004) emphasises that this issue needs investigation.

Related to the deficiencies of the rearing trials, and beyond, the project initiative TROUTCHECK aims to identify solutions accomplishing the needs for sound conservation purposes. In this sense, rearing experiments are conducted which intend to provide environmental conditions as effectively as possible. The rearing experiments are carried out in the field, adopting natural rearing situations for culture strategies instead of adapting facilities in production hatcheries. Rearing attributes that detract from the natural appearance of fish are unfavourable for conservation purposes (cf. Berejikian and Tezak 2005). Therefore the potentialities of natural creeks or a near-natural (artificial) channel are compared with conventional rearing methods. Emphasis is also put on the origin (i.e., the genetic integrity) of the fish, following the approach of rearing and releasing locally adapted (native) trout strains. In comparison to the reviewed studies, conservation approaches and therewith related investigations in Austria apply to smaller structured drainage basins as well as to smaller production volumes of hatcheries. These framework conditions on top of the legal requirements for stocking fish in Austria (cf. Chapter 4.1) as well as the need for sustainable management strategies demand appropriate conservation practices. In this context, a question raised by scientists is how to run a conservation hatchery (AQUAWILD 2002). This question is related to both ecological and economic components of propagating fish. Highlighting the economic characteristics of propagated brown trout in Austria, the following Chapter deals with an inquiry of hatchery operators which has been conducted within the frame of this thesis. Next to production- and stocking related topics, the potentials for an ecosystemic integration of hatcheries into conservation purposes are part of this investigation.

# 4. Introduction to the Survey of Fish Farmers

## 4.1 Background of the Study

In Austria, as in other European countries, *Salmo trutta* is an important native fish due to its natural abundance and its high economic value (Lahnsteiner and Jagsch 2005, see also Elliott 1994). The commercial relevance can be affiliated to both the production of edible fish and predominately to fish reared for stocking activities. Stocking of fish in Austria is based on legal requirements which should be briefly illustrated. In comparison to other countries (e.g., New Zealand, United States) the freshwater fishing rights in Austria are almost completely privatized (Weiss and Schmutz 1999). Furthermore, Austrian beat holders of river stretches are committed by law to compensate angling induced removal rates of fish through periodical re-stocking activities; regarding this, even river reaches with naturally reproducing (i.e., self-sustaining) salmonid populations are not excluded from this commandment (Weiss and Schmutz 1999). In ecological terms stocking of brown trout is demonstrably related to a series of problems encompassing negative demographic effects on wild populations (Bachman 1984, Weiss and Schmutz 1999, Flagg 2000), the endangerment of the genetic integrity of native stocks (Weiss et al. 2001) and the introduction of diseases and parasites (Krueger and Menzel 1979, Hindar et al. 1991, Heggberget et al. 1993, Hansen and Loeschke 1994, Campton 1995 in: Weiss and Schmutz 1999, see also Chapters 2.2 and 2.3). With regard to Austrian brown trout populations, significant differences in the phenotype and genotype of current and historical data have already been demonstrated (Jagsch and Lahnsteiner 2005). However, stocking may not be the only cause of phenotypic changes, even though it is assumed that continued stocking of the present hatchery strains erodes the genetic integrity of native populations (Weiss et al. 2001); after all, a wide range of hatchery strains consists of allochthonous brown trout (Weiss et al. 2001, Lahnsteiner and Jagsch 2005, unpublished data) deriving from Atlantic brown trout strains.

As a consequence of the impacts on wild living populations and to avoid further degradation of wild stocks there is a growing need to implement sound conservation-oriented management strategies. The project-initiative TROUTCHECK was founded to investigate measures which can fulfil the aims of these conservation purposes.

Dealing with the conservation of brown trout, several areas of responsibility need to be addressed. These areas are summarized within the four main objectives (modules) of the project-initiative (see Table 1:). The social-scientific investigation presented in this thesis is part of module three. In particular, the questioning should serve as a preliminary study for the development and implementation of ecologically and economically sound management strategies for Austrian brown trout populations. In respect of the specific aims of the study, the remainder of this Chapter describes the questions that have been pursued.

**Table 1:** Modules of the project-initiative TROUTCHECK

| | |
|---|---|
| **Module 1** | Development of a Multi-Locus test for precise acquisition of the genetic composition of brown trout populations. |
| **Module 2** | Investigation and risk assessment of the current ecological and genetic situation of Lower Austrian and Styrian brown trout populations. |
| **Module 3** | Development and implementation of sound rearing practices, renaturation measures, and management strategies for stocking purposes. |
| **Module 4** | Accomplishment of an ecological- and genetic pilot study conducted at four different water bodies, for measurement of results and ongoing monitoring. |

## 4.2 Aims of the study

The overall aims of this inquiry are: (1) to deliver an insight into the situation of the brown trout stocking-market within the federal states of Lower Austria and Styria. Special emphasis will be put on the specification of the origin of the fish as well as on trading induced routes hatchery reared brown trout strains pass through; (2) Perceptions of fish farmers regarding profession oriented topics as well as concerning matters of conservation; (3) A network analysis of hatchery operators is brought into focus to describe the network of relations between them and to identify special positions of single elements within this network. To fulfil the aims of this study a survey of aquaculture operators by way of questionnaire (Appendix II) was undertaken – the questionnaire was designed around four sections each covering a major area of interest. The questions for the inquiry were set in a way that the hatchery operators could report about present as well as about past stocking activities. The particular aims of the four sections of the questionnaire are now illustrated.

### Section I: Pisciculture

It is widely known that rearing conditions of hatcheries affect the survival rates of bred individuals. The introduction of non-native strains, in turn, has a major impact on the genetic integrity of native populations. This section of the inquiry aims to outline the current operating principles of piscicultures regarding qualitative and quantitative aspects. Besides an analysis of the current husbandry conditions in hatcheries, the quantity and heterogeneity of brood stocks within the area of investigation are verified. In this sense the dispersal and abundance of brood stocks containing genetic material of allochthonous origin as well as the preparation for release of brown trout are assessed. Another major aspect of this section is to clarify output figures of the consulted pisciculturists. These figures are widely unknown, even though they play an important role in the understanding of the economical situation of the stocking-market.

Along with these specific questions other more general questions build the general framework of the surveyed piscicultures (also referred to hereafter as aquaculture or hatchery operators).

## Section II: Distributive Trading

Brown trout strains bred in hatcheries get widely distributed by diffused stocking among Austrian streams. Besides the introduction of allochthonous trout, geographical borders (e.g., watersheds, catchment areas) within Austria and therewith associated adaptations of fish to certain regions are not considered when stocking is carried out. Among experts there is talk of genetic pollution of native stocks (Utter 1998 in: Brown and Day 2002; Doyle et al. 2001); in this context, Brown and Day (2002) claim that hatcheries must give careful consideration to the choice of brood stocks.

As indicated, the distribution of hatchery reared trout strains in Austria is widely unknown. To develop sustainable conservation strategies it is necessary to understand the current situation of brown trout trading; a better understanding should be provided with the questions from this section of the survey.

## Section III: Qualitative Criteria

This section covers a diverse field of attitudes and associations of fish farmers. Decision-related aspects of rearing fish such as the current selection criteria for breeding material (e.g., coloration, phenotypical appearance, growth rates) are examined. Another important aspect is to verify preferences of fish farmers for qualitative criteria (i.e., the bio-physical characteristics) of bred trout. Overall, a basic understanding of the driving forces for current management strategies should be established. Furthermore, the attitude of hatchery operators towards fish-conservation related topics as well as the disposition of the interviewees for the adaptation of corresponding production strategies is considered. In this sense the potential for the ecosystemic integration of hatcheries should be clarified.

## Section IV: Network

The final part of the inquiry aims to identify the network of relations within the investigated market sector. In detail, important players that influence the market of brown trout rearing are identified. Therefore, the role of hatchery operators, customers, governmental and non-governmental organisations is analysed. Together with the second section (Distributive Trading), central points of supply and partnerships are described. With regard to reconsidering current management strategies, potential starting points within the network of brown trout farming may be identified. This section also contains qualitative questions dealing with the satisfaction of fish farmers regarding their representation by profession related associations.

# 5. Methodology

To gain the necessary information to meet the aims of the study, an integrated qualitative inquiry (cf. Lamnek 2005) and quantitative survey was carried out between January and June 2007. This approach is based on oral interviews with hatchery operators. According to the project initiative TROUTCHECK, the investigation area primarily focuses on the federal states of Lower Austria and Styria. However, the nationwide influence of brown trout production from hatcheries in the federal state of Upper Austria also required an incorporation of the most influential hatcheries of this federal state. Thus pisciculturists rearing brown trout for stocking purposes from Lower Austria, Styria, and Upper Austria were asked to participate in the study (Figure 1). In general, all three federal states are located in the catchment area of the river Danube. The drainage basins of the Mur in Styria and the Danube in Lower Austria and Upper Austria are situated so far apart from one another that it can be assumed that the brown trout, which colonized Austria along the Danube, show regional differences.

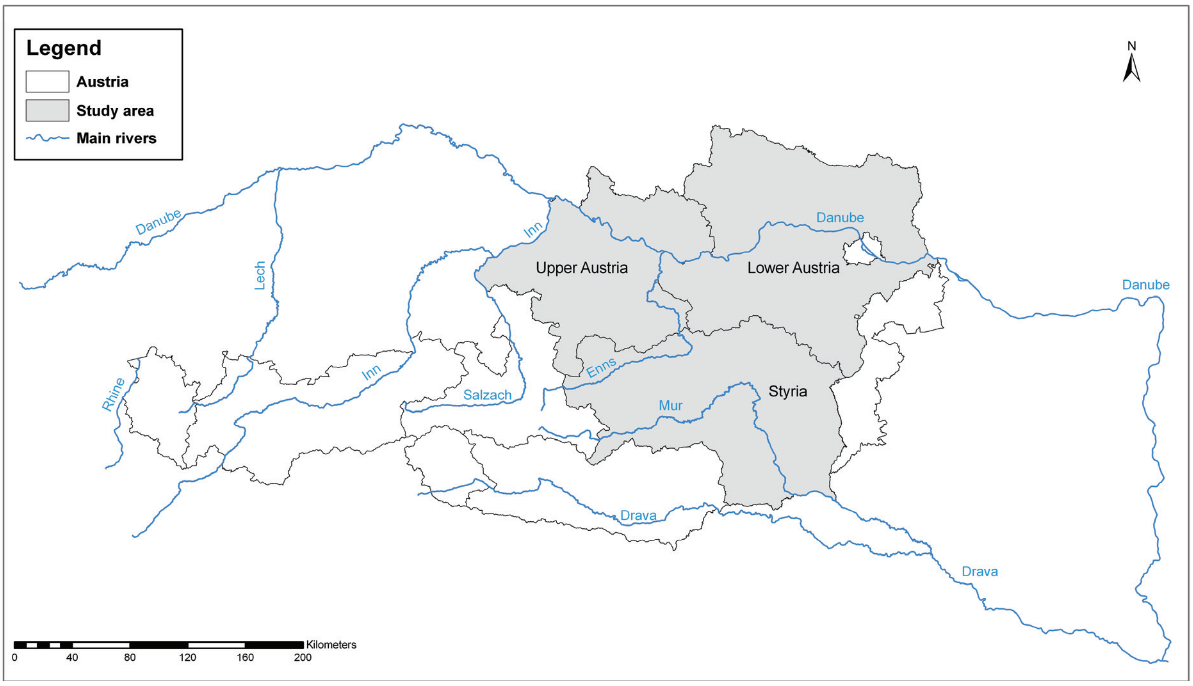


**Figure 1:** An overview of Austria and the federal states where the investigation was carried out. The map also shows a section of the Danube drainage basin and a few of the major tributary systems. Despite the geographical closeness, many rivers (e.g., Enns and Mur) are characterized by divergent drainage basins.

A list of piscicultures in Austria was compiled by means of the website of the "Verband der Österreichischen Forellenzüchter" (VOEF 2007), the "Bezugsquellennachweis" (2007), and by a list of Austrian piscicultures provided by the "Verband der Österreichischen Arbeiter Fischerei Vereine" (VOEAF). On the basis of this list, piscicultures in Lower Austria and

Styria were contacted to ascertain whether brown trout are being reared for stocking purposes. No differentiation was set regarding the scope of production. Piscicultures that are not producing edible trout or those that stock trout solely in ponds are not included in the study. In total 16 hatcheries in Lower Austria and 12 in Styria have been identified which produce *Salmo trutta* that get stocked in streams. The most influential piscicultures in Upper Austria have been identified by consultation with fish farmers from the remaining investigation area (cf. question 30 of the questionnaire).

The inquiry/survey is based upon a non-standardised questionnaire (Atteslander 2006) consisting of four different sections and 31 questions. The questions are open or free-response questions which are not followed by any kind of choice (Oppenheim 2004). In addition to the questionnaire, the interviewees were asked to fill in a nationwide contact list of pisciculturists rearing brown trout (Appendix III) which was prepared by means of the sources mentioned above.

A pilot study was first carried out with the aim to improve the questionnaire design (Oppenheim 2004). Within the scope of this pilot study two pisciculturists were interviewed. Subsequent to these two interviews the questionnaire was revised and finalised. The survey of the pisciculturists from the pilot work was completed by means of the redesigned questionnaire; this also allowed the incorporation of the two piscicultures into the study.

The first approach to the hatchery operators was via phone. In the course of this phone call it was possible to find out whether the surveyed hatchery operator fulfilled the criteria for further involvement in this study. In the case of their acceptance, an appointment was arranged and the interview was carried out at the home of the pisciculturists. The interviews were recorded with a dictating machine and then transcribed. Coding and the analysis of the gathered data were carried out using Microsoft Excel. For the illustration of the networks the online available programme Pajek was used (Pajek 2007). This is a program for the analysis and visualisation of networks. The data obtained from the questionnaire as well as from the contact list has been prepared in an input file which, in succession, is used for the illustration of the network.

The data collected from the interviews will be handled anonymously in this study. Thus the hatchery operators will not be named but are allocated letters for further analysis and demonstration in the results.

# 6. Results

From a total of 28 piscicultures identified in Lower Austria and Styria, 22 were interviewed. In detail, 12 pisciculturists from Lower Austria and 10 hatcheries from Styria participated in the study. One of the six pisciculturists who did not participate in the study refused the interview explicitly. meanwhile the remaining five were either not available or did not to take part due to a lack of time. Additionally, four aquaculturalists were questioned from the federal state of Upper Austria. Accordingly, a total of 26 hatcheries contributed to this survey.

The presentation of the results is oriented to the four sections of the questionnaire. Appendix IV contains a table of all output figures of the particular hatcheries.

## 6.1 Section I: Pisciculture

### 6.1.1 Origin and Regeneration of Broodstocks

The repercussions of genetic divergences between farmed fish and wild populations are a well investigated subject (cf. Chapter 2.3). Accordingly the ample distribution and ongoing input of farmed brown trout into Austrian drainage basins (Weiss and Schmutz 1999, Weiss et al. 2001) raises two essential questions. On the one hand, the origin of the broostocks, that is to say, the genetic composition of these stocks constitutes a vital question. On the other hand, the question concerning genetic adaptations to the rearing conditions (i.e., domestication), due to ongoing regeneration of the broodstocks and therewith related intentional and unintentional selection, arises.

It now appears that among the surveyed fish farms 21 firms hold brown trout as broodstock (Figure 2). With the exception of one hatchery in Lower Austria (L in Figure 2) all of these hatcheries use their broodstocks for spawning, hence for the production of brown trout. Those fish farmers who do not keep a broodstock purchase brown trout eggs or hatched trout from other aquaculture operations.

With regard to the origin of the 21 stocks all pisciculturists declared that their stock contain domestic material originating from regional streams (Figure 2). Fourteen pisciculturists stated that their broodstocks also include fish from Denmark (B, H, I, K, L, T, U, V, W, and Y, and

Z). Three farmers (M, P, and R) additionally imported brown trout from further European countries to supplement their stocks.

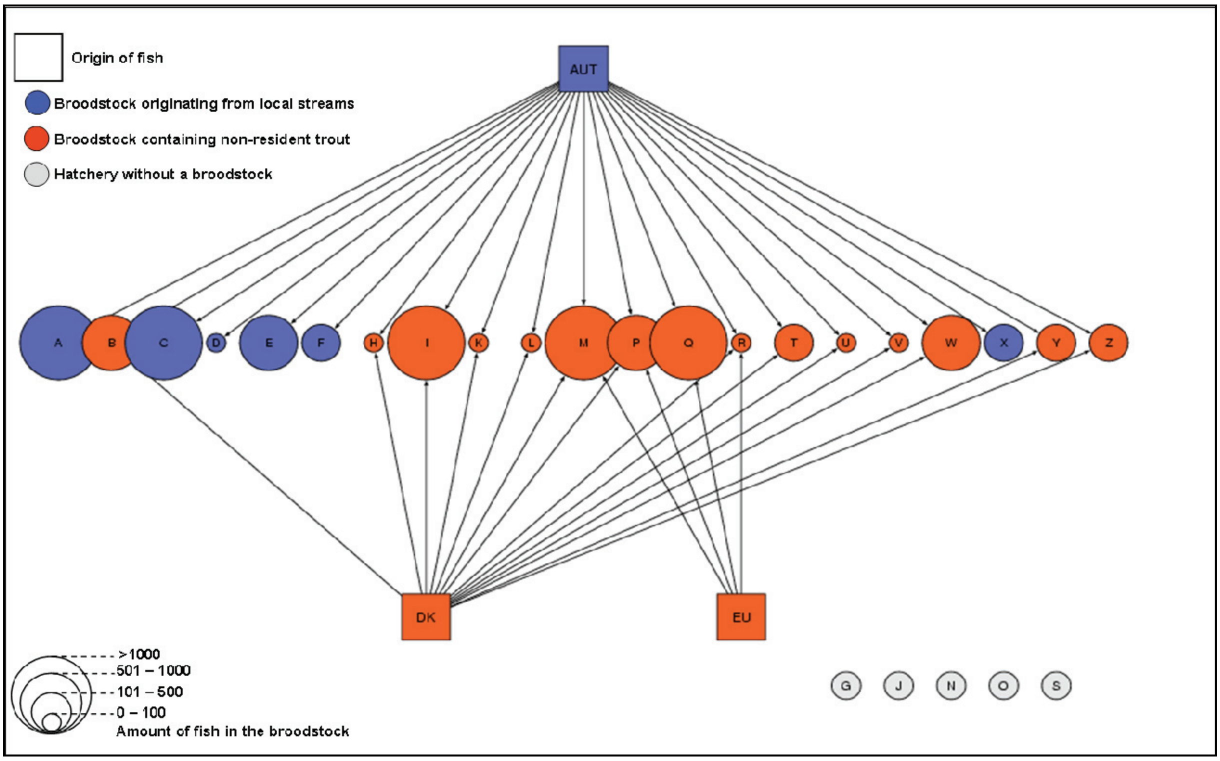


**Figure 2:** Composition of the broodstocks; AUT= Austria, DK= Denmark, EU= Further European countries

Two pisciculturists (B and Z) stated that their broodstocks initially consisted exclusively of Danish material but have lately been replenished by wild fish from regional streams. Six hatcheries (A, C, D, E, F, and X) breed stocks consisting of fish which exclusively originate from regional streams. Admittedly, since stocking has been carried out over decades, it can not be excluded that the domestic judged stocks comprise a mixture of resident and non-resident brown trout strains.

Broodstocks including genetic material of non-resident origin are seemingly widely distributed. Altogether the ratio of broodstocks deriving from Austrian streams and admixed broodstocks is 6:15. In terms of output figures this implies that almost 70 % of the produced eggs originate from broodstocks containing non-resident strains.

Reconsidering the origin of the broodstocks from another perspective, it appears that several stocks are partly or even completely identical. In detail, the broodstocks of eight fish farms (K, R, Y, T, U, L, Z, and P in Figure 3) have been built up with brown trout from other hatcheries. Four broodstocks (T, U, L, and Z) derive from a single source whereby three (T, U, and L) are supplemented with their own breed. Accordingly these stocks are still identical with those of their origin. Other broodstocks have been built up from multiple sources (K, R, Y, and P) whereat combinations of different hatcheries and brown trout from Austrian streams and external sources exist.

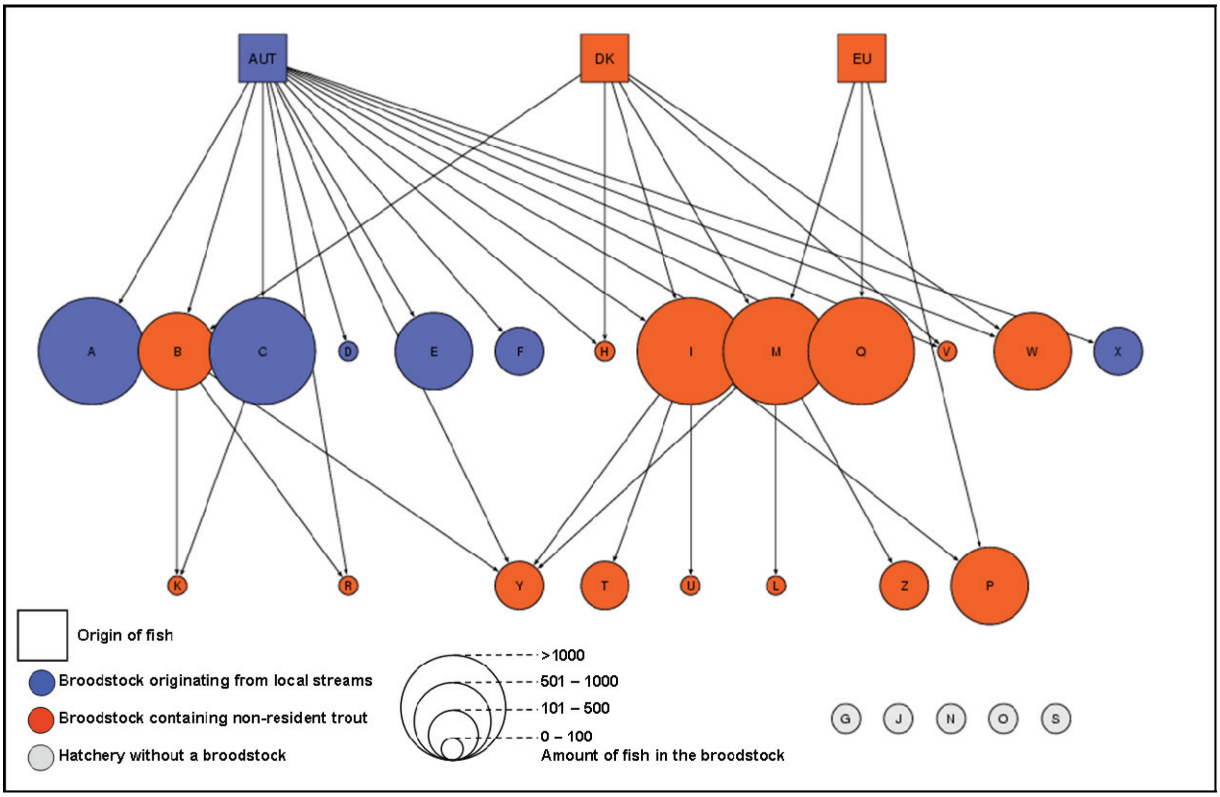


**Figure 3:** Origin of the broodstocks and distribution between the fish farms; AUT= Austria, DK= Denmark, EU= Further European countries

A few hatchery strains are widely distributed across aquaculture operations of several federal states (Figure 4). The broodstock of hatchery "I", for example, shows a wide spatial extent within the whole study area. Another three hatcheries ("B", "C", "M") distributed their genetic material across the three federal states where the investigation was carried out. An expansion of the stocks throughout Austria (i.e., beyond the investigated area) is likely but was not a part of the investigation. Therefore it appears that due to the widespread distribution of particular strains among several aquaculture operations, the genetic variability of all broodstocks is to some degree simplified. Accompanied by this spatial extent is, ultimately, the distribution of these "homogenous" strains across several drainage areas where the breed gets stocked.

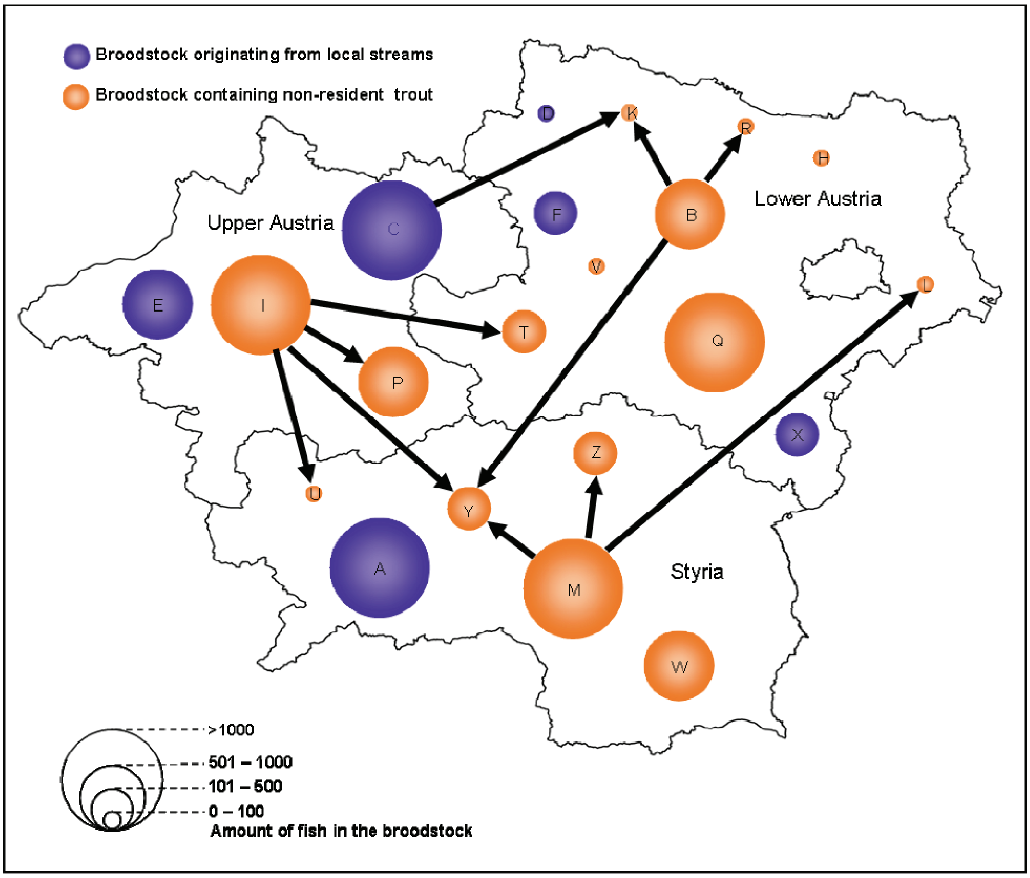


**Figure 4:** Distribution of broodstocks related to the federal states; the illustration of broodstocks within a federal state is randomized.

As already mentioned, the genetic constitution of the stocks is also dependent on the broodstock supplementation. Overall, 17 hatcheries artificially supplement their broodstocks with mature brown trout. Three of the remaining four hatcheries do not need to artificially renew their wild living broodstocks due to natural reproduction (i.e., natural regeneration). One hatchery is rearing a new broodstock which has not yet needed replenishment.

Regeneration of the stocks is carried out using five different methods (Figure 5).The most frequently practiced way is to use their own breeding. Fourteen hatcheries fall back on their own breed whereby three of them additionally introduce bought or wild fish; two piscicultures solely use bought fish; one hatchery replenishes with wild trout (Figure 5). When the duration since the broodstocks are already reared is considered, it becomes evident that six hatcheries, which replenish their broodstocks solely by their own breeding, have kept their stocks for more than 30 years (Figure 5). These hatcheries cover about 75 % of the annually produced brown trout eggs within the study area. Proceeding on the perception that domestication and the related genetic response already appear after a few generations of artificial rearing (Fleming and Einum 1997), it can be assumed that especially those broodstocks which are replenished with their own breeding show significant signs of domestication. After all, Reisenbichler and Rubin (1999) emphasise that hatchery programs rearing fish for one year or longer genetically change the initial population. In fact, along with the intentional and unintentional artificial selection by humans, genetic alterations appear due to adaptations to the rearing environments. (cf. Chapter 2.3). On top of that, multi-generation hatchery stocks differ even more from wild fish than first-generation stocks (Einum and Fleming 2001). The specific criteria, on which the selection for regeneration is based on, are discussed in Chapter 6.3.

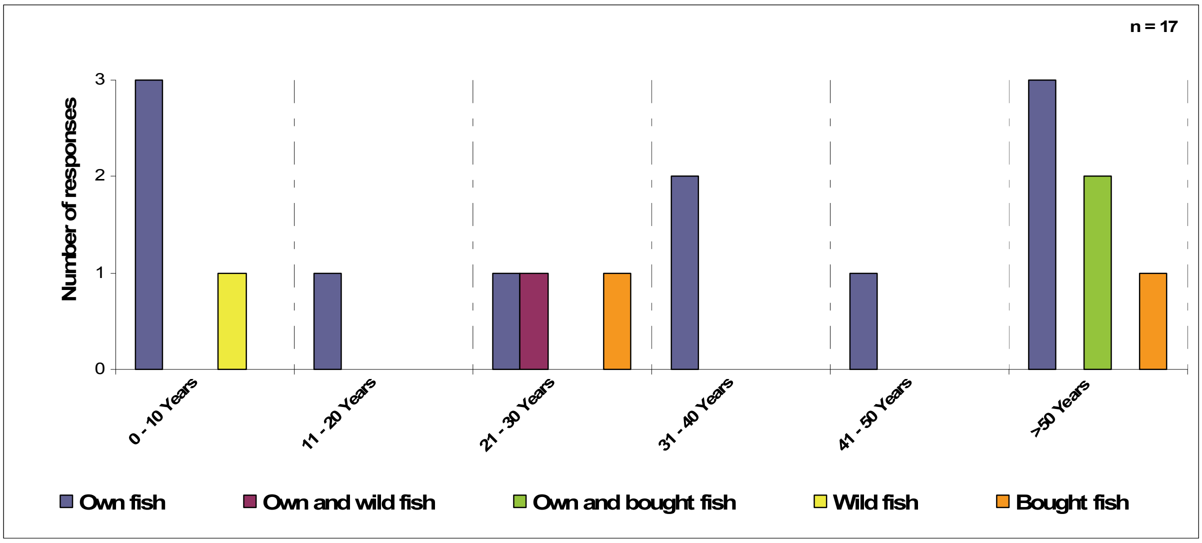


**Figure 5:** Broodstock supplementation in relation to the duration since the broodstock was first started

### 6.1.2 Husbandry Conditions

Scientific findings revealed that the rearing environments of fish play a significant role in the development of behavioural as well as physiological patterns (Chapter 2.3.1). Moreover, it has been ascertained that in the long run the rearing environments are reflected in genetic adaptations. Since the rearing environments are crucial for the development of the fish it was important to gain an impression about what kind of environments the broodstocks become adapted to and how the brown trout are reared before they are released into the streams.

With regard to the rearing conditions of the broodstocks the study showed that the majority of the stocks are reared in typical ponds or raceways within the aquaculture operation. Two of the questioned pisciculturists (A and Q) exclusively use wild living brown trout for reproduction. Parent fish of those two hatcheries are annually caught and re-released into the particular streams after artificial spawning. However, the ponds or raceways where the other broodstocks are reared resemble those of the brood and will be specified below. In the context of the husbandry conditions of the brood, it should be mentioned that almost all aquaculture operators rear the trout for stocking purposes up to the adult stage; only two fish farmers solely produce trout which get stocked before the adult stage is reached (Figure 6).

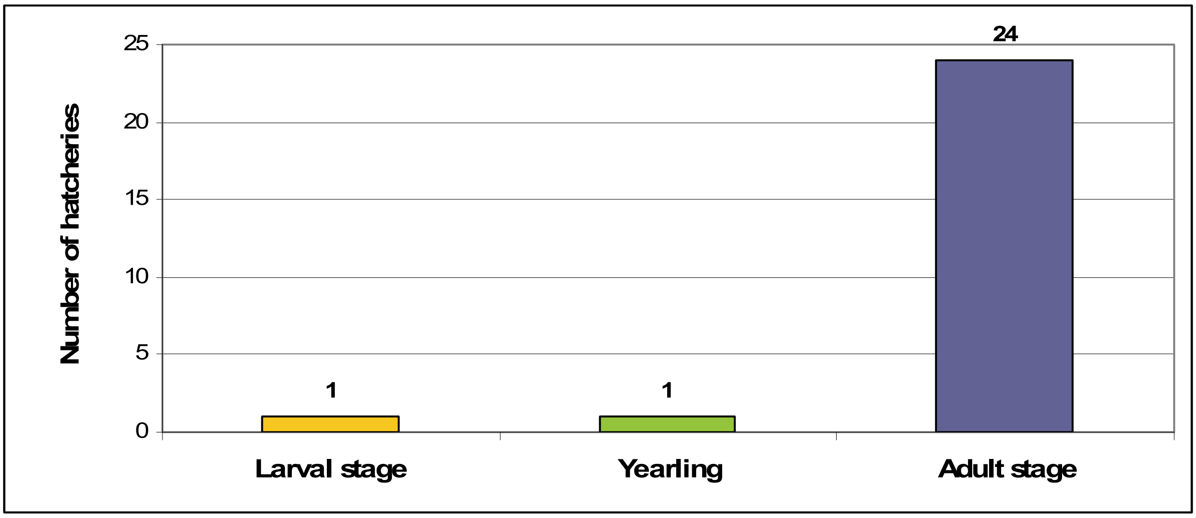


**Figure 6:** Production of varying age-classes of brown trout for stocking purposes; Aquaculture operators rearing up to adult-stage partly stock juvenile trout as well (n= 26)

The period of time in which fish are reared in the hatchery environment until they reach the adult stage lasts at least two and a half years. Even if several hatcheries sell yearlings (juveniles) for stocking, most fish stocking occurs in the adult stage (Figure 7). As an exception, one pisciculturist already releases its brown trout during the larval stage, after the yolk sac has been absorbed (cf. Figure 6).

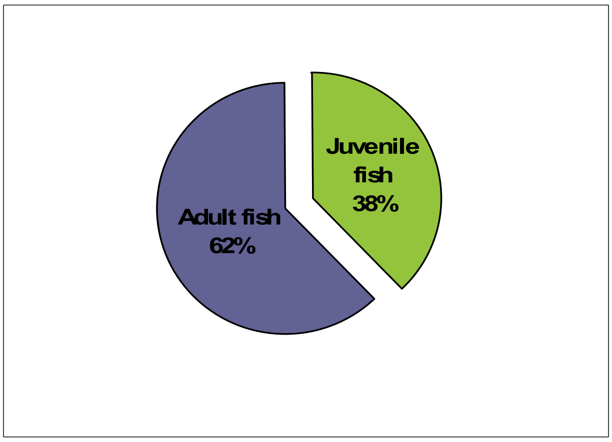


**Figure 7:** Percentage of brown trout (individuals) stocked at the different age-classes

Considering the husbandry conditions of the bred fish, three stages of life and therewith related rearing environments can be distinguished. The first stage refers to the fertilised eggs - which are solely reared in typical incubation systems (e.g., Zuger jar system, vertical incubators) – and additionally encompasses the alevins stage (yolk-sac-fry) where the fish are kept in either round tanks or other plastic vessels. For the brown trout fry (second stage, after the yolk-sac has been absorbed) the hatchery operators admitted to using elongated plastic tanks or round tanks. These vessels and the incubation systems are indoor located whereby feeding of the fish is either carried out by humans or automatic feeding systems.

After a couple of months, when the fish outgrow the fry stage, the majority of the pisciculturists continue rearing in ponds and / or raceways (Figure 8). These environments can be characterized by slow flow velocities and earthy bottoms (Figure 9). According to a few fish farmers some ponds or raceways feature adequate flow velocities which are higher than the average flow velocities of such rearing environments. Another exception from the usually earthy ponds is made by one pisciculturist who equipped the ponds with gravel substrate. However, the majority of the ponds and raceways appear as described above.

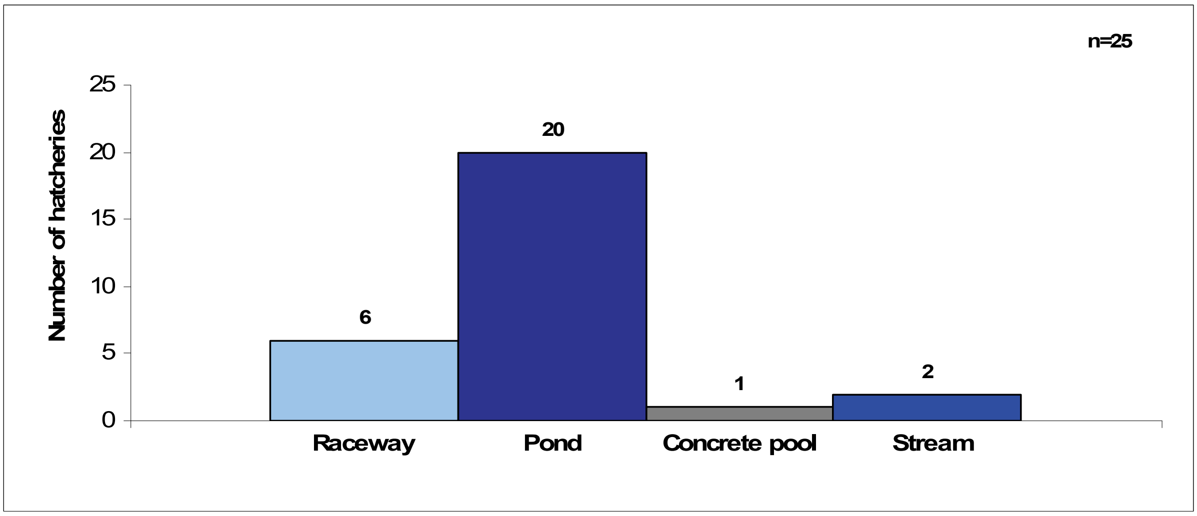


**Figure 8:** Rearing environments for fish that outgrew the smolt stage (n=26)

In some cases the ponds or raceways are shadowed by natural cover (i.e., trees, bank vegetation). Feeding of the fish is done with automatic feeding systems or by the fish farmers, using pelleted feeds. The period of time the fish are reared in these environments depends on when they get finally stocked in a stream. A few pisciculturists reported rearing their fish for up to three years. As an exception, during this third stage of life, two hatcheries rear most of their fish in natural stream environments; in addition a small proportion of brown trout are also reared in raceways or ponds. The breeding of those two hatcheries derives from fish living in the streams.

**Figure 9:** Rearing ponds; (Photo: Markus Payr)

With regard to the stocking figures of all aquaculture operations roughly 80 % of the annually stocked trout are reared in ponds or raceways. Approximately 20 % of the bred brown trout grow in natural streams (Table 2). However, the exact figures about the distribution of trout in the breeding-streams and other rearing environments (ponds, raceways) of the two mentioned hatcheries have not been determined. The presented figures are based on the assumption that all fish are reared in the streams and therefore overestimate the real facts.

**Table 2:** Stocking figures in relation to the husbandry conditions; (n= 25)

| **Rearing environment** | **Individuals** (rounded figures) | **Percentage [%]** |
|---|---|---|
| Concrete pool | 1.500 | 0,1 |
| Pond / Raceway | 1.400.000 | 79,9 |
| Stream | 350.000 | 20,0 |
| **Total** | **1.751.500** | **100** |

Finally, most of the hatcheries (23 out of 26) produce both edible fish as well as fish for stocking. Differences in the rearing environments are not made in the majority of the cases. Only four hatcheries grow fish for consumption in different environments than the trout for stocking.

### 6.1.3 Output Figures

Twenty out of 26 hatcheries operate an incubation unit; hence they incubate brown trout eggs (Table 3). Six hatcheries abandoned artificial spawning and therefore buy brown trout eggs and grown up brown trout (subadult- / adult trout) or both from other hatcheries. In total approximately 9.3 million eggs are annually produced by the interviewed piscicultures. The majority of these eggs (69 %) are bred in hatcheries of the federal state Upper Austria, followed by Styria (21%) and Lower Austria (10%).

**Table 3:** Production of eggs per federal state

| Federal state | No. of interviewed hatcheries | Hatcheries operating incubation units | No. of produced eggs | Percentage [%] |
|---|---|---|---|---|
| Lower Austria | 12 | 10 | 904.000 | 10 |
| Styria | 10 | 6 | 1.960.000 | 21 |
| Upper Austria | 4 | 4 | 6.500.000 | 69 |
| **Total** | **26** | **20** | **9.364.000** | **100** |

The scope of egg production ranges from 4.000 to 4.000.000 eggs per aquaculture operation (Figure 10). Comparing the egg production of the investigated federal states, it becomes apparent that the Lower Austrian market is smaller structured than the Styrian. Ten hatcheries in Lower Austria hatch around 900.000 eggs whereby 8 of these hatcheries produce less than 90.000 eggs each (Table 3, Figure 10). In Styria, however, almost 2 million eggs are produced by six hatcheries.

The four surveyed fish farms in Upper Austria have double the amount of the production of both Lower Austrian and Styrian farms together. That is to say that the Upper Austrian hatcheries play a particularly important role in the market. Reconsidering the constitution of the Upper Austrian broodstocks it is obvious that the majority of the reared trout derive from stocks which have been reared over multiple generations. The broodstocks of the Upper Austrian fish farms are primarily regenerated by their own breeding, whereby at three hatcheries it is known that the stocks have been reared for a minimum of 40 years. Additional input of brown trout from other hatcheries or streams presents a rare exception when it comes to the regeneration of these stocks.

Considering the production of brown trout eggs in relation to their origin, it turns out that more than 80 % of the total amount of produced eggs derives from five broodstocks. Overall, these stocks partly share brown trout of the same origin. Hence, the genetic diversity of the majority of the produced eggs is limited and is controlled by a few broodstocks.

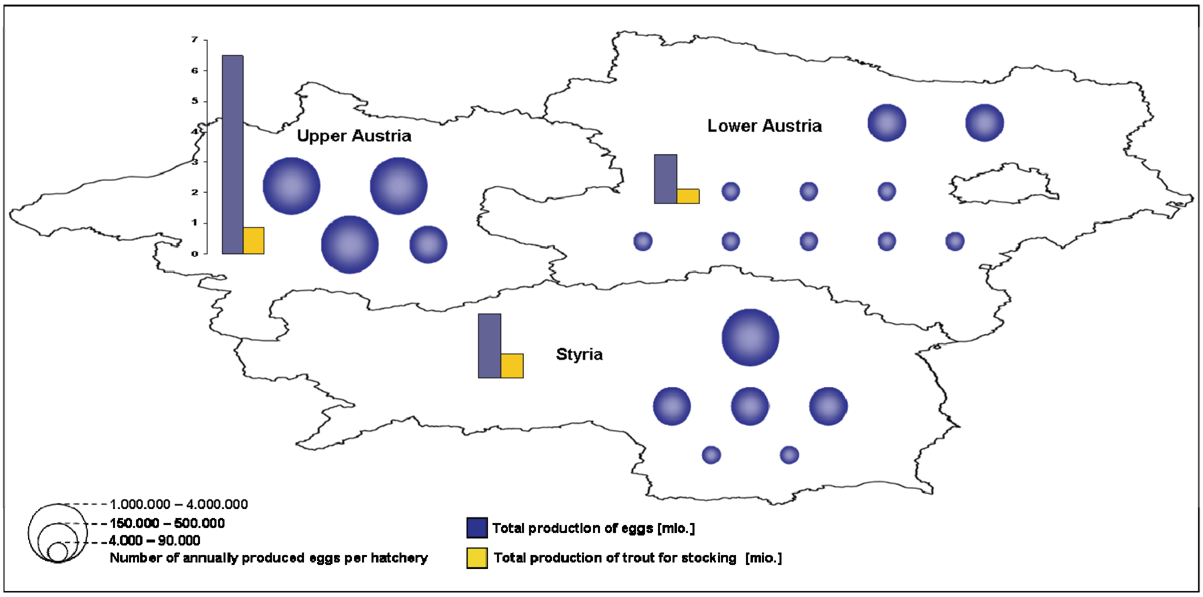


**Figure 10:** Hatcheries incubating brown trout eggs divided into three groups of production volumes - the bar graph shows the relation of annual produced eggs per federal state to the scope of annually stocked trout [individuals in millions.]

The rearing environments of the broodstocks can be distinguished between wild living and domesticated broodstocks (cf. Chapter 6.1.1). Volumes of production by those fish farms that solely fall back on wild living trout correspond roughly to 11 % of the total egg production (Figure 11). Another three aquaculture operations use both wild living fish as well as artificial reared brown trout for spawning. The sum of produced fish by those three hatcheries makes up a small part of the total production which comes to 4 %. Accordingly, approximately 85 % of the annually produced brown trout eggs derive from parent fish which are reared in broodstock ponds or raceways. On closer examination of these rearing environments, it is possible to see that they deviate in many aspects from natural rearing environments (cf. Chapter 6.1.2).

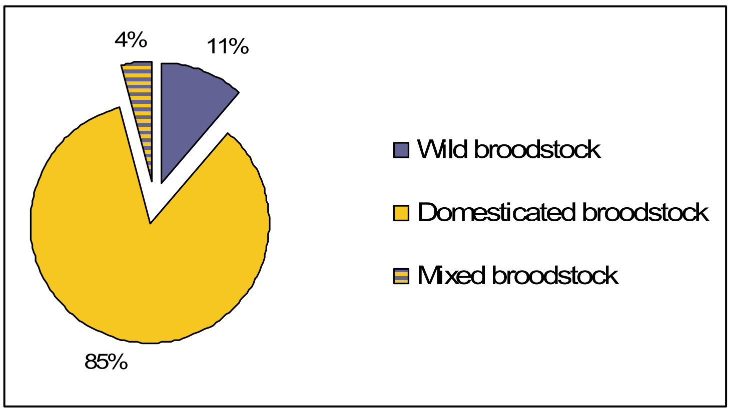


**Figure 11:** Origin of the incubated eggs

The total amount of produced eggs does not indicate how many fish are produced and sold for stocking purposes. Many hatcheries sell fertilised eggs or already hatched trout to further hatcheries which are, among others, beyond the study area. Furthermore, a certain proportion of the hatched eggs contribute to the production of edible fish. After all, 23 of the questioned hatcheries produce both fish for consumption and fish for stocking; only three fish farmers produce *Salmo trutta* solely for stocking purposes. In the course of determining the amount of fish sold for stocking all but one Styrian pisciculturist agreed to declare their scale of production.

In summary, the production comes to approximately 1.8 million stocked brown trout. The particular volume of production per hatchery ranges from 1.500 to 400.000 fish. In contrast to the output of brown trout eggs, the comparison between the federal states turns out to be more balanced. In particular, Upper Austria and Styria produce a similar percentage of trout for stocking (Table 4); Lower Austria bears the smallest amount which comes to 12 %. As measured by the volume of produced eggs it can be seen that a huge amount (81 %) of the initially bred eggs are either sold to other hatcheries or go into the production of edible fish (cf. Figure 10).

**Table 4:** Sale of brown trout for stocking purposes

| **Federal state** | **No. of interviewed hatcheries** | **Hatcheries declaring volumes of production** | **No. of produced trout** (rounded figures) | **Percentage [%]** (rounded figures) |
|---|---|---|---|---|
| Lower Austria | 12 | 12 | 227.000 | 12 |
| Styria | 10 | 9 | 734.000 | 40 |
| Upper Austria | 4 | 4 | 860.000 | 47 |
| **Total** | **26** | **25** | **1.821.000** | **100** |

The production of those two hatcheries which use wild living trout for reproduction constitutes approximately 18 % of all brown trout that are sold for stocking (Figure 12). Incorporating the fish farms which breed brown trout of a mixed origin (i.e., wild and domesticated) the output figures come to 26 % of the total production. Viewing the production of stocked trout from a different perspective, it appears that the majority of the stocked trout (68 %) originates from three different broodstocks. The remaining brown trout (32 %) branch out to the other 17 broodstocks which are currently used for spawning.

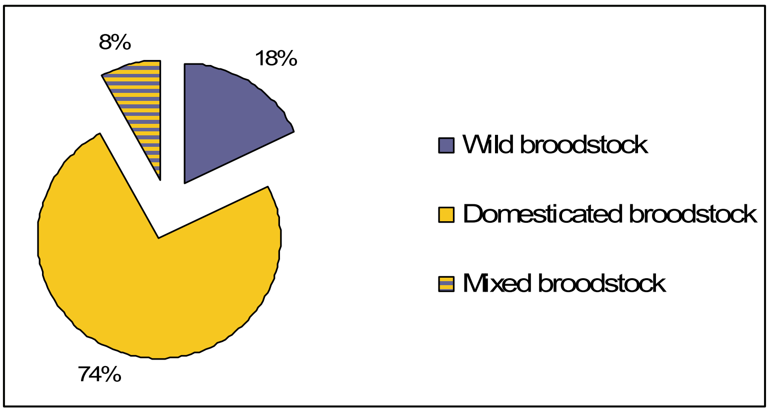


**Figure 12:** Origin of the stocked trout

Calculating the scale of produced brown trout in tons, approximately 187 tons are annually stocked. These output figures clearly deviate from those of STATISTIC AUSTRIA which presents an annual estimation of the production volumes throughout Austria. According to this governmental information system the annual production of the past years increased from 135 tons in 2004 to 154 tons in 2006. According to the gathered data the output figures of the interviewed hatcheries exceed those of STATISTIC AUSTRIA, even though the inquiry covers only a small part of the whole production in Austria.

As already mentioned, the period of time brown trout are reared in the hatcheries varies and these periods are customized. A differentiation of juvenile fish (≤ 150 g) and adult fish (≥ 300 g) implies that the majority of the hatcheries (24 firms) rear their trout through to the adult stage (Table 5). Nine of the piscicultures also produce juvenile fish for stocking; two hatcheries solely produce juvenile brown trout.

Not all pisciculturists revealed their scale of production or how much fish are stocked at the different stages of life. However, a comparison of the different stocked age classes, for those hatcheries which made precise declarations about production volumes, is possible. Accordingly, 62 % of the fish are reared through to the adult stage and 38 % are raised until the juvenile stage is reached (Table 6, Figure 7). Therefore, almost twice as much fish are stocked as adults than as juveniles.

**Table 5:** Period of time brown trout are reared in the farms; Juvenile fish correspond to a fish weight of ≤ 150 g; Adult fish correspond to a weight of ≥ 300 g (n=26)

| Period of time | Age class | Number of hatcheries |
|---|---|---|
| ≤ 1 year | Juvenile fish | 2 |
| ≥ 2 years | Adult fish | 15 |
| ≤ 1 year, ≥ 2 years | Juvenile- and adult fish | 9 |

**Table 6:** Summarized output figures of annually stocked brown trout (n=23)

| **Age class** | **Individuals** (rounded figures) | **Percentage [%]** |
|---|---|---|
| Juvenile fish | 496.000 | 38 |
| Adult fish | 819.000 | 62 |
| **Total** | **1.315.000** | **100** |

## 6.2 Section II: Distributive Trading

### 6.2.1 Commercial Relationships between Aquaculture operations

In Austria brown trout are artificially reared for either consumption or for stocking purposes. Regardless of the final purpose bred fish may pass through several stations (i.e., fish farms) before they get stocked in a stream or processed for consumption. The significant differences between the volume of produced eggs on the one hand and the number of produced trout for stocking on the other hand (cf. Chapter 6.1.3) demonstrate the central role that the trading of brown trout plays for Austrian fish farms. Related to trading activities is of course the translocation of brown trout strains to various regions and catchment areas. With regard to geographical variations, the trading of brown trout between hatcheries can be seen as the preliminary stage of the introgression of non-local strains, not least because the drainage basins of the investigated area are quite different (cf. Chapter 5.). Next to the distribution of stocks by trading, the spatial extent of stocking measures constitutes its own issues which will be discussed in Chapter 6.2.2.

The commercial relationships between the surveyed hatcheries show that many are trading brown trout (eggs) with other firms or hobby breeders respectively. In total 17 out of 26 fish farmers sell either brown trout eggs or brown trout to further piscicultures. By contrast, half of all surveyed fish farmers declared they purchased fish eggs or fish from another producer. Only four fish farmers do not either purchase or sell at other aquaculture operations. A general view of the market structures can be made by means of the sold brown trout eggs (Table 7). Accordingly, 10 out of 20 fish farms which incubate brown trout eggs put up eggs for sale. All but one fish farmer from Styria declared the amount of sold brown trout eggs. To obtain a complete impression of the sales figures the scale of sold eggs of this farmer has been estimated by means of the total amount of incubated eggs and buying transactions of his clients.

In total 39 % of all fertilised brown trout eggs are sold to further hatcheries. The remaining eggs stay in the fish farms for continuing rearing. Upper Austrian hatcheries, which are by far the biggest producers of eggs, clearly dominate the sale of eggs (85 %). After all, almost half of all produced eggs in Upper Austria end up being sold. In comparison the federal states Lower Austria and Styria play a minor role. In comparison, hatcheries in these two federal states purchase eggs from Upper Austrian enterprises.

**Table 7:** Relation of produced and traded brown trout eggs per federal state

| Federal State | No. of Hatcheries producing eggs | Total egg production | Percentage of total production [%] | No. of hatcheries selling eggs | Amount of sold eggs | Percentage of total production [%] |
|---|---|---|---|---|---|---|
| Lower Austria | 10 | 904.000 | 9 | 4 | 315.000 | 35 |
| Styria | 6 | 1.960.000 | 6 | 3 | 230.000 | 12 |
| Upper Austria | 4 | 6.500.000 | 85 | 3 | 3.100.000 | 48 |
| **Total** | **20** | **9.364.000** | **100** | **10** | **3.645.000** | **39** |

The commercial relationships of those piscicultures trading with other farms are illustrated in Figure 13; clarifying the relevancy of trading brown trout among aquaculture operations. It reveals that particularly between the federal states Upper Austria and Styria active trading is carried out. Correlating with the sales figures of Table 7, Upper Austria constitutes the starting point for the trading activities. Taking a closer look at those two federal states three major nodal points (I, M, and O) for trading with brown trout eggs, fry or mature fish can be recognized. Those three fish farms have different strategies. Whilst hatchery "I" as the biggest producer of brown trout eggs solely trades their own fertilised eggs, hatchery "M" acts as an intermediary additionally purchasing and selling brown trout eggs from another (foreign) aquaculture operation. Finally, hatchery "O" does not produce its own brown trout and solely runs an intermediate trade of trout which have primarily been purchased from aquaculture "I".

Trading of brown trout in Lower Austria is not as highly rated as within Styria and Upper Austria (Figure 13). Apparently, only one aquaculture operation which has not been surveyed appears to play an important role at the distribution. However, the following conclusions describing the trade connections can be drawn. Commercial relations among fish farmers strongly contribute to the distribution of hatchery strains whereby a few (big) aquaculture operations stand out due to their widespread connections. Furthermore, the distribution of certain hatchery strains is encouraged by intermediaries. In other words, due to the widespread trading relationships of individual fish farmers and the role of intermediaries of other pisciculturists, certain hatchery strains undergo an extensive distribution across the investigated area.

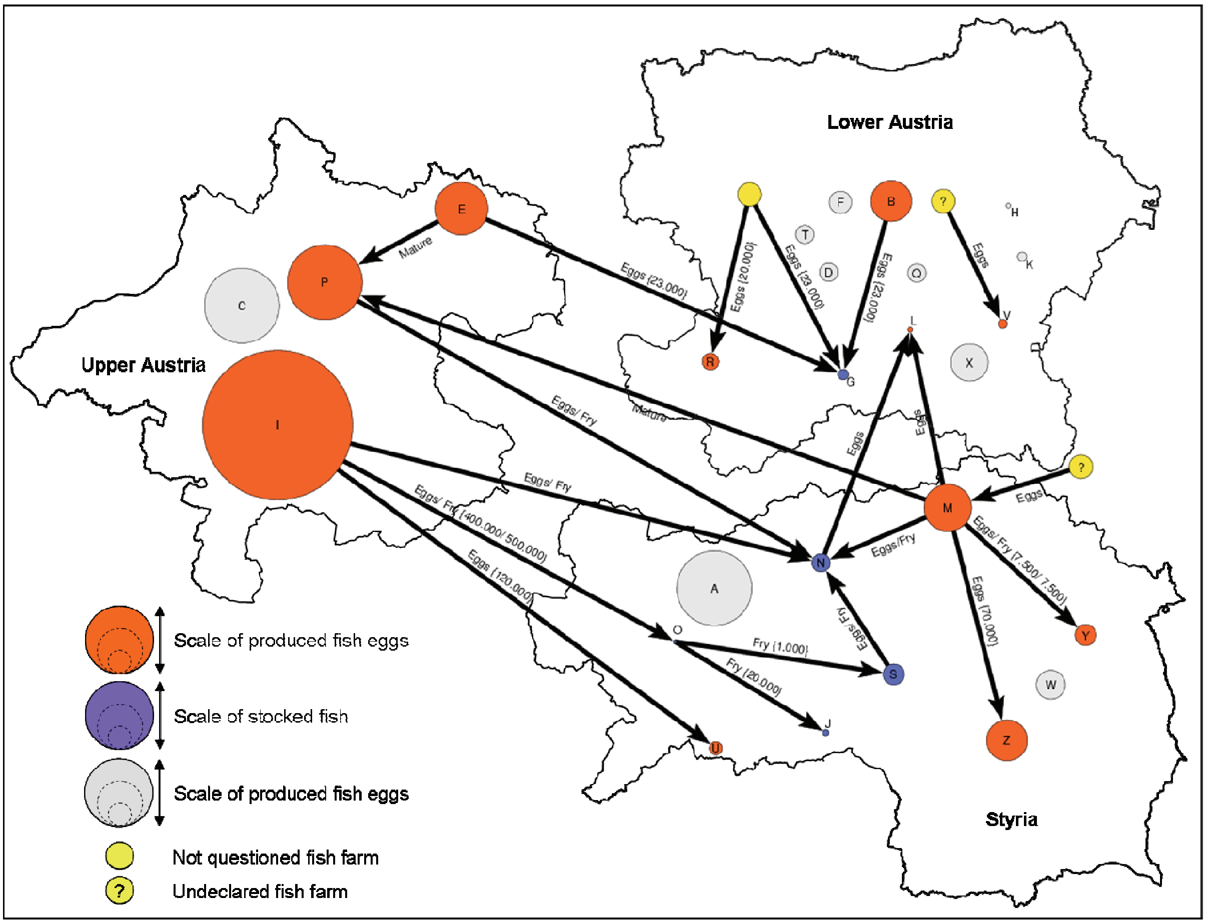


**Figure 13:** Commercial relations of fish farms within the investigated area; The illustration is based on the question where the fish farmers purchased brown trout (eggs) from; The trading figures have been added to the figure when they have been mentioned at the interview; The illustration of the locations of the hatcheries within a federal state is randomized

Figure 13 primarily shows the network of trade connections among the surveyed fish farmers. Trading relationships of fish farmers with large production volumes though, exceed the investigated area. Pisciculturist “I”, for example, declared to produce four million brown trout eggs per year, whereby two million eggs are sold to further aquaculture operators. In fact, only a small amount of these two million eggs are sold to fish farmers who participated in this study (cf. Figure 13). The full range of aquaculture operations which are provided with eggs and incubated brown trout by pisciculturist “I” is significantly larger. In total 34 fish farms among five federal states are supplied with brown trout from this hatchery (Figure 14). According to this data it appears that even two of the interviewed fish farms in Lower Austria (F and T) obtain brown trout (eggs) from pisciculturist “I”.

However, the fact that commercial relationships of a few aquaculture operators are quite extensive emphasises the wide distribution of some hatchery strains. Reconsidering the constitution of the broodstocks of interviewed fish farmers, it shows that especially those piscicultures which contributed to the generation of broodstocks additionally distribute their brown trout by trading.

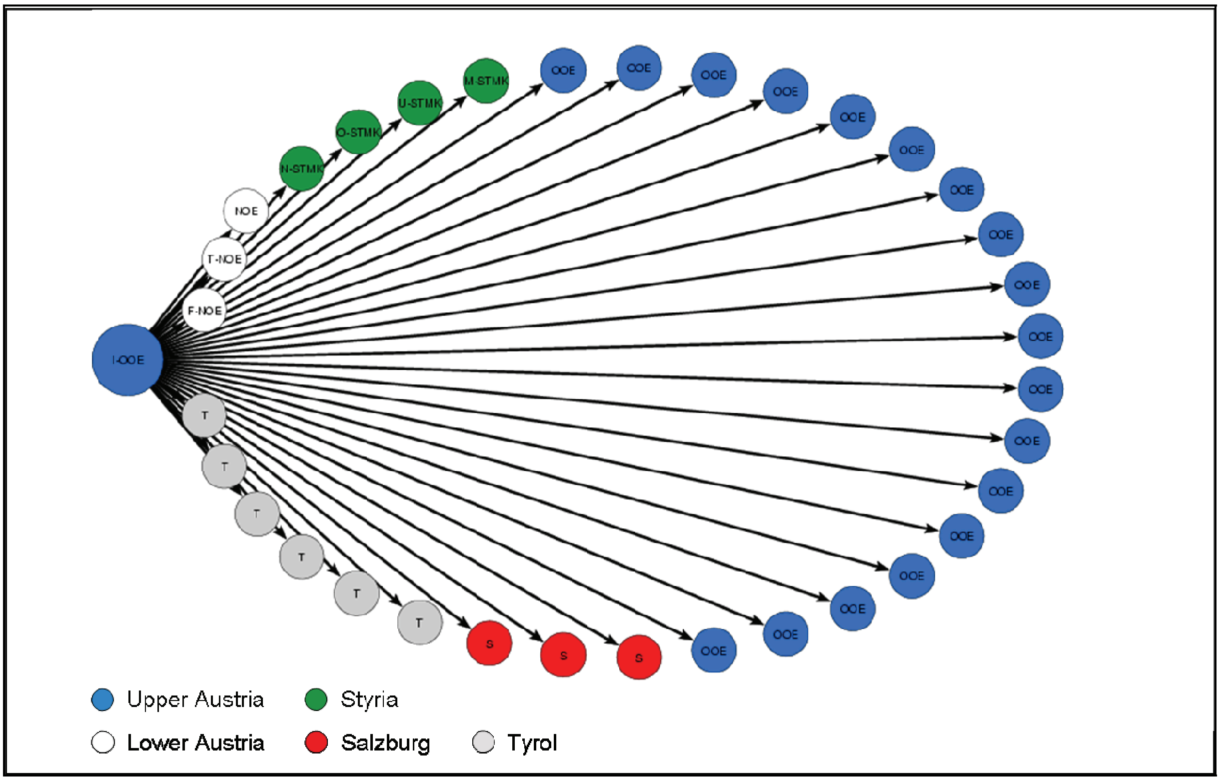


**Figure 14:** Austrian fish farms of different federal states purchasing brown trout (eggs) from aquaculture „I"

### 6.2.2 Stocking Brown Trout in Austrian Rivers

Commercial relationships of fish farmers expressed in the form of broodstock distribution as well as the sale of brown trout (eggs) among fish farmers reveil a diverse distribution of brown trout strains among the operators. Sale of fish to customers for stocking purposes ultimately constitutes the crucial factor for the distribution of hatchery strains in the rivers of Austria. Since the addressed commercial relationships have already been identified, the spatial extent of stocking activities by the particular hatcheries needs to be considered.

Generally speaking, stocking is either commissioned or carried out by clients of fish farms such as fishing associations or private persons. With regard to both, but especially in the case of fishing associations, it is common that several reaches of different rivers and tributaries are managed. The number of rivers and therein managed reaches depends on the association and may vary between one and a variety of rivers. For instance, one of the biggest fishing associations in Austria, the Austrian Fishing Association (OEFG), manages sections of approximately 20 rivers where at each river several sections are held. The lengths of the particular sections vary greatly, encompassing dimensions of a few hundred meters to a few kilometres. That is to say that a river in Austria is usually separated into a series of sections, managed by several fishing associations or private persons. Consequently, brown trout hatchery strains from different fish farms are introduced into the same river. For the determination of the spatial coverage of stocking by the particular hatcheries, a restriction of the stocking activities to the stocked sections would be unrewarding. Furthermore, a determination would not be possible by interviewing pisciculturists. Therefore the fish farmers were asked to specify which rivers have already been stocked with their fish.

The wide-ranging stocking activities of aquaculture operations are presented by means of three major fish farms (one of each investigated federal state). Since these fish farms provide other hatcheries with brown trout, a network including further enterprises can be illustrated.

Aquaculture “B” – Lower Austria

Aquaculture “B” is located in the federal state Lower Austria. Figure 15 shows that this fish farm is rearing a broodstock consisting of fish from both Austrian streams as well as from Denmark. In total 14 fishing associations are provided with brown trout from this company. Those associations manage reaches in 40 different rivers and tributaries. In addition to these associations fish farmer “B” is trading brown trout with 14 other hatcheries. Eleven of these hatcheries have not been surveyed. The remaining three hatcheries either buy brown trout at “B” or rear a broodstock containing brown trout from “B”. With the exception of those hatcheries which have not been surveyed the rivers where the fish have already been stocked are known and are also illustrated in Figure 15.

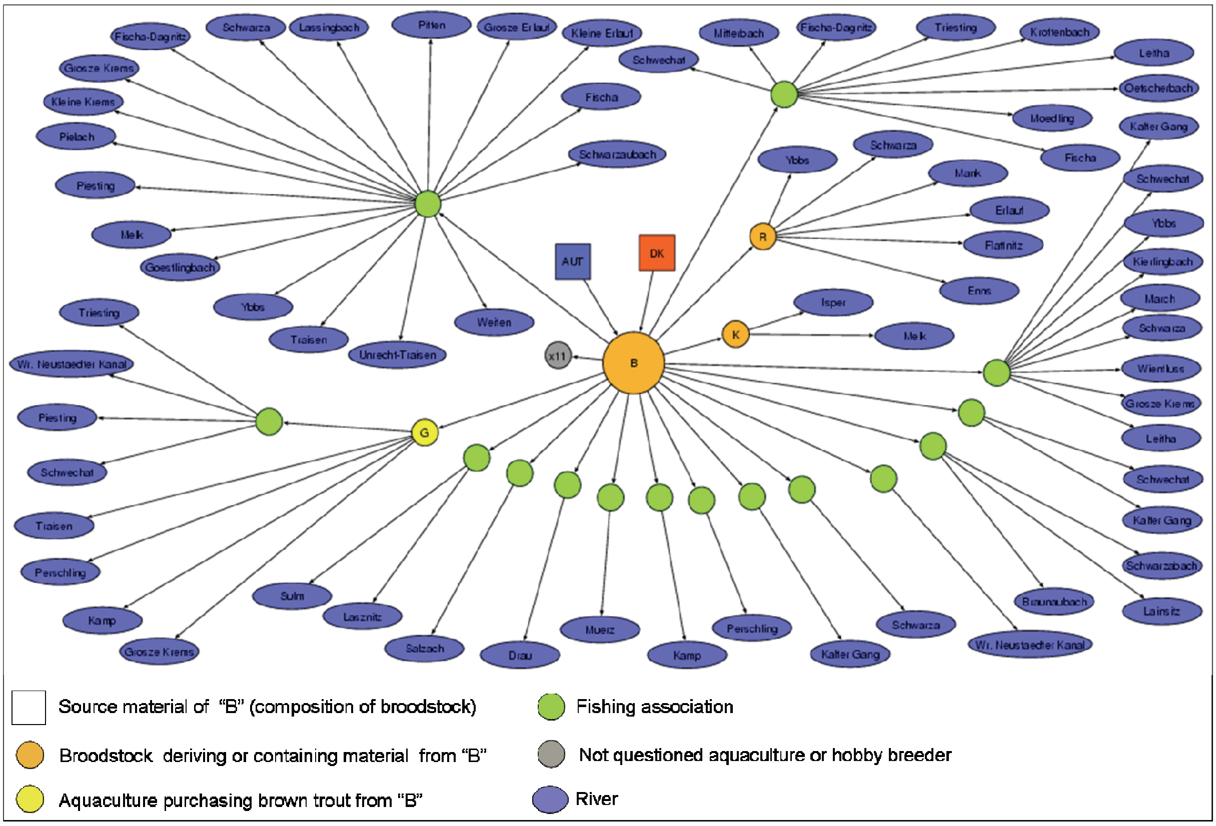


**Figure 15:** Origin and distribution of brown trout from the Lower Austrian hatchery "B"; The illustration describes present and past sale of fish to either fish farms or fishing associations; AUT= Austria, DK= Denmark

In summary, breeding of the broodstock "B", which originally consisted of solely Danish material, has been sold to 29 institutions which stock fish in about 45 Austrian rivers, distributed over at least four different federal states (Lower Austria, Styria, Carinthia, Salzburg). Some of the above mentioned fishing associations or hatcheries stock fish in the same river, but in different sections. The river Schwechat, for example, gets stocked with brown trout deriving from three different fishing associations which are all purchasing brown trout from hatchery "B". Another fishing association releasing fish in the same river purchases the trout at hatchery "G" which, in turn, obtains brown trout from "B". Therefore some rivers may be stocked with brown trout primarily deriving from one hatchery strain.

Aquaculture "I" – Upper Austria

Considering the distribution of brown trout from the Upper Austrian hatchery "I" a very large branching between hatcheries and fishing associations is discernable (Figure 16). Addressing the issue in which rivers brown trout of the interviewee's fish farm have already been stocked, the fish farmer refrained from itemising the individual streams. Due to the multiple commercial relationships with other fish farms and the sale of brown trout for stocking, this fish farmer concludes that his fish have already been stocked all over Austria.

In particular, pisciculturist “I” declared having commercial relationships with 36 aquaculture companies. Seven of these hatcheries are within the investigated area and have been interviewed. Two of these fish farms (T and U) rear the same broodstock as “I” does; the broodstocks of another two hatcheries (P and Y) contain brown trout from “I”. The remaining four farmers purchase brown trout (eggs) from aquaculture “I”. Some of the mentioned aquaculture operations (e.g., N, O, and P) trade brown trout with further hatcheries or hobby breeders, hence continuing the distribution of the hatchery strain from “I”. Fish farmer “P”, for example, admitted to trading brown trout with another 23 fish farmers within Austria which, in turn, led to stocking activities all over Austria. In other words, the genetic material of brown trout from aquaculture “I” shows a widespread distribution across Austria. It shows that some rivers, like the river Mur, are more intensively stocked with brown trout originating from “I”, than other rivers, since several fish farmers supply the same rivers.

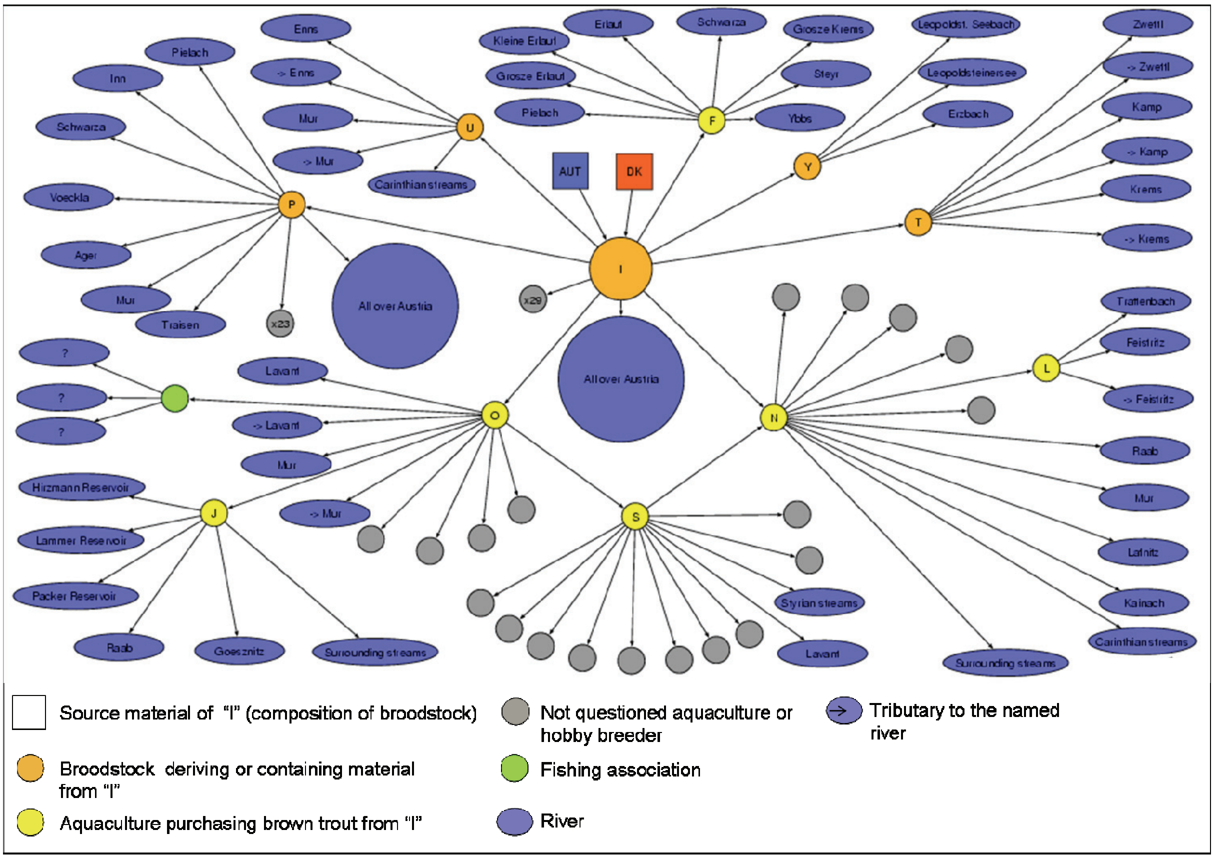


**Figure 16:** Origin and distribution of brown trout from the Upper Austrian hatchery “I”; The illustration describes present and past sale of fish to either fish farms or fishing associations as well as in which rivers the fish have been stocked; AUT= Austria, DK= Denmark

<u>Aquaculture “M” – Styria</u>

The broodstock of pisciculturist “M” consists of material from Austria, Denmark and another European country (Figure 17). Besides the distribution of brood from the broodstock, brown trout eggs are purchased and sold to customers. According to one customer of aquaculture company “M”, those brown trout eggs derive from Denmark and are traded by fish farmer “M”.

The network of stocked streams is wide ranging whereby pisciculturist “M” declared that breeding stock from his aquaculture operation has been stocked in streams all over Austria. Apparently a wide range of streams are stocked with the same genetic material from other fish farms. After all the broodstock of “M” is also reared in the hatcheries “L” and “Z” whereby “L” additionally purchases brown trout from “M”. In total this fish farmer keeps commercial contact with 21 hatcheries. Sixteen of these hatcheries have not been interviewed. However, by means of those hatcheries which have been interviewed the widespread distribution of brown trout across Austria becomes obvious. Solely those hatcheries rearing the same stock named more than 30 main rivers and tributaries in several federal states that have already been stocked.

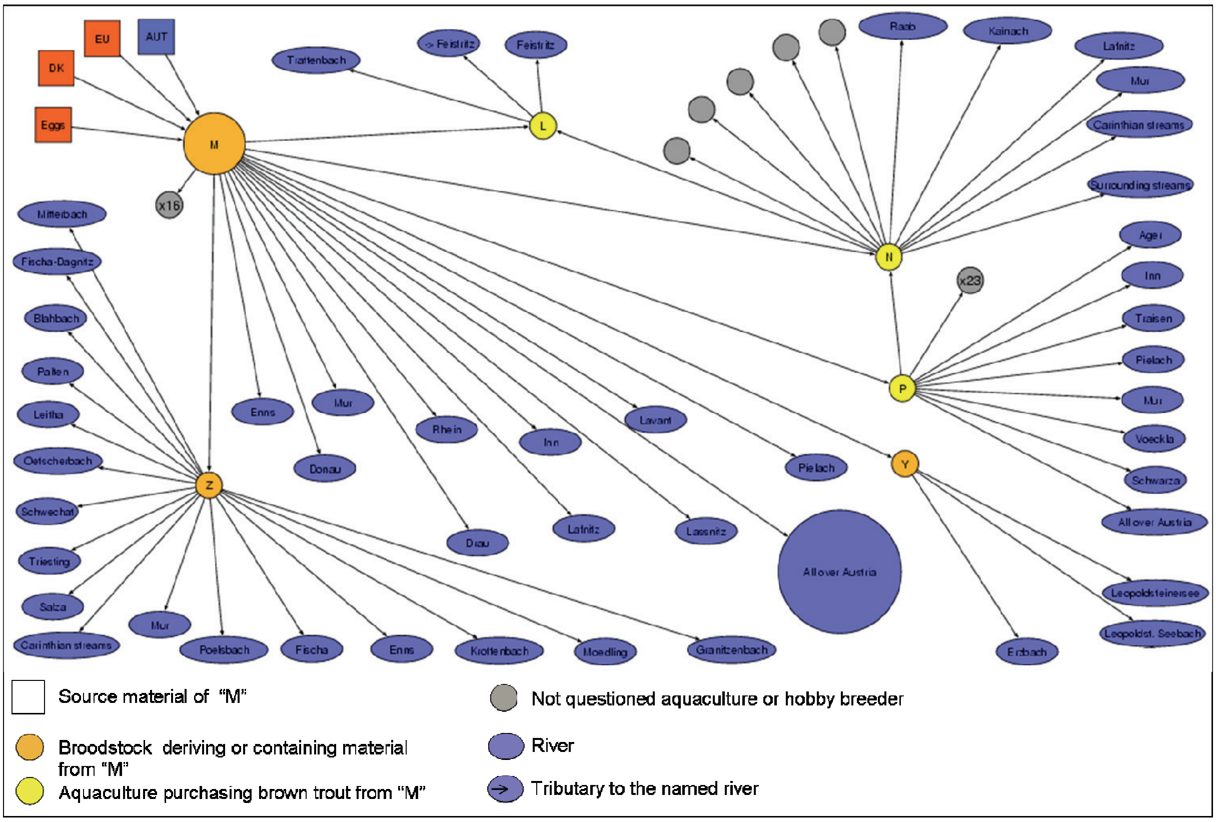


**Figure 17:** Origin and distribution of brown trout from the Styrian hatchery “M”; The illustration describes present and past sale of fish to either fish farms or fishing associations as well as in which rivers the fish have been stocked; AUT= Austria, DK= Denmark; EU= Further European Countries

# 6.3 Section III: Quality Related Criteria

## 6.3.1 Quality Related Aspects of Rearing Fish

Operating procedures of fish farmers influence the attributes of the reared brown trout. Decisive points are, for example, the criteria considered at the supplementation of the broodstocks. Within the scope of this inquiry it was crucial to find out about the attitudes of the farmers and where the benchmarks for the quality of the produced trout are set. Regarding the quality related questions the interviewed fish farmers were able to identify more than one requirement

In view of important qualities for rearing brown trout, the statements can be allocated to two different categories. The first category concerns the quality of rearing parameters (Figure 18), the second category deals with features defining the quality of the fish (Figure 19Figure 19). The first category covers a diverse range of criteria (31 entries). Most importance is given to water quality. Adequate water temperatures, water current, and near-natural rearing conditions are the second most mentioned parameters. In a narrow sense a differentiation can also be made within this category (cf. Figure 18). The right water temperature and an adequate water quality, on the one hand, are crucial criteria for artificial rearing of fish, hence, for the productivity of the aquaculture. Criteria such as the existence of near-natural rearing conditions, on the other hand, rather focus on the quality of the produced fish. The suggestions for near-natural rearing encompass rearing in natural streams, the introduction of natural predators into the rearing ponds or high discharge capacities in the rearing facilities. Overall, fish quality related properties of the rearing conditions slightly outbalance the productivity related aspects.

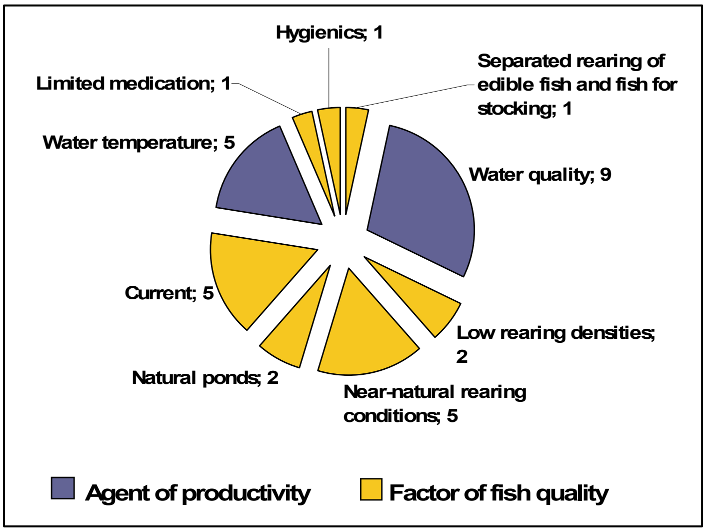


**Figure 18:** Assessment of quality related parameters of rearing conditions for brown trout (n= 26)

Parameters defining the quality of the reared brown trout serve to be the second main category of aspects for rearing fish (14 entries; Figure 19). Most emphasis is put on the general appearance of the produced brown trout (8 entries). Pisciculturists primarily refer to the colouration of the trout, which need to fulfil their expectations. The interviewees principally share similar perceptions. The majority describe a beautifully coloured brown trout with small red dots and a yellowish abdomen. A minority describe brown trout with a rather dark abdomen. Discordances exist regarding the density of the red dots. In the case of explicit statements the fish farmers distinguished between brown trout with many or just a few dots, whereas the majority prefer brown trout with only a few dots. A few pisciculturists even specify their expectations of a beautifully coloured brown trout. One interviewee, for example puts emphasis on the formation of a red adipose fin, whilst another one associates beautiful brown trout with red dotted fins. The question concerning the colouration of brown trout was of special interest since the stocked brown trout show very different colourations which actually, among other things, can be affiliated to the perceptions of the pisciculturists that are reflected in the breeding aims. A few farmers admitted to enforce breeding lines which resemble the colouration of the former autochthonous brown trout. Even though, the perceptions about the colouration of the native brown trout are not detailed. In general these farmers independently agree that growing of so called “multicoloured” brown trout should be avoided. Accordingly it shows that some fish farmers recognize the problems deriving from the current production processes. Besides the colouration the appearance of the fish also depends on the proper formation of the fins, gill covers and the general constitution of the fish. However, these features play a minor part in this context.

Besides the appearance in each case two fish farmers stressed the importance of the prevention of domestication and the need to rear domestic strains. Healthiness in the context of the ability to resist pathogenic agents was also mentioned by one fish farmer. In general, each farmer averagely named two parameters, whereby fish quality related attributes dominate ahead of productivity related ones.

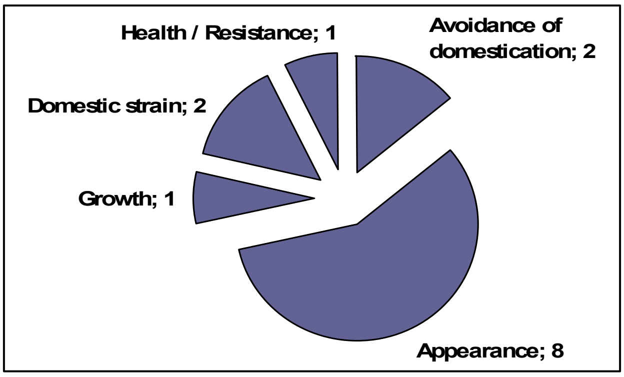


**Figure 19:** Most important quality related parameters of the reared brown trout (n= 11)

Addressing the issue as to whether hatcheries should change their methods of operation, 13 fish farmers (i.e., 50 % of all interviewees) acknowledge that changes might be important for the quality of stocked trout. Five pisciculturists claim that fish farms should force the cultivation of domestic brown trout strains to avoid further impacts on the autochthonous populations (Figure 20). In this context two other farmers highlighted the maintenance of the genetic diversity of the broodstocks to minimize intentional or unintentional selection and inbreeding.

Three fish farmers share the opinion that intelligent stocking concepts need to be promoted and implemented. These stocking concepts require better collaboration between the fish farms and the customers (e.g., fishing associations) so that stocking is carried out in the right season and in a proper way. Apparently, incorrect stocking practices are considered to be responsible for high losses of stocked fish.

Further suggestions for improved rearing methods encompass near-natural rearing conditions. Summarized, near-natural rearing conditions, including the promotion of low rearing densities, comprise the most frequently mentioned suggestions. More precise declarations, though, about near-natural rearing practices have not been made in this context. Separated rearing of edible fish and fish for stocking have also been mentioned, whereas this suggestion is also related to the idea of rearing fish for stocking purposes in near-natural environments.
Finally, ten pisciculturists believe that there is no need for a change to the current rearing practices in aquaculture. Three farmers refused to assess this situation.

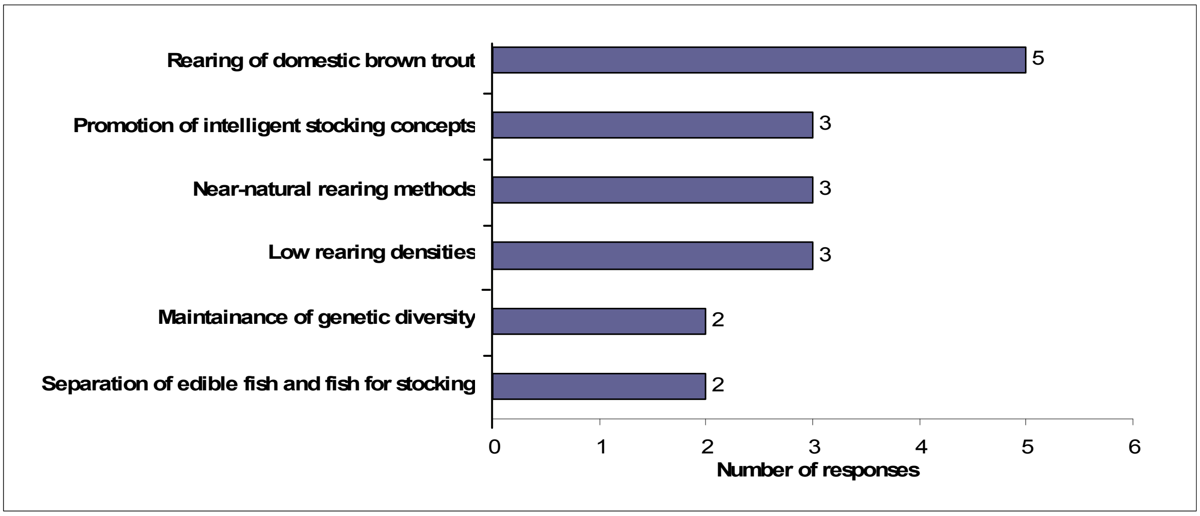


**Figure 20:** Suggestions for improved rearing (n= 13)

As already mentioned five fish farmers voluntarily suggested increased rearing of domestic brown trout strains (Figure 20). Addressing the issue of rearing regional strains, 20 out of 26 fish farmers agreed that aquaculture operations should rear regional strains instead of allochthonous fish (Figure 21). Nevertheless, a few of these pisciculturists emphasise that rearing of domestic strains should not be structured at a too small scale, that is to say that rearing of fish of regional limited catchment areas is doubted to be possible. However, the idea of producing catchment oriented brown trout is supported by one pisciculturist, who stresses the necessity to stock regionally adapted brown trout. Those pisciculturists who do not agree with this idea are not opposed but are rather undecided. Finally, one fish farmer leaves this decision to the customers without showing any preferences.

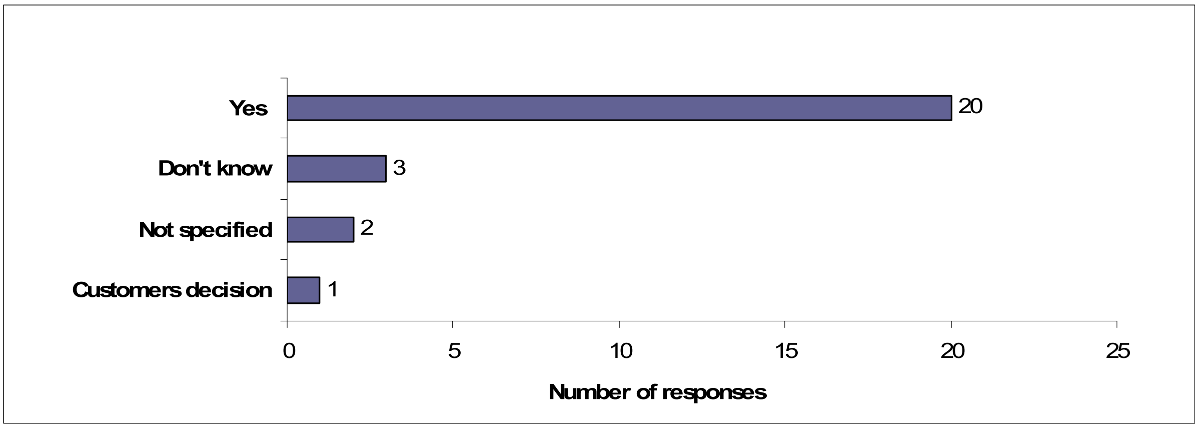


**Figure 21:** Frequency distribution of agreement and disagreement to whether fish farms should rear regional brown trout strains (n= 26)

Another matter of interest was whether the surveyed fish farmers would consider changing their rearing practices towards semi-natural methods. Six farmers recommended that aquaculture operations should either reduce the rearing densities or practice semi-natural rearing methods (Figure 20). Furthermore, near-natural rearing conditions are partially assumed to be an important quality related parameter for rearing brown trout (Figure 18). However, almost half of the questioned fish farmers would not change their rearing practices towards semi-natural conditions (Figure 22). The main counter-argument is that such rearing practices are economically inefficient.

Eight of the pisciculturists would consider changing their rearing practices, even though they had reservations. Most of these fish farmers also doubt the economic efficiency and postulate increased prices for stocking material when improved rearing methods are applied. The farmers doubt that the customers would be willing to pay the corresponding price. Furthermore, doubts concerning the practicability due to infrastructural limitations are expressed. Two fish farmers see the possibility of accomplishing a few adaptations to the current rearing environments, whereby one of those two pisciculturists took into consideration rearing fish in a natural stream environment. Finally, four interviewees do not see a need to change the rearing methods because near-natural rearing is already practiced; two of these four fish farms rear brown trout partly in natural stream environments.

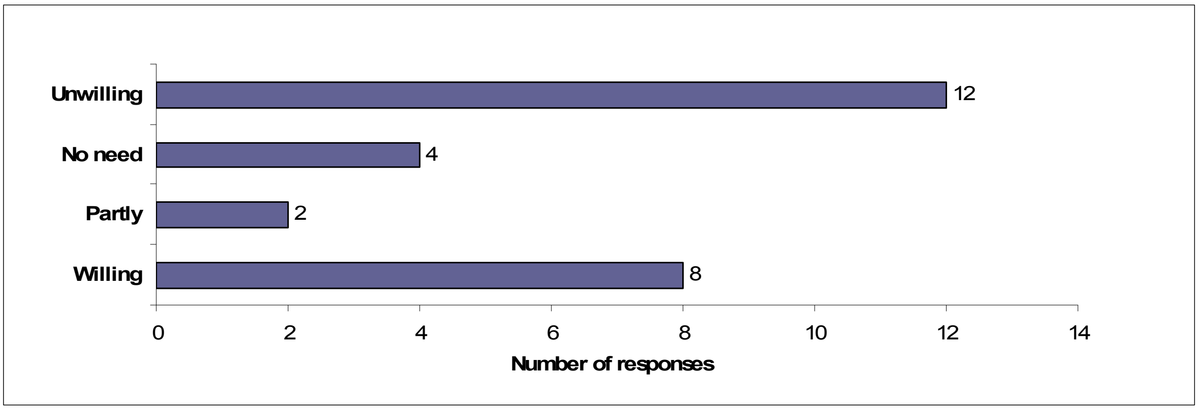


**Figure 22:** Willingness of fish farmers to change their rearing practices towards semi-natural rearing (n=26)

When the interviewees were asked whether they would consider changing their own broodstock, 15 farmers agreed. Five of the remaining farmers possessing broodstock disliked this idea. In relation to the size of the broodstocks it turns out that those aquaculture operations with small broodstocks (< 500 fish) would be willing to rear domestic stocks (Figure 23). Those farms account for about 37 % of the documented egg production.

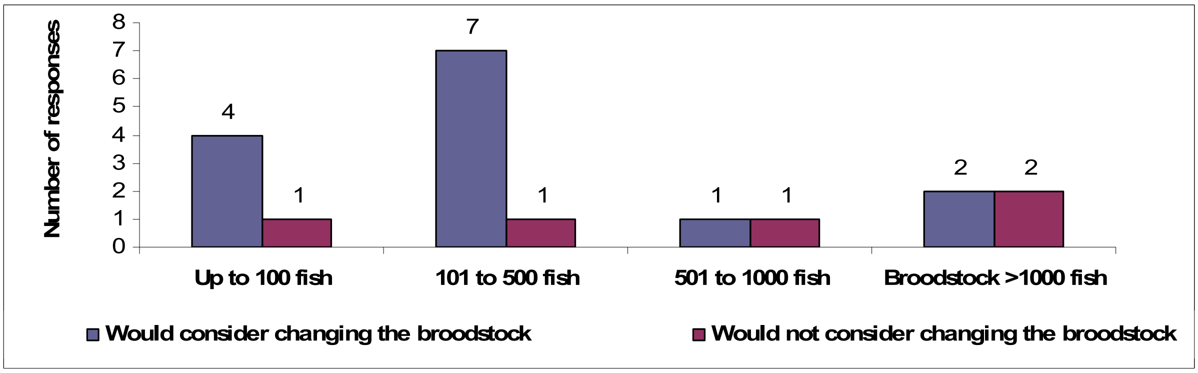


**Figure 23:** Willingness of fish farmers to change their broodstock in relation to the size of the broodstock (n= 19)

### 6.3.2 Demands on Quality of Reared Brown Trout

When the interviewees were asked what the important requirements for stocked brown trout are, the emphasis lay on fin condition (Figure 24). The fin condition is crucial for the ability to survive with complex and high water currents in natural environments. Since fin erosion is one of the most commonly documented grievances of hatchery reared fish (cf. Chapter 3.4.2), the pisciculturists appear to be sensitised to this matter. According to scientific findings the reduction or avoidance of fin erosion could be achieved from the reduction of the rearing densities, which only three interviewees suggested to be one of the primary improvements of current rearing practices (cf. Figure 20).

Along with the importance of the fin condition seven fish farmers refer to the rearing conditions whereby five pisciculturists emphasise the necessity of near-natural rearing conditions. However, not all the interviewees elaborate on this point. Only three farmers specified their statement by means of single attributes; for example, that the fish should be familiar with natural food and that the raring densities need to be low or that adequate water current exists. In general, though, the understanding of near-natural rearing encompasses a broad range of rearing practices.

Fish farmers emphasised seven times the importance of the constitution of the fish. Admittedly, the opinions about the constitution are divided. Some interviewees claim that the stocked fish should resemble the wild conspecifics whereat the typical constitution features a slim body. Other fish farmers, in contrast, recommend to stock well-fed brown trout. Well-fed trout are believed to be more capable of surviving during the first period of time in the stream, since the fish need some time to discover the natural food sources.

The colouration is another feature that has been raised. Generally the interviews refer to the customer wish for a beautifully coloured trout (see below). One interviewee recommends to stock brown trout which resemble the ancient (native) brown trout.
The proper condition of the gills, with special emphasis on the gill cover, was mentioned by three farmers. This issue is, similar to the fin condition and related to the fact that hatchery reared fish very often have badly developed gill covers.

Two fish farmers raised the point that the fish need to be adapted to the river where they get stocked. In detail this means that those two farmers recommend to stock local strains which may be better adapted to the stream environment than alien strains.

Another point that one breeder mentioned was the size of the fish. This breeder stresses that rather small (young) and non distorted fish should get stocked. This opinion is principally shared by another fish farmer who already stocks the larval stage, but who did not comment on this in the context of this question. Finally, one pisciculturist was not aware of any special attributes a hatchery reared brown trout should fulfil when stocked.

Overall, most fish farmers raised two to three features that stocked brown should fulfil. In most cases one of these features is related to the ability of the fish to cope with flow velocities of the stream environment (i.e., in terms of fin condition, fitness or constitution). This issue is, of course, relevant for the customers since the stocked fish need to stay in the stocked area. In this context fish farmers also often emphasise that stocked fish should not show any physical damage like fin erosion or reduced gill covers. Twice the matter of conformity was mentioned. In one case the fish farmer clarified that the fish have to be typical for the region where they get stocked.

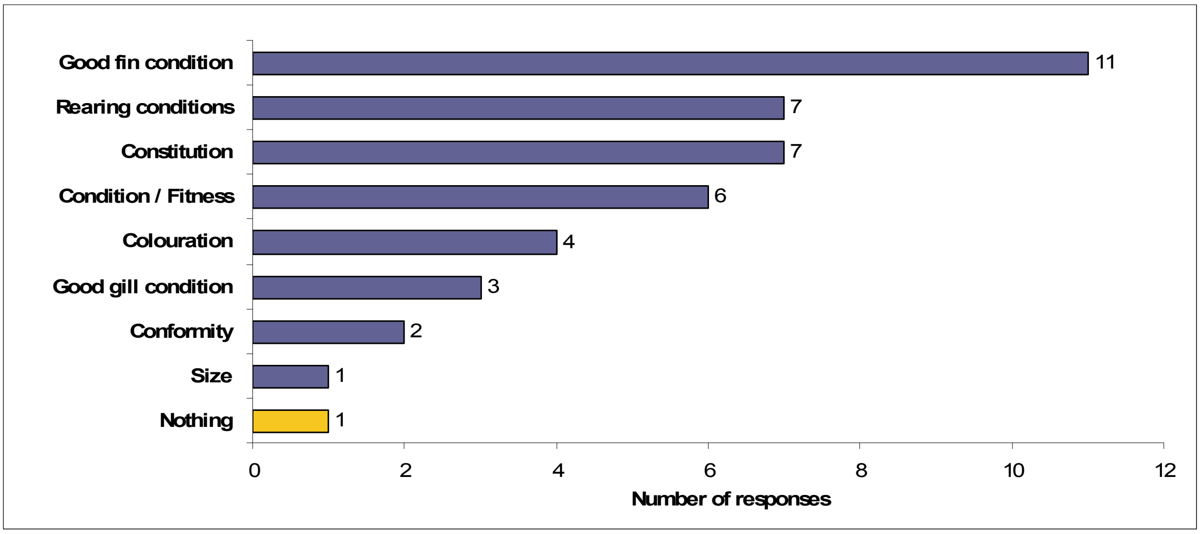


**Figure 24:** Assessment of quality related requirements for stocked brown trout (n= 26);

As already mentioned, fish farmers who keep their own broodstock regularly need to supplement their stocks with mature brown trout. The sources of supplementation have already been described in Chapter 6.1.1. The selection of the fish is based on the criteria listed in Figure 25. It shows that two criteria (growth and colouration) clearly rule the selection. In particular, the interviewees preferred fast growing fish which promises a fast growing breed. The importance of growth patterns is also reflected in the trials on semi-natural rearing (cf. Chapter 3.4.1) since this factor is very often taken into account. Colouration patterns, in turn, correlate with the individual preferences of the farmers which have already been described in Chapter 6.3.1. For many fish farmers both criteria need to fulfil their preferences to select a fish for the broodstock. Only one pisciculturist solely selects by means of colouration; another two only consider the growth of the fish. Further parameters which have been named in connection with growth or colouration are the condition, the maturity or the constitution of the fish.

Whilst five fish farmers claim to consider the overall impression including parameters such as healthiness, fitness, the colouration or the constitution, three farmers are exceptions since they do not select by any particular criteria. Two of these fish farmers explicitly emphasised that they avoid any selection to maintain the genetic variability within the broodstock.

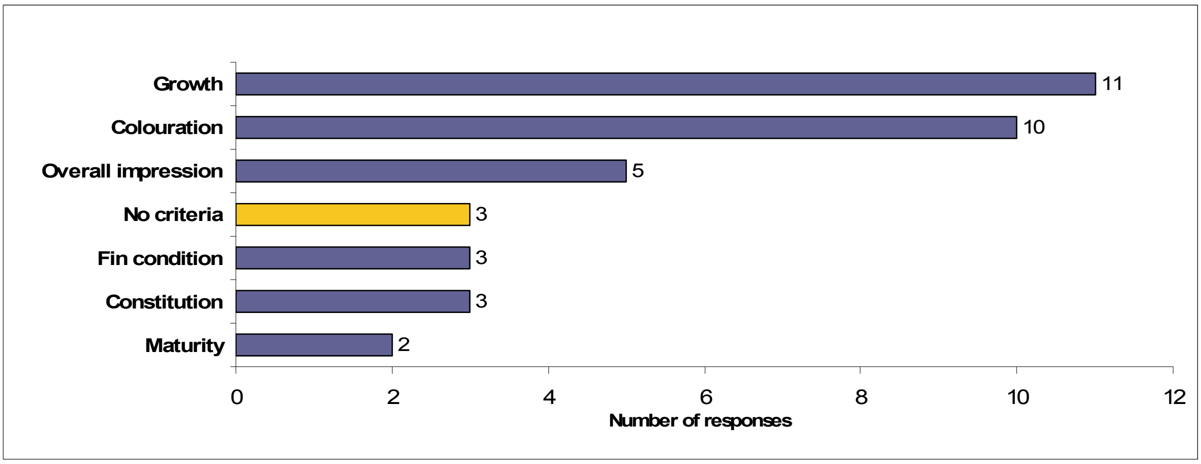


**Figure 25:** Criteria for the selection of fish for supplementation of the broodstocks (n= 21)

Another matter of interest was the preferences of the customers buying fish for stocking. Primarily it appears that the customers pre-eminently consider the quality of the fish (Figure 26). In comparison to the quality the price plays a minor part. Five fish farmers stated that both price and quality are important for their clients.

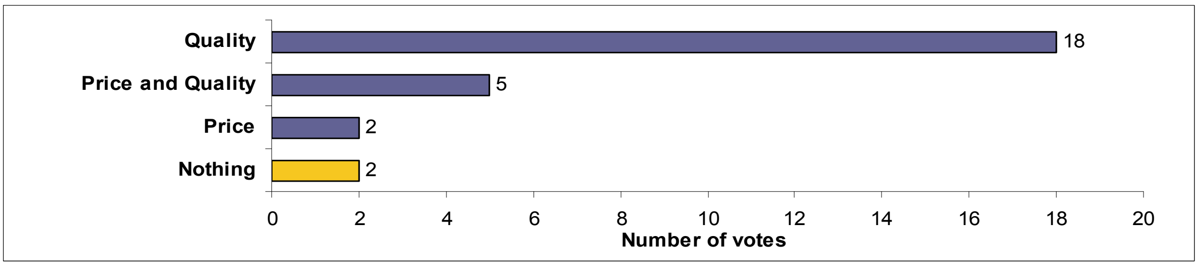


**Figure 26:** Important criteria for the customers purchasing trout for stocking (n= 26)

A closer determination of the quality related criteria shows that the majority of the fish farmers believe that customers put emphasis on the overall impression (Figure 27). Clients of piscicultures purchasing trout for stocking seem to particularly pay attention to the condition of the fins, the colouration and other parameters such as healthiness and fitness of the fish.

The origin of the fish appears to be less relevant in comparison to the physiological parameters. However, one special criterion seems to be the fertility. In fact, infertility of the fish appears to be a deliberately generated feature at some fish farms. Apparently one fish farmer experienced that customers dislike stocking of infertile brown trout, since the natural reproduction of the stocked trout becomes impossible.

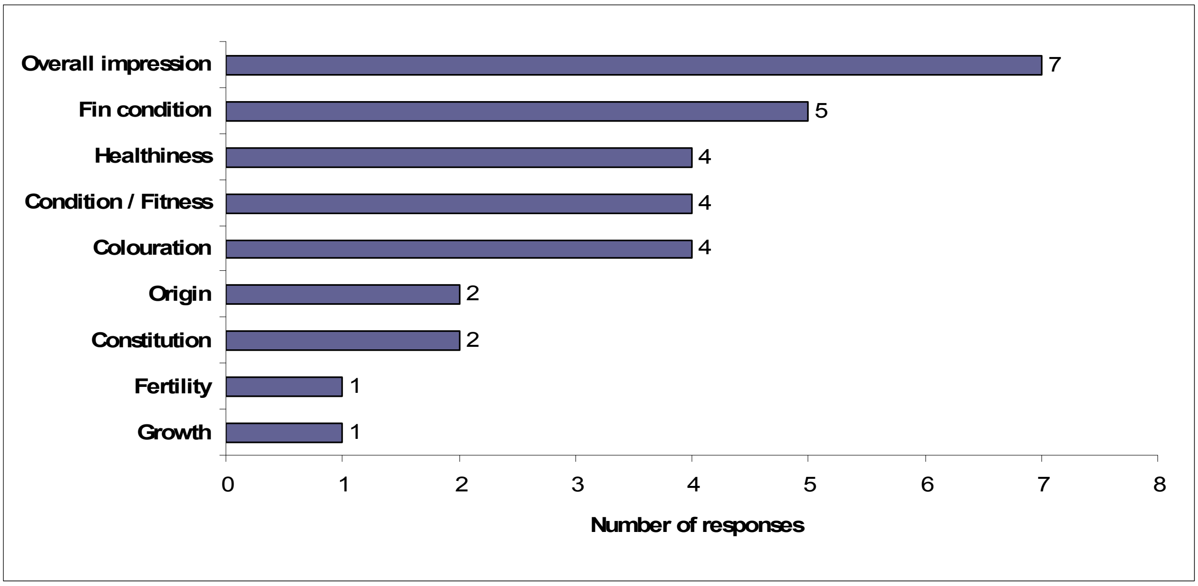


**Figure 27:** Fish farmers' statements about quality related criteria the customers put emphasis on (n= 26)

## 6.4 Section IV: Networks

The social network of fish aquaculture operators comprises the relationship of the fish farmers among themselves, with their customers and with related associations. Gaining an insight into the network of fish farmers provides the ability to determine the complexity of relationships and the important players within the networks. Along with the social relationships, market structures can be observed from an additional perspective.

The fish farmers were asked whether their stock of customers alternates regularly. Exclusively all interviewees declare that regular customers are supplied with brown trout (Figure 28). Only seven fish farmers noted a slight change in their customers. However, generally the customers regularly buy at the same hatchery. In relation to the stocking activities of the hatcheries (cf. Chapter 6.2.2) it can be assumed that the rivers are stocked with brown trout from the same hatchery over a long period of time.

Looking at the tools the interviewed pisciculturists use for advertising, all fish farmers trust word-of-mouth advertising (Figure 28). Only four interviewees use further advertising media such as the internet or an advertising folder. However, even those four farmers using additional advertising media consider word-of-mouth propaganda as the primary advertising media.

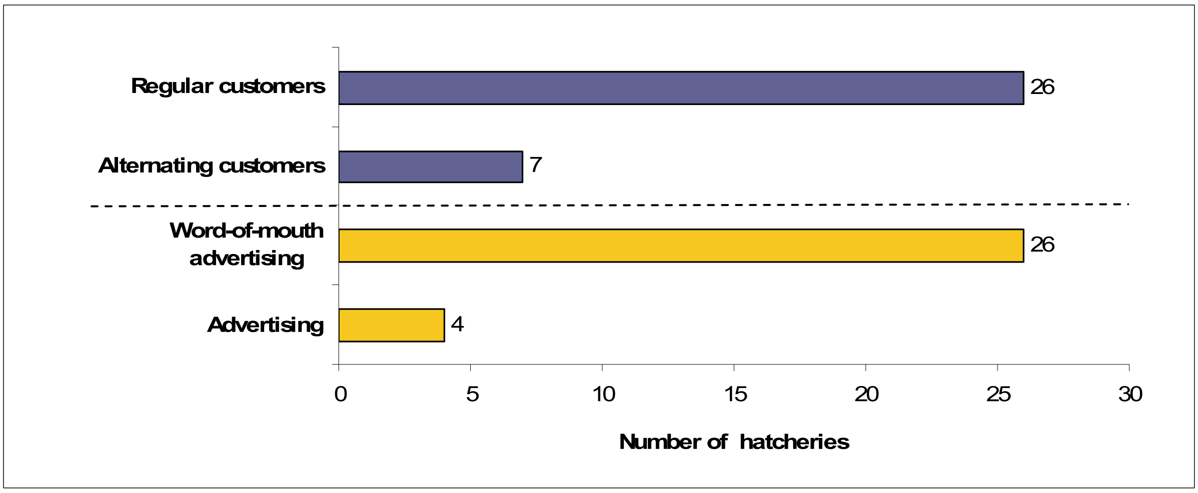


**Figure 28:** Fluctuation of customers and means of advertising of the fish farms (n= 26)

Next to the customers the memberships of the interviewees in pertinent associations as well as their functions as legal experts play an important part in overviewing the formal relationships. In total, 22 of the 26 interviewed fish farmers hold one or more memberships of associations which are related to either fish farming or fisheries management. In particular, 19 interviewees are a member of an umbrella association for fish farming (Figure 29). The majority of these fish farmers (15 persons) are member of the “Verband Österreichischer Forellenzüchter” (VOEF, association for Austrian fish farmers rearing trout); four of the interviewees are members of the board of the VOEF. A few interviewees are members of the “Tewichwirteverband” which is also an umbrella association for (small) fish farms. The VOEF especially intends to provide a basis for trout farmers to share information, to represent interests, to offer advisory support and to maintain the social network of pisciculturists. Furthermore it serves as an online platform for members to present their enterprises.

Next to the memberships of umbrella associations for piscicultures 11 pisciculturists are members of a governing body such as the “Österreichischer Fischereibeirat” or the “Österreichischer Fischereiverband” and the “Österreichisches Kuratorium für Fischerei und Gewässerschutz”. These organisations have in common that they act as advocacy groups for fisheries on either a governmental level or as an umbrella organization. Aims of these establishments are, for example, the coordination of concerns of fish farms and fisheries, the protection and maintenance of water bodies or the provision of dialog abilities. Another organisation of this category is the so called “Fischereirevierausschuss” which acts as a consulting service for government agencies.

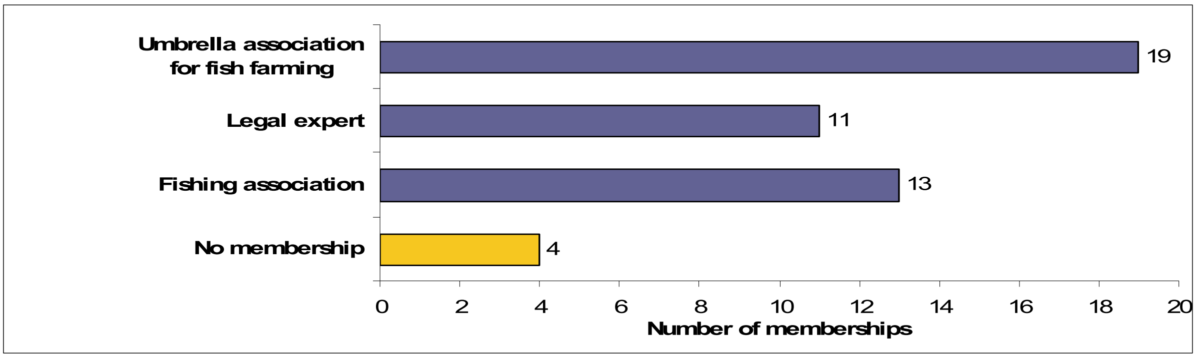


**Figure 29:** Memberships of fish farmers in relevant associations (n= 26)

Half of all the interviewees are members of a fishing association, hence, practise fishing. Four fish farmers currently do not have any memberships.

Those fish farmers who are members of any of the mentioned organisations were asked whether they feel satisfactorily represented by such institutions. Apparently only ten interviewees are satisfied with the work of the association they belong to (Figure 30). This is a small number considering that some of these farmers are also members of the executive boards. Nine pisciculturists were dissatisfied with their association. In the context of their dissatisfaction a few farmers claim that the insufficient flow of information is one of the main grievances. This result is reflected in the fact that only 11 interviewees feel satisfactorily informed about legislative European proceedings concerning aquaculture. In this context one fish farmer expressed the wish for a competence centre concerning aquaculture issues.
Three pisciculturists holding a membership abstained from responding. Those interviewees who did not make use of their membership which, according to them, does not justify them responding.

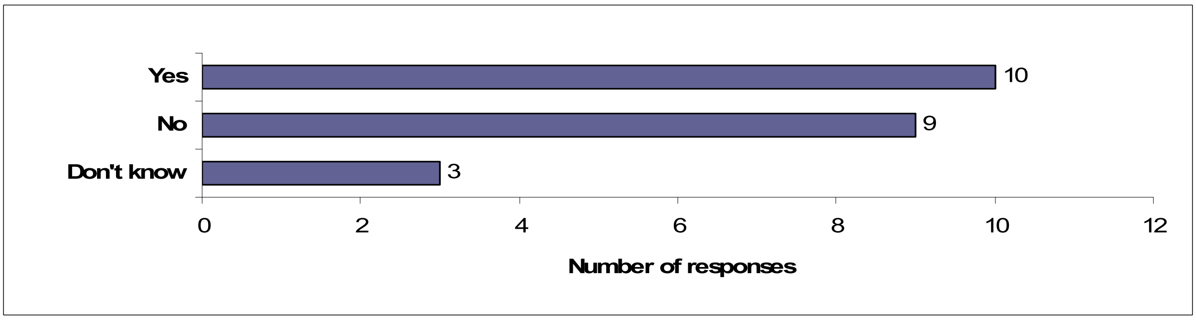


**Figure 30:** Frequency distribution of the degree of satisfaction (yes) and dissatisfaction (no) with the representation of the associations where the farmers are members (n= 22)

In summary, the majority of the interviewed fish farmers are members of organisations connected to the subject of fisheries management. A quite remarkable number of interviewees practice fishing, hence, experience the spectrum of fisheries management from the perspective of the producer of fish and the consumer.

With the background knowledge that 25 of 26 interviewees appreciate the efforts of the project-initiative TROUTCHECK and the many-sided linkages of fish farmers, the question arises, who can provide the leadership to change things in the field of aquaculture production. In this case the most important role is attached to customers (Figure 31). In this context many fish farmers mentioned the fishing associations. However, the second greatest influence is attached to the legislator. Only eight interviewees claim the necessary influence to themselves and their corresponding umbrella organisations.

Even less influence is attached to non-governmental authorities such as scientific institutions. The interviewees are awarding non-governmental organisations the development of alternative fisheries management practices. Their influence, though, for the realization of these methods is estimated to be very small.

Two interviewees suggest that changes can only be carried out when all protagonists in the field of fisheries management act together. The least weight is attached to the media.

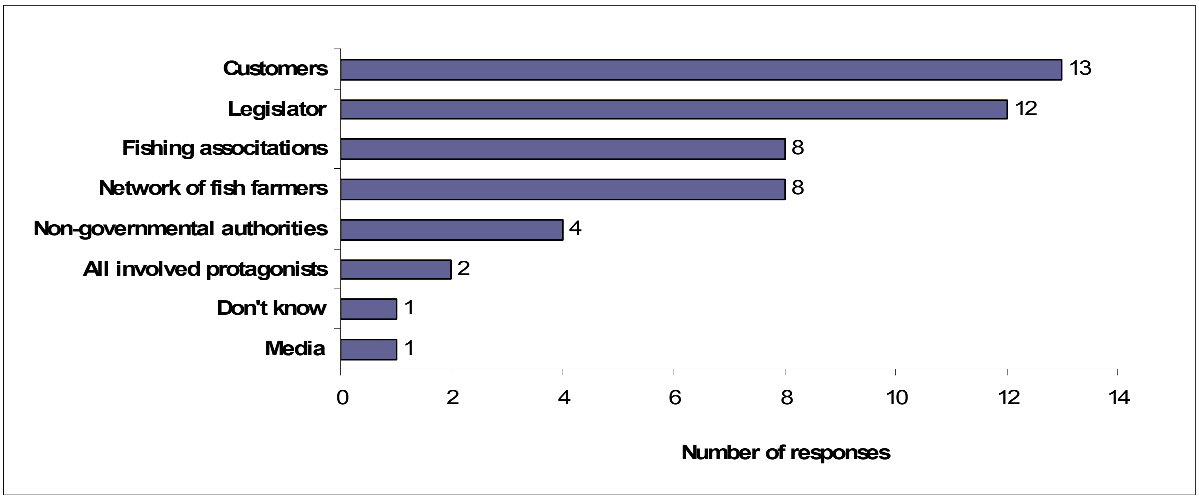


**Figure 31:** Importance attached to various actors regarding their influence changing current rearing methods (n= 26)

Even if the fish farmers do not accredit themselves with very much influence on the future development of fisheries management, it was of interest to identify the key players within the network of farmers. Therefore two different approaches have been chosen. The first one was to identify the complexity of relationships among the farmers throughout Austria (Figure 32).

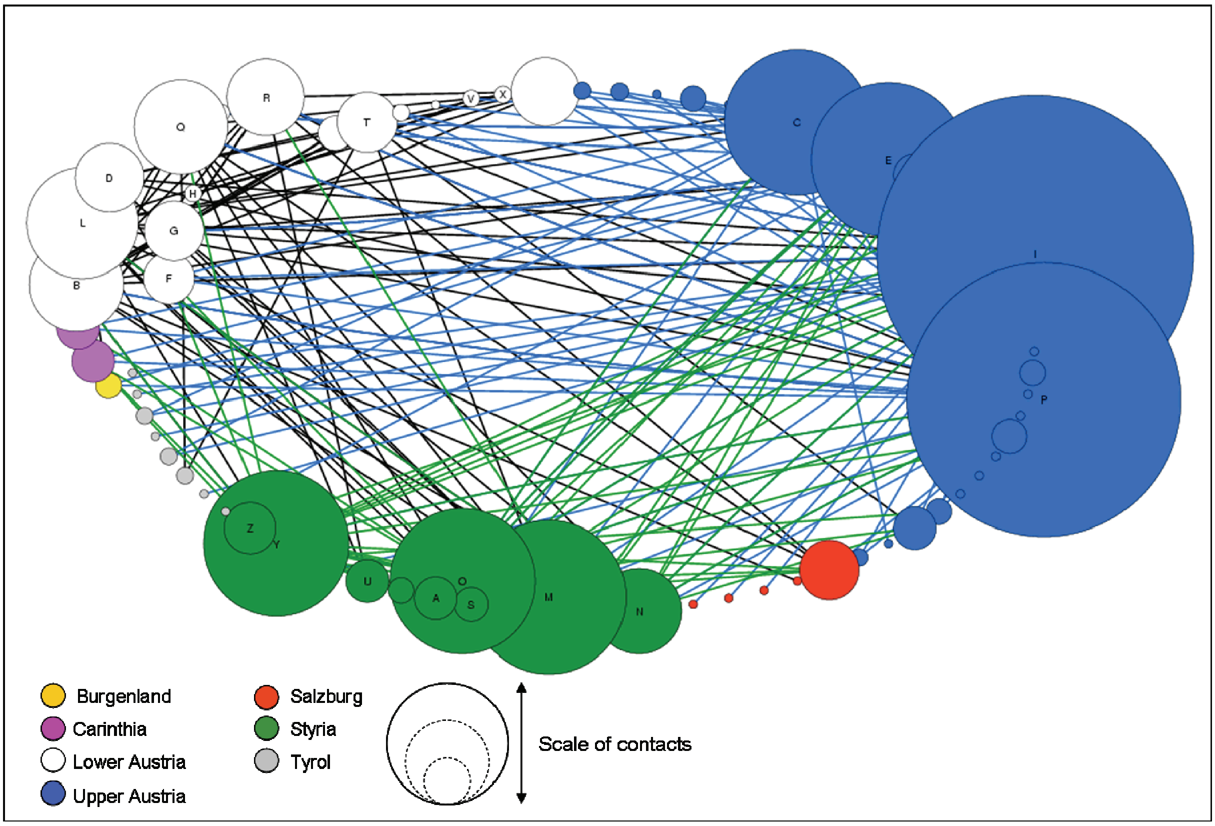


**Figure 32:** Contacts of the questioned fish farmers with further aquaculture operators throughout Austria; Each line symbolises a connection between two different fish farms (n= 26)

It shows that the Upper Austrian hatcheries share the most contacts throughout Austria with aquaculture "I" leading the way. Many contacts are held with Styrian fish farms which obviously also play an important role in the whole network. The relations of Lower Austrian piscicultures are mainly restricted to contacts with Upper Austria, Styria, and contacts between themselves.

The lines in Figure 32 symbolise different kinds of relationships including commercial relationships, formal relationships or simply communication relationships. Thus, those hatcheries sharing most contacts determine the central points of supply in terms of products and information. That is to say that a decision-making role can be affiliated to these fish farmers since their large number of relations and therewith related active communication determine them as opinion leaders (cf. FAS 2008).

Looking only at those farms which have been interviewed (Figure 33), the far-reaching role of the Upper Austrian fish farms becomes evident. After all, Styrian hatcheries share the most contacts with aquaculture “M” leading the way. The minor role of the upper Austrian hatcheries implies that a lot of contacts are beyond those three federal states.

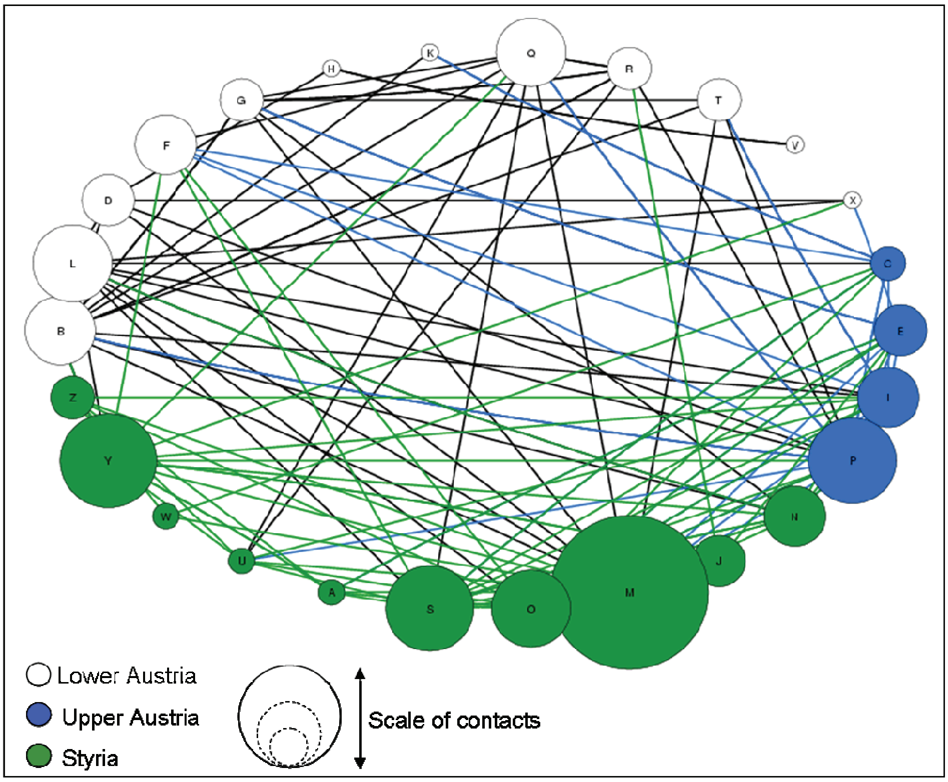


**Figure 33:** Contacts of the questioned fish farmers among each other; Each line symbolises a connection between two different fish farms (n= 26)

The second approach identifying important key players was to ask the interviewees about which pisciculturists should also be part of this survey. In doing so, the hatcheries “M”, “I”, “E” and “P” are among the most mentioned (Figure 34) farms. Apparently these farmers are also among those sharing the most contacts with further hatcheries (cf. Figure 32). Furthermore, the recommendations especially refer to fish farms showing the largest output figures in terms of produced brown trout eggs, hence, the biggest producers. The same fish farmers are also assumed to be those with the best knowledge within the field of rearing fish (Figure 35).

In summary it is obvious that a group of four to five fish farmers are held in high esteem. These farmers are basically central points for fish supply. Furthermore, they represent important communication partners, hence, opinion leaders.

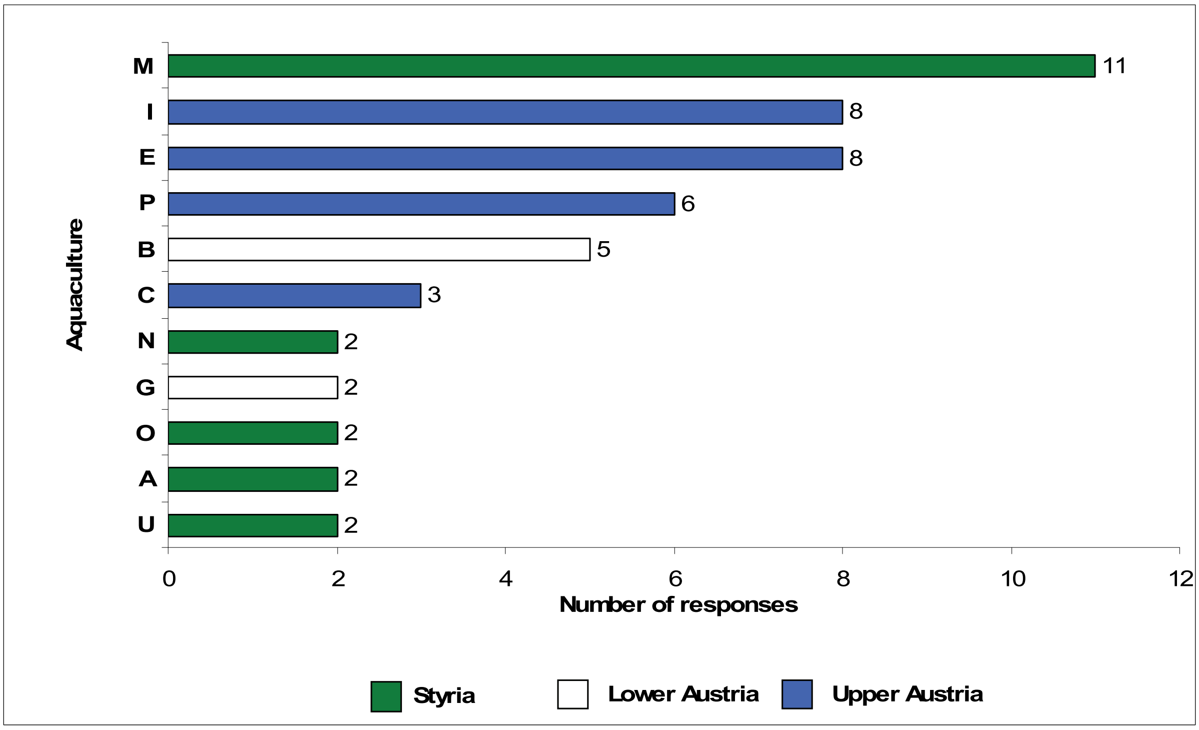


**Figure 34:** Recommended aquaculture operators to be part of this study (n= 23)

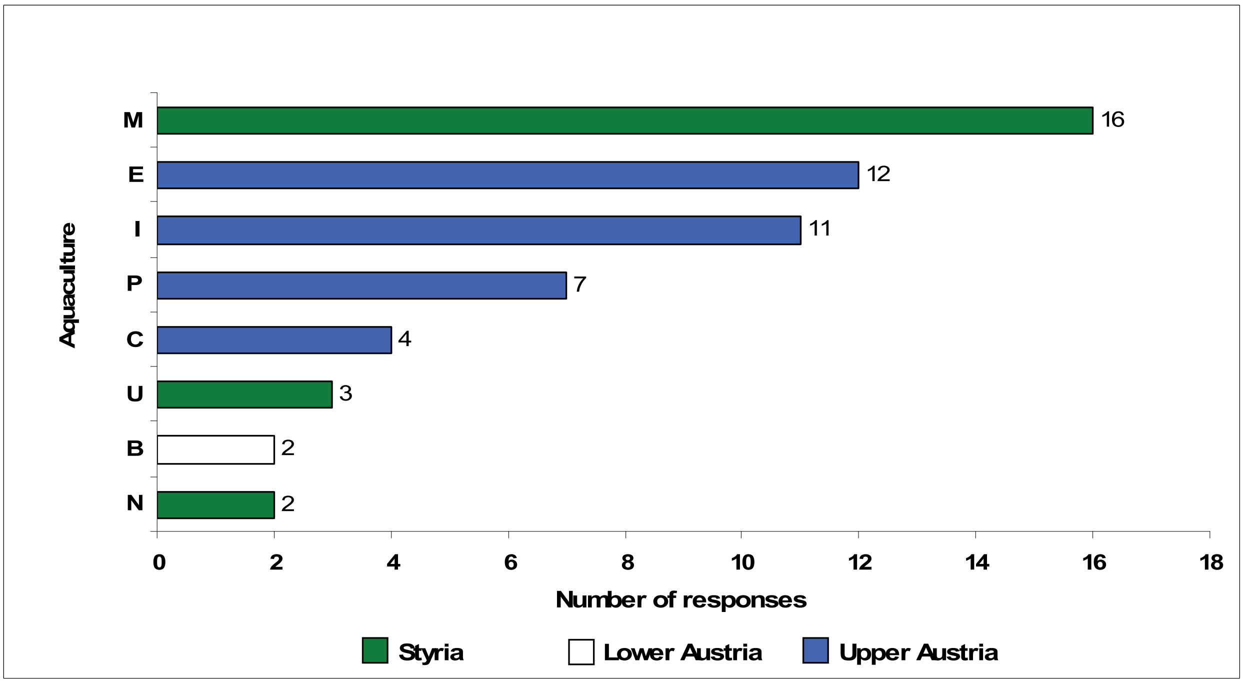


**Figure 35:** Fish farmers assessed to be well versed in the area of rearing brown trout (n= 24)

# 7. Discussion

A broad range of aquaculture operators have been consulted for this study, including farms with very small production volumes to those with the biggest production in Austria. In those two federal states where the project-initiative TROUTCHECK is carried out it was possible to incorporate almost all the relevant hatcheries which are involved in stocking brown trout. Most of the fish farmers interviewed were willing to answer all of the questions.

Overall, the results of this investigation clearly illustrate that the current stocking activities in Austria are detrimental to the recipient wild and native brown trout populations. The threats arise due to a number of different aspects. Firstly, it can be assumed that in all probability all questioned aquaculture companies produce brown trout containing non-domestic (Atlantic) clades. Apparently, even the fish of those fish farmers whose broodstock originally descends from wild brown trout populations may contain non-domestic mitochondrial DNA (mtDNA), since non-domestic fish may have already been stocked in advance to the founding of these stocks. Furthermore, initially domestic broodstocks have possibly been adulterated by the supplementation with fish of non-domestic origin. Even if natural colonization of Atlantic Basin fish occurred in the past, it is assumed that the continued stocking of allochthonous strains erodes the genetic integrity of the natural populations (cf. Weiss et al. 2001). More in detail, alterations of the gene frequencies cause a loss of local adaptation and as a result a loss of fitness (Cross et al. 1998). This process of losing fitness due to hybridisation of individuals of the same species but different in populations is also known as *Outbreeding Depression* (Largiadèr and Hefti 2002). In this context Largiadèr and Hefti (2002) emphasise the potential endangerment of locally adapted populations due to *Outbreeding Depression* and point out that the endangerment could be underestimated since the reduction of fitness may initially occur after a few generations of hybridisation. Viewed in this light the introduction of hatchery reared fish into Austrian rivers - which has been carried out for decades - continuously affects negatively the integrity and physiology of locally adapted (native) populations.

On the part of the fish farmers, rearing of domestic brown trout clades is not considered to be an important issue and even less of an ecological problem. Although half of all interviewees acknowledge that rearing of fish requires improvements, only a minority emphasise the relevance of rearing domestic strains. Even fewer stressed the meaning of domestic trout to be important quality criteria of the stocked fish. Accordingly it appears that most fish farmers are not aware of the consequences of stocking allochthonous trout strains. In contrast, if asked, most interviewees agreed that regionally adapted brown trout strains should be reared in Austrian aquaculture operations; even though different opinions exist about the delimitation of these regions. However, considering the largely positive attitude of the interviewees towards the rearing of domestic strains as well as the fact that many farmers would be willing to replace their broodstock, a significant potential does exist to force the rearing of regionally adapted strains. Furthermore, improved awareness of the customers for the problems resulting from the current stocking material could be of need. After all, the interviewees rate the greatest influence on the development of the market to the customers. Therefore it would be necessary to raise customer consciousness, since at present almost no emphasis is put on the origin of the stocked trout. Increased desire for domestic brown trout on the part of the customers could also exert leverage on those aquaculture operations which are currently unwilling to change their broodstocks.

Along with the dangers of introducing external strains, the loss of genetic diversity constitutes another ecological risk that wild brown trout populations are exposed to (cf. Hilborn 1992, Waples and Do 1994, Einum and Fleming 1997, Cross et al. 1998, Koljonen et al. 2002). This study reveals that for a long time almost exclusively captive broodstocks have been used for reproduction. Such practices of hatchery rearing entail the risk of losing genetic diversity due to the accelerated rate of genetic drift in limited broodstocks (Koljonen et al. 2002, see also Reisenbichler and Rubin 1999). According to Waples and Do (1994) "[…] artificial genetic bottlenecks can lead to increased levels of inbreeding and erosion of genetic diversity" in the postsupplementation population (see also Cross et al. 1998). Fisheries managers who try to avoid these negative effects constantly turn over the broodstocks to maximise the genetic diversity (cf. Simpson and Jackson 1996). In this context, Flagg et al. (1999), clearly attribute responsibility to conservation aquaculture operations for the maintenance of the genetic diversity of each population.

Within the investigated area about three-quarters of the annually produced brown trout eggs are derived from broodstocks which have already been reared over several decades and have solely been supplemented by their own brood. Eleven out of 17 fish farmers possessing a broodstock use their own breed for broodstock supplementation. These rearing practices, though, are considered to be responsible for a variety of negative effects through domestication (cf. Chapter 2.3.2). According to Reisenbichler and Rubin (1999) domestication can lead to substantial genetic differences which may occur after only a few generations of hatchery rearing. In addition to these supplementation practices most of the stocked trout are reared in typical hatchery environments, i.e., ponds or raceways, which show almost no resemblance with the natural environments of brown trout. Taking these facts into account, one can assume that the majority of the stocked brown trout decisively differ from wild fish due to intentional and unintentional selection. This assumption is substantiated by the fact that, at least on the part of intentional selection, the questioned fish farmers promote designated features for the supplementation of their broodstocks. Those pisciculturists who deliberately avoid selection by specific criteria form a minority.

Overall, the substantial alterations of hatchery reared trout constitute endangerments to wild living brown trout populations. Furthermore, it can be assumed that the named deficits cause poor survivorships of hatchery reared trout in the wild (cf. Chapter 2.3), hence, the stocked fish fail to enlarge the natural stocks.

The willingness of the surveyed fish farmers to change their rearing practices towards semi-natural rearing is low. Only about a third of all interviewees could imagine making modifications, whereby all of them expressed reservations concerning the profitability of alternative rearing methods. The lack of ambitions for near-natural rearing can be considered from another perspective, whereas the low number of suggestions for improved rearing indicates that the interviewed pisciculturists do not necessarily see the need to make major adjustments. Only two interviewees expressed that the avoidance of domestication constitutes a parameter of high quality for the stocked brown trout. This parameter though, constitutes one of the major threats to the wild populations.

By means of this study it can be ascertained that, regarding demands on quality, the interviewees put emphasis on other issues. Generally, quality criteria which are considered to be important comply with those which have been attested by the fish farmers' customers. These are criteria such as the general appearance comprising proper fins, a good condition or fitness, healthiness or colouration. In consequence, more or less the same criteria are considered for the supplementation of broodstocks. Some parameters such as the fitness or healthiness of released trout are undoubtedly of importance for the survival of released trout (cf. Brown and Day 2002, Maynard et al. 2004); this is a view which is also shared with most of the interviewees. The rearing ponds currently used, though, do not comply with rearing environments that encourage the development of proper fin conditions or sufficient fitness. Contradictory to that, only a few pisciculturists suggested that the application of near-natural rearing methods would constitute improvements for fish farming, hence, for the quality of the fish. Accordingly, it appears that the current rearing methods are considered to be appropriate to fulfil the farmers' ideas. One could further assume that the current rearing methods are considered to be near-natural. However, this investigation clearly demonstrates that instead of visually significant parameters, those features of hatchery reared trout which are essential for their survival and for their genetic integrity need to be increasingly promoted among fish farmers. Successful (re)introduction of brown trout can only happen when near-natural behaviours and physiques can develop during the time of captivity (cf. Brown and Day 2002). Growth and colouration which are, on the part of the fish farmers, considered to be the most important criteria for the supplementation of the stocks should, in comparison to features such as the genetic integrity or the ability to deal with natural environments, play a minor part. In other words, sound fish farming practices should produce native fish in near-natural rearing environments whereby artificial selection has to be avoided.

Additional to the endangerment of the genetic diversity through artificial genetic bottlenecks further endangerment derives from another perspective, which is the matter of wide ranging trading and stocking activities carried out by most of the interviewed aquaculture operators. The current situation of propagating fish indicates that hatchery strains reared within the investigated area undergo a broad distribution across Austria. Apparently, the majority of the stocked brown trout (68 %) derive from only three broodstocks. In other words, the limited pool of genetic information of the hatchery strains gets widely distributed across Austria. The distributive processes are many-sided. First of all it shows that hatchery strains experience a translocation among several fish farms in the form of new-founded broodstocks. In some cases broodstock supplementation additionally contributes to the distribution of different strains across Austria.

The annual commercial relationships of fish farmers contribute even more to the distribution of fish. This study reveals that those hatcheries with big production volumes supply many other, generally smaller, farms with fish. Thus, two different kinds of fish farming exist; those owning a broodstock, hence, producing and selling trout and those which solely purchase and resell brown trout. From the viewpoint of those aquaculture operations with big production volumes it appears that a variety of trading relationships with usually smaller structured hatcheries exist all over Austria. Each of these smaller hatcheries, in turn, supply customers such as fishing associations and further, even fish farms. Accordingly, a complex network branches out from single aquaculture operations over a variety of smaller fish farms to a large number of customers, hence, to rivers and tributaries which are ultimately stocked. In this sense, trading of trout ahead of stocking on the one hand represents an important economic factor for many fish farms. On the other hand it strongly contributes to the widespread and extensive distribution of fish.

In the context of trading it also appeared that a few fish farmers disapprove of the trading relationships of some aquaculture operators with enterprises from abroad. Apart from the fact that such trading activities contribute to the introduction of non-domestic strains, the interviewees criticise the unfair competition due to low prices for brown trout from neighbouring states.

Finally, stocking of fish emerged as the factor with the highest distribution implications. Primarily, all interviewed hatcheries have in common that rivers and tributaries near to their fish farms are stocked with their trout. In general though, the majority of the interviewed fish farms also have stocked rivers situated further away, with the biggest producers leading the way with to stocking activities all over Austria. Only a small number of fish farmers restrict stocking to neighbouring waters. Overall, the range of stocking activities can assumedly be attributed to the extent of the fish farmers' reputation among fishing associations. It appears that many fishing associations do not consider the regionality of the aquaculture operation or of the produced trout. Fish are purchased at the hatchery of the customers' choice, independently of aspects concerning the regionality. This assumption is supported by the interviewed fish farmers, with the exception of two who claimed quite the opposite, i.e., that customers did put emphasis on the origin of the fish.

Another reason for the wide ranging distribution of some strains may be the fact that some fishing associations manage a large number of running waters in different catchment areas which get stocked with fish from the same hatchery strain.

Overall, the wide ranging distribution of the homogenous broodstocks and its breed contrasts strongly with the biological, hydrological, and geological diversity of Austrian rivers.

As already mentioned, increased customer awareness could contribute to a significant step towards rearing and stocking of regionally adapted brown trout. Beyond that, improvements of the stocking strategies which have also been claimed by three interviewed fish farmers need to be implemented. In this sense, a large number of studies could be consulted, dealing with recommendations for sustainable stocking strategies (cf. Cowx 1998, Brown and Day 2002, Largiadèr and Hefti 2002, Holzer et al. 2003, 2004)

On the whole a variety of adaptations in the field of aquaculture are important to achieve ecologically and economically sound fishery management practices. On the part of the fish farmers the incorporation of legislators next to the customers appears to be unavoidable for the implementation of such practices, even though, many interviewees criticised the ongoing bureaucratization of their business. Another important issue would be the incorporation of scientific research institutes even though the interviewed fish farmers do not attach much influence to science. However, the current situation of cooperation between scientists and fish farmers is insufficient. In this context Largiadèr and Hefti (2002) claim that a general set-up for sustainable fishery management needs at least the following conditions to be fulfilled: Scientists, politicians and fishery managers need to be involved in the process of developing sustainable management; the management concept has to be based on a reasonable scientific background; management has to be imbedded in a coherent legal framework; and, the wishes and worries of the users of fish stocks need to be considered.

Other important players are inevitably the fish farmers themselves. This investigation shows that certain farmers hold exceptionally important positions as trading partners and also as opinion leaders. The incorporation of these farmers into sustainable operating methods would be significant since they may be taken as an example by other pisciculturists. In this context the current situation of intercommunication would need to be improved. Corresponding umbrella organisations for fish farmers exist but a lack of information flow as well as a relatively high rate of dissatisfaction about these associations has been expressed. In this sense an advisory committee including key fishery managers, key aquaculture leaders, and fishery biologists could, on the one hand, improve communication among these groups and, on the other hand, the implementation of sustainable fisheries management could be promoted.

# 8. Conclusion

Until now little was known about the hatchery production of brown trout in Austria. By means of this study it was possible to gain the first significant insight into the situation of artificial brown trout production with special focus on the federal states of Lower Austria and Styria. Perceptions could be recorded concerning output figures, distribution of brown trout, qualitative parameters of rearing and diverse external and internal factors influencing the market.

Considering the worldwide scientific knowledge about the effects of rearing and stocking of salmonids, it can be summarized that to a large extent the current rearing practices within the investigated area are likely to be having detrimental effects on the wild *Salmo trutta* populations of Austria. The main threats derive from those reasons which are extensively described in the literature (cf. Chapters 2.2 and 2.3). Regarding this the findings of this investigation are encapsulated in the overview of the different threats published by Einum and Fleming (2001), namely

1. The phenotypes of most of the hatchery reared brown trout may be considerably shaped due to the differing environmental characteristics of rearing environments when compared with natural environments;
2. the intensity and direction of selection strongly differs between the natural situation and hatchery conditions; and
3. Austrian brown trout populations face the threats caused by the ongoing introduction of non-native brown trout strains;

This investigation further reveals that the surveyed hatchery operators transfer brown trout clades across Austria and therefore assumedly far beyond their natural distribution areas. Until now the extent of the distribution of brown trout by hatcheries was unknown. This information, though, constitutes an important starting point for future development of sustainable conservation management strategies. In fact, compared with the current situation, future stocking practices need to be tailored to the populations in question, taking their local adaptations into account. Viewed in this light the ascertained presence of non-native brown trout strains in hatchery-broodstocks constitutes an important future working point.

Further starting points for the reconsideration of the current rearing practices offer the interviewees' views regarding quality criteria. In particular, the verification of the interviewees' perceptions concerning profession oriented topics shows that they do not comply with the requirements of conservation practices. A need for change of thinking concerning selective influence, quality of the rearing environment, and demands on quality of stocked fish has been ascertained. In general, the awareness of the fish farmers and their customers for ecological consequences of current rearing practices turned out to be low. As a result consciousness-raising processes will be a decisive tool for the implementation of proper conservation strategies.

Next to the visualisation of grievances concerning present rearing practices, limits and starting points for an ecosytematic integration of hatcheries have been identified. The information gained by means of the social network survey represents a key for the incorporation of important contacts and for the development of participatory processes. In fact, key players among the interviewed fish farmers and their current role within the network of farmers have been identified. Furthermore, the weighting of participants such as the customers or the legislator for the adaptation of changes in rearing of fish gives crucial information about starting points for future developments. Finally, the need for improvements within the social network of fish farmers emerged by means of the network analysis. In fact, a gathering of important players including, fishery managers, fish farmers, and fishery scientists would contribute to improving the communication among these groups. Furthermore, the presently underrated role of the science would become more relevant. A joining of the named groups would promote future developments in the area of sustainable fishery management.

Since stocking of brown trout has been carried out over decades, domestic (wild) populations have faced the demonstrated threats from hatchery reared fish for a long period of time. The results of this study can be associated with already ascertained introgression of Atlantic Basin fish or changes in phenotype and genotype of Austrian brown trout populations (Lahnsteiner and Jagsch 2005, Weiss et al. 2001). The study results show the urgent need for changes to the current practices of supplementing brown trout. The willingness of the interviewed fish farmers to change their working methods existents to some existent. The scope of compliance reaches from fish farmers, who to a certain extent practice ecologically sound rearing, and who can also imagine how to improve their methods to those who are not willing to adapt to changes. In other words, the related perceptions concerning the meaningfulness of ecologically sound rearing principles and the economic viability of any subsequent modifications vary between the interviewees.

However, the information obtained obtained for this thesis provides a solid basis for further steps towards the implementation of ecologically sound supplementation of fish stocks. To complement this conclusion additional research in the area of near-natural rearing methods will be necessary since the methods investigated so far are insufficient.

# 9. References

Alvarez, D., A.G. Nicieza, 2003, "Predator Avoidance Behaviour in Wild and Hatchery-Reared Brown Trout: The Role of Experience and Domestication", Journal of Fish Biology 63: 1565 – 1577

Aprahamian, M.W., K.M. Smith, P. McGinnity, S. Mc Kelvey, J. Taylor, 2003, "Restocking of Salmonids – Opportunities and Limitations", Fisheries Research 62: 211 – 227

AQUAWILD, 2002, "Performance and Ecological Impacts of Introduced and Escaped Fish: Physiological and Behavioural Mechanisms", Final Report to: European Commission, National Board of Fisheries, Institute of Freshwater Research, Sweden

Araguas, R.M., N. Sanz, C. Pla, J.L. Garcia-Marin, 2004, "Breakdown of the Brown Trout Evolutionary History due to Hybridization between Native and Cultivated Fish", Journal of Fish Biology 65(A): 28 – 37

Arndt, R.E., M.D. Routledge, E.J. Wagner, and R.F. Mellenthin, 2001, "Influence of Raceway Substrate and Design on Fin Erosion and Hatchery Performance of Rainbow Trout", North American Journal of Aquaculture 63: 312 – 320

Atteslander, P., 2006, "Methoden der Empirischen Sozialforschung"; 11., neu bearbeitete und erweiterte Auflage, Erich Schmidt Verlag GmbH & Co., Berlin 2006

Bachman, R.A., 1984, "Foraging Behavior of Free-Ranging Wild and hatchery Brown Trout in a Stream", Transactions of the American Fisheries Society 113, 1 – 32

Berejikian, B.A., S.B. Mathews, T.P. Quinn, 1996, "Effects of Hatchery and Wild Ancestry and Rearing Environments on the Development of Agonistic Behavior in Steelhead Trout (*Oncorhynchus mykiss*) Fry", Canadian Journal of Fisheries and Aquatic Sciences 53: 2004 – 2014

Berejikian, B.A., R.J.F. Smith, E.P. Tezak, S.L. Schroder, C.M. Knudsen, 1999, "Chemical Alarm Signals and Complex Hatchery Rearing Habitats Affect Antipredator Behavior and Survival of Chinook Salmon (*Oncorhynchus tshawytscha*) Juveniles", Canadian Journal of Fisheries and Aquatic Sciences 56: 830 – 838

Berejikian, B.A., E.P. Tezak, T.A. Flagg, A.L. LaRae, E. Kummerow, C.V.W. Mahnken, 2000, “Social Dominance, Growth, and Habitat use of Age-0 Steelhead (*Oncorhynchus mykiss*) Grown in Enriched and Conventional Hatchery Rearing Environments”, Canadian Journal of Fisheries and Aquatic Sciences 54: 628 – 636

Berejikian, B.A., E.P. Tezak, S.C. Riley, A.L. LaRae, 2001, “Competitive Ability and Social Behavior of Juvenile Steelhead Reared in Enriched and Conventional Hatchery Tanks and a Stream Environment”, Journal of Fish Biology 59: 1600 – 1613

Berejikian, B.A., E.P. Tezak, S.L Schroder, C.M. Knudsen, 2001a, “Effects of Modified Rearing Environments on the Vulnerability of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) to Natural Predators”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1996 – 1998 Progress Report, Project NO: 199105500, 174 electronic pages, (BPA Report DOE/BP-0004768-1)

Berejikian, B.A, E.P. Tezak, S. Riley, A.L. LaRae, 2003, “Development of Social Behavior and Competitive Ability of Juvenile Steelhead Grown in Enriched and Conventional Environments, and Their Competitive Impacts on Naturally Reared Fish (Final Report for the Period March 1, 1999 through Feb 29, 2000)”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, Project No. 1991-05500, 188 electronic pages, (BPA Report DOE/BP-00000548-1)

Berejikian, B.A., E.P. Tezak, 2005, “Rearing in Enriched Hatchery Tanks Improves Dorsal Fin Quality of Juvenile Steelhead”, North American Journal of Aquaculture 67: 289 – 293

Bohlin, T., L.F. Sundström, J.I. Sundström, J. Höjesjö, J. Petterson, 2002, “Density-Dependent Growth in Brown Trout: Effects of Introducing Wild and Hatchery Fish”, Journal of Animal Ecology 71: 683 – 692

Boss, S.M., J.S. Richardson, 2002, “Effects of Food and Cover on the Growth, Survival, and Movement of Cutthroat Trout (*Oncorhynvhus clarki*) in Coastal Streams”, Canadian journal of Fisheries and Aquatic Sciences 59: 1044 – 1053

Brown, G.E., R.J.F. Smith, 1998, “Acquired Predator Recognition in Juvenile Rainbow Trout (*Oncorhynchus mykiss*): Conditioning Hatchery – Reared Fish to Recognize Chemical Cues of a Predator”, Canadian Journal of Fisheries and Aquatic Sciences 55: 611 – 617

Brown, C., R.L. Day, 2002, "The Future of Stock Enhancements: Lessons for Hatchery Practice from Conservation Biology", Fish and Fisheries 3: 79 – 94

Brown, C., T. Davidson, K. Laland, 2003, "Environmental Enrichment and Prior Experience of Live Prey Improve Foraging Behaviour in Hatchery-Reared Atlantic Salmon", Journal of Fish Biology 63(A): 187 – 196

Brown, C, K. Laland, 2003, "Social Learning in Fishes: A Review", Fish and Fisheries 4: 280 - 288

Cowx, I.G., 1998, "Stocking Strategies: Issues and Options for Future Enhancement Programmes", In: Cowx, I.G. (Ed.), "Stocking and Introduction of Fish", Fishing News Book, Hull International Fisheries Institute, University of Hull, pp: 3 – 13

Cross, T.F., P. Galvin, P. McGinnity, 1998, "Genetic Considerations in Stocking of Atlantic Salmon, *Salmo Salar*", In: Cowx, I.G. (Ed.), "Stocking and Introduction of Fish", Fishing News Book, Hull International Fisheries Institute, University of Hull, pp: 355 – 370

Dannewitz, J., 2003, "Genetic and Ecological Consequences of Fish Releases: With Focus on Supportive Breeding of Brown Trout *Salmo trutta* and Translocation of European Eel *Anguilla anguilla*", PhD thesis, Department of Evolutionary Biology, Uppsala University, Sweden

Dickson, T.A., H.R. MacCrimmon, 1982, "Influence of Hatchery Experience on Growth and Behavior of Juvenile Atlantic salmon (*Salmo salar*) Within Allopatric and Sympatric Stream Populations", Canadian Journal of Fisheries and Aquatic Sciences 39: 1453 – 1458

Doyle, R.W., R. Perez-Enriquez, M. Takagi, N. Taniguchi, 2001, "Selective Recovery of Founder Genetic Diversity in Aquacultural Broodstocks and Captive, Endangered Fish Populations", Genetica 111, 291 – 304

Einum, S., I.A. Fleming, 1997, "Genetic Divergence and Interactions in the Wild among Native, Farmed and Hybrid Atlantic Salmon", Journal of Fish Biology 50: 634 – 651

Einum, S., I.A. Fleming, 2001, "Implications of Stocking: Ecological InteractionsBetween Wild and Released Salmonids", Nordic Journal of Freshwater Research 75: 56 – 70

Elliott, J.M., 1994, "Qualitative Ecology and the Brown Trout", Oxford University Press, Walton Street, Oxford

Ewing, R.D., S.K.Ewing, 1995, "Review of the Effects of Rearing Density on Survival to Adulthodd for Pacific Salmon", The Progressive Fish Culturist 57: 1 – 25

Flagg, T.A., C. E. Nash, 1999, "A Conceptual Framework for Conservation Hatchery Strategies for Pacific Salmonids", U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-38, 46 p., U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-38, 48 p.

Flagg, T.A., B.A. Berejikian, J.E. Colt, W.W. Dickhoff, L.W. Harrell, D.J. Maynard, C.E. Nash, M.S. Strom, R.N. Iwamoto, C.V.W. Mahnken, 2000, "Ecological and Behavioral Impacts of Artificial Production Strategies on the Abundance of Wild Salmon Populations - A Review of Practices in the Pacific Northwest", National Marine Fisheries Service, Northwest Fisheries Science Center, Resource Enhancement and Utilization Technologies, 2725 Montlake Blvd. E., Seattle, WA-98112-2097

Flagg, T.A., D.J. Maynard, 2004, "Summary of 1991 – 2004 Research", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 2004 Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Fleming, I.A., B. Jonsson, M.R. Gross, 1994, "Phenotypic Divergence of Sea-ranched, Farmed, and Wild Salmon", Canadian Journal of Fisheries and Aquatic Sciences 51: 2808 – 2824

Fleming, I.A., S. Einum, 1997, "Experimental Tests of Genetic Divergence of Farmed from Wild Atlantic Salmon due to Domestication", ICES Journal of Marine Science 54: 1051 - 1063

Fleming, I. A., E. Petersson, 2001, "The Ability of Released, Hatchery Salmonids to Breed and Contribute to the Natural Productivity of Wild Populations", Nordic Journal of Freshwater Research 75: 71 – 98

Fleming, I.A., A. Thorleifur, F. Bengt, J.I. Johnsson, B.T. Björnsson, 2002, "Effects of Domestication on Growth Physiology and Endocrinology of Atlantic Salmon (*Salmo salar*)", Canadian Journal of Fisheries and Aquatic Sciences 59(8): 1323 – 1330

Fraser, J.M., 1974, "An Attempt to Train Hatchery-eared Brook Trout to Avoid Predation by the Common Loon", Transactions of the American Fischeries Society 103(4): 815 – 818

Ford, M.J., 2002, "Selection in Captivity during Supportive Breeding May Reduce Fitness in the Wild", Conservation Biology 16, No. 3: 815 - 825

Ford, J.S., R.A. Myers, 2008, "A Global Assessment of Salmon Aquaculture Impacts on Wild Salmonids", PLos Biology 6(2): e33. doi:10.1371/journal.pbio.0060033

Fuss, H.J., C. Johnson, 1988, "Effects of artificial Substrate and Covering on Growth and Survival of Hatchery-Reared Coho Salmon", The Progressive Fish Culturist 50: 232 – 237

Gross, M.R., 1998, "One Species with Two Biologies: Atlantic Salmon (*Salmo salar*) in the wild and in Aquaculture", Canadian Journal of Fisheries and Aquatic Sciences 55 (1): 131 – 144

Hatchery Reform, 2004, "Hatchery Reform: Principles and Recommendations of the Hatchery Scientific Review Group", Hatchery Scientific Review Group (HSRG), L. Mobrand, J. Barr, L. Blankenship, D. Campton, T. Evelyn, T. Flagg, C. Mahnken, R. Piper, P. Seidel, L. Seeb, B. Smoker, 1305 Fourth Avenue, Suite 810, Seattle, WA98101

Healey, M.C., U. Reinhardt, 1995, "Predator Avoidance in Naive and Experienced Juvenile Chinook and Coho Salmon", Canadian Journal of Fisheries and Aquatic Sciences 52: 614 – 622

Heath, D.D., J.W. Heath, C.A. Bryden, R.M. Johnson, C.W. Fox, 2003, "Rapid Evolution of Egg Size in Captive Salmon", Science 299: 1738 – 1740

Hickson, B., D. Leith, 1996, "Review of Feeds and Feed Delivery Systems Suitable for the Natures Program"; In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Hilborn, R., 1992, “Hatcheries and the Future in the Northwest”, Fisheries 17: 5 – 8

Hill, M.S, G.B. Zydlewski, W.L. Gale, 2006, “Comparisons between Hatchery and Wild Steelhead Trout (*Oncorhynchus mykiss*) Smolts: Physiology and Habitat Use”, Canadian Journal of Fisheries and Aquatic Sciences 63: 1627 – 1638

Holzer, G., A. Peter, H. Renz, E. Staub, 2003, “Fischereiliche Bewirtschaftung heute – vom klasischen Fischbesatz zum ökologischen Fischereimanagement”, Teilprojekt-Nr. 00/15, EAWAG

Holzer, G., G. Unfer, M. Hinterhofer, 2004, “Gedanken und Vorschläge zu einer Neuorientierung der fischereilichen Bewirtschaftung österreichischer Salmonidengewässer”, Österreichs Fischerei 57: 232 – 248

Huntingford, F.A., 2004, “Implications of Domestication and Rearing Conditions for the Behaviour of Cultivated Fishes”, Journal of Fish Biology 65(A): 122 – 142

Johnson, J.H., J.F McKeon, D.S Dropkin, 1996, “Comparative Diets of Hatchery and Wild Atlantic Salmon Smolts in the Merrimack River”, North American Journal of Fisheries Management 16: 440 – 444

Johnsson, I.J., M. Carlsson, L.F. Sundström, 2000, “Habitat Preference increases Territorial Defence in Brown Trout (*Salmo trutta*)”, Behavioral Ecology and Sociobiology 48: 373 – 377

Koljonen, M.L., J. Tähtinen, M. Säisa, J. Koskiniemi, (2002), “Maintenance of Genetic Diversity of Atlantic Salmon (*Salmo Salar*) by Captive breeding programmes and the Geographic Distribution of Microsatellite Variation”, Aquaculture 212: 69 - 92

Lamnek, S., 2005, “Qualitative Sozialforschung”, 4. vollständig überarbeitete Auflage, Beltz Verlag, Weinheim, Basel 2005

Langton, R.W, J.A. Wilson, 1998, “Economic Considerations for Fish Stoking and Enhancement”, In: Cowx, I.G. (Ed.), “Stocking and Introduction of Fish”, Fishing News Book, Hull International Fisheries Institute, University of Hull, pp: 414 – 421

Lahnsteiner, F., A. Jagsch, 2005, "Changes in Phenotype and Genotype of Austrian *Salmo trutta* Populations during the last Century", Environmental Biology of Fishes 74: 51 – 65

Largiadèr, R., D. Hefti, (2002), "Genetische Aspekte des Schutzes und der Nachhaltigen Bewirtschaftung von Fischarten", Bundesamt für Umwelt, Wald und Landschaft BUWAL, 3003 Bern

Lorenzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., de Silva, S.S., araway, C.J., Hartmann, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., ugunan, V.V. & Swar, D.B. 2001, "Strategic Review of enhancements and culture-based fisheries", In: R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery (Eds). Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 221 – 237

Lynch, M., M. O'Hely, 2001, "Captive Breeding and the Genetic Fitness of Natural Populations", Conservation Genetics 2: 363 – 378

Maynard, D.J.m M.S. Kellett, D.A. Frost, E.P. Tezak, W.C. McAuley, T.A. Flagg, C.V.W. Mahnken, 1992, "The Behavior and Postrelease Survival of Fall Chinokk Salmon Reared in Conventional and Seminatural Raceways", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J., M. Crewson, E.P. Tezak, W.C. McAuley, T.A. Flagg, 1994, "The Postrelease Survival of Yakima River Spring Chinook Salmon Acclimated in Conventional and Seminatural Raceways", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J, T.A. Flagg, C.V.W Mahnken, 1996, "A Review of Seminatural Culture Strategies for Enhancing the Postrelease Survival of Anadromous Salmonids", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J, G.C. McDowell, E.P. Tezak, T.A. Flagg, 1996a, “Effects of Diets Supplemented with Live Food on the Foraging Behavior of Cultured Fall Chinook Salmon”, The Progressive Fish Culturist 58: 187 – 191

Maynard, D.J., T.A. Flagg, B.A. Berejikian, 1996b, “A Comparison of Hatchery and Wild Salmon Biology”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J., E.P. Tezak, B.A. Berejikian, T. Flagg, 1996c, “The Effect of Feeding Spring Chinook Salmon a live Food Supplemented Diet During Acclimation, 1995”, In: Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J., M. Crwson, E.P. Tezak, W.C. McAuley, S.L. Schroder, C. Knudsen, T.A. Flagg, C.V.W. Mahnken, 1996d, The Postrelease Survival of Satsop River Fall Chinook Salmon Reared in Conventional and Seminatural Raceway habitats, 1994”, In: Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Maynard, D.J, J.L. Hackett, M.R. Wastel, A.L. LaRae, G.C. McDowell, T.A. Flagg, C.V.W Mahnken, 2001, “The Effect of Automated Sub-Surface Feeders on the Behavior and Predator Vulnerability of Fall Chinook Salmon”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1996 – 1998 Progress Report, Project NO: 199105500, 174 electronic pages, (BPA Report DOE/BP-0004768-1)

Maynard, D.J., A.L. LaRae, G.C. McDowell, G.A. Snell, T.A. Flagg, C.V.W. Mahnken, 2001a, “Effects of Predator Avoidance Training on the Postrelease Survival of Fall Chinook Salmon”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1996 – 1998 Progress Report, Project NO: 199105500, 174 electronic pages, (BPA Report DOE/BP-0004768-1)

Maynard, D.J., G.C. McDowell, G.A. Snell, A.L. LaRae, T.A. Flagg, C.V.W. Mahnken, 2001b, “Effect of Live Food Diets on the Foraging Behavior of Cultured Fall Chinook Salmon”, In: “Development of a Natural Rearing System to Improve Supplemental Fish Quality”, 1996

– 1998 Progress Report, Project NO: 199105500, 174 electronic pages, (BPA Report DOE/BP-0004768-1)

Maynard, D.J., G.E. Vander Haegen, J.E. Colt, G.C. McDowell, T.A. Flagg, 2003, "Effects of Seminatural Rearing on Coho Salmon, 2000-2002", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", Project No. 1991-05500, 188 electronic pages, (BPA Report DOE/BP-00000548-1)

Maynard, D.J., T.A. Flagg, R.N. Iwamoto, C.V.W. Mahnken, 2004, "A Review of Recent Studies Investigating Seminatural Rearing Strategies as a Tool for Increase Pacific Salmon Postrelease Survival", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 2004 Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Maynard, D.J., J.E. Colt, J. Dixon, G.C. McDowell, G.E. Vander Haegen, T.A. Flagg, 2004a, "Effects of Seminatural Habitat Rearing on Coho Salmon, 2000 – 2003", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Maynard, D.J., S.C. Riley, T.A. Flagg, 2004b, "Development of a Natural Rearing System to Improve Supplemental Fish Quality – Final Report", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

McDonald, D.G., C.L. Milligan, W.J. McFarlane, S. Croke, S. Currie, B. Hooke, R.B. Angus, B.L. Tufts, K. Davidson, 1998, "Condition and Performance of Juvenile Atlantic Salmon (*Salmo salar*): Effects of Rearing Practices on Hatchery Fish and Comparison with Wild Fish", Canadien Journal of Fisheries and Aquatic Sciences 55, 1208 – 1219

McNeil, W., 1991, "Expansion of Cultured Pacific Salmon into Marine Ecosystems", Aquaculture 98: 173 – 183

Mesick, C.F., 1988, "Effects of Food and Cover on Numbers of Apache and Brown Trout Establishing Residency in Artificial Stream Channels"; Transactions of the American Fisheries Society 117: 421 – 431

Metcalfe, N.B., S.K. Valdimarsson, I. J. Morgan, 2003, "The Relative Roles of Domestication, Rearing Environment, Prior Residence and Body Size in Deciding Territorial Contests Between Hatchery and Wild Juvenile Salmon", Journal of Applied Ecology 40: 535 – 544

Olla, B.L., W. Davis, C.H. Ryer, 1996, "Predation on Hatchery-Reared Pacific Salmon: Possible Causes of Vulnerability; A Literature Review, Synthesis, and Preliminary Experiments", In: "Development of a Natural Rearing System to Improve Supplemental Fish Quality", 1991 – 1995 Progress Report, Project No. 199105500, 233 electronic pages, (BPA Report DOE/BP-20651-1)

Oppenheim, A., 2004, "Questionnaire Design, Interviewing and Attitude Measurement", Pinter Publishers, London

Patino, R., C. Schreck, J. L. Banks, W. S. Zaugg, 1986, "Effects of Rearing Conditions on the Developmental Physiology of Smolting Coho Salmon", Transactions of the American Fisheries Society 115: 828 – 837

Petersson, E., T. Järvi, N.G. Steffner, B. Ragnarsson, 1996, "The Effect of Domestication on Some Life History Traits of Sea Trout and Atlantic Salmon", Journal of Fish Biology 48: 776 – 791

Philippart, J.C., 1995, "Is Captive Breeding an Effective Solution for the Preservation of Endemic Species?", Biological Conservation 72: 281 – 295

Reisenbichler, R.R., S.P. Rubin, 1999, "Genetic Changes from Artificial Propagation of Pacific Salmon Affect the Productivity and Viability of Supplemented Populations", ICES Journal of Marine Science 56: 459 – 466

Reisenbichler, R.R., 2004, "Uncertainty and Research Needs for Supplementing Wild Populations of Anadromous Pacific Salmon"; American Fisheries Society Symposium 44: 263 – 275, In: "Propagated Fish in Resource Management", American Fischeries Society Symposium 44, Bethesda, Maryland 2004

Riley, S.C., C.P. Tatara, T.A. Flagg, R.C. Endicott, J.A. Atkins, 2004, "Growth and Survival of Hatchery- and Naturally-Reared Steelhead Fry in a Semi-Natural Stream Channel", In: Development of a Natural Rearing System to Improve Supplemental Fish Quality, Final

Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Riley, S.C., B.A. Berejikian, T.A. Flagg, 2004a, "Effects of Density and Rearing Environment on the behavior of Steelhead trout *Oncorhynchus myiss* fry in a laboratory stream", In: Development of a Natural Rearing System to Improve Supplemental Fish Quality, Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Riley, S.C., T.A. Flagg, R.C. Endicott, J. Atkins, A. Larae, 2004b, "Effects of Density and Rearing Environment on the Agonistic Behavior and Habitat use of Steelhead *Oncorhynchus mykiss* in the Presence of Competitors and Predators in a Laboratory Stream", In: Development of a Natural Rearing System to Improve Supplemental Fish Quality, Final Report, Project No. 199195500, 174 electronic pages, (BPA Report DOE/BP-00004768-2)

Salvanes, A.G.V., 2001, "Ocean Ranching", In: Encyclopedia of Ocean Sciences (eds. J. Steele, K. K. Turkian and S. A. Thorpe), Academic Press 4: 1973 - 1982

Simpson, R., P. Jackson, 1996, "The Mary River Cod Research and Recovery Plan", Queensland Department of Primary Industries Fisheries Group, Australia

Smith, M.L., 2004, "Perceptions About Science and Scientism in Fisheries Management: An Angler's View", American Fisheries Symposium 44: 145 – 149, In: "Propagated Fish in Resource Management ", American Fisheries Society Symposium 44, Bethesda, Maryland 2004

Snyder, N.F.R., Derrickson S.R., Beissinger S.R., Wiley, J.W., Smith T.B., Toone W.D., Miller B., 1996, "Limitations of Captive Breeding in Endangered Species Recovery", Conservation Biology 10 No.2: 338 – 348

Soderberg, R.W., J.W. Meade, 1987, "Effects of Rearing Density on Growth, Survival, and Fin Condition of Atlantic Salmon", The Progressive Fish-Culturist 49: 280 – 283

Soderberg, R.W., J.W. Meade, L.A. Redell, 1993, "Growth, Survival, and Food Conversion of Atlantic Salmon Reared at Four Different Densities with Common Water Quality", The Progressive Fish-Culturist 55: 29 – 31

Sundström, L.F., M. Lohmus, J.I. Johnsson, 2003, "Investment in Territorial Defence Depends on Rearing Environment in Brown Trout (*Salmo trutta*)", Behavioral Ecology and Sociobiology 54: 249 – 255

Sundström, L.F., T. Bohlin, J.I. Johnsson, 2004, "Desnity-Dependent Growth in Hatchery-Reared Brown Trout Released into a Natural Stream", Journal of Fish Biology 65: 1385 – 1391

Sundström, L.F, E. Petersson, J.I. Johnsson, J. Dannewitz, J. Höjesjö, T. Järvi, 2005, "Heart Rate Response to Predation Risk in *Salmo trutta* are Affected by the Rearing Environment", Journal of Fish Biology 67: 1280 – 1286

Taylor, E.B., 1986, "Differences in Morphology between Wild and Hatchery Populations of Juvenile Coho Salmon", The Progressive Fish-Culturist 48: 171 – 176

Vehanen, T., P.L. Bjerke, J. Heggenes, A. Huusko, A. Mäki-Petäys, 2000, "Effect of Fluctuating Flow and Temperature on Cover Type Selection and Behaviour by Juvenile Brown Trout in Artificial Flumes", Journal of Fish Biology 56: 923 – 937

Vidergar, D., T. Petering, P. Kline, 2003, "Chinook Salmon Seminatural Rearing Experiment: Sawtooth and Clearwater Fish Htcheries, Idaho; 1992–2003 Progress Report", Idaho Department of Fish and Game, 600 South Walnut Street, IDFG Report Number 03-35

Wagner, E.J, M.D. Routledge, S.S Intelmann, 1996, "Fin Condition and Health Profiles of Albino Rainbow Trout Reared in Concrete Raceways with and without Cobble Substrate", The Progressive Fish-Culturist 58: 38 – 42

Wagner, E.J., T. Jeppsen, R. Arndet, M.D. Routledge, Q. Bradwisch, 1997, "Effects of Rearing Density upon Cuthroat Trout Hematology, Hatchery performance, Fin Erosion, and General Health and Condition", The Progressive Fish Culturist 59: 173 – 187

Waples, R.S., C. Do, 1994, "Genetic Risk Associated with Supplementation of Pacific Salmonids: Captive Broodstock Programs", Canadian Journal of Fisheries and Aquatic Sciences 51(1): 310 – 329

Weber, E.D., K.D. Fausch, 2003, “Interactions between Hatchery and Wild Salmonids in Streams: Differences in Biology and Evidence for Competition”, Canadian Journal of Fisheries and Aquatic Sciences 60: 1018 – 1036

Weiss, S., S. Schmutz, 1999, “Performance of Hatchery-Reared Brown Trout and Their Effects on Wild Fish in Two Small Austrian Streams”, Transactions of the American Fisheries Society 128: 302 – 316

Weiss, S., C. Schlötterer, H. Waidbacher, M. Jungwirth, 2001, “Haplotype (mtDNA) Diversity of Brown Trout *Salmo trutta* in Tributaries of the Austrian Danube: Massive Introgression of Atlantic Basin Fish – by Man or Nature?”, Molecular Ecology 10, 1241 – 1246

Wiley, R.W., 2004, “Fundamentals of Fisheries Management, 2003: Developments in Wyoming since 1994”, American Fisheries Society Symposium 44: 139 – 144

**Retrieved via Internet:**

Clemmons, J.R., R. Buchholz, 1997, “Behavioral Approaches to Conservation in the Wild”, Cambridge University press, Cambridge, 389p., Retrieved November 2007, URL: http://books.google.at/books?hl=de&lr=&id=9wCReZ-ito8C&oi=fnd&pg=PR11&dq=behavioural+approaches+to+conservation+in+the+wild&ots=0MYM2pynO0&sig=AVpkR5ZizK-fH2OWXJf-Vpq9uD4

FAO, 2007, „World Aquaculture Production by Species Group“, Retrieved October 2007, URL: ftp://ftp.fao.org/fi/stat/summary/b-1.pdf

Hatchery Reform, 2007, „Puget Sound and Coastal Washington Hatchery Reform Project“, Retrieved October 2007, URL: http://www.lltk.org/pages/hatchery_reform_project/HRP_About.html

Olney, P.J.S., G.M. Mace, A.T.C. Feistner, 1994, “Creative Conservation: Interactive Maegement of Wild and Captive Animals”, Chapman & Hall, London 517p., Retrieved November 2007, URL: http://books.google.at/books?hl=de&lr=&id=xbprc5CjGVgC&oi=fnd&pg=PR15&dq=Interactive+management+of+of+wild+and+captive+animals&ots=SCei13yhlm&sig=3J3VO-pn1TvifrEQ_eCqqM9tibA

STATISTIK AUSTRIA, 2007, “STATISTIK AUSTRIA – Die Informationsmanager”, Retrieved December 2007, URL: http://www.statistik.at/web_de/statistiken/land_und_forstwirtschaft/viehbestand_tierische_erzeugung/aquakultur/index.html

VOEF, 2007, „Verband Österreichischer Forellenzüchter”, Retrieved January 2007, URL: http://www.forellenzuchtverband.at/index.php?id=4

Bezugsquellennachweis, 2007, „Karpfen, Forelle und Co.“, Retrieved January 2007, URL: http://www.teichwirteverband.at/Aktuelles/Bezugsquellen.pdf

Pajek, 2007, „Networks/Pajek Programme for Large Network Analysis“, Retrieved November 2007, URL: http://vlado.fmf.uni-lj.si/pub/networks/pajek/

FAS, 2008, „FAS.research Network Analysis for Science and Business”, Retrieved March 2008, URL: http://www.fas.at/science/learning/index.htm

# 10. List of Figures

# 11. List of Tables

# 12. Appendices

## Appendix I: Interviewees

**Lower Austria**

Thomas Dolezal

Herbert Frenzl

Johannes Hager

Josef Härtensteiner

Johann Haimel

Anton Holl

Christoph Hübner

Kuppelwieser'sche Forstverwaltung

Erich Lanzenberger

Thomas Muschl

Dieter Sigl

Karl Strohmayer

**Styria**

Hannes Igler

Helga Igler

Erwin Kölbl

Rudolf Leger

Österreichische Bundesforste AG

Schwarzenberg'sche Familienstiftung

Josef Stock

Klaus Taxacher

Hofer Wilfried

Jürgen Wuitz

**Upper Austria**

Martin Ebner

Peter Hartl

Erich Glück

Alois Köttl

## Appendix II: Questionnaire

### I Section: Pisciculture

1. How long have you been rearing fish?
2. In addition to brown trout, which fish species are you rearing in your hatchery?
3. Besides rearing brown trout for stocking purposes, do you also produce brown trout for consumption?
   If so, are there any differences in the rearing practice?
4. Can you describe the husbandry conditions for brown trout with regard to the different age classes?
5. Are you operating an incubation unit?
   If so, how many brown trout fish eggs are you producing annually in your pisciculture?
6. Are you keeping your own brown trout-brood stock?
   If so:
   a. What do you know about the origin of your brood stock?
   b. Since when have you been rearing this brood stock?
   c. How many individuals does your brood stock comprise of?
   d. How do you supplement your brood stock?
7. How many brown trout are you rearing annually for stocking purposes?
8. Up to which age class (size) are you growing brown trout?
9. If you could fulfil one wish regarding your area of operation, what would you wish?

### II Section: Distributive Trading

10. Are you purchasing additional brown trout and fertilized fish eggs from other hatcheries?
    If so:
    a. Where do you get the additional eggs/fish from?
    b. How many fish and fertilized fish eggs do you purchase annually?
11. Do you provide other piscicultures with your brown trout?
12. Do you supply other piscicultures with fertilized fish eggs of brown trout?
    If so:
    a. How many fertilized fish eggs are you trading annually?
    b. Which hatcheries do you supply with fertilized fish eggs?
13. Which rivers are stocked and have been stocked with brown trout from your hatchery?

### III Section: Qualitative Criteria

14. Which qualities do you consider to be important for hatcheries rearing brown trout?

15. By means of which criteria do you select brown trout for supplementation of your brood stock?
    How would you describe a beautiful coloured brown trout?
16. Which criteria do you regard to be important for high quality brown trout?
17. Which criteria are important for your customers?
18. Do you believe that piscicultures should change their methods of operation?
19. Do you believe that piscicultures should rear regionally adapted brown trout?
20. Can you imagine changing your rearing methods over to (semi-) natural rearing methods?
21. Can you imagine changing your brown trout brood stock?
22. How would you assess the level of prices for hatchery reared brown trout?
23. At the moment the trading of brown trout for stocking purposes is done in kilo, do you believe that other accounting method might be better?
24. Have you already heard from the project-initiative TROUTCHECK?
    If so, what is your opinion of this project-initiative?

**IV Section: Network**

25. Is your stock of customers alternating regularly?
26. How are customers made aware of your company?
27. Are you member of any professional associations?
    If so, do you feel yourself satisfactorily represented by these associations?
28. Which hatchery operators apart from you are especially well versed in the area of rearing brown trout?
29. Who has got sufficient knowledge and means in the area of pisciculture to be able to change things?
30. Which pisciculturists do you think should also take part in this survey?
31. Do you feel well informed about the (legislative) European proceedings concerning aquaculture?

**<u>Interviewleitfaden</u>**

**Block I: Fischzucht**

1. Wie lange züchten Sie bereits Fische?
2. Welche Arten, neben der Bachforelle, züchten Sie in Ihrer Fischzucht?
3. Züchten Sie ausschließlich Besatzfische, oder auch Speisefische?
   Wenn ja, gibt es Aufzuchtsunterschiede?
4. Wie halten Sie Ihre Bachforellen im Bezug auf die unterschiedlichen Altersstadien?
5. Betreiben Sie ein Bruthaus?
   Wenn ja, wie viele Bachforelleneier werden jährlich in ihrer Fischzucht produziert?
6. Haben Sie einen eigenen Bachforellen-Mutterfischstamm?
   Wenn ja:
   a. Was wissen Sie über die Abstammung Ihrer Mutterfische?
   b. Wie lange züchten Sie diesen Mutterfischstamm bereits weiter?
   c. Wie groß ist Ihr Mutterfischstamm?
   d. Aus welchem Fischmaterial ergänzen Sie Ihren Mutterfischstamm?
7. Wie viele (Bachforellen-) Besatzfische werden in Ihrer Fischzucht jährlich produziert?
8. Bis zu welcher Altersklasse (Größe) ziehen Sie ihre Fische heran?
9. Wenn Sie einen auf Ihren Beruf bezogenen Wunsch frei hätten, was würden Sie sich wünschen?

**Block II: Fischhandel**

10. Kaufen Sie Bachforelleneier oder Bachforellen von anderen Fischzüchtern zu?
    Wenn ja:
    a. Bei wem?
    b. Wie viele jährlich?
11. Beliefern Sie Fischzuchten mit Ihren Bachforellen?
12. Verkaufen Sie Augenpunkteier?
    Wenn ja:
    a. Wie viele jährlich?
    b. An wen?
13. Welche Gewässer werden bzw. wurden von Ihnen mit Bachforellen besetzt?

**Block III: Qualitative Kriterien**

14. Was sind für Sie die wichtigsten qualitativen Voraussetzungen für einen Bachforellenzuchtbetrieb?
15. Anhand welcher Kriterien wählen Sie eine Bachforelle für die Weiterzucht aus?

Wie würden sie einschön gefärbte Forelle beschreiben?

16. Was kennzeichnet für Sie einen qualitativ hochwertigen Bachforellen-Besatzfisch?
17. Welche Kriterien sind für Ihre Kunden wichtig?
18. Glauben Sie, dass Fischzuchtbetriebe an ihrer Arbeitsweise etwas ändern müssten?
19. Sollten Fischzüchter gebietstypische Bachforellen züchten?
20. Können Sie sich vorstellen, Ihre Aufzuchtsmethoden auf naturnahe Methoden (Seitenbachbewirtschaftung, naturnahe Fließrinnen, etc.) umzustellen?
21. Können Sie sich vorstellen, Ihren Mutterfischstamm zu verändern?
22. Wie beurteilen Sie die Preislage der Bachforellensetzlinge?
23. Beim Handel von Besatzfischen wird meistens in Kilo abgerechnet. Sollte man Ihrer Meinung nach die Abrechnungsmethode ändern und zum Beispiel in Stück abrechnen?
24. Haben Sie bereits von der Projekt-Initiative „TROUTCHECK“ gehört?
    Wenn ja, finden Sie diese Projekt-Initiative gut?

**Block IV: Züchternetzwerk**

25. Haben Sie hauptsächlich Stammkunden oder wechselt Ihr Kundenstock regelmäßig?
26. Wie werden Kunden auf ihren Betrieb aufmerksam?
27. Sind Sie Mitglied beim Verband österreichischer Forellenzüchter, Fischereivereinen oder verwandten Institutionen
    Wenn ja, fühlen Sie sich von den Vereinen gut vertreten?
28. Wer außer Ihnen kennt sich noch besonders gut in der Forellenzucht aus?
29. Wer hat genügend Einfluss, um in der Forellenzucht etwas zu verändern (Aufzuchtmethoden, etc.)?
30. Welche Fischzüchter sollte man zu diesem Befragungsthema noch interviewen?
31. Fühlen sie sich ausreichend über die EU-weiten Geschehnisse hinsichtlich Aquakultur informiert?

## Appendix III: Contact list

| Bundesland | Fischzüchter | Kenne ich | Habe Kontakt |
|---|---|---|---|
| Burgenland | Preisegger Rudolf | | |
| Kärnten | Feichtinger Christian | | |
| Kärnten | Jobst Alois | | |
| Kärnten | Kärnter Landesfischzuchtgenossenschaft | | |
| Kärnten | Marzi Gerhard | | |
| Kärnten | Offner Albin | | |
| Kärnten | Payr Markus | | |
| Kärnten | Sterz Peter | | |
| Niederösterreich | Dolezal Thomas | | |
| Niederösterreich | Hübner Christoph,Forellenzuchtanstalt Wechselforelle | | |
| Niederösterreich | Frenzl Herbert | | |
| Niederösterreich | Hager Johannes | | |
| Niederösterreich | Haimel Johann | | |
| Niederösterreich | Härtensteiner Josef und Stefanie | | |
| Niederösterreich | Holl Anton | | |
| Niederösterreich | Kuppelwieser'sche Forstverwaltung Seehof | | |
| Niederösterreich | Lanzenberger Erich, Fischzucht Anton Füsselberger | | |
| Niederösterreich | Lengauer Dieter | | |
| Niederösterreich | Mandl'sche Forstverwaltung | | |
| Niederösterreich | Muschl Thomas, Fischzucht Bründlmühle | | |
| Niederösterreich | Rabenhaupt Karl, Fischerei | | |
| Niederösterreich | Schagerl Hubert | | |
| Niederösterreich | Scheinhart K. und K. | | |
| Niederösterreich | Schlosser Markus | | |
| Niederösterreich | Sigl Dieter | | |
| Niederösterreich | Straka Robert, Die Wathosen gesnbR | | |
| Niederösterreich | Strohmayer Forellenzucht | | |
| Niederösterreich | Weinzettl Josef | | |
| Niederösterreich | Yanka Mathey | | |
| Oberösterreich | Baumgartner Heinz | | |
| Oberösterreich | Brandstätter Rudolf | | |
| Oberösterreich | Buchegger Hans | | |
| Oberösterreich | Dietl Christa | | |
| Oberösterreich | Dürnberger Horst | | |
| Oberösterreich | Ecklbauer Walter | | |
| Oberösterreich | Enne Gerhard | | |
| Oberösterreich | Forellen Pöttinger | | |
| Oberösterreich | Forellenzucht St. Florian Fam. Ebner | | |
| Oberösterreich | Frauscher Christian | | |
| Oberösterreich | Friedl Christian | | |
| Oberösterreich | Ganser Friedrich | | |
| Oberösterreich | Glück Erich | | |
| Oberösterreich | Glück Johann und Rosina | | |

| Bundesland | Fischzüchter | Kenne ich | Habe Kontakt |
|---|---|---|---|
| Oberösterreich | Grubmüller Josef | | |
| Oberösterreich | Haas Erich | | |
| Oberösterreich | Haas Georg | | |
| Oberösterreich | Hager Johann | | |
| Oberösterreich | Haider Johann | | |
| Oberösterreich | Hartl Peter | | |
| Oberösterreich | Kaltenriener Hubert | | |
| Oberösterreich | Köstler Franz | | |
| Oberösterreich | Köttl Alois | | |
| Oberösterreich | Kratschmayr Josef | | |
| Oberösterreich | Krieger Ferdinand | | |
| Oberösterreich | Leitner Helmut | | |
| Oberösterreich | Leitner Karl | | |
| Oberösterreich | Maier Hans | | |
| Oberösterreich | Maier Karl | | |
| Oberösterreich | Maierhofer Margarete | | |
| Oberösterreich | Österreichische Bundesforste AG, Forstbetrieb Inneres Salzkammergut | | |
| Oberösterreich | Platzer Erwald | | |
| Oberösterreich | Raffeetseder Josef | | |
| Oberösterreich | Reischenböck Johann | | |
| Oberösterreich | Reisinger Manfred | | |
| Oberösterreich | Riegler Gerold | | |
| Oberösterreich | Scheichl Josef | | |
| Oberösterreich | Taschner Walter | | |
| Oberösterreich | Unger Manfred | | |
| Oberösterreich | Weinberger Alois | | |
| Oberösterreich | Wiesinger Franz | | |
| Oberösterreich | Zöls Rudolf | | |
| Salzburg | Bundesanstalt für Fischereiwirtschaft, Fischzuchtbetrieb Kreuzstein | | |
| Salzburg | Gassner Matthias | | |
| Salzburg | Grundner Anton | | |
| Salzburg | Rainer Othmar | | |
| Salzburg | Schatteiner Siegfried | | |
| Salzburg | Siller Johann | | |
| Salzburg | Steiner Volker, Fischzucht Wallersee | | |
| Steiermark | Bültermann-Igler Helga | | |
| Steiermark | Hofer Wilfried | | |
| Steiermark | Igler Forellenzucht | | |
| Steiermark | Kölbl Erwin | | |
| Steiermark | Leger Rudolf | | |
| Steiermark | Mauerhofer Franz | | |
| Steiermark | Österreichische Bundesforste | | |
| Steiermark | Reimoser Helfried | | |
| Steiermark | Reisinger Anna | | |
| Steiermark | Schwarzenbergsche Familienstiftung | | |
| Steiermark | Steiger Leo | | |
| Steiermark | Steiererhof | | |
| Steiermark | Stock Josef | | |
| Steiermark | Taxacher Klaus | | |

| Bundesland | Fischzüchter | Kenne ich | Habe Kontakt |
|---|---|---|---|
| Steiermark | Unger Gottfried | | |
| Steiermark | Wuitz Karin | | |
| Tirol | Angerer Thomas | | |
| Tirol | Ernst Peter | | |
| Tirol | Gundolf Josef | | |
| Tirol | Hechenberger Simon | | |
| Tirol | Hochleithner Martin | | |
| Tirol | Kandler Anton | | |
| Tirol | Kirchmair Roman | | |
| Tirol | Mayr Toni | | |
| Tirol | Oettl Forellenhof - Fischzucht | | |
| Tirol | Ruprechter Erwin | | |
| Tirol | Steger Volkmar | | |
| Tirol | Thaler Wolfgang | | |
| Vorarlberg | Fischereiverein Nenzing | | |
| Vorarlberg | Grass Werner Hirschbrunnen | | |
| Vorarlberg | Güfel Elmar und Peter | | |
| Wien | Martinic Mira | | |
| | | | |
| Sonstige: | | | |
| | | | |
| | | | |
| | | | |

# Appendix IV: Output Data from the Surveyed Aquaculturalists

| Federal state | Aquaculture | Broodstock [Ind.] | Produced eggs | Sale of eggs | Purchase of eggs | Sale of trout | Purchase of trout | Stocked trout [Ind.] | Stocked trout [t] |
|---|---|---|---|---|---|---|---|---|---|
| Styria | A | 5.000 | 1.000.000 | 10.000 | 0 | Yes | 0 | 300.000 | 2 |
| Lower Austria | B | 600 | 300.000 | 100.000 | 0 | Yes | 0 | 60.000 | 10 |
| Upper Austria | C | 1.200 | 1.000.000 | 500.000 | 0 | Yes | 0 | 400.000 | 20 |
| Lower Austria | D | 100 | 60.000 | 10.000 | 0 | No | 0 | 50.000 | 5 |
| Upper Austria | E | 800 | 500.000 | 0 | 0 | Yes | 0 | 30.000 | 10 |
| Lower Austria | F | 120 | 90.000 | 0 | 0 | Yes | 0 | 10.000 | 3 |
| Lower Austria | G | 0 | 0 | 0 | 70.000 | No | 0 | 20.000 | 5 |
| Lower Austria | H | 30 | 4.000 | 0 | 0 | Yes | 0 | 1.500 | 0,01 |
| Upper Austria | I | 5.000 | 4.000.000 | 2.000.000 | 0 | Yes | 0 | 400.000 | 40 |
| Styria | J | 0 | 0 | 0 | 0 | No | 20.000 | 7.500 | 3 |
| Lower Austria | K | 30 | 15.000 | 0 | 0 | No | 0 | 5.000 | 1 |
| Lower Austria | L | 70 | 0 | 0 |  | No | 0 | 4.000 | 1 |
| Styria | M |  | 400.000 |  |  | Yes | 0 |  |  |
| Styria | N | 0 | 0 | 0 |  | Yes |  | 60.000 | 6 |
| Styria | O | 0 | 0 | 0 | 400.000 | Yes | 500.000 | 20.000 | 5 |
| Upper Austria | P | 500 | 1.000.000 | 600.000 | 0 | Yes |  | 30.000 | 10 |
| Lower Austria | Q | 5.000 | 60.000 | 0 | 0 | No | 0 | 23.000 | 2 |
| Lower Austria | R | 100 | 50.000 | 0 | 20.000 | No | 0 | 20.000 | 2 |
| Styria | S | 0 | 0 | 0 | 0 | Yes | 1.000 | 80.000 | 8 |
| Lower Austria | T | 200 | 60.000 | 0 | 0 | No | 0 | 40.000 | 12 |
| Styria | U | 50 | 30.000 | 20.000 | 120.000 | No | 0 | 100.000 | 12 |
| Lower Austria | V |  | 15.000 | 5.000 |  | Yes | 0 | 5.000 | 2 |
| Styria | W | 400 | 150.000 | 0 | 0 | No | 0 | 40.000 | 12 |
| Lower Austria | X | 200 | 250.000 | 200.000 | 0 | No | 0 | 15.000 | 2 |
| Styria | Y | 150 | 80.000 | 0 | 7.500 | No | 7.500 | 80.000 | 0,50 |
| Styria | Z | 400 | 300.000 | 0 | 70.000 | Yes | 0 | 50.000 | 15 |
| **Total** | **26** | **19.950** | **9.364.000** | **3.445.000** | **687.500** |  | **528.500** | **1.851.000** | **187** |

**Appendix IV:** Key figures of the questioned aquaculture operations; Grey shaded fields indicate unanswered questions