150 years of Fish Stocking in the Archipelago of Stockholm: Gambling with ecological and social resilience?

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Abstract
The focus of this paper is the evolution between the use of fish stocking, common-pool fish resources, and resource user structures in the Archipelago of Stockholm between 1850-2000. Major drivers for fish stocking include development of hatchery techniques, governmental policy, overexploitation, environmental degradation and urbanization. The dominating management incentive of fish stocking is to counteract uncertainty by creating constant fish catches, thereby supporting sports fishing, tourism and providing local employment. Three major categories of fish stocking are used to attain these goals: new introduction, enhancement or complementation, and supplementation. A new culture-based, mixed-stock, put-grow-and-take fishery has been built-up in the archipelago, focusing on a narrow range of piscivorous food and game species. Consequences of fish stocking include loss of social resilience due to masking effects of ecosystem disturbances, support of user shift from commercial to sport fishery, loss of traditional ecological knowledge, and increasing open-access fishing. Ecological and genetic effects, resulting in loss of functional diversity, risk rendering the archipelago ecosystem less resilient to withstand sudden perturbations. In all, the rapid development and use of fish stocking in combination with the mis-match of temporal and spatial scales between the social systems and nature, has resulted in a spiral effect: fish stocking –> new drivers emerging –> increasing pressure on managers to release fish – > new fish stockings, etc. The short-term and

single-species focus among managers and resource users is not consistent with developing an adaptive co-management to secure the future generation of ecosystem services.

Key words: fish stocking, resilience, cross-scale, culture-based fishery, adaptive management

1. Introduction

The use of fish stocking as a managment tool is believed to have the potential to augment the future fishery production of the global water resources (FAO 1998,1999). Fish stocking, a form of aquaculture[1], is when native or non-native fish, reared in hatcheries or transfered from other areas, are introduced into marine- or freshwaters. Recent estimates show that almost 160 million juveniles are produced to be "released to the wild" per day around the world (FAO 1998). In fact, using fish from aquaculture is the most widely practiced tool used for augmenting the inland fish production (FAO 1999). For example, the capture fishery in lakes and reservoirs in China and India increased with 10 and 19 % respectively between 1994-1995 mainly due to fish stocking practices (FAO 1998). Fish stocking to improve the fish production in marine environments is also focused but no international data is available (Munro and Bell 1997, Grimes 1998). In all, much of today's recreational and commercial fisheries along coasts, in lakes, and in water reservoirs have come to rely on hatchery-produced fish (Sterne 1995).

To incorporate ecosystem objectives into fisheries and ocean management is increasingly focused at the international arena, such as considering ecosystem effect of marine capture fishery (Dayton et al. 1995, Jennings and Kaiser 1998, ICES/SCOR 1999). Ecosystem effects may influence the generation of fundamental services for maintaining ecosystem functioning and resilience, and demand-derived ecosystem services based on human values (Holmlund and Hammer 1999). There is also a

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Aquaculture is the farming of aquatic organisms /...(and).../ implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection of predators etc. Farming also implies individual or corporate ownership of the stock being cultivated /.../ aquatic organisms which are harvested by an individual or corporate body which has owned them throughout growing body of examples of functioning management regimes, including the studies of ”parametric management” looking at ”how” fishing is done rather than ”how much” fish that are caught (Acheson et al. 1998). However, ecosystem consequences of fish stocking, operating at different spatial and temporal scales and at different hierarchial levels do not recieve appropriate attention. The numerical approach of conventional fishery management frequently operates under short-term and narrow-range social and institutional pressures in contrast to the long and wide-range scales of many natural processes (HANNA?). Managers treat fish stocks as discrete commodities in space and time, and ignore interactions and variability of ecosystems (Acheson et al. 1998). For example, the success or failure of fish stocking are generally measured in terms of quick responses, such as catch rates of a few species, in the geographic area where the fish stocking occured. The capacity of linked socio-ecological systems to generate goods and services is rarely considered. For example, introducing hatchery fish into the wild, and increasing mixed-stock fishery, may result in ecological competition, predation, and habitat alteration (Krueger and May 1991, Utter 1994). Genetic effects may also result including loss of inter- and intrapopulational diversity, reduced population size, and decreased variabilty and quality of hatchery fish (Allendorf and Ryman 1987, Waples 1991, Laikre et al. 2000). Socio-economic effects may include masking of natural parameters for monitoring, loss of feedback mechanisms, loss of ecological knowledge, loss of conservation incentives among resource users, conflicts of allocation between resource user groups, and the evolution of a culture-based fishery (Gadgil 1987, FAO 1999). These social effects in turn are likely to cause indirect ecosystem effects.

Important drivers for the use of fish stocking include development of hatchery techniques, governmental policy, stakeholder curiosity, overexploitation, loss of spawning and nursery habitats, population pressure, urbanization and industrialization processes (Figure 1). The goal is in many cases to mitigate these natural or anthropogenic disturbances and create constant, non-fluctuating fish stocks. Uncertainty is to be counteracted by means of exploiting under-utilised parts of the food chain, improve the natural recrutiment, and to favour species that would not breed naturally in the system (FAO 1999). Three major categories of fish introduction

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their rearing period contribute to aquaculture while auqtic organisms which are exploitable by the public as a common property resource /.../ are the harvest of fisheries (FAO 1999).

can be identified: new introduction, enhancements or complementations, and supplementations.

Non-dynamic approaches to fish stocking are associated with many risks, including the evolution of more vulnerable ecosystems, weakened feedback mechanisms, rigid and unresponsive management agencies, and more dependent societies (Holling 1986). Instead, fish stocking practices must assure that both present and future generations have the possibility to use healthy and viable natural resources for a sustainable production of local fish stocks. It is crucial to prevent future human exploitation patterns from forcing the already strained fishery resources. Approximately 70% of the highly demanded fish resources around the world are fully- to overharvested, depleted, or slowly recovering (World Resources Institute 1996, FAO 1997). To secure the resilience of ecological and social systems, scale-related effects of management tools must be included in the scope of fishery governance (Berkes and Folke 1998, Folke et al. 1998).

In this paper, I focus on the evolution between fish stocking as a management practice, common-pool fish resources and resource user structures in the Archipelago of Stockholm between 1850-2000. I discuss if it is suitable to replace or enhance wild fish resources with hatchery-reared fish for a long-term sustainable resource use, and what the socio-ecological consequences are with the build-up of culture-based fisheries that depend on material from aquaculture. I argue that the development of hatchery techniques has been one prominent influence on:

- The evolution of social resilience, including arrangements of monitoring, local knowledge systems, and resource user structures.
- Ecological resilience including the generation of ecosystem services.

2. History of fish cultivation

As early as in 600 B.C. fish were kept in cultivation ponds in China, and during the Roman Empire, most Christian monasteries cultivated fish from neighbouring waters in ponds (Holcík, 1991). Such ponds were probably used as either grow-out areas for fish, or to improve aesthetical values. Introduction of self-reproducing fish into open and closed waters is another form of fish cultivation that has a long tradition. For example, the inscription on a Scandinavian runestone from the 12th century tells us a story of fish transfer from one water area to another (Huitfeldt-Kaas 1918). Such transfers occured sparsely during the 17th-18th centuries (Welcomme 1988, Filipsson 1994).

In the middle of the 19th Century, advances of the modern aquaculture technology, in combination with the expansion of mechanized fishing fleets, the building of transport systems, and other infrastructure changes, resulted in large-scale fish stocking operations (Stickney 1994). Since then, worldwide introductions of cultivated fish have occured in marine environments, in lakes, and in water resevoirs, often under governmental control (Welcomme 1988, McKaye et al. 1995, Munro and Bell 1997; Filipsson 1994, Holcik 1991, FAO 1999).

2.1 New introduction of fish species

New introduction of fish species outside of their native ranges started in large scale at the turn of the 20th Century. Major drivers were overexploitation, draugh, pollution, or pure curiosity (Figure 1). New species were mostly stocked to increase the production of fish for consumption, either as catchable fish, as prey fish of popular food fish, or as fodder for domesticated animals such as pigs and hens (Holcík 1991, Kruger and May 1991, Allendorf and Waples 1996, Filipsson 1994). New introductions have lessened since the 1960's (Welcomme 1988). However, in industrialized countries exotic fish are still used to control weed in eutrophic lakes (Jeppesen et al. 1998). And in poor countries with scarce food supply, experimental transfers of fish from one geographical area to another, are still frequent with the goal to enhance commercial fisheries, increase protein production, or enhance predation pressure on disease-carrying insects (Sugunan 1995, Marchall and Maes 1994, De Iongh and Van Zon 1993). Sometimes, the exotic species is not expected to reproduce, so that managers can stop stocking in case of negative consequences. Other times, the new species is expected to reproduce or even replace the indigenous species. This was the case of the extensive stocking and cage farming program of the non-native African tilapia (genus *Oreochromis)* into Lake Nicaragua in the 1980's, an attempt to increase the fishery and also to start exporting fish. The result has been a stock explosion of the introduced species, with declining indigenous fish stocks as a result. Additional effects on biodiversity are also likely to be discovered in the future (McKaye et al. 1995). Another example is the introduction of 10,000 pike-perch fry to Lake Egridir, Turkey, in 1955, resulting in the depletion of seven of ten native fish species before 1970 (Celikkale 1990).

2.2 Enhancement or compensation stocking

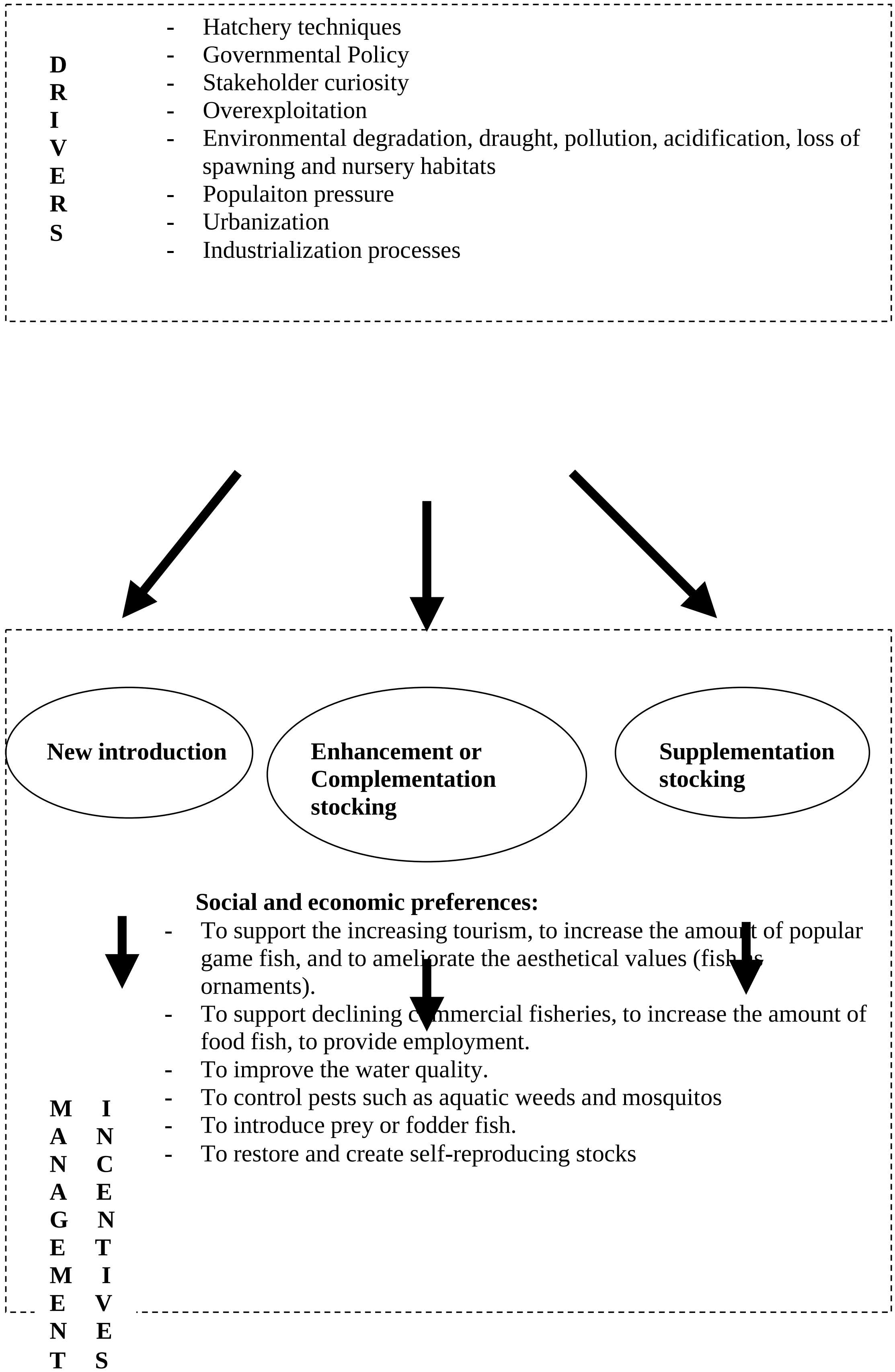
Overharvesting, environmental pollution, and loss of spawning and nursery habitats due to human exploitation of natural resources have resulted in various kinds of enhancement or compensation stockings of fish inside of their native ranges (Figure 1). The objective with such traditional hatchery programmes is to increase the supply of catchable fish (Stickney, 1994). Hatchery and wild stocks are allowed to interbreed.

For example, the building of hydroelectric power plants in major river systems in Sweden during the 1950-60’s, resulted in large-scale enhancements of Atlantic salmon *(Salmo salar)*. The extensive aquaculture of Atlantic salmon has resulted in surprising long-term biological effects. The gene pool has been altered and biodiversity is lost. Nowadays, approximately 90% of the salmon stock in the Baltic Sea origin from hatcheries. The diversity of these hatchery individuals has been estimated to only 72% of the wild individuals (Koljonen et al 1999). Futher, the outburst of the M74 syndrome in 1974 is causing the death of the majority of hatchery smolts.

2.3 Supplementation stocking

Recent progress and integration of population genetics, population ecology, and ecosystem approaches have resulted in the development of supplementation technologies (Waples 1991, Sterne 1995, Vitousek 1990). Supplementation uses native, wild broodstock for the aquaculture production. This selective gene hatchery strategy strives to ensure that the released individuals have equal diversity and genetic compatibility as the recipient stock (Waples 1991, Sterne 1995). Supplementation are often completed with habitat restoration operations or installations of nature reserves. Supplementation may also involve transfer of genetically similar fish stocks from heavily to scarcely populated streams (Sterne 1995). Drivers often include loss of spawning and nursery habitats and overexploitation (Figure 1). The objective of supplementation is to restore and create self-reproducing fish stocks of desireable game and food fish.

Figure 1. Drivers and management incentives of fish stocking.



3. The case study of fish stocking in the Archipelago of Stockholm

The focus of this paper is the interplay between the use of fish stocking techniques, capture fishing structures, and ecosystem and institutional resilience in the Archipelago of Stockholm between 1850-2000. First, the archipelago ecosystem is described as well as the institutional context of fish stocking. The following historical compilation of fish stocking and institutional drivers is divided into time periods based on statistics, rather than on ecological changes. In the end of this paragraph, socio-ecological influences of fish stocking are discussed.

Figure 2. The Archipelago of Stockholm and the Baltic Sea Drainage Basin.

3.1 The Archipelago of Stockholm

The Archipelago of Stockholm is suitable as a case study since it offers good conditions for making a historical survey of the co-evolution between social and natural dynamics. Also, the archipelago reflects much of the general use of fish stocking in Sweden. Fish stocking data is available from the 1940's. Relevant international and national information is included to make the description more complete.

The Archipelago of Stockholm is situated along the Swedish coast of the brackish Baltic Sea (Figure 2). The archipelago constitutes of thousands of islands, islets, and skerries surrounded by bays and lagoons. Stockholm City is part of the archipelago ecosystem. In this unique nature, intimate and dynamic relationships between humans and nature are shaped. In the coastal zone European eel *(Anguilla anguilla)* is one of the most economically important species for the small-scale commercial fishery. The Atlantic salmon *(Salmo salar)* is important for both the coastal commercial and recreational fisheries. The Swedish recreational fishery, as defined by the Swedish National board of Fisheries, consists of sport (hand gears), and household (other than hand-gears) fisheries (Anon. 1995b). Other popular coastal game and food species are herring *(Clupea harengus)*, cod *(Gadus morhua)*, perch *(Perca fluviatilis)*, pike *(Esox lucius)*, pike-perch *(Stizostedion lucioperca)*, Sea trout *(Salmo trutta)*, and whitefish *(Coregonus lavaretus)* (Anon.1995b).

The fish community structure in the Baltic Sea has been dramatically altered since the 1850's owing to natural and anthropogenic disturbances, including low inflow of salinity water, large-scale hydrographic variations, climate change, eutrophication, acidification, and overfishing (Hansson and Rudstam 1990). Hydropower exploitation in major tributary rivers, and damming has also destroyed nursery and spawning areas of many fish populations (Montén 1988). Cod, salmon, and eel stocks have decreased, while sprat has increased (HANSSON?).

3.2 Historical compilation of fish stocking and important instiutional drivers

As is described below, the management incentives and types of fish stocking in the Archipelago of Stockholm have shifted several times between 1850-2000. In the end of the 19th Century, self-reproducing exotic food fish species were frequently introduced to increase the total production of consumption fish. At the turn of the 20th Century, new introductions decreased. Instead enhancments of indigenous food fish grew in popularity. Between 1940-1965, a new switch of incentives for stocking occurred. The enhancement of indigenous fish decreased, while both new introductions and enhancements of salmonid game fish increased. The objective was to support the growing sport fishery. As from 1970, new introductions decreased once again. During the 1990's enhancements of mainly Sea trouts have bursted (Diagram 2).

As from 1995, the Swedish National Board of Fisheries is moving towards an ecosystem approach in their fishery management policies (Anon. 1995b). Tradeoffs between the development of commercial and recreational fisheries and biodiversity conservation should be considered. Fish populations should be conserved from a scientific view, for the conservation of environment, and for future rearing and farming practices. For example, enhancements of decreasing fish stocks are often made in combination with habitat restorations. However, a dominating part of the stocking operations are still made with fish that are not expected to reproduce. The major objective is to augment fish catches of a growing sports fishery and a commercial fishery in crisis in order to economically and socially support the sparsely populated archipelago. Regional and local fishery management expects the future fishery to partly rely on stocked fish from aquaculture (Anon. 1999). Today, the following fish stocking practices occur in the Archipelago of Stockholm (Table 1):

- Eel transfers to support an archipelago commercial fishery in crisis
- Sea trout supplementation in restored rivelets to support the growing sports fishery
- Sea trout and pike-perch enhancements to support the growing sports fishing, prolong the fishing season, and benefit the social and economic status of the sparsely populated archipelago
- Salmon and rainbow Sea trout introductions to attract tourists to the area of Stockholm City

In all, a substantial put-grow-and-take fishery of Sea trout, salmon, and perhaps also eel and pikeperch has been established in the Archipelago of Stockholm. The evolution of this culture-based household, sport and commercial fishery, has impacted on the development of new fishing groups and the decline of others (Holmlund 1996). This mixed-stock fishery has implications on (1) the operational scales of the players in the system, (2) certain characteristics of the system, and (3) the pattern of disturbances (Table 2). These in turn affect the resilience of the socio-ecological system (Box 1, Box 2).

Stocked fish species	**Target groups**	**Financially responsible**	**Management incentive**	**Drivers**
Eel transfers	Commercial fishermen	Governmental grants	Support cultural values Provide employments Increase present catches	Decreasing return of eels from the Sargasso Sea Global or/and local pollution problems Overfishing Governmental policy
Sea trout supplementation	Anglers	Stockholm municipality Sports fishing clubs	Augment game fish stocks Restore/create self-reproducing populations	Habitat losses Self-organizing sports fishing clubs Municipality and County policy
Sea trout and pike-perch enhancements	Anglers	Stockholm municipality Sports fishing clubs Vattenfall (Gov. owned company)	Augment game fish stocks Prolong tourist season Support local residents	Self-organizing sports fising clubs Municipality and County policy Decreasing density of local residents Urbanization
Atlantic salmon and rainbow Sea trout, new introductions	Tourists	Stockholm municipality	Increase tourism PR for the City of Stockholm	Stakeholder curiosity County and municipality policy Tourism

Table 1. *The incentives of today's fish stocking in the Archipelago of Stockholm*

BOX 1. Fish stocking – a risk for the social resilience?

- a diminishing commercial archipelago fishery risk to result in loss of ecological knowledge about long-term natural processes
- hatchery fishes may mask and block out natural disturbances, pulses and fluctuations, making it more difficult for managers, policy-makers and resource users to read and adapt to the system
- open access fishery for hand-gear sports fishers risk to result in lost interest among property owners in sustaining local non-renewable fish stocks (Åqvist-Almlöv 1999)
- diminishing commercial fishery, lost ecological knowledge may result in weekened feedback signals between the socio-ecological systmes which in turn risk to render social institutions and organizations less adaptive to situations of surprise

+/- the evolution of sports fishing associations results in the emergence of species-specific knowledge in connection wigh restoration and supplementation actions

+/- the evolution of influential stakeholder associations at the local level may influence governance of fish resources at regional and national levels

+/- the emergence of new fishing groups increases the conflicts about common-pool resource, such as migrating fish stocks

BOX 2. Fish stocking - a risk for the ecological resilience?

- the evolultion of a large mixed-stock fishery on Sea trouts increases the total harvest and threatens the few still existing wild Sea trout populations
- the lowered genetic diversity of, and the large amounts of, hatchery individuals, may reults in an overall loss of functional diversity (Ryman et al. 1995)
- mixed-stock fishing on wild stocks and the release of hatchery individuals with less genetic diversity, risk to result in an overall loss of functional diversity with consequences for ecological renewal during recovery time in future

+/- in case of competition, predation, habitat destruction, or disease introduction, the generation of ecosystem services may be altered, including food web dynamics, nutrient recycling, ecosystem linkages, and energy transport (Krueger and May 1991, Holmlund and Hammer 1999)

+/- the establishment of aquaculture facilites, including net cages in the archipealgo result in local eutrophication (Laurén-Määttä et al. 1991, Blomqvist 1994)

+/- resource user shift results in new emerging fishing patterns followed by altered environmental effects of the total archipelago fishery (Dayton et al. 1995)

\+ species-specific restoration in connection to Sea trout supplementation

1850-1916

The first European fry-hatchery was built in Hüningen, France, in 1843. This technological development impacted on both national and local fisheries management in Sweden. In 1853-54, the Swedish Parliament presented a bill about improving the lake fishery by introducing fish fry from aquaculture. In 1858, the first Swedish hatchery was built, financed by the government. Seven years later, 1865, two hatcheries were built in the County of Stockholm. In 1890, two foreign species were imported to Sweden, Rainbow and Brook Sea trout *(Oncorhynchus mykiss, Salvelinus fontinalis)*, with the objective to use un-exploited natural resources and encourage the production of more valuable food fish. However, the poor success with new introductions of exotic species led to a stronger focus on indigenous food fish species such as pike and whitefish. At the turn of the 20th Century, these native species dominated the Swedish hatchery production, and were used in large-scale enhancements in lakes.

1917-1939

New introductions of indigenous species in lakes were still frequent. Young eels started to be transfered from England to Swedish lakes to compensate for losses of eel due to industrial exploitation of rivers and sewage outlets. In 1939, the Swedish hatchery production reached a peak and 350 million of fish fry were stocked in Swedish waters (Diagram 1). The major objective was to enhance the production of the indigenous food fish species whitefish and pike. The production of fry was increasingly replaced by the production of young-of-the-year (YOY) fish.

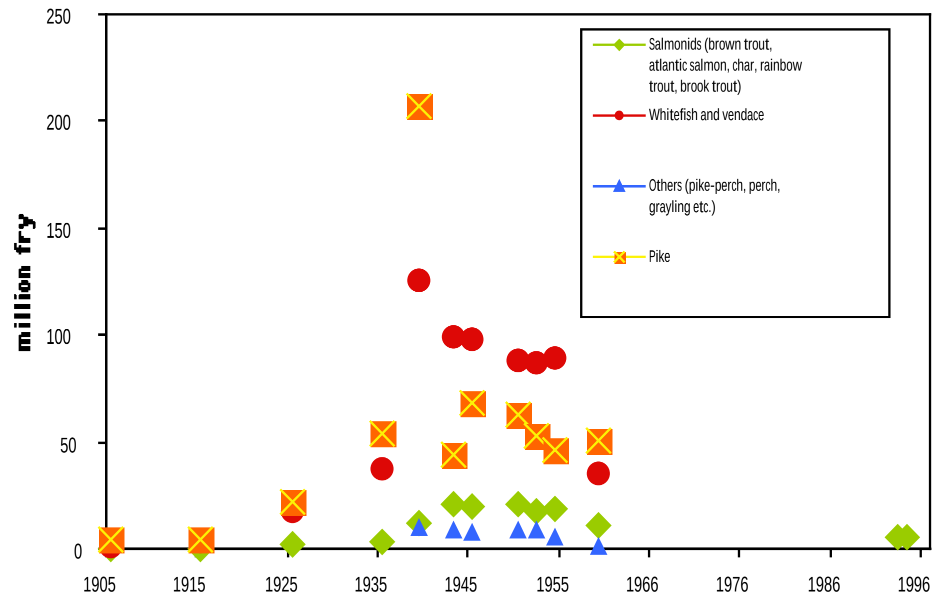


Diagram 1 *Number of produced fish fry or YOU in millions in Swedish fish farms. (Information from: Svensk Fiskeri Tidskrift 1939-1962; and Älvkarleby Research Institute).*

<u>1940-1959</u>

The Swedish hatchery production declined in the beginning of the 1940's, partly because the economics of enhancements were questioned, partly because the Second World War broke out. However, fish stocking never stopped completely. As the leisure time increased, sports fishing grew into a popular movement in Sweden. The Swedish State purchased coastal areas between 1945 and 1956, including parts of the archipelago. And in 1952 the Law of Shore Protection safeguarded the general public's access to the archipelago. Open access areas for the growing outdoor life, including the "amateur fishery" were instituted. Salmonids were prefered to stock as game fish before other species since these fishes were "big, quite easily caught with a hook, and very tasty" (Puke 1965). The Swedish National Board of Fisheries was established in 1948.

Simultaneously, increasing sewage outlets, steamboat traffic, and fishery resulted in declining stocks of many food fish resources in the archipelago. To counteract this decline and to support the household and commercial fisheries, governmental grants financed introductions of pike, whitefish, and perch from quays and bridges near Stockholm City and in the archipelago during the end of 1940's. However, during this period many voices were raised against the hatcheries. It was claimed that fry enhancements were non-profitable, and biologically insignificant due to low survival rate, and many hatcheries of indigenous food fish were closed.

Further, the expansion of hydroelectric power stations in Swedish rivers during the 1950-60's resulted in mass loss of crucial spawning and nursery habitats for salmonids and other organisms. The government financed yearly large-scale compensations of salmon and Sea trout, in these exploited rivers.

1960-1979

There are no comprehensive data compilations of the Swedish hatchery production or of the fish stocking activites after 1959. However, governmental policy was at this point a major driver of using salmonids from aquaculture to enhance fish production. For example, in 1961 the national agency KOSS was created, with the mission to improve the angling conditions especially in lakes, but also in coastal areas. Governmental legislation and subsidies supported large-scale enhancements of game fish as well. Other influential drivers developed as well, such as networks of angling clubs. A resulting put-grow-and-take fishery was created both in lakes and along coasts, during the 1970-80's. Sports fishing had now developed into one of the most powerful popular movements in Sweden.

This evolution of sports fishing is clearly illustrated by the large-scale salmonid introductions in the Archipelago of Stockholm. These stockings started by coincidence, rather than planned by fishery biologists or managers. In 1966, a governmental hatchery facility offered leftover hatchery Sea trouts to Stockholm municipality and these were then stocked near Stockholm City. Since then, Sea trouts are regularly enhanced and salmons are regularly introduced in the Archipelago of Stockholm, to support the growing sports fishery, and impress on tourists. Supplementation of Sea trout has also been made since 1975 in rivelets tributary to the archipelago.

During the 1960's, disease spreading in connection to the traditional compensation programmes of salmon was debated. Genetic effects including interspecific competition between fish species, and intraspecific competition between stocked and wild individuals, were also discussed since the hatchery and wild stocks interbred.

As from 1972, regular compensation stockings of eel have occured along the Swedish East Coast, and in lakes, which flow into the Baltic Sea. Eel transfers were made to counteract the fact that fewer eels entered through the passage between Denmark and Sweden since the 1940's. This in turn had resulted in decreased eel catches as from the 1960's. Many alternative explanations for this decline have been put forward, including climatic changes, altering Gulf streams affecting the transfer of eel fry from the Sargasso Sea to Europe, overfishing, and decreased reproduction capacity owing to environmental pollution.

In all, the hatchery production of pike and whitefish continued to decrease during the 1970's as well as new introductions. The production and enhancements of salmonids continued to increase. However, the objectives of enhancements had shifted. Most stocked individuals were not expected to reproduce in the wild, but to be caught by fishers.

1980-2000

In the beginning of the 1990's, 40,000-70,000 salmon smolt were stocked a year in the Archipelago of Stockholm, in 1994 none were stocked, in 1995 only 10,000 were introduced (Diagram 2). This decrease of introduced salmon during the 1990's due is explained by the extremely low survival rate of salmon smolt caused by the M74 syndrome. However, to support the evolved, high demand of catchable game and food salmonids, Stockholm County and municipality looked for a quick alternative. In 1995, a tourist fishery project was initiated and the enhancements of Sea trouts increased by over 30% between 1990-1995 and amount to approximately 150,000 smolt a year (Diagram 2). The incentive is to prolong the sports fishing season during winter and early spring, in order to improve the economic and social situation of the sparsely populated archipelago. An important culture-based put-and-take fishery of Sea trout has been created in the archipelago. Other important factors for the expanding sports fishing is the establishment of an open-access hand-gear fishing in 1986 enforced by national legislation. In addition, 20 new Sea trout stocks have been created as a result of successful supplementation and restoration of rivelets, much thanks to the initiatives and financing by both private fishing clubs and the Stockholm muncipality.

A varying amount of eels are transfered yearly to the Archipelago of Stockholm, ranging from 0-200,000 betwen 1990-1995. The eels originate from the Swedish West Coast and England.

Pike-perch is also introduced as a game fish for sports fishers, but not in large numbers (approx. 10,000/year). The stocked pike-perch are expected to be caught rather than reproduce in the wild.

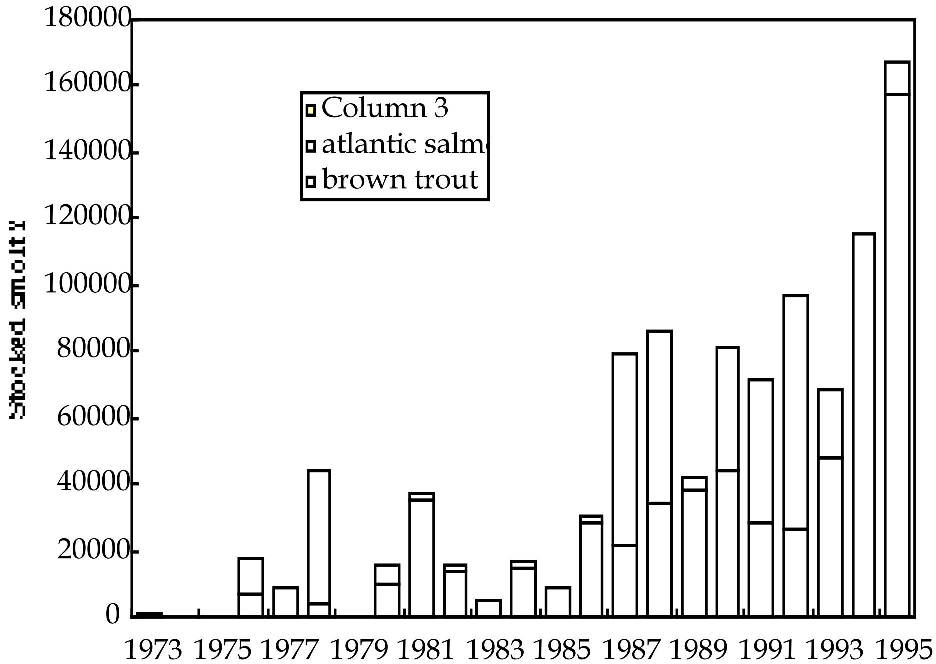


Diagram 2. *There exists no official limits for fish stocking in the county of Stockholm. The introduction of salmon has decreased, while enhancements of Sea trout has increased (Source: Stockholm municipality).*

3.4 Fish stocking to support the traditional commercial fishery

The small-scale traditional fishery in the archipelago has evolved during centuries in congruence with the natural flucutations of wild resources, and has adapted to these daily, monthly, seasonal or yearly disturbances. However, there has been a dramatic change in resource use structures during the period 1860-2000. The number of commercial fishermen has steadily decreased during this period. In 1860, the Swedish capture fishery along the Baltic coast consisted mostly of small-scale household and commercial fisheries exploiting a broad variety of species. With the increased use of motor boats, and of more efficient fishing techniques, the scale of the fishery changed and resulted in a large mechanized commercial fishing fleet focusing on a few offshore species. The off-shore fishery in combination with lack of functioning distribution networks, has more or less outcompeted the archipelago fishery. There were over 6,000 fishermen in 1945 in the Archipelago of Stockholm,, 3,000 in 1960, 88 in 1995, and only 46 in 2000 (Anon. 1995a, pers. comm. Yngve Ungsgård County Administrative Board 2000).

The small-scale commercial fishery is considered to be important to provide employment in the sparsely populated archipelago. Also, the fishermen are part of a strong cultural tradition, and are much appreciated by urban and foreign tourists. The decline of economically valuable eel stock is mitigated by regular eel stockings in the archipelago since the 1970’s. The tranfered eels are not expected to return to Sargasso to reproduce but to be caught. Eels are transfered from other geographic areas because so far it is impossible to produce eel fry in aquaculture. No investements in preventing further decline of the Euopean eel stock are made at national or local levels. The difficulty to identify the reasons for the declining eel stock results in a situation of uncertainty and eel transfers continue. Also, the demand for eel transfers is growing. However, the price of juvenile eel is rising due to increasing competition from the Chinese market, which in turn reflects a gap between supply and demand.

Salmonids is also an economically valuable resource for the fishery. Large-scale enhancements of Atlantic salmon made in rivers exploited for hydro-electric power along the Swedish East Coast affect the archipelago fishery. The migrating salmons cross many institutional boundaries during their life cycles, and is a common-pool resource chared by the coastal and offshore fisheries. The introduction of salmon within the boundaries of the archipelago may also be caught by the archipelago fishermen. These stockings are made with hatchery individuals originating from other coastal areas in Sweden than the archipelago, since there are no self-reproducing salmon stocks here.

Further, the increasing availability of Sea trouts in the archipealgo due to the large enhancements and supplementations since 1966, has resulted in emerging interest for Sea trouts among commercial fishers.

3.5 Fish stocking to support the culture-based recreational fishery

The recreational fisheries has grown into a major popular movement in Sweden and in the Archipelago of Stockholm (Anon. 1995c). This is the case in many parts of the world, where the multiple use pattern of common-pool fish resources seem to result in conflicting interests among users (West and Gordon 1994, Aas and Skurdal 1996, FAO 1999) . Estimates show that hundreds of thousands of sports fishermen probably visit the archipelago every year. The total Swedish recreational fisheries involve approximately 16% of the population (Anon. 1995c). As a result of the growing recreational fishery, a selection of piscivorous species such as Sea trout, pike, perch, pikeperch, and salmon are mainly harvested. In fact, it has been shown that anglers appear to be the dominant harvesters of many coastal fish species (Svedäng et al. 1998, West and Gordon 1994).

The major obejctive of the ongoing new introductions of salmon is to support the inhabitants of the archipelago by augmenting sports fishing and tourism.

The mixed objectives of Sea trout stocking are more complex. In 1995, 9% of the Sea trouts were supplemented in rivers, while 91% were stocked further out in the archipelago (Holmlund 1996). All of the stocked Sea trouts originate from the local rivelet Åvaån in the archipelago. The 9% supplementation of Sea trout in the often restored rivelets are expected to successfully spawn in the wild and thereby assure the abundance of the few still existing self-reproducing stocks, in present and in future. Supplementation of Sea trout acknowledges that the Sea trout populations are part of the ecosystem. However, the habitat restorations are made to improve the reproductive success of Sea trout, not other fish, or other species. The supplementation is hence not made from an ecosystem perspective, but from a ”Sea trout perspective”. A more holistic ecosystem approach would take into account the rivelet’s capacity to generate a broad variety of ecosystem services on top of producing Sea trouts. Such ecosystem services include filter nutrients, provide habitats for other species than Sea trout, link land-water-air food webs, contribute valuable food resources for terrestrial and avial organisms, contribute to ecological memory and resilience, etc. In all, the major objective of the Sea trout supplementation is to enhance the number of popular game fish and support the growing sports fishing.

The 91 % Sea trouts that are enhanced at a distance from the coastline are believed to be stationary to the area of introduction and enhance fish catches here, not to find suitable reproduction areas. However, artificially reared individuals may stray and spawn together with wild ones (REF). Gene flow can occur and risk disrupting the genetic make-up of wild Sea trout. In fact, important traits have shown to be altered in hatcheries, resulting in lower survival rate of reared individuals compared to wild ones (Järvi 1995, Henricson et al. 1995, Allendorf and Ryman 1987, Hedenskog 1995). Further, when looking at a rough estimate of the total smolt production in the archipelago duirng 1995, the risk of gene flow is real. Wild Sea trout smolt made up approximately 7% of teh total addition of new smolt, 23% constituted of supplemented smolts in rivelets, and 70% of enhanced smolts at a distance from the coastline (Holmlund 1996). (THE SURVIVAL RATE OF THESE ONE YEAR LATER?)

4. Discussion

The development and use of hatchery and stocking techniques in the Archipelago of Stockholm during the last 100 years, have to a large extent shaped the incentives for archipelago residents and visitors to access and become interested in the common pool fish resources with consequences for the socio-ecological resilience. Most of the fish stockings have been under governmental control, by means of financial grants or national legislation.

In 1890, the general incentive for fish stocking in Sweden was to increase the production of fish by means of creating or enhancing self-reproducing fish stocks. This incentive has since then dominated fishery governance, and resulted in large-scale enhancements, supplementations, and a few new introductions. The intensive use of fish stocking as a management tool in the Archipelago of Stockholm during the last 30 years, have influenced the structure of fishers, by means of supporting the shift from commercial to recreational fishery. In 1986, an open-access hand-gear sports fishing was initiated. In 1995, the Tourist Fishing Project started and resulted in large-scale game fish stockings. The outcome of these institutional changes has been the evolution of an important sport fishing in the archipelago, including on private waters. Simultaneously, the stocking of food species has decreased since the 1960's, except for eels which are still transfered from England or the Swedish West Coast to support the archipelago commercial fishery. Instead, the commercial fishermen increasingly harvest the stocked salmon, Sea trout, or pikeperch.

Most of the fish stockings are expected to increase present catches, and not to augment the future self-reproducing stocks. The main goals are (1) to support the archipelago residents economically and socially, (2) to support the growing interest on mainland for sports fishing, and (3) to attract tourists to Stockholm City. In all, the local household and commercial fisheries, the mainland-based sports fishing, and the fishing by foreign tourists have discovered the emerging fish resources. A new fishing pressure has evolved focusing aon a narrow range of species, including the wild resources.

The evolution of an open-access culture-based fishery that depend on harvesting aggregations of a mix of naturally and artificially propagated common-pool fishes have consequeces for the social and ecological resilience. However, the success of fish stocking is generally measured in terms of increased yields by using frameworks of short time scales and geographically limited areas. Positive or negative long-term and wide-range ecosystem effects of the use of fish stocking are rarely monitored.

4.1 Consequences of fish stocking related to the social system

The evolving culture-based fishery do not need to adapt to or learn about daily, monthly, seasonal or yearly fluctuations in the same manner as the traditional small-scale fishery did. Many sports fishers come from mainland, or are foreign tourists, and fish on a daily basis. They do not live near their resources. Their target game fishes are sustained at a rather constant level due to the regular addition of hatchery individuals. They can move freely from poor to rich fishing areas owing to the open access hand-gear fishing. As a consequence, sports fishermen are probably less inclined to learn about and comprehend long-term and wide-range signals from the natural system (Åqvist-Almlöv 1999). Simultaneously, the growing number of local angling clubs have developed a large body of species-specific knowledge in connection to restoration actions and supplementations of Sea trouts made in over 20 rivelets in the Archipelago of Stockholm since 1975. These community-based angling associations have strong economic and political influences on local management and cooperate with Stockholm municipality. This emerging body of knowledge does not however take an ecosystem approach with focus on ecosystem services, functional diversity, and ecological resilience.

The traditional commercial fishery, on the other hand, are limited by strict property and user rights and depend on wild, local resources. They need to know how the system works to be prepared in times of disturbances and seek alternative sources for their livelyhood.

Hence, the evolved culture-based fishery can build up structures that adapt to, and build up knowledge about, artificial and rather constant levels of fish catches rather than on fluctuating access to wild resources. There may also be loss of necessary ecological knowledge for cultural practices of sustainable resource use. Instead, users and managers rely on the development of alternative technological innovations and declining stocks are believed to be replaced by substituting ones from aquaculture (Gadgil 1987). Society risk becoming ignorant about natural variations.

The regular introductions of hatchery individuals may mask or mitigate natural or antropocentric disturbances in the archipelago. The natural feedback signals from the ecosystem become blurred and difficult to interpret. The masking of disturbances, the increasing open-access fishery on private waters, and loss of traditional ecological knowledge, make it difficult for the managers to monitor system processes and total resource use, in order to be flexible. Hence, the build-up of a culture-based fishery on common-pool fish resources risk to render resource users and property owners succesively less prone to collect ecological knowlege about their local resources or to take personal initiatives and responsibility for organizing restoration or conservation actions (Gadgil 1987, Berkes 1995, Åqvist-Almlöf 1999). Instead, conflicts among the resource users intensifies, and they become dependent on rigid management policies and detatched from the fluctuating natural resources (Holling 1986, Aas and Skurdal 1996). This evolution does not correspond to the design principles for achieving institutional robustness, suggested by Ostrom (1990, p. 90) According to these principles it is important to have clearly defined boundaries of user and owner rights, the rules of appropriation should be related to local conditions, the local residents and resource users should be able to participate in modifying the operational rules, and in monitoring, there should be rapid conflict-resolution mechanisms, and the local, regional and national institutions should be nested, etc.

4.2 Direct and indirect ecological consequences of fish stocking

The evolution of the culture-based commercial and recreational fishery has most likely affected the ecological system both directly and indirectly. Although no scientific studies have been made to analyze ecological or genetic consequences, risks associated with fish stocking have been described elsewhere (Allendorf and Waples 1996, Alledorf and Ryman 1987, Waples 1991, Ryman et al. 1995, Laikre 2000 KOLLA DESSA). Directly, the genetic diversity of fish populations may decrease as a result of low variation among hatchery individuals, and gene flow mechanisms. Further, impacts of fish stocking are rarely limited to the local context and specific temporal boundaries defined by management. Rather, impacts of predation and competition disperse througout the whole water-land-air ecosystem that the fish are part of during its whole life cycle. This is due the inherent attributes of fish populations, in combination with the linking qualities of the ecosystem. Fish individuals act as mobile linkers as they move horisontally and vertically in the water mass (Holmlund and Hammer 1999. For example, stocked salmons and Sea trouts is a common-pool resource and migrates across many geographical areas, and may influence both the archipelago and other coastal and offshore ecosystems. Fish individuals are also preyed upon by terrestrial or avial predators, and thereby act as passive energy linkers between ecosystems (Holmlund and Hammer 1999).

The ecological system has also been affected indirectly as a result of altered operational units of fishing. The evolved culture-based fishery occurs in specific seasonal and geographical pulses. For example, sports fishing from small boats or along shores has increased in areas where fish stocking are made, and during early spring and winter when the stocked fishes are easily caught. Hence, the frequency and distribution of fishers has changed including the use of motor boats, fishing from shores, and the length of the fishing season. In turn, these social patterns cause indirect ecosystem effects during periods when the archipelago is vulnerable for external pertubations. Spring for example is an important reproduction period for fish, birds and other organisms, and the ecosystem is easily disturbed by shore deterioration, high frequency of motor boats, or gas outlets. Further, the emerging mixed-stock fishery increases the total outtake of fish, and is not related to the temporal and spatial fluctuations of the wild resources. The high and constant fishing pressures on certain fish resources may result in overexploitation of wild stocks, with negative effects on the genetic and population diversity, and on the capacity of the system to withstand disturbances (Ryman et al., 1995, Jennings et al. 1998).

Another indirect effect may result from the focus on a narrow range of popular game and food species. The stocking programmes in the Archipelago of Stockholm involve mainly four piscivorous species, Sea trout, salmon, eel and pikeperch. The restoration and supplementations involve only one species, Sea trout. This ”species management approach” may affect the restoration of other natural resources. Endangered non-commodity goods and services risk to be depleted, with loss of functional diversity as a result (Hanna 1999). Since genetic, population, species and functional diversities are prominent components of the buffer capacity, parts of the ecological resilience thereby risk to be successively lost (Holling 1973).

4.3 Mis-match of temporal and spatial scales

The evolved culture-based fishery in the Archipelago of Stockholm during the 20th Century exemplifies the importance of relating the success of fisheries management tools to the cross-scale features of the socio-ecological system. Among managers, policy-makers, and resource users the fish stocking operations are considered to be successful as the total catch of popular piscivorous fish has been kept at a high level during the last three decades. However, governing authorities have not considered long-term dynamic ecosystems consequences. Natural and social systems operate under different temporal and spatial scales, which is important for the scope of the analysis (Holling 1973, Reeves et al. 1995, Gibson et al. 2000). The fish stockings have been made in a local context and are defined by specific temporal management objectives. However, the stocked fish are not limited by these, rather, the stocked fish impacts on linked ecosystems and are harvested by different user groups including the off-shore, coastal and riverine commercial and recreational fisheries during various life-stages of the fish. This mis-match of scales between management and the natural and social systems is partly the result of that managers look for fast-operating tools to respond to the urgent needs of the fishers (Hanna 1999). Such tools often involve new technological solutions mitigating rather than preventing the problem. An illustrative example of the time stress of fishery governance to find appropriate solutions, is the case of salmonid introductions in the archipelago. When the hatchery production of Atlantic salmons decreased due to M74, the hatchery production of Sea trout increased instead very quickly to support the evolved sports fishing. In only five years (1990-1995), the Sea trout stockings increased by 220 %. The existing wild Sea trout populations in the area are now threatened by overfishing by this fast evolution of a mixed culture-based fishery on Sea trouts, since the expected survival of hatchery Sea trout exceeds the expected survival of wild stocks (Holmlund 1996).

Another scale-related issue is the short time perspective of management goals. The major part of the present fish stocking in the Archipelago of Stockholm are made to support fish catches in the near future, and not to preserve fish stocks for future generations. The most illustrative example is the transfer of eels to support a threatened small-scale commercial fishery in the archipelago, without securing the future eels stocks. Another example is that only 9% of the stocked Sea trouts in 1995 was expected to reproduce and improve future archipelago sports fishing (Holmlund 1996).

Present fishery management policy and monitoring are designed to fit time and space scales of fishers, rather than of the fish resource or the ecosystem variables (Table 2). Change of long-term and wide-range ecological processes or structures is therefore not easily detected. There are also few functioning cross-scale feedback mechanisms between nature and society, as well as within the social hierarchies. Such links are necessary in order to sustain the resilience of the archipelago society . They should exist at multiple social layers and be nested i order to have a sufficient buffer capacity to discover change and then communicating the ecoloigcal information to the appropriate level.

Table 2. *Comparisons between fish resources, traditional commercial fishery, and culture-based sports fishery in the Archipelago of Stockholm. The focus is on fish stocking impacts on the resilience of socio-ecological systems.*

	FISH RESOURCES	TRADITIONAL ARCHIPELGO COMMERCIAL FISHERY	CULTURE-BASED SPORTS FISHERY
SCALES	- are part of ecosystem processes operating at short and long time scales - are part of the linked air-water-land ecosystems connecting e.g. the archipelago with mainland	- depend on and adapt to short and long term fluctuations in nature - derive the fish from their own fishing properties in the archipelago	- depend on adapt to stable catches supported by hatchery production - derive their resources from the whole archipelago, an open-access resource (free hand-gear fishery)
SYSTEM CHARACTERISTICS	- nested generation times - part of food web dynamics - part of functional diversity, ecological memory, and ecoloigcal resilience	- supported by economic subsidies from GO's - have inherent ecological knowledge about ecosystem processes and structures	- supported by economic subsidies from GO's and NGO's - ecological knowledge about a narrow range of fish species is evolving
DISTURBANCE PATTERNS	- natural or anthropoenctric changes / fluctuations occur often with a time lag of decades or longer	- natural or anthropocentric changes / fluctuations are detected instantly (e.g. low catch rate) - monitoring provide adaptive tools	- natural or anthropocentric changes are masked by extensive production and stocking of hatchery fish (constant caches) - socio-ecological feedbacks excluded
FISH STOCKING IMPACTS ON RESILIENCE	- risk of lessened inter- and intraspecific genetic diversity of the target fish species - unpopular fish species risk to be forgotten and depleted - loss of functional diversity	- sustained catches of a narrow range of species (e.g. eel, salmon) - support of a cultural tradition - loss of incentives for instititonal novelty among the fishers - mixed-stock capture fisheries - hatchery fish act as a masking veil of natural disturbances - loss of traditional ecological knowledge - monitoring difficulties - allocation conlficts	- increased fish catch - more fishers - emerging interests in restoring rivelets - emerging interests in supplementation of Sea trout stocks - emerging demands on continuing large-scale stocking operations - fishers become mentally separated from long-term and wide-range scales of the resource base - conflicts of allocation of common-pool fish resources

4.4 The spiral effect – a gamle with resilience?

Due to the time lag of the feedback mechanisms within the socio-ecological system, a spiral effect is evolving. The initial ”success” of the fish stocking operations in the Archipelago of Stockholm during the last decades, in terms of increased fish yields, has triggered the evolution of new drivers, including urban and international sports fishermen. For example, no intensive fishery occured on Sea trouts in the archipelago before the large-scale Sea trout enhancements because of the small stock size. The following self-organizations of angling clubs has resulted in economically and politically influential stakeholders. These community-based associations pressure the managers to continue to stock fish. Additionally, the commercial fishermen gets increasingly used to fish on mixed stocks. The dependency on hatchery produced fish increases, and the culture-based fishery becomes more established and influential. The pressure on management to support the fishery on released fish gets even higher, and the large-scale fish stocking operations must continue. A spiral develops: fish stockings –> evolution of culture-based fishery and new drivers –> emerging pressure on managers by fishermen –> more fish stockings. The fish stockings may increase unlimited since there exists no national regulations for coastal fish stocking operations. This spiral effect with focus on mitigating declining fish harvests by the addition of hatchery fish, takes away the incentives for preventing the underlying problems causing the decline, such as habitat losses and environmental degradation (Reeves et al. 1995). Also, the spiral effect is a likely scenario as long as the scales of fishery governance continue to mis-match the scales of ecosystems. Instead, rigid social structures dependent on artifical conditions are built-up and the variables and processes that control the capacity of the socio-ecological system to withstand perturbation risk to be altered, and the system may – in future - suddenly flip into another stability domain (Folke et al 1998).

Fish stocking should preferably harmonize with ecosystem processes and structures, and recognize the importance of when, where, and by whom fishing is done rather to than how much is caught (Acheson et al. 1998). In all, the scope of fishery governance should rely on co-management approaches involving nested hierarchial levels of policy-making, and allow cross-scale analysis of socio-ecological consequences, in order to discover and adapt to disturbances caused by fish stocking (Walters 1997, Costanza et al. 1999).

5. Conclusion

As suggested by Gadgil (1987), the development of technological innovations, such as fish stocking techniques, and the increased size of human groups having access to a particular resource, have played a vital role and affected harvest patterns in the Archipelago of Stockholm. The spatial and temporal distribution of fishers have been altered partly as a result of fish stockings during the 20th Century. A large and influential culture-based fishery has evolved and affects the buffer capacity of both the social and ecological systems. Also, the case study shows that property and user rights are crucial for the implementation of fish stocking and for the consequences following fish stocking. In all, the development of hatchery techniques and the use of fish stocking has influenced the social and ecological resilience:

- The author argues that if the relatively large amounts of stocked fishes mask the natural fluctuations of populations, the capacity of the social systems to adapt to disturbances decreases. Further, traditional ecological knowledge among local fishermen has been lost for monitoring purposes, as the commercial fishery decreases in the archipelago. Thus, the institutional flexibility risk to diminish, and social resilience may be lost.

- Direct or indirect loss of genetic, population, species and functional diversities in the archipelago ecosystem, lowers the system's capacity to absorb natural disturbances.

The short-term and single-species focus among managers and new resource user groups, is not consistent with developing an adaptive co-management to secure the future generation of ecosystem services. Fish stocking must be viewed in a context of uncertainty where socio-ecoloigcal consequences operating at different temporal and spatial scales and levels often are difficult or impossible to foresee. Therefore, fish stocking should harmonize with essential ecological processes to sustain or even rebuild the preconditions for resilient socio-ecological systems. To secure an adaptive fishery management in the dynamic and complex Archipelago of Stockholm, resource management policies need a more decentralized and holistic ecosystem approach with highly nested communication networks.

The evolving spiral effect of increasing pressure on managers to continue to stock fish as the new resource user groups become more economically and politically influential, is one of the major consequences of the evolved culture-based archipelago fishery. This spiral effect could hopefully be prohibited by using a cross-scale analytical framework, combining the temporal and spatial scales of management to those of nature.

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