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Effects of Fish Stocking on Ecosystem Services: An Overview and Case Study Using the Stockholm Archipelago

CECILIA M. HOLMLUND
Natural Resource Management
Department of Systems Ecology
Stockholm University
S-106 91
Stockholm Sweden

MONICA HAMMER
Södertörn University College
Box 4101, S-141 04
Huddinge, Sweden

ABSTRACT / In this article, we focus on documented and possible effects of fish stocking in terms of ecosystem services. The increasing use of fish stocking between 1970 and 2000 in the semiurban setting of Stockholm archipelago, Sweden, is used as case study. The objective is to analyze this management practice from an ecosystem perspective, accounting for both the ecological and social context of releasing fish. The results show that enhancements of four native species (*Salmo S. trutta, Salmo salar, Stizostedion lucioperca, and Anguilla anguilla*) have dominated over new introductions of one nonnative species. (*Oncorhynchus mykiss*). The major objective has been to increase fish catches for local resource users. Involved stakeholders include three management agencies, one hydropower company, and several local sport fishing associations. Documented effects focus on recapture and production rates. However, our analysis suggests that additional positive or negative effects on biodiversity, food web dynamics, mobile links, or ecological information may also result, with possible consequences for the long-term provision of food, game, and aesthetic values. We conclude that a more adaptive and cooperative management approach could benefit from a deeper analysis of where, when, and what species is released, by whom, which stakeholders that use the fish and those ecosystem services the fish generate, and of the role of formal and informal institutions for monitoring and evaluating the success of releasing fish.

Different forms of cultivating fish, ranging from enclosed land-based monoculture systems to releasing capture or hatchery fish into the wild by fish stocking, have been developed to bridge the gap between human demands and diminishing wild fish resources. The global aquaculture production has increased by 10% per year since the 1990s (Food and Agriculture Organization 2000). An estimate of fish stocking by FAO, based on the hatchery production of member countries in the year 1996, revealed a total reported production of approximately 160 million fish juveniles per day, of which most were intended for release into the wild (FAO 1998). The implications of intensive monoculture cage farming have been extensively discussed in the literature, including problems connected to the needs for auxiliary inputs such as feed, labor, and energy (Folke and Kautsky 1989, Naylor and others 1998). In the case of fish stocking, these problems are relatively less pronounced because the released fish often are only cultivated during the juvenile stage, or transferred from other natural sites. More important are the biological effects related to biodiversity and food web dynamics. The released fish that survive generally become an integrated part of the wild aquatic ecosystem, whether a lake or an open coastal area. Long-term or widespread biological effects have been increasingly considered and documented on the native fauna or discussed in terms of risks of slow changes of genetic diversity (Welcomme 1988, Hindar and others 1991, Krueger and May 1991, Meffe 1992, Wahl and others 1995, White and others 1995, Hall and Mills 2000). Fish stocking also has important social implications as a result of changed fish catches, and in some cases also of conflicts arising between stakeholders with different interests in using the local natural resources (Hall and Mills 2000, Landres and others 2001).

Fish stocking in this article refers to the repeated release of fish fry, juveniles, or adults into an ecosystem, and is here divided into the two commonly defined strategies "new introduction" and "enhancements." New introduction is the intentional or accidental re-

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*Author to whom correspondence should be addressed, *email:* cecilia@system.ecology.su.se

lease of fish outside of its historically known native range (IUCN 1987). Fish enhancement, also often referred to as fish stock enhancement, mostly involves an intentional, and often regular release of farmed or transferred fish within their past or present native ranges (IUCN 1987). New introductions have decreased since the 1960s on a global scale because of an increasing environmental awareness and stricter international policies (Regier and Applegate]1972, Welcomme 1988, Krueger and May 1991). Fish enhancements have increased since the 1960s, especially in coastal areas (Blankenship and Leber 1995, Munro and Bell 1997, Grimes 1998, Howell and others 2001).

In this article, we focus on both documented and possible effects of fish stocking in terms of ecosystem services. The analysis is based on the ecological, social and institutional (i.e., norms and rules sensu North 1990) context of using fish stocking as a fisheries management tool in the semiurban setting of Stockholm archipelago, Sweden. Ecosystem services may provide a useful analytical framework in environmental planning and decision-making (Groot 1992), and are in this article defined as the benefits human populations derive from the structures and functions of ecosystems (Costanza and others 1997, Daily 1997, Limburg and Folke 1999), that is, the complex interactions between biotic and abiotic ecosystem components (Groot and others 2002). Our focus is on ecosystem services that fish populations, as integrated components of the aquatic ecosystems, may generate (Holmlund and Hammer 1999). Fish may, for example, participate in and regulate food web dynamics, provide biodiversity, generate various goods as well as aesthetic and recreational values, and be used as indicators in monitoring programs. The concept of ecosystem services is here used as a communicative concept for illuminating the importance of considering objectives, interests, and needs of the involved stakeholders for the process of monitoring and evaluating the ecological consequences. We acknowledge that this concept is context-dependent because of the subjectivity, for example, between various stakeholders, in distinguishing an ecological consequences as improving or undermining ecosystem services (Groot and others 2002). However, our major aim with this article is not mainly to describe actual effects of fish stocking, but to analyze the fish stocking effects from a more holistic ecosystem perspective to natural resource management, where both short-term needs as well as possible, unexpected, and often long-term consequences for an integrated and dynamic human–nature system are addressed (Anon. 1998, Berkes and Folke 1998).

In the article, we review the increasing use of fish stocking in Stockholm archipelago between 1970 and 2000. We first describe the involved stakeholders and their incentives and objectives with the fish stocking. We go on to describe the fish stocking programs including released species, area of release, and origin of fish. The next section analyzes documented and possible effects of fish stocking in terms of ecosystem services. The analysis is based on a selective literature review of identified or often suggested effects of fish stocking. We conclude with a discussion on the issue of monitoring and evaluating fish stocking programs as successful or unsuccessful.

Stockholm Archipelago

Study Area and Archipelago Fishers

Stockholm archipelago (4500 km^2) is situated along the Swedish East Coast of the brackish semienclosed Baltic Sea and constitutes more than 30,000 islands and islets surrounded by bays and lagoons (Figure 1). The archipelago includes the Swedish capital, Stockholm, and can be characterized as a complex, semiurban, multiple-resource user system (Hammer and others 2003). The region has a significant seasonal population pulse in the summers, when the approximately 11,000 permanent inhabitants are complemented with 1 to 2 million summer residents and tourists. In addition to beautiful scenery and recreation, the diverse archipelago generates a wide range of additional ecosystem services, including the provision of important nursing grounds and feeding areas for the approximately 50 local and migratory fish species that live in or pass through the archipelago during different stages of their life cycle. Natural and human-induced disturbances intrinsic to the open archipelago system include land-uplift, salt/freshwater influx, storms, intense human fisheries, pollution, and eutrophication leading to often unpredictable algal blooms (Jansson and Dahlberg 1999).

This highly dynamic archipelago ecosystem sustains a recreational fishery consisting of urban-based sport fishers (hand-gears with line and maximum 10 hooks) and local household fishers (other than hand-gear), and a small-scale licensed commercial fishery. The small-scale commercial fishery is one of the major traditional occupations for the islanders. However, it has declined from some 600 full-time fishers in the mid-1930s to less than 50 in 2000, much because of increased competition from the large-scale offshore fisheries, altered subsidies systems, and to declining fish catches (Hammer 1995). Recreational fishery, on the other hand, has developed rapidly since the 1940s. It has become an economically and politically influential

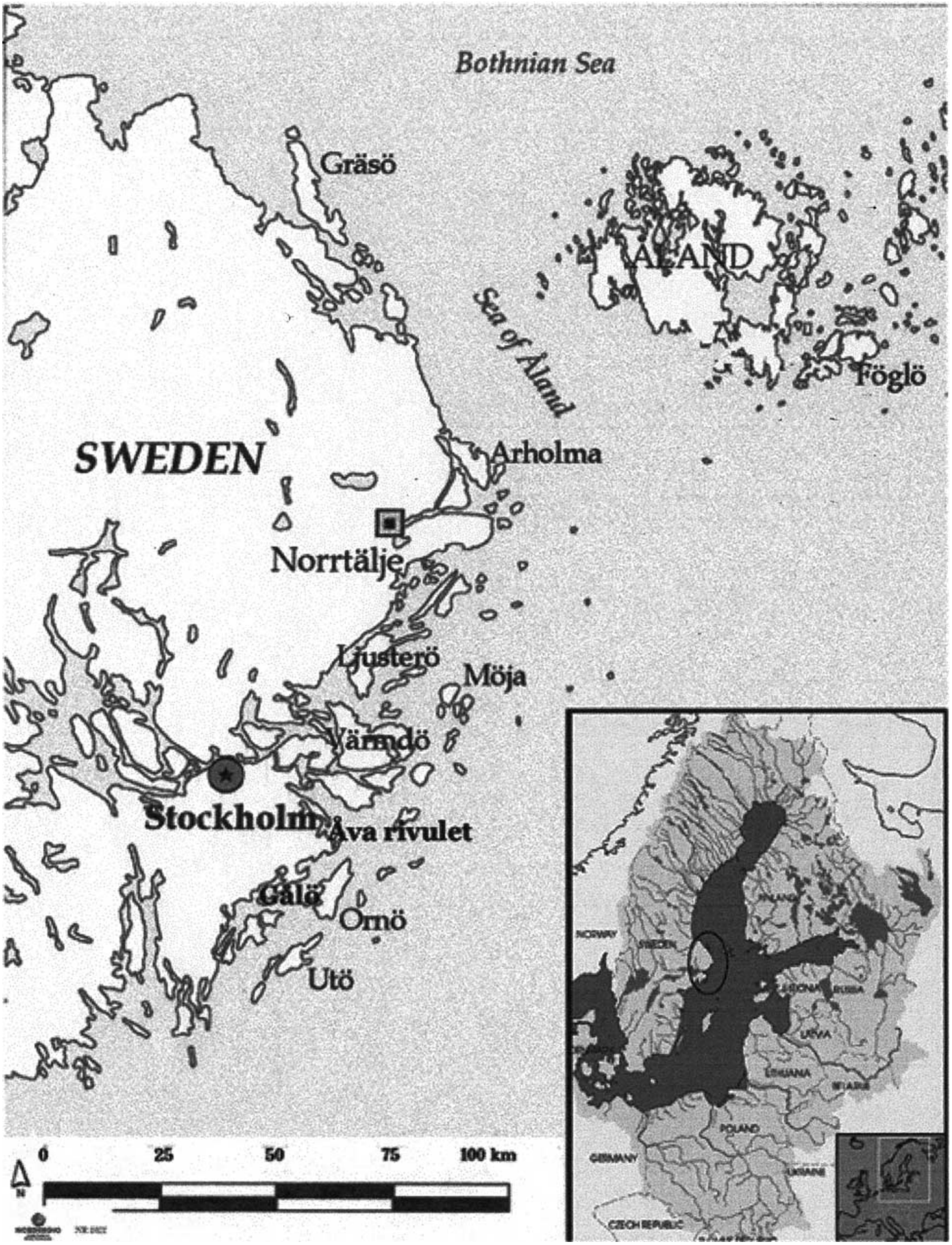

Figure 1. Stockholm archipelago.

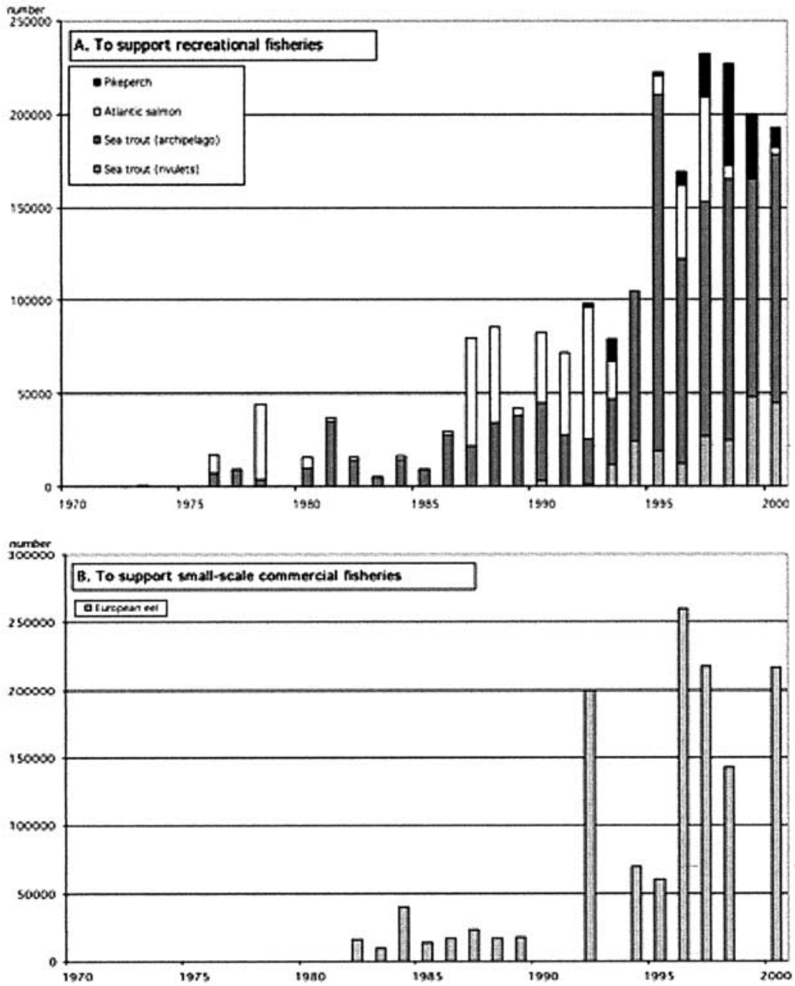

Figure 2. Fish enhancements in Stockholm archipelago 1970–2000. (**A**) To support the recreational fisheries, the number of released sea trout (mostly smolt), and pikeperch (0+) has increased rapidly since the mid-1990s, while the number of released Atlantic salmon smolt has declined. The new introduction of approximately 600 rainbow trout smolt on a few occasions is not included in the diagram. (**B**) The number of transferred yellow and glass eels to support the small-scale coastal commercial fisheries has also clearly increased during the 1990s.

industry, enhanced by a statutory public access to shore areas since 1952, a policy of free fishing with hand-gear in private archipelago waters since 1985, and by an increasing leisure time. There are more than 100 local sport fishing associations in Stockholm County, and some 150,000 fishing visits to the archipelago are estimated to take place each year. There are no available data of recreational or commercial fish catches in Stockholm archipelago.

Data Collection

Swedish fisheries management agencies have not compiled any historical records of stocked species, number of released fish, area of release, involved stakeholders, monitoring activities, or ecological effects. Thus, the compilation of fish stocking activities in Stockholm archipelago that is presented in this study is unique (Figure 2).

We began the study by investigating the institutional structure of national, regional, and local stakeholders actively involved in fish stocking done in Stockholm archipelago. We also gathered available published and unpublished data and policy documents concerning the area, quantity, and origin of released fish. Before 1970, we found no data. For the period 1970–2000, data on fish stocking were provided by the Swedish National Board of Fisheries (SNBF), Stockholm County Administrative Board (SCAB), and Stockholm municipality (Figure 2).

The fish stocking data were complemented by semi-structured, open-ended interviews focusing on objectives with fish stocking. Persons responsible for or engaged in fish stocking programs in Stockholm archipelago were chosen at the SNBF, (Institute of Freshwater Research), SCAB, Stockholm municipality, the umbrella sport fishing association Sportfiskarna Stockholmsdistriktet, and at the hydroelectric power company Vattenfall. Additionally, we participated in fish stocking operations made by Stockholm municipality in cooperation with Vattenfall and local sport fishing associations. The interviews, together with participant observations, provided useful insights into issues and objectives of managers and local fishers involved in releasing fish in the archipelago. Thus, this study has adopted a multimethod approach relying on both quantitative and qualitative data about fish stocking management from primary and secondary sources (Bernard 1994, Kvale 1996). The results are presented first according to involved stakeholders, and then in the next section to released fish species, followed by an analysis of documented and possible effects on ecosystem services.

Social and Institutional Context of Fisheries Management

Fish hatcheries have existed in Stockholm County since 1865, whereas the first indication of fish stocking along the coast of Stockholm archipelago dates from the 1940s (Holmlund 1996). Our survey found little evidence of any regular use of fish stocking in the archipelago before the 1970s. Between 1970 and 2000, however, our interviews identified the following management agencies and stakeholders to be active in releasing fish in Stockholm archipelago (Table 1).

The Swedish National Board of Fisheries (SNBF). This is a governmental agency with legislative power. Permits for releasing fish in Swedish waters have been required from SNBF since 1954. New introductions are forbidden in open Swedish waters except for rainbow trout (*Oncorhynchus mykiss*). Enhancements of native fish species are recommended to support coastal fisheries (Fiskeriverket 2001). All fish stocking should consider potential effects or risks concerning native genetic diversity, and preferably be combined with habitat restorations and regular monitoring (Sparrevik 2001). In Stockholm archipelago, the SNBF has been responsible for and kept records of regular transfers of European eels (*Anguilla anguilla*) to the archipelago since 1982. The major objective of these nationally or EU-funded eel transfers is to provide economic income and mitigate the decline of the small-scale commercial coastal fisheries, which is an important cultural inheritance of the sparsely populated archipelago. SNBF also gives grants to the fisheries management of Stockholm municipality to compensate for lost incomes, because of the institution of a free handgear fishery in 1985. The grants are mostly used for fish stocking. SNBF have ongoing monitoring programs of eel enhancements in lakes as well as along the Swedish coast, but not specifically in the archipelago.

The Stockholm County Administrative Board (SCAB). This is a regional-level management agency, governed by the SNBF. In 1977, the SNBF assigned the SCAB to be responsible for authorizing all local requests of fish stocking. SCAB has a complete data set of area, quantity, and origin of all released fish in Stockholm archipelago as of 1989. SCAB is responsible for identifying suitable release areas for the eel transfers and also to release the eels in practice. SCAB collaborates with Stockholm municipality in monitoring, especially regarding sea trout (*Salmo S. trutta*) enhancements. Together, the agencies perform monitoring in approximately 50 archipelago rivulets once per decade.

Stockholm municipality. Stockholm municipality is one of seven local municipalities in Stockholm archipelago. Since 1973, Stockholm municipality has been responsible for the majority of sea trout, Atlantic salmon (*Salmo salar*), and pikeperch (*Stizostedion lucioperca*) enhancements to support the growing recreational fisheries. In connection to a new fishery manager entering upon his duties in 1989/1990, Stockholm municipality has a mandate to manage most of the sports fishery in the entire archipelago including the rivulets tributary to the archipelago. Since 1989, municipality managers have also been active in engaging local sport fishing associations in sea trout enhancements and teaching them restoration and monitoring procedures in rivulets (rivulet godmothers, see below). The sea trout enhancements are also made in collaboration with Vattenfall. The 30-year-long collaboration between Stockholm municipality, local stakeholders, and a power company is unique for Swedish coastal waters. The monitoring of sea trout enhancements is partly made in collaboration with SCAB (see above). The municipality also put tags on some of the released sea trout. Local fishers report catches of tagged individuals back to the municipality. A complete data set of sea trout and Atlantic salmon enhancements exists since 1973, and of pikeperch enhancements since 1993.

Vattenfall. This is a hydroelectric power company with hatchery facilities producing, for example, Atlantic salmon and sea trout. Since the 1970s, Vattenfall has sponsored 50% of the sea trout enhancements, and occasionally some of the Atlantic salmon enhancements. The company also participates in the sea trout enhancements by providing the tank motor truck containing the hatchery-produced sea trout that are released in the rivulets tributary to the archipelago. Fish stocking is part of the company's public relations, and the major incentive is to promote good will.

Sportfishers of the Stockholm district (Sportfiskarna Stockholmsdistriktet) . This is a local sport fishing umbrella association with approximately 35 member associations in the area of Stockholm archipelago. A fishing association is generally organized to protect and improve the production of game fish in one or a few specific rivulets. Since 1989/1990, local sports fishing associations have

Table 1. Fish stocking programs in Stockholm archipelago 1970–2000

Species/start year	Biology	Origin of released fish	Area of release	Involved stakeholders	Management objectives
Sea trout 1973[a]	Native	Hatchery produced	Archipelago landscape[b]	Stockholm municipality[d]	Support sportfishing
	Anadromous	Source population:...-1994 various, 1994-...Åva rivulet	Rivulets with spawning locales[c]	Local sportfishing associations[e]	Prolong fishing season[h]
	Local migration pattern			Stockholm County Administrative Board[f]	Restore or recreate self-reproducing sea trout populations
	Spawning in 28 archipelago rivulets			Vattenfall[g]	
	5–7 genetically distinct populations				
Atlantic salmon 1978[i]	Native	Hatchery produced	Stockholm stream[j]	Stockholm municipality	Stimulate urban tourism
	Anadromous	Source population: Dalälven		Hydroelectic power company Vattenfall[k]	Support sportfishing
	National/international migration pattern				
	Passing through, but not spawning in the archipelago				
Pikeperch 1993[l]	Native	Hatchery produced	Archipelago landscape[m]	Stockholm municipality	Support sportfishing
	Freshwater species	Source population: inland freshwaters			Spread pikeperch to new areas (within native ranges)
	Spawning in archipelago bays				
	Unknown population structure				
European eel 1982[n]	Native	Transferred	Archipelago landscape	National Board of Fisheries[o]	Support traditional small-scale commercial fisheries
	Catadromous	From Swedish west coast and river Severn in England		Stockholm County Administrative Board[p]	Mitigate decline of Baltic Sea eels
	International migration pattern				
	Living as adults in the archipelago before returning to spawning grounds in Sargasso Sea				
	Panmictic (?) population structure				
Rainbow trout 1993[q]	Nonnative (originally from North America)	Hatchery produced	Rivulets	National organization of aquaculture[r]	Stimulate urban tourism
	Anadromous		Stockholm stream	Local sportfishing associations[s]	Support sportfishing

[a]Unpublished, Idrottsförvaltningen, Stockholm municipality.
[b]In areas with no spawning locales.
[c]In rivulets with or without self-reproducing trout populations.
[d]Governs where, when, and how many trout to be released in most rivulets.
[e]Volunteer as rivulet godmothers in over 20 sea trout rivulets in cooperation with Stockholm municipality. A few associations also release trout by own initiative.
[f]Authorizes all requests of local fish stocking; the County was especially involved in a Tourist Fishery Project 1993–1996.
[g]The government-owned Vattenfall sponsors by providing with 50% of the released trout.
[h]Sea trout may be fished during late autumn, winter, and early spring.
[i]Unpublished, Idrottsförvaltningen, Stockholm municipality.
[j]No spawning locales.
[k]Smolt mostly originating from Dalälven, sometimes offered as gift from national hatcheries.
[l]Data of pikeperch enhancements prior to 1993 has not been compiled.
[m]Unknown possibilities for spawning.
[n]Unpublished, Freshwater Institute, National Board of Fisheries.
[o]Provides the funding.
[p]Decides the area of release.
[q]A few documened cases according to unpublished records at Stockholm County Administrative Board since 1993.
[r]Vattenbrukarnas Riksförbund. Introduced in connection to Stockholm Water Festival in Stockholm Stream.
[s]In rivulets.

been invited by Stockholm municipality to become "rivulet godmothers" (see above). A rivulet godmother association receives an informal right to participate and monitor sea trout enhancements. The number of associations cooperating with the municipality have varied during the years. In general, 10–15 associations are active rivulet godmothers for some 20 rivulets. A few other sport fishing associations with no or little collaboration with the municipality also release fish by their own initiative, mostly involving sea trout but also the nonnative rainbow trout (*O. mykiss*). Sportfiskarna Stockholmsdistriktet also collects money from volunteer sport fishers to support fish stocking operations made in collaboration with Stockholm municipality.

National Organization of Aquaculture (Vattenbrukarnas Riksförbund). This is a nongovernmental trade organization for the Swedish aquaculture. It has sponsored the introduction of rainbow trout on one occasion.

Fish Stocking Programs

Fish stocking in Stockholm archipelago has been regularly used since the 1970s and increased from some 10,000 to an average of 370,000 released fish individuals per year in the late 1990s. In total, between 1970 and 2000, more than 3,000,000 fish of various ages have been released into archipelago waters as well as in freshwater tributaries (Holmlund 1996). Four native and one nonnative fish species have been utilized in the fish stocking. In the following sections, we describe the fish stocking programs, including quantity (Figure 2), biology and population structure, area of release, origin of released fish, and involved stakeholders (Table 1).

Sea trout enhancements. Sea trout (*Salmo S. trutta*), is a native, piscivorous, and anadromous species, linking its natal freshwater rivulet with the brackish archipelago waters (Table 1). The migration patterns of trout are relatively local and they live mostly within the archipelago waters. The sea trout in Stockholm archipelago are mostly exploited by the recreational fisheries. In the mid 1970s, there were 14 archipelago rivulets with spawning sea trout. In 1995, sea trout were found to spawn in 28 rivulets, as a result of habitat restorations and regular enhancements (Lovén and Ungsgård 1999). Five to seven of these rivulets are believed to sustain genetically distinct sea trout populations with no or little history of fish enhancement. In the more than 20 remaining rivulets, the sea trout are of either wild or hatchery origin, or a mixture of both. Local managers estimate the total production of sea trout smolt in rivulets to be approximately 24,000–30,000 per year (H. Andersson, Stockholm County Administrative Board, pers. comm. 2002).

After some first experimental stocking in 1973 of sea trout smolt in Stockholm Stream downtown, by Stockholm municipality in collaboration with Vattenfall, the yearly enhancements have increased from only a few thousand in the 1970s-1980s to approximately 125,000 trout smolt between 1996 and 2000 (Figure 2). Most of the released trout are 1–2 years old, except for in the year 2000, when roe also were released.

Sea trout are released in areas both with and without spawning locals. First, sea trout are released more or less regularly in more than 30 rivulets tributary to the archipelago with or without self-reproducing sea trout populations. Most of these rivulets have been restored after several years of severe pollution, eutrophication, and destructive land-use changes. These rivulet enhancements have increased especially since the end of the 1980s, as a direct consequence of a new national regulation in 1985 of free sports fishing with handheld gears in private waters. This regulation enabled the municipality to use governmental funds for releasing fish not only on state-owned property but also on private property (S. Lovén, Stockholm municipality, personal communication 2001). Second, sea trout are released by Stockholm municipality in areas of little likelihood of spawning activity, including the Stockholm Stream in the city of Stockholm, and further out in the archipelago landscape. Per year between 1996 and 2000, 24% of the trout (approximately 30,000) were released in rivulets and 76% (approximately 95,000) were released in nonspawning areas.

Up until 1994, the origin of the released trout have varied and included broodstock from more than 10 different locals along the Swedish east coast. Hereafter, one local archipelago population (Åva rivulet) has dominated as the source population for all sea trout enhancements in both the rivulets, Stockholm Stream, and the archipelago. The enhancements made in the archipelago landscape generally involve delayed release, that is, roe originating from the Åva rivulet are first hatched in the hatcheries of Vattenfall. Then, the trout are kept in net cages in the inner part of the archipelago (Gålö island) over the summer before being released in the vicinity of the cages (Figure 1). The Åva sea trout population is used by managers as source population mainly because it is considered to be stationary to the archipelago and also because a comparatively large number of sea trout return to the Åva rivulet for spawning each year.

Atlantic salmon enhancements. Atlantic salmon (*Salmo salar*) is a native, piscivorous, and anadromous species (Table 1). It spawns in several Swedish rivers tributary to the Baltic Sea, however, not within the archipelago boundaries. One of the closest natal rivers is Dalälven, situated some 200 km north of Stockholm. Atlantic salmon is a highly migratory species and passes through the outer parts of the archipelago during its migration of hundreds of kilometers in the Baltic Sea. During its migration, the salmon are exploited by both the commercial and the recreational fisheries. Large-scale enhancements of salmon have been made regularly since the 1950s in Sweden. At present, approximately 2,000,000 Atlantic salmon are released yearly in major Swedish East Coast rivers. These national enhancements, based on Water Rights Court decisions, compensate the commercial fisheries for hydropower exploitation in salmon spawning locales. Some 90% of the salmon stock in the Baltic Sea is estimated to originate from hatcheries (Petersson and Järvi 1999). There are indications that the hatchery-produced salmon is less genetically diverse compared to their wild counterparts (Koljonen and others 1999).

Salmon enhancements in Stockholm stream are run by Stockholm municipality, partly funded by Vattenfall, and partly in collaboration with a local sport fishing association. The enhancements have been more or less regular since 1978. The average number of yearly released salmon have declined from some 30,000 per year during 1986–1990 to 22,000 between 1996 and 2000 (Figure 2). Most of the released salmon smolt have originated from the river Dalälven, produced in the hatcheries of Vattenfall. However, during the 1990s, the Swedish hatchery production of salmon smolt has suffered from sudden outbreaks of a disease called the M74 syndrome, killing 60% to 95% of the captive salmon. The reasons behind M74 still are not fully understood. In 1994, for example, much of the national hatchery production failed because of M74, leaving no salmon to be released in Stockholm archipelago. The salmon are not primarily expected to reproduce but to be caught by urban sport fishers in the city of Stockholm.

Pikeperch enhancements. Pikeperch (*Stizostedion lucioperca*), is a native, piscivorous, and originally a freshwater species (Table 1). However, it also reproduces in the brackish waters of the Swedish east coast, including the inner parts of the archipelago. Pikeperch are exploited both by the commercial and the recreational fisheries. The population structure is unknown, but the pikeperch found in the archipelago are likely part of a larger regional stock of the Swedish east coast (S. Hansson, Department of Systems Ecology, Stockholm University, personal communication 2002). The abundance of pikeperch in the brackish coastal waters has been increasing since the 1950s, most likely in response to coastal eutrophication (Lehtonen and others 1996).

Pikeperch enhancements, run by Stockholm municipality, have been made occasionally in the 1970s and 1980s, and on an annual basis since the beginning of the 1990s. An average of 26,000 pikeperch were released per year between 1996 and 2000 (Figure 2). Generally, the released pikeperch (0+) originate from hatcheries using roe from Swedish inland freshwaters, and not roe from the coastal stock. The objective is to spread this species to new areas and support sport fishing (Lovén and Ungsgård 1999).

European eel enhancements (transfers). European eel (*Anguilla anguilla*), is a catadromous, highly migratory omnivorous fish species (Table 1). It crosses several national borders while moving between the spawning locales in the Sargasso Sea and the European feeding areas including the brackish Baltic Sea and the archipelago. Eel is one of the most economically important target species of the small-scale commercial fisheries in the archipelago, but this species is also exploited by recreational fishers. In general, European eel is considered to be one panmictic population. However, some evidence suggests that the Baltic Sea eel may be one of several genetically and geographically separated eel populations of the European eel (Wirth and Bernatchez 2001). The Baltic Sea eels have been declining since the 1940s, probably as a result of a combination of natural and human-induced changes (for review see, e.g., Wickström 2001). The stock of eels along the other European coasts has also been steadily declining since approximately the 1960s.

Eel enhancements, governed by the SNBF, have been made regularly along the Swedish east coast, including the archipelago since 1982. During the 1990s, an average of 120,000 eels were released per year, which is an increase by an order of magnitude compared to the 1980s (Figure 2). Both yellow eels aged 2–6 years, originating from the Swedish west coast, as well as glass eels, aged 1–2 years, imported from the river Severn in England are regularly released. The eels are transferred to Stockholm archipelago from other areas, because rearing of eel fry has been unsuccessful (Fiskeriverket 2001). The major objective is to provide economic income for the declining coastal small-scale commercial fisheries.

Rainbow trout new introductions. Rainbow trout (*Oncorhynchus mykiss*) is an anadromous nonnative species, imported to Sweden in 1892 from the North American lands bordering the Pacific Ocean (Table 1). In Stockholm archipelago, the introduced rainbow trout are mostly exploited by the recreational fisheries. In general, rainbow trout have shown difficulty in establishing self-sustaining populations in Swedish waters, despite their well-known adaptive capacity to new environments (Landergren 1999).

Some 600 hatchery-produced rainbow trout have been introduced in rivulets on a few occasions during the 1990s by local sport fishing associations, and once in Stockholm Stream downtown by the National Organization of Aquaculture in connection with a tourist event, the Water Festival. In addition, an unknown number of rainbow trout is also believed to have escaped from the approximately 10 net cage farms that are situated in the archipelago. Objectives with introducing rainbow trout are to support sport fishing and tourism.

Fish Stocking Effects on Ecosystem Services

In the forthcoming sections, a number of ecosystem services that fish populations participate in or generate are first described (Holmlund and Hammer 1999). Then, based on a selective literature review (Table 2), an analysis follows of documented and possible effects in terms of ecosystem services of fish stocking in Stockholm archipelago between 1970 and 2000 (Table 3). The documented effects are based on data of the voluntary monitoring of fish stocking that has been made by authorities and local stakeholders, as well as on our interviews. The possible effects refer to the findings of case studies presented in Table 2 Ecological effects within the borders of the archipelago are focused, because of the high degree of uncertainty concerning the migratory patterns of the released fish.

Ecosystem Services Generated by Fish

Regulate food web dynamics. Fish may participate in the ecosystem service of regulating food web dynamics. Fish living in aquatic ecosystems consume, or are consumed by, other organisms and can thereby influence the trophic structure and food web dynamics. For example, piscivores (fish that eat fish) preying on zooplanktivores (fish that eat zooplankton) can exert a strong top-down control, resulting in a cascade of effects down the food web (Carpenter and others 1985). Moreover, these regulatory influences change as fish pass from one life stage to another, depending on their choice of prey.

Act as mobile links. Fish may act as mobile links (Lundberg and Moberg 2003) and as such, generate ecosystem services related to their movement patterns (daily, seasonal, or yearly migration patterns). For example, anadromous salmonid fishes in North America and Russia have been shown to represent mobile links and transport marine-derived carbon and nutrients to their natal freshwater rivers through fish excretion, production of gametes, and fish carcass decomposition, and thereby contribute to the river biomass (Krokhin 1975, Naiman and others 2002).

Provide and generate biodiversity. Fish contribute to the aquatic biodiversity both as individuals (larvae, juvenile, adult, and carcass), populations, and species. Biodiversity at different levels provide genetic sources of renewal needed to cope with and adapt to the dynamics of ecosystems (Holling 1973, Wilson and others 1999, Gundersson and Holling 2002).

Provide food, game, and aesthetic values. Fish are frequently valued for generating ecosystem services related to various forms of goods including food and game for fisheries, as well as providing recreational and aesthetic values.

Provide ecological information. The features and functions of fish populations provide information to scientists, managers, and resource users. Individual fish are often easily sampled research objects for studying growth rate, age, identification of spawning locales, migrating and colonization patterns, environmental history, and so on. Fish can be used as bioindicators, for example, by analyzing the earstones (otoliths) or the genetic makeup of the fish. At the population level, fish catches are frequently used in fisheries management for estimating stock sizes or compositions, migratory patterns, and so on.

Documented and Possible Effects on Ecosystem Services

Table 2 presents a review of case studies of both documented and possible effects on ecosystem services of fish stocking. With regard to the brackish state of the archipelago waters harboring both marine and freshwater fish species, case studies of both marine and freshwater ecosystems are included. Notably, the ecological effects of fish stocking presented in Table 2, to a large degree, depend on the ecosystem context. The described effects depend on a combined set of biotic and abiotic variables, including ecological behavior, life-stage, density of released and recipient fish species, prevailing temperature, time of day, area, depth of release, and season, as well as the state of the recipient ecosystem. The evaluation of the ecological consequences of fish stocking as either stimulating or undermining specific ecosystem services depends on the social and institutional context, that is, on which stakeholders that are involved and what their objectives and expectations are. Thus, the information in Table 2 may not be generally applicable because of the broad spectrum of ecological and social mechanisms behind the findings. Nevertheless, some general observations can be made.

New introductions, on the one hand, are generally made in lakes and reservoirs. The objective is often to alter ecosystem functions with regard to specific, de-

Table 2. Effects of new introductions (A-B) and fish enhancement (C-D)[a]

A. New introduction: documented effects on ecosystem services

Ecosystem services	Examples of mechanisms	Literature references
Food web dynamics	Nonnative r-selecting fish compete for space or food with native K-selecting fish, influencing their growth, survival, reproductive success, and habitat	McKaye and others 1995, Hall and Mills 2000
	Nonnative fish predate on native fish of different life-stages	Holcik 1991, Tyus and Saunders 2000
	Nonnative fish predate on other aquatic species than native fish fauna	Kitchell and others 2000
	Nonnative fish predate on native fish, zooplankton, benthic/terrestrial prey or aquatic weed, and influence nutrient cycling and algae production	Shapiro and Wright 1984, DeMelo and others 1992, Marchall and Maes 1994, Parker and others 2001, Schindler and others 2001
	Hybrid fish show different ecological behavior	Leary and others 1995
	Nonnative fish control pest in polyculture rice production (e.g., Silver barb, *Barbodes gonionotus,* common carp, *Cyprinus carpio L,* Nile tilapia, *Oreochromis niloticus L.*)	Halwart and others 1996, Vromant and others 2001
	Nonnative fish influence water clarity by controlling aquatic weed (e.g. common carp and Nile tilapia) or algae (e.g., pike, *Esox lucius,* bass, *Micropterus salmonides*)	Vighi and others 1995, Søndergaard and others 1997
	Nonnative fish cause nonsignificant or only short-term effects on water clarity	McDermot and Rose 2000, Seda and others 2000
	Nonnative small larvivorous fish (e.g., *Gambusia or Poecilia*) control snail vectors for schistosomiasis, or mosquito larvae	Welcomme 1988, Marchall and Maes 1994
Linking aquatic ecosystems	Predation and migration patterns of nonnative fish result in "new" linkages, including transport of benthic nutrients to the pelagic	Tátrai and others 1997, Schindler and others 2001
	Nonnative fish spatially displace native fish juveniles in spawning ocales	Leary and others 1995, Landergren 1999
Linking aquatic–terrestrial ecosystems	Nonnative game fish in wilderness lakes predate on littoral species, including embryonic/larval stages of amphipods at landscape scales	Pilliod and Peterson 2001
Biodiversity	Nonnative and native salmonids hybridize and genetic diversity is lost	Krueger and May 1991, Leary and others 1995
	Nonnative fish of high and low trophic levels compete with natives that decline or go extinct	Nilsson 1972, Celikkale 1990, Krueger and May 1991, McGurrin and others 1995, Kitchell and others 1997, Hall and Mills 2000, Parker and others 2001
	Contamination of disease pathogens or parasites cause massive decline of natives	Holcik 1991, Krueger and May 1991, Hall and Mills 2000
Food and livelihood	Nonnative forage or food fish (e.g., Nile perch, *Lates niloticus,* mullets, Mugilidae) have in some cases increased local/regional commercial or subsistence fish catches, but not in others	Holcik 1991, Kitchell and others 1997, Hall and Mills 2000
	Nonnative fish (e.g., carp or Nile perch) outcompete native sources of local subsistence or commercial exploitation	Iongh and Zon 1993, McKaye and others 1995, Sugunan 2000, Hall and Mills 2000
Game and recreation	Established nonnative salmonid fish alter spatial angling patterns, from, e.g., nearshore to offshore	Lange and others 1995
	Established nonnative salmonid fish increase short-term angling and economic benefits	Stephanou 1990, Lange and others 1995
Aesthetic values	Manipulated ecosystems where nonnative fish replace natives compromise wilderness values	Landres and others 2001
	Nonnative fish provide ornamental values (e.g., gold fish, *Carasstus auratus auratus,* or smaller-sized species for aquarium)	Welcomme 1988

Table 2. (Continued)

B. New introduction: possible effects on ecosystem services		
Ecosystem services	Examples of mechanisms	Literature references
Food web dynamics	Unpredictable long-term food web changes may result, even after removal of nonnative fish	McDermot and Rose 2000, Donald and others 2001
	Regulating feedbacks mechanisms of, e.g., spawner densities may be decoupled by high densities of competing nonnative fish, especially if the ecological niche of introduced fish overlap with the niche of native species	Krueger and May 1991, Iongh and Zon 1993
	Predation/competition by nonnative fish may lead to simplified food web and altered nutrient cycling capacity	Hall and Mills 2000
	Top-down forces by nonnative predatory fish may contribute to improved water quality	Carpenter and others 1985, DeMelo and others 1992, Jeppesen and others 1998
Linking aquatic ecosystems	Agressive dispersal behavior of nonnative fish within lake-stream networks may increase colonization rate of new habitats	Hrabik and Magnuson 1999, Adams and others 2001
Biodiversity	Nonnative fish (e.g., Nile tilapia) may release threatened native fish from fishing pressure	1. Lorenzen and others 1998
Cope with environmental change	1. Nonnative predatory fish may provide short-term buffer capacity to effluent nutrient inputs	Carpenter and others 2001
	Simplified food web in, e.g., Lake Victoria, where hundreds of native fish were replaced by a few dominating nonnative fish, may reduce response diversity	Hall and Mills 2000
	If native K-selecting fish that response to slower variables are replaced by r-selecting nonnative fish, responding to faster variables, the disturbance regimen may be influenced	Kitchell and others 2000
Ecological information	Put-and-take fishery may stimulate local environmental education, nature experiences, and engagement, e.g., among urban citizens	Schramm and Mudrak 1994
	Released nonnative fish may generate good publicity for involved stakeholders	Schramm and Mudrak 1994

C. Fish enhancement: documented effects on ecosystem services		
Ecosystem services	Examples of mechanisms	Literature references
Food web dynamics	Released salmonid fish have shown different ecological behavior (e.g., predation, competition) in spawning locales compared to their wild counterparts	Waples 1999, Sundström and Johnsson 2001
	Released salmonid fish have caused massive predation on juveniles of recipient fish	Wright 1981
Linking aquatic ecosystems	Released hatchery/transfered salmonid fish have shown different timing and duration of migration	Heard and others 1995, White and others 1995
	Massive release of salmonid fish has spatially displaced wild fish	Hindar and others 1991, White and others 1995
Biodiversity	Domestication, defined as any genetic change of a fish population that result from human control, cause reduced behavioral, morphological or physiological fitness (e.g., fecundity, growth, size, behavior) across life-stages of released salmonid fish, with negative consequences for their survival rate	Ryman and others 1995, White and others 1995, Petersson and Järvi 1999, Waples 1999
	Mixing of released and recipient salmonid fish reduce diversity between populations	Hindar and others 1991, Leary and others 1995

Table 2. (Continued)

A. New introduction: documented effects on ecosystem services		
Ecosystem services	Examples of mechanisms	Literature references
	Released native salmonid fish have mixed with fish of other species, likely because of large densities and different mobility patterns of released fish	Hindar and others 1991, Jansson and Öst 1997
	Contamination of disease pathogens or parasites reduce abundance of wild fish	Hindar and others 1991
Food and livelyhood	Mixed fish populations have shown nonsignificant harvest changes	White and others 1995
	Mixed fish populations have contributed to increased commercial harvests (e.g., chum salmon, red sea bream, lake sturgeon, *Acipenser fulvescens*) when filling seemingly empty ecological niches after previous depletion/overfishing or after creation of new habitats	Liao 1997, Schram and others 1999, Blaxter 2000
	Released native salmonid fish have mixed with fish of other species, likely because of large densities and different mobility patterns of released fish	Hindar and others 1991, Jansson and Öst 1997
	Contamination of disease pathogens or parasites reduce abundance of wild fish	Hindar and others 1991
Food and livelyhood	Mixed fish populations have shown nonsignificant harvest changes	White and others 1995
	Mixed fish populations have contributed to increased commercial harvests (e.g., chum salmon, red sea bream, lake sturgeon, *Acipenser fulvescens*) when filling seemingly empty ecological niches after previous depletion/overfishing or after creation of new habitats	Liao 1997, Schram and others 1999, Blaxter 2000
Game and recreation	Released fish (e.g., chinook salmon, *Oncorhynchus ishawytscha*, and largemouth bass, *Micropterus salmonides*) have contributed to short-term increased recreational harvests	Buynak and others 1999, Peck and others 1999

D. Fish enhancement: possible effects on ecosystem services		
Ecosystem services	Examples of mechanisms	Literature references
Food web dynamics	Released prey/predator fish may compete with resident populations/species for food and space	Wahl and others 1995, Pearsons and Hopley 1999
	Released fish with reduced predator response, because of hatchery selection processes, may increase the availability of prey for wild fish	White and others 1995, Pearsons and Hopley 1999, Blaxter 2000, Kellison and others 2000, Höjesjö 2002
	Larger, numerous, and behaviorally different released fish may increase predation on other aquatic species	. Pearsons and Hopley 1999
	Predation on released fish may stimulate predation on wild fish	Hindar and others 1991, Waples 1991
	Released planktivorous fish may improve local water clarity in costal waters	Hansson and others 1997
Linking aquatic ecosystems	Timing and duration of migration or increased straying rate among released salmonid fish or eel may influence spawning or energy transport between ecological subsystems	White and others 1995, Westin 1998, Pearsons and Hopley 1999
Linking aquatic–terrestrial ecosystems	Released salmonid fish may constitute prey for terrestrial or avian species	White and others 1995, Pearsons and Hopley 1999, Blaxter 2000
Biodiversity	Released fish may have higher straying rate, mix with wild fish, and cause an unnoticed loss of genetically defined traits during several generations	Waples 1991, Campton 1995, Heard and others 1995, Palm and Ryman 1999, Busack and Currens 1995, White and others 1995, Laikre and Ryman 1996, Waples 1999

Table 2. (Continued)

A. New introduction: documented effects on ecosystem services		
Ecosystem services	Examples of mechanisms	Literature references
	Releasing fish in native spawning locales may cause loss of diversity within population	White and others 1995
	Fertile hybrids between released and wild fish, in turn breeding with wild fish, may reduce diversity	Leary and others 1995
	Competition with wild fish may reduce genetic diversity and weaken wild fish populations	Hindar and others 1991
	Spread of disease pathogen or parasite by resistant fish to an area of nonresistant fish may cause extinctions	Waples 1991, White and others 1995, Laikre and Ryman 1996
	Fishery on mixed fish stocks may lead to overharvest of small/weak or adjacent local populations, or else may provide a protective buffer against overharvesting	Wright 1981, Hindar and others 1991, Heard and others 1995, Laikre and Ryman 1996
Cope with environmental change	Diversity loss (within or between fish populations) may lead to less efficient use of the environment	Waples 1995
	Diversity loss may reduce the genetic heritage as source of renewal in times of disturbances, and lose capacity to cope with periodic changes including thermal or seasonal fluctuations	Busack and Currens 1995, Leary and others 1995, White and others 1995
Aesthetic values	Releasing fish may be perceived as "manipulating the wilderness," and reduce the sense of naturalness among resource users	Landres and others 2001
Ecological information	Feedback signals of ecosystem change may be altered, e.g., if mixed fish populations make it difficult for managers/resource users to monitor the status of small populations	Wright 1981, Utter and Ryman 1993
	Initial success of regular fish enhancement may instill a false sense of security, and undermine incentives for long-term monitoring, evaluation, and adaptive practices	White and others 1995, Holling and Meffe 1996

[a]A selective literature review of documented (A and C) and possible effects (B and D) of releasing nonnative (A-B) or native (C-D) fish in open or closed water systems. Depending on the management objectives, the major mechanisms behind the role of released fish may be interpreted as either stimulating or undermining specific ecosystem services.

sired, ecosystem services, including to increase water clarity, to create new sport or commercial fisheries, or as ornaments (Table 2A–B). New introductions may also be accidentally made, for example, when fish escape from net cage aquaculture production (Food and Agriculture Organization 1998) or from internationally transported ballast waters (Wonham and others 2000). Expected and unexpected consequences of new introductions are well documented, and often result from competition, predation, interbreeding, or the introduction of diseases by the nonnative fish. Examples include cascading food web changes at the level of species, not only in the area of release but also in nearby, linked ecosystems including shore and land ecosystems (Table 2A). Possible long-term changes of new introductions are also often discussed, including effects on the ecosystem capacity to cope with and adapt to environmental change (Table 2B).

Enhancements, on the other hand, are often made with the objective of not causing any dramatic changes of ecological functions, but rather to enhance already existing ecosystem services, such as native fish production that support various forms of marine, coastal, or freshwater fisheries (Table 2C–D). In some cases, the released fish originate from the same area where the enhancement takes place, that is, the recipient fish population is used as source population in the hatchery production. In other cases, fish populations from other areas are used as either source population in the hatchery production, or directly transferred. Fish used in enhancement programs are thus native to the area at the level of fish species but not necessarily at the level of fish population. Enhancements of native fish, originating from either the recipient fish population or from another genetically distinct population, result in a mixture of released and recipient fish that may interbreed, that is, reproduce together (Utter and Ryman 1993). For simplicity, in this article all such mixtures are referred to as "mixed fish stocks." Consequences of fish enhancements have been relatively sparsely docu-

Table 3. Fish stocking effects: documented and possible effects in Stockholm archipelago in terms of ecosystem services

Species	Ecosystem services	Documented effects	Possible effects
Rainbow trout	Food web dynamics		x
	Biodiversity	x	
	Game	x	
Sea trout	Food web dynamics		x
	Mobile links		x
	Biodiversity		x
	Game/recreation	x	
	Ecological information	x	
Atlantic salmon	Biodiversity, mobile links		x (nationalscale)
	Game	x	
	Tourism (aesthetic values)	x	
Pikeperch	Food web dynamics		x
	Biodiversity		x
	Game		x
European eel	Biodiversity	x	x
	Mobile links		x(internat,scale)
	Food		x
	Ecological information		x

mented (Table 2C), but the more discussed and speculated about concerning various risks for biodiversity, especially at the population level, at the time scales of decades (Table 2D). For example, if the behavioral, morphological or physiological fitness of the hatchery produced fish is different compared to their wild counterparts, a mixing between hatchery and wild fish of the same species may cause biodiversity changes (Table 2D). Also, it has been suggested that regular enhancements may stimulate a high and steady fishing pressure and either mask an overfishery on declining wild fish resources, or provide some buffer against overfishing (Table 2D). In addition, mixed fish stocks may be problematic to use as indicators of ecological change for fisheries managers or resource users, because the wild fish may be difficult to discern from the hatchery-produced fish.

Effects of Sea Trout Enhancements

Food web dynamics. The large scale of sea trout enhancements (125,000 released smolt per year, of which 30,000 smolt were released in archipelago rivulets, compared to the yearly production of 24,000–30,000 wild smolt in the rivulets) may influence local food webs, for example. In accordance with other studies of salmonid enhancements in rivers (Table 2C–D), the released trout smolt in the archipelago rivulets may, for example, influence predation patterns by being preyed on by other aquatic, terrestrial, or avian organisms in the rivulet or near the outlets. Hatchery-produced sea trout may also have different ecological behavior, and compete with or result in an increasing predation on the recipient sea trout, as has been found in other cases (Table 2C–D).

Mobile links.

The establishment of sea trout in an additional 14 rivulets since the 1970s may increase the transport of nutrients and carbon from the brackish archipelago waters to these freshwater systems, as the adults migrate to the rivulets for spawning (Table 3). An increasing number of migrating sea trout may thus be beneficial for the biomass production in the rivulets (Table 2D). This consequence would be in line with the objectives of managers and the sport fishers who are actively engaged in restoring archipelago rivulets. However, in contrast to the case studies presented in Table 2, the archipelago stocks of sea trout do not generally die after spawning, but return to their home rivulet several times as adults for spawning.

Biodiversity. The biodiversity of especially the five to seven genetically distinct sea trout populations may be influenced. These populations are believed to have a relatively high degree of diversity, as has been shown in other cases of trout populations in Sweden (Ryman and others 1986). The strategy to only use the local Åva rivulet as source population for all sea trout enhancements since 1994 is believed to better preserve the genetic diversity of the archipelago sea trout populations (S. Lovén, Stockholm municipality, personal communication 2002). Still, the Åva sea trout released in the archipelago landscape may find the spawning locales of the genetically distinct sea trout populations and successfully reproduce (Table 2D). This risk is supported by evidence that sea trout has been found to be able to reproduce in the brackish waters of other Swedish rivulet outlets tributary to the Baltic Sea (Landergren 2001). This would not be in accordance with the management objective of protecting these populations, and will likely be analyzed in the near future (H. Andersson, Stockholm County Administrative Board, Personal communication 2002). However, if the released sea trout stray to the approximately 20 other archipelago rivulets, which already harbor mixtures of various sea trout populations, it would be in accordance with the management objectives of increasing the total production of sea trout smolt. The five to seven genetically distinct sea trout populations may also be increasingly exposed to a mixed stock fishery with risks of over fishing, where the hatchery-produced sea trout are not possible to discern from those sea trout that need protection (Table 2D). Even a small-scale overfishing has been suggested to cause significant loss of population diversity, with possible cascading consequences to the level of species, or even to the level of its life-supporting ecosystems (Kitchell and others 1997, Wilson and others 1999, Hall and Mills 2000).

Game and aesthetic values. Recapture rates of approximately 10% to 25% of the released sea trout, the doubling of the number of rivulets harboring spawning trout between 1976 and 1995 from 14 to 28, and the exclusive use of the stationary Åva sea trout as source population since 1994 are all factors that endorses a general notion of success (Holmlund 1996). Local managers are convinced the sea trout production and sport fishery has increased as a result of sea trout enhancements (Lovén and Ungsgård 1999). However, the monitoring has not concluded whether the estimated increased catch rates rely on the rivulet enhancements, the habitat restorations, or the delayed release further out in the archipelago, or a combination of them all. Also, some of the interviews revealed a possible conflict between an increasing traffic of small motor boats and the vision of the archipelago as an undisturbed recreational area (Hammer and others 2003).

Ecological information. SCAB and Stockholm municipality monitor the production of sea trout in approximately 50 archipelago rivulets once per decade. The rivulet monitoring is based on electric fishing and analysis of the bottom fauna composition as an indicator of pollution, acidification, and of the existence of suitable food resources for sea trout. This type of monitoring is not likely affected negatively by fish enhancements (Table 2C–D). Rather, the sea trout enhancements have regularly attracted some 10–15 sport fishing associations to become engaged in and learning about sea trout and the rivulet ecosystem. These "rivulet godmothers" perform a nonofficial monitoring, resulting in an exchange of experiences and knowledge between sport fishers and municipality managers. Through seasonal observations, the rivulet godmothers improve the spawning locales by ameliorating the water-bearing and streaming capacity, adding gravel, stones, and hideouts, removing migration obstructions, and planting trees and shrubs along the rivulet as protection against erosion, nitrogen leakage, and as sunshade. They also cooperate with the municipality managers and inventory the environmental status of the rivulet. Our interviews reveal that during these activities, the sport fishers accumulate experiences that they confer to a large extent to the local managers at the municipality through an informal dialogue (S. Lovén, Stockholm municipality, personal communication 2001). However, it should be noted that the bulk of fishers or private owners of archipelago waters have not been integrated in either fish stocking or monitoring activities. This is likely partly because of the free handgear fishing in all archipelago waters, instituted by the 1985 national legislation. As a result, the uncontrolled public fishing on private waters increased, and the incentives and possibilities for the water owners to take responsibilities for monitoring was partly undermined. Furthermore, it should be noted that the building up of a mixed stock fishery may undermine the potential to monitor wild sea trout in the archipelago landscape (Table 2D). It may also become increasingly difficult for recreational fishers to adapt their fishery and recognize signals of overfishing the small, genetically distinct sea trout populations.

Effects of Atlantic Salmon Enhancements

Food web dynamics, biodiversity, mobile links, and bioindicators. Atlantic salmon enhancements in Stockholm stream are relatively small (30,000 compared to the release of millions of Atlantic salmon along other sites of the Swedish East Coast). Also, salmon only stay for a shorter period within the borders of the archipelago, according to a few tagging experiments. Because these factors, possible effects on food web dynamics, biodiversity, and mobile links within Stockholm archipelago are not very likely (national effects, see for example Koljonen and others 1999, Petersson and Järvi 1999).

Food, game, and aesthetic values. Even though most of the released salmon seem to migrate out of the archipelago, some are caught in the city of Stockholm by urban fishers (Table 3). The salmon also "splash about" in the stream to the satisfaction of tourists. These effects are in line with the major objectives of both managers and the actively engaged sport fishers to generate valuable cultural values to the urban population.

Effects of Pikeperch Enhancements

Food web dynamics. The regular additions of pikeperch have been suggested to mitigate some of the local symptoms of the continuous eutrophication in the archipelago through their predation patterns (Hansson and others 1997). The authors claim that the trophic cascading hypothesis, developed for lakes (Carpenter and others 1985, Kitchell and others 2000), may apply in the case of releasing the freshwater species pikeperch in the brackish archipelago. According to other freshwater case studies (Table 2A), adding pikeperch may increase the predation on the zooplanktivorous fish, and thereby allow the grazers to flourish, reduce the algae, and improve the water clarity locally. Some of the interviews indicate that such effects would be considered positive, and in line with the common assumption that added top predators may fill a vacant niche in the generally eutrophic archipelago ecosystem.

Biodiversity. The use of pikeperch originating from freshwaters and not the coastal waters may influence the diversity of the coastal stock of pikeperch. Our literature review, however, found little discussion regarding diversity in connection to pikeperch enhancements (Table 2C–D).

Game. At the municipality, the managers are convinced that pikeperch enhancements have spread this species to new areas in the archipelago and thereby increased the sport fishing catches (Lovén and Ungsgård 1999). However, there is no evidence supporting these perceptions. Managers and researchers have little knowledge about the mobility, spawning, or population patterns of pikeperch, and there was virtually no monitoring of the pikeperch enhancements between 1970 and 2000.

Effects of European Eel Enhancements

Mobile links. To transfer eels from other sites and countries to the Baltic Sea and Stockholm archipelago may not necessarily have any influence on the migratory pattern of european eels, not as long as those eels escaping fisheries have the capacity to find their way back out of the Baltic Sea, return to the Sargasso Sea, and successfully spawn (Westin 1998). Recent research on eel otoliths has shown that almost a third of the eels leaving the Baltic Sea have been released (Limburg and others 2003), but whether or not the eels reach the spawning grounds has not been established.

Biodiversity. The diversity of European eel may be influenced both by transferring eels from other sites, from risks of overfishery, or from the introduction of a nonnative parasite (Table 2C–D). First, if the European eel is not panmictic, but consists of genetically or geographically distinct eel populations with different spawning patterns in time and space in the Sargasso Sea, as suggested by Wirth and Bernatchez (2001), eel transfers from other Swedish and European coastal areas to the Baltic Sea may influence biodiversity. For example, if the third of the eels that are transferred from elsewhere leave the Baltic Sea, migrate back to the Sargasso Sea, and spawn together with the Baltic sea eels, there might be an increased gene flow between the subpopulations. Second, the fishing pressure on eels may be kept on a high level due to the regular and large-scale enhancements, and mask a continuing decline of the European eels. Or else, eel transfers may provide some buffer against a regional overfishing of Baltic Sea eels, on the condition that these eels escape the fisheries and return to the Sargasso Sea. Third, the eel transfers may influence biodiversity as a result of the unexpected introduction of a nonnative swim-bladder parasite (*Anguillicola crassus*) to the Swedish east coast (Wickström 2001), and most likely to the archipelago as well. This parasite may, for example, reduce the abundance, or interfere with the ocean migration and reproduction success of the wild eels (Table 3).

Food. Managers at the SNBF have high expectations that the eel transfers, in general, are successful, and provide socioeconomic benefits for the small-scale commercial fisheries (Fiskeriverket 2001, Wickström 2001). However, the actual capacity of glass or yellow eels, released into the open archipelago system, to support the declining coastal small-scale commercial fishers is unknown, mostly because of difficulty in tagging the eels and mapping their migratory patterns. Also, eel transfers can only be considered a short-term solution because the entire stock of European eel is still declining, not only in the Baltic Sea but also along the European coasts.

Ecological information. Eel is not used in any monitoring program within the archipelago. However, eel has been suggested to be useful as an indicator species of the general status of its life-supporting ecosystems (Feunteun 2002). Regular additions of eel may result in masking effects and may undermine the potential of managers and local fishers to adapt the fishery to fluctuating eel stocks (Table 2D).

Effects of Rainbow Trout New Introductions

Food web dynamics and biodiversity. Monitoring done by Stockholm municipality has documented one case of successful reproduction of the nonnative rainbow trout in one archipelago rivulet (Table 3). This effect was not in line with the objective to only increase sport fishing catches. The ecological consequences of this, however, have not been analyzed. As in many cases of releasing nonnative piscivorous fish species (Table 2A–B), the rainbow trout may influence ecosystem services such as food web dynamics and biodiversity in the rivulet. The rainbow trout may compete with or spatially displace native sea trout in the rivulet, as was found in another case along the Swedish east coast (Landergren 1999). Rainbow trout may also hybridize with native sea trout, although this has not been found so far.

Game and aesthetic values. Fishers increasingly report about rainbow trout catches. Such a development is in line with those sport fishers who are responsible for the few new introductions. However, other case studies show that new introductions of nonnative fish may be considered to compromise the values of wilderness (Table 2A). Actually, in Sweden in general, recreational fishers evaluate aesthetic ecosystem services as highly as catching fish (Bengtsson and others 2000). Our interviews also indicate that local resource users in the archipelago, in general, are little aware of the artificial support of nonnative fish, and may not necessarily approve this policy.

Institutional and Environmental Context of Fish Stocking

Fish stocking in Stockholm archipelago has increased from some 10,000 to an average of 370,000 released fish individuals per year between 1970 and 2000 (Figure 2). Enhancements of sea trout, Atlantic salmon, pikeperch, and European eel have dominated by far, over only a few new introductions of rainbow trout. Major stakeholders actively involved in the fish stocking programs include three management agencies, one hydropower company, more than a dozen local sport fishing associations and, on one occasion, the National Organization of Aquaculture. The interviews done during this survey with the dominating involved key stakeholders indicate that, in general, their objectives with releasing fish have been rather congruent, that is, to increase fish catches for specific resource users, within the boundaries of Stockholm archipelago (Table 1). The enhancements of the native fish species aim at supporting ecosystem services that already are generated in the archipelago, including to support the recreational and the small-scale commercial fisheries as well as to provide aesthetic values. The new introductions of rainbow trout aim at creating a new ecosystem service, that is, to provide an additional source of game for local sport fishers.

The interviews also indicate that, in general, the fish stocking programs during this 30 year period have been desirable and considered successful in meeting the objectives. These opinions are based on a few documented data confirming an increased production of sea trout in rivulets, satisfying recapture rates of sea trout released in the archipelago landscape, and sport fishing catches of Atlantic salmon in Stockholm stream in the city of Stockholm. Also, in general, the managers consider it positive to add native top predators to the archipelago ecosystem, based on the assumption that the fish may fill a vacant niche and profit from the supposedly ample food supplies in the eutrophic archipelago.

Gaps of Knowledge

However, our analysis of possible fish stocking effects based on a literature review (Table 2) illustrates that fish stocking in Stockholm archipelago may have additional positive or negative influences on a broad variety of ecosystem services, at different time and space scales (Table 3). For example, two unexpected effects have been documented, but not analyzed in terms of consequences for ecosystem services. The introduction of a nonnative parasite by the eel transfers, and the case of nonnative rainbow trout reproducing in one archipelago rivulet, may influence the species biodiversity, with unknown cascading effects.

The fish enhancements, including the resulting mixed stock fisheries on sea trout, Atlantic salmon, pikeperch, and European eel may also result in changes of biodiversity, at the population level, or altered food web dynamics in rivulets as well as in the bays and lagoons of the archipelago . Diversity loss may lead to a long-term reduced capacity of some archipelago fish stocks to cope with and evolve in accordance to the dynamics of the archipelago ecosystem. Such changes may in turn influence, for example, the provision of food, game, and aesthetic values. The development of mixed fish stocks may also make it more difficult for managers and resource users to monitor and adapt to the status of small or declining fish populations. One may also speculate that ecosystem services used by stakeholders other than fishers may be influenced. For example, the addition of hatchery-produced fish, in general, may be considered as compromising the aesthetical values of a pristine archipelago nature. Some stakeholders may also consider an increasing traffic of sport fishing boats, e.g. in parts of the archipelago where regular enhancements are made, e.g. during spring and summer, as conflicting with the vision of the archipelago as an undisturbed recreational area. Thus, fish stocking may not only result in short-term increased fish catches, but also in possible consequences for the long-term provision of ecosystem services generated by archipelago fish stocks, and in a possible development of conflicts.

Monitoring and Evaluating Success

Our review reveals that possible fish stocking effects operate at quite different time and space scales. As a consequence, the effects can be monitored at different locales and at different time scales—depending on the life supporting ecosystems of the fish—and by different stakeholders, depending on their interests and user patterns. Changes of some ecosystem services, such as altered production rates or extra input of nutrients to rivulets by migrating salmonids, could likely be monitored by local managers or resource users within periods of years. Others, such as loss of biodiversity at the population level as a result of a mixing between released and wild fish, or of overfishing mixed fish stocks, may take decades to evolve and require detailed analysis of the population structure, in order to be discovered. Also, the evaluation of fish stocking effects might involve tradeoff situations between the demands of various archipelago stakeholders. A specific fish stocking effect may be considered as successful by fishers, but as nonsuccessful by other stakeholders. Whether the exemplified fish stocking effects are regarded as positive or negative, as either improving or undermining specific ecosystem services, is thus case-specific and should not only be monitored and evaluated in accordance with the prevailing objectives of fisheries management, but also by integrating and benefiting from the interests and user patterns of a broad setup of archipelago stakeholders.

Furthermore, because the coastal ecosystem of Stockholm archipelago is complex and highly variable, the knowledge about ecosystem services needs to be regularly updated (Gunderson and others 1995, Gundersson and Holling 2002). Management of such a dynamic and multiple resource user system necessitates caution with regard to the high unpredictability of the physical forces and the variability of the needs of the stakeholders (Costanza and others 1993, Ludwig and others 1993). This highlights the importance of taking a holistic ecosystem approach to fish stocking, where managers and resource users cooperate and formulate long-term monitoring programs, evaluate effects operating across time and space scales, and together adapt future fish stocking policies and objectives (Berkes and Folke 1998, Lovell and others 2002, Olsson and others in press).

Adaptive and Cooperative Management—Promises and Barriers

An extended integration of the local, regional, and national management agencies engaged in the archipelago fish stocking with local stakeholders of different interests may provide a platform (1) to accumulate ecological knowledge generated at several levels of society, in order to increase the possibility of discovering ecosystem changes at different scales (Berkes and Folke 2002), and (2) to deal with conflicting or changing objectives or perspectives on ecosystem services, and for seeking compliance or discussing alternative practices (Jentoft and others 1998, Noble 2000, Hilborn and others 2001).

In the archipelago case, this is to some extent exemplified by the cooperation between agency managers, sport fishers, and a hydroelectric power company in connection to the sea trout enhancements in rivulets. The ecological knowledge that is regularly accumulated by the sport fishers is integrated and likely complements the more experimental scientific knowledge of management. However, the majority of the fish stocking programs involve few resource users, and is little monitored. A combination of factors has likely restrained the development of a more extensive analysis of the long-term ecological and social consequences. For example, the free, and more or less uncontrolled, handgear recreational fisheries have likely undermined many of the incentives of both water rights owners and fishers to monitor their resources. The strong notion among agency managers of increased fish catches, in combination with readily available and generous national and local-level grants and sponsorships, have likely created few incentives for them, as well, to control the economic or ecological efficacy of releasing fish. Finally, to monitor released fish in the open, dynamic archipelago ecosystem is difficult as long as few fish are tagged and their migration patterns are not well known. The role of such impediments is important to account for in the future development of fish stocking policies, especially because the fish stocking in the archipelago will proceed or expand, according to our interviews.

Conclusions

Our results suggest that monitoring and evaluating various fish stocking effects on ecosystem services are closely related to the ecological and social contexts, that is, where, when, and what species are released, by whom, and also which stakeholders that use the fish and those ecosystem services the fish generate. Within the existing system of the archipelago fisheries management, a more adaptive and cooperative approach could improve the prospects of choosing a trajectory that successfully secures not only fish as goods, but also a wider range of coastal ecosystem services generated by the fish populations. Such an approach could, for example, benefit from identifying and analyzing the following:

- ecosystem services that archipelago fish populations may generate as embedded components in the dynamic life-supporting ecosystems,
- local stakeholders actively involved in or likely affected by fish stocking, and time and space scales of their user patterns, interests, needs, priorities, and objectives, and,
- the role of economic support, property rights and other institutions, and technological development for both releasing fish in the first place, but also for monitoring and evaluating the success of fish stocking.

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References

Adams, S. B., C. A. Frissell, and B. E. Rieman. 2001. Geography of invasion in mountain streams: consequences of Headwater Lake fish introductions. *Ecosystems* 4:296–307.

Anonymous. 1998. Report of the Workshop on the Ecosystem Approach, Lilongwe, Malawi, 26–28 January. UNEP/COP/4Inf.9.

Bengtsson, B., R. Lundgren, and G. Johansson. 2000. Fiske 2000. En undersökning om svenskarnas sport-och husbehovsfiske. Finfo 2000:1, Fiskeriverket, Göteborg, 92 pp.

Berkes, F., and C. Folke. 1998. Linking social and ecological systems. Cambridge University Press, Cambridge 459.

Berkes, F., and C. Folke. 2002. Back to the future: ecosystem dynamics and local knowledge. Pages 121–146 *in* J. H. Gunderson, and C. S. Holling. (eds.), Panarchy. Understanding transformations in human and natural systems. Island Press, Washington, Covelo, London.

Bernard, H. 1994. Research methods in anthropology: qualitative and quantitative approaches. SAGE Publications, Newsbury Park, California.

Blankenship, H. L., and K. M. Leber. 1995. A responsible approach to marine stock enhancement. Pages 167–175 *in* J. H. L. Schramm, and R. G. Piper. (eds.), Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Bethesda, Maryland.

Blaxter, J. H. S. 2000. The enhancement of marine fish stocks. *Advances in Marine Biology* 38:1–54.

Busack, C. A., and K. P. Currens. 1995. Genetic risks and hazards in hatchery operations: fundamental concepts and issues. Pages 71–80 *in* J. H. L. Schramm, and K. G. Piper. (eds.), Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Bethesda, Maryland.

Buynak, G. L., B. Mitchell, D. Michaelson, and K. Frey. 1999. Stocking subadult largemouth bass to meet angler expectations at Carr Creek Lake, Kentucky. *North American Journal of Fisheries Management* 19:1017–1027.

Campton, D. E. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and Steelhead: What do we really know. *American Fisheries Society Symposium* 15:337–353.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From metaphor to measurement: Resilience of what to what. *Ecosystems* 4:765–781.

Carpenter, S. R., J. F. Kitchell, and J. R. Hodgson. 1985. Cascading trophic interactions and lake productivity—fish predation and herbivory can regulate lake ecosystems. *BioScience* 35:634–639.

Celikkale, M. S. 1990. Inland fisheries of Turkey. Pages 493–504 *in* W. L. T. v. Densen, B. Steinmetz, and R. H. Hughes. (eds.), Management of freshwater fisheries. Proceedings of a symposium organized by the European Inland Fisheries Advisory Commission. Göteborg, Sweden. Pudoc, Wageningen.

Costanza, R., R. d'Arge, R. d. Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. v. d. Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253–260.

Costanza, R., W. M. Kemp, and W. R. Boynton. 1993. Predictability, scale and biodiversity in coastal and estuarine ecosystems: Implications for management. *Ambio* 22:88–96.

Daily, G. C. 1997. Nature's services. Societal dependence on natural ecosystems. Island Press, Washington, DC 392.

DeMelo, R., R. France, and D. J. McQueen. 1992. Biomanipulation: Hit or myth. *Limnology and Oceanography* 37:192–207.

Donald, D. B., R. D. Vinebrooke, R. S. Anderson, J. Syrgiannis, and M. D. Graham. 2001. Recovery of zooplankton assemblages in mountain lakes from the effects of introduced sport fish. *Canadian Journal of Fisheries and Aquatic Sciences* 58:1822–1830.

Feunteun, E. 2002. Management and restoration of European eel population *(Anguilla anguilla):* An impossible bargain. *Ecological Engineering* 18:575–591.

Fiskeriverket. 2001. Småskaligt kustfiske och insjöfiske—en analys. The National Board of Fisheries, Sweden, Göteborg, 217 pp.

Folke, C., and N. Kautsky. 1989. The role of ecosystems for a sustainable development of aquaculture. *Ambio* 18:234–243.

Food and Agriculture Organization. 1998. The state of the world fisheries and aquaculture 1998 (SOPHIA). FAO, Rome, ONLINE: http://www.fao.org/docrep/w9900e/w9900e00.htm#TopOfPage.

Food and Agriculture Organization. 2000. The state of the world fisheries and aquaculture 2000 (SOPHIA). FAO, Rome, ONLINE: http://www.fao.org/DOCREP/oo3/X8002E/X8002E00.htm.

Grimes, C. B. 1998. Marine stock enhancement: sound management or techno-arrogance. *Fisheries* 23:18–23.

Groot, R. S. d. 1992. Functions of nature. Evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff, 315 pp.

Groot, R. S. d., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classification, description, and valuation of ecosystem functions, goods and services. *Ecological Economics* 41:393–408.

Gunderson, L. H., and C. S. Holling. 2002. Panarchy. Understanding transformations in human and natural systems. Island Press, Washington, Covelo, London 507.

Gunderson, L. H., C. S. Holling, and S. Stephen. 1995. Barriers and bridges—to the renewal of ecosystems and institutions. Columbia University Press, New York 587.

Hall, S. R., and E. L. Mills. 2000. Exotic species in large lakes of the world. *Aquatic Ecosystem Health and Management* 3:105–135.

Halwart, M., M. Borlinghaus, and G. Kaule. 1996. Activity pattern of fish in rice fields. *Aquaculture* 145:159–170.

Hammer, M. 1995. Diversity conservation in relation to fisheries in the Baltic sea. Pages 57–67 *in* C. A. Perrings (ed.), Biodiversity conservation. Klyver Academic Publications, .

Hammer, M., C. M. Holmlund, M. Åqvist Almlöv. 2003. Social-ecological feedback links for ecosystem management: a case study of fisheries in the Central Baltic Sea archipelago. Ocean and Coastal Management, 46: 527–545.

Hansson, S., F. Arrhenius, and S. Nellbring. 1997. Benefits from fish stocking—experiences from stocking young-of-the-year pikeperch (*Stizostedion lucioperca* L.) to a bay in the Baltic Sea. *Fisheries Research* 32:123–132.

Heard, W., R. Burkett, F. Thrower, and S. McGee. 1995. A review of Chinook salmon resources in Southeast Alaska of an enhancement program designed for minimal hatchery-wild stock interaction. *American Fisheries Society Symposium* 15:21–37.

Hilborn, R., J.-J. Maguire, A. M. Parma, and A. A. Rosenberg. 2001. The precautionary approach and risk management: can they increase the probability of successes in fishery management. *Canadian Journal of Fisheries and Aquatic Sciences* 58:99–107.

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. *Canadian Journal of Fisheries and Aquatic Sciences* 48:945–956.

Holcik, J. 1991. Fish introductions in Europe with paricular reference to its central and eastern part. *Canadian Journal of Fisheries and Aquatic Sciences* 48:13–23.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1–23.

Holling, C. S., and G. K. Meffe. 1996. Command and control and the pathology of natural resource management. *Conservation Biology* 10:328–337.

Holmlund, C. 1996. Fish stocking—consistent with sustainable management of the natural resources? Incentives and effects of fish stocking in the County of Stockholm. Degree thesis. Stockholm University, Stockholm, 108 pp.

Holmlund, C. M., and M. Hammer. 1999. Ecosystem services generated by fish populations. *Ecological Economics* 29:253–268.

Howell, B. R., E. Moksness, and T. Svåsand. 2001. Stock enhancement and sea ranching. Fishing News Books, Oxford, England 606.

Hrabik, T. R., and J. Magnuson. 1999. Simulated dispersal of exotic rainbow smelt (*Osmerus mordax*) in a northern Wisconsin lake district and implications for management. *Canadian Journal of Fisheries and Aquatic Sciences* 56:35–42.

Höjesjö, J. 2002. Behavioral tactics and domestication effects in salmonids. Doctoral thesis. Göteborg University, Göteborg, 125 pp.

Iongh, H. H. d., and J. C. J. v. Zon. 1993. Assessment of impact of the introduction of exotic fish species in north-east Thailand. *Aquaculture and Fisheries Management* 24: 279–289.

International Union for Conservation of Nature and Natural Resources. 1987. IUCN position statement on translocation of living organisms: introductions, reintroductions and restocking. IUCN, The World Conservation Union, Species Survival Commission, Gland, Switzerland.

Jansson, B.-O., and K. Dahlberg. 1999. The environmental status of the Baltic Sea in the 1940s, today, and in the future. *Ambio* 28:312–319.

Jansson, H., and T. Öst. 1997. Hybridization between Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) in a restored section of the River Dalälven, Sweden. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2033–2039.

Jentoft, S., B. J. McCay, and D. C. Wilson. 1998. Social theory and fisheries co-management. *Marine Policy* 22:423–436.

Jeppesen, E., M. Søndergaard, M. Søndergaard, and K. Christoffersen. 1998. The structuring role of submerged macrophytes in lakes. Springer, New York 423.

Kellison, G. T., D. B. Eggleston, and J. S. Burke. 2000. Comparative behavior and survival of hatchery-reared versus wild summer flounder (*Paralichtys dentatus*). *Canadian Journal of Fisheries and Aquatic Sciences* 57:1870–1877.

Kitchell, J. F., S. P. Cox, C. J. Harvey, T. B. Johnson, D. M. Mason, K. K. Schoen, K. Aydin, C. Bronte, M. Ebener, M. Hansen, M. Hoff, S. Schram, D. Schreiner, and C. J. Walters. 2000. Sustainability of the Lake Superior fish community: interactions in a food web context. *Ecosystems* 3:545–560.

Kitchell, J. F., D. E. Schindler, R. Ogutu-Ohwayo, and P. N. Reinthal. 1997. The Nile perch in Lake Victoria: Interactions between predation and fisheries. *Ecological Application* 7:653–664.

Koljonen, M.-L., H. Jansson, T. Paaver, O. Vasin, and J. Koskiniemi. 1999. Phylogeographica lineages and differentiation pattern of Atlantic salmon (*Salmo salar*) in the Baltic

Sea with management implications. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1766–1780.

Krokhin, E. M. 1975. Transport of nutrients by salmon migrating from the sea into lakes. Pages 153–156 *in* A. D. Hasler (ed.), Coupling of land and water systems. Springer, New York.

Krueger, C. C., and B. May. 1991. Ecological and genetic effects of salmonid introductions in North America. *Canadian Journal of Fisheries Aquatic Sciences* 48:66–77.

Kvale, S. 1996. InterViews, an introduction to qualitative research interviewing. SAGE Publications, Thousands Oaks, London, New Delhi 326.

Laikre, L., and N. Ryman. 1996. Effects on intraspecific biodiversity from harvesting and enhancing natural populations. *Ambio* 25:504–509.

Landergren, P. 1999. Spawning of anadromous rainbow trout, *Oncorhynchus mykiss* (Walbaum): a threat to sea trout, *Salmo trutta* L., populations. *Fisheries Research* 40:55–63.

Landergren, P. 2001. Sea trout, *Salmo trutta* L., in small streams on Gotland; the coastal zone as a growth habitat for parr. Doctoral dissertation. Stockholm University, Stockholm.

Landres, P., S. Meyer, and S. Matthews. 2001. The wilderness act and fish stocking: An overview of legislation, judicial interpretation, and agency implementation. *Ecosystems* 4:287–295.

Lange, R. E., G. C. LeTendre, T. H. Eckert, and C. Schneider. 1995. Enhancement of sportfishing in New York waters of Lake Ontario with hatchery-reared salmonines. *American Fisheries Society Symposium* 15:7–11.

Leary, R. F., F. W. Allendorf, and G. K. Sage. 1995. Hybridization and introgression between introduced and native fish. Pages 91–101 *in* J. H. L. Schramm, and R. G. Piper. (eds.), Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Bethesda, Maryland.

Lehtonen, H., S. Hansson, and H. Winkler. 1996. Biology and exploitation of pikperch, *Stizostedion lucioperca* (L.), in the Baltic Sea area. *Annual Zoologica Fennici* 33:525–535.

Liao, I. C. 1997. Status, problems and prospects of stock enhancement in Taiwan. *Hydrobiologia* 352:167–180.

Limburg, K. E., and C. Folke. 1999. The ecology of ecosystem services: introduction to the special issue. *Ecological Economics* 29:179–182.

Limburg, K. E., H. Wickström, H. Svedäng, M. Elfman, and P. Kristiansson. 2003. Do stocked freshwater eels migrate? Evidence from the Baltic suggests "yes". Pages 275–284 *in* Biology, management and protection of catadromous eels. American Fisheries Society, Bethesda, Maryland.

Lorenzen, K., C. J. Garaway, B. Chamsingh, and T. J. Warren. 1998. Effects of access restrictions and stocking on small water body fisheries in Laos. *Journal of Fish Biology* 53(supplement A):345–357.

Lovell, C., A. Mandondo, and P. Moriarty. 2002. The question of scale in integrated natural resource management. *Conservation Ecology* 5:25. Online: http://www.consecol.org/vol5/iss2/art25/index.html.

Lovén, S., and Y. Ungsgård. 1999. Fiskevårdplan för treårsperioden 1999–2001. Länsstyrelsen i Stockholms Län, Stockholm, U 7: 41 pp.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: Lessons from history. *Ecological Application* 3:547–549.

Lundberg, J., and F. Moberg. 2003. Mobile link organisms and ecosystem functioning: Implications for ecosystem resilience and management. *Ecosystems* 6:87–98.

Marchall, B., and M. Maes. 1994. Small water bodies and their fisheries in southern Africa. CIFA technical paper 29, FAO, Rome.

McDermot, D., and K. A. Rose. 2000. An individual-based model of lake fish communities: Application to piscivore stocking in Lake Mendota. *Ecological Modelling* 125:67–102.

McGurrin, J., U. Christopher, and D. Duff. 1995. Use of cultured salmonids in the federal aid in sport fish restoration program. *American Fisheries Society Symposium* 15:12–15.

McKaye, K. R., J. D. Ryan, J. R. J. Stauffer, L. J. L. Perez, G. I. Vega, and E. P. v. d. Berghe. 1995. African tilapia in Lake Nicaragua. *BioScience* 45:406–411.

Meffe, G. K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific coast of North America. *Conservation Biology* 6:350–354.

Munro, J. L., and J. D. Bell. 1997. Enhancement of marine fisheries resources. *Reviews in Fisheries Science* 5:185–222.

Naiman, R. J., R. E. Bilby, D. E. Schindler, and J. M. Helfield. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. *Ecosystems* 5:399–417.

Naylor, R. L., R. J. Goldburg, H. Mooney, M. Beveridge, J. Clay, C. Folke, N. Kautsky, J. Lubchenco, J. Primavara, and M. Williams. 1998. Nature's subsidies to shrimp and salmon farming. *Science* 282:883–884.

Nilsson, N.-A. 1972. Effects of introductions of salmonids into barren lakes. *Journal Fisheries Research Board of Canada* 29:693–697.

Noble, B. F. 2000. Institutional criteria for co-management. *Marine Policy.* 24:69–77.

North, D. C. 1990. Institutions, institutional change and economic performance. Cambridge University Press, Cambridge, UK 152.

Olsson, P., C. Folke, and F. Berkes. In press. Adaptive co-management for building resilience in social-ecological systems.

Palm, S., and N. Ryman. 1999. Genetic basis of phenotypic differences between transplanted stocks of brown trout. *Ecology of Freshwater Fish* 8:169–180.

Parker, B. R., D. W. Schindler, D. B. Donald, and R. S. Anderson. 2001. The effects of stocking and removal of a nonnative salmonid on the plankton of an alpine lake. *Ecosystems* 4:334–345.

Pearsons, T. N., and C. W. Hopley. 1999. A practical approach for assessing ecological risks associated with fish stocking programs. *Fisheries* 24:16–23.

Peck, J. W., T. S. Jones, W. R. MacCallum, and S. T. Schram. 1999. Contribution of hatchery-reared fish to Chinook salmon populations and sport fisheries in Lake Superior. *North American Journal of Fisheries Management* 19:155–164.

Petersson, E., and T. Järvi. 1999. Odling, domestisering och bevarandebiologi hos laxfiskar. Pages 51–79 *in* Fiskeriverket Rapport. Fiskeriverket, The Swedish National Board of Fisheries, Drottningholm.

Pilliod, D. S., and C. R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. *Ecosystems* 4:322–333.

Regier, H. A., and V. C. Applegate. 1972. Historical review of the management approach to exploitation and introduction in SCOL Lakes. *Journal Fisheries Research Board of Canada* 29:683–692.

Ryman, N., R. Öhman, G. Ståhl, A. Nilsson, U. Lagercrantz adn A. Herlitz. 1986. Genetisk variation hos laxartad fisk—en snabbt försvinnande naturresurs. Genetiska institutionen, Stockholms Universitet, Lantbruksnämaden in Jämtlands län, 18 pp.

Ryman, N., F. Utter, and K. Hindar. 1995. Introgression, supportive breeding, and genetic conservation. Pages 341–365 *in* J. D. Ballou, M. Gilpin, and T. J. Foose. (eds.), Population management for survival and recovery. Analytical methods and strategies in small population conservation. Columbia University Press, New York.

Schindler, D. W., R. A. Knapp, and P. R. Leavitt. 2001. Alteration of nutrient cycles and algal production resulting from fish introductions into mountain lakes. *Ecosystems* 4:308–321.

Schram, S. T., J. Lindgren, and L. M. Evrard. 1999. Reintroduction of Lake Sturgeon in the St. Louis River, Western Lake Superior. *North American Journal of Fisheries Management* 19:815–823.

Schramm, H. L. J., and V. A. Mudrak. 1994. Use of sport fish restoration funds for put-and-take trout stocking. Beneficial uses of put-and-take trout stocking. *Fisheries* 19:6–7.

Seda, J., J. Hejzlar, and J. Kubecka. 2000. Trophic structure of nine Czech reservoirs regularly stocked with piscivorous fish. *Hydrobiologia* 429:141–149.

Shapiro, J., and D. I. Wright. 1984. Lake restoration by biomanipulation: Round Lake, Minnesota, the first two years. *Freshwater Biology* 14:371–383.

Sparrevik, E. 2001. Utsättning och spridning av fisk. Fiskeriverket, The Swedish National Board of Fisheries, Göteborg, Finfo 9:30 pp.

Stephanou, D. 1990. Twenty years of experience in managing Cyprus reservoirs for angling. Pages 1–13 *in* W. L. T. v. Densen, B. Steinmetz, and R. H. Hughes. (eds.), Management of freshwater fisheries. Proceedings of a symposium organized by the European Inland Fisheries Advisory Commission. Göteborg, Sweden, Pudoc, Wageningen.

Sugunan, V. V. 2000. Ecology and fishery management of reservoirs in India. *Hydrobiologia* 430:121–147.

Sundström, L. F., and J. I. Johnsson. 2001. Experience and social environment influence the ability of young brown trout to forage on live novel prey. *Animal Behavior* 61:249–255.

Søndergaard, M., E. Jeppesen, and S Berg. 1997. Pike (*Esox lucius* L.) stocking as a biomanipulation tool 2. Effects on lower trophic levels in Lake Lyng, Denmark. *Hydrobiologia* 342/343:319–325.

Tátrai, I., J. Oláh, G. Paulovits, K. Mátyás, B. J. Kawiecka, V. Józsa, and F. Pekár. 1997. Biomass dependent interactions in pond ecosystems: Responses of lower trophic levels of fish manipulations. *Hydrobiologia* 345:117–129.

Tyus, H. M., and I. J. F. Saunders. 2000. Nonnative fish control and endangered fish recovery: Lessons from the Colorado River. *Fisheries* 25:17–24.

Utter, F., and N. Ryman. 1993. Genetic markers and mixed stock fisheries. *Fisheries* 18:11–21.

Vighi, M., D. Sandroni, and G. Ferri. 1995. Biomanipulation of trophic chain in two small eutrophic lakes. Memorie—dell'Isituto Italiano di Idrobiologia. *International Journal of Limnology* 53:157–175.

Vromant, N., N. T. H. Chau, and F. Ollevier. 2001. The effect of rice seeding rate and fish stocking on the floodwater ecology of the rice field in direct-seeded, concurrent rice-fish systems. *Hydrobiologia* 445:151–164.

Wahl, D. H., R. A. Stein, and D. R. DeVries. 1995. An ecological framework for evaluating the success and effects of stocked fishes. *American Fisheries Society Symposium* 15:176–189.

Waples, R. 1999. Dispelling some myths about hatcheries. *Fisheries* 24:12–21.

Waples, R. S. 1991. Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences* 48:124–133.

Waples, R. S. 1995. Genetic effects of stock transfers of fish. Pages 51–69 *in* D. Philipp and others (eds.), Protection of aquatic biodiversity. Proceedings of the World Fisheries Congress, Theme 3. Oxford and IBH Publishing Co, Pvt. Ltd., New Delhi.

Welcomme, R. L. 1988. International introductions of inland aquatic species. Food and Agriculture Organization, Rome 318.

Westin, L. 1998. The spawning migration of European silver eel (*Anguilla anguilla* L.) with particular reference to stocked eel in the Baltic. *Fisheries Research* 38:257–270.

White, R. J., J. R. Karr, and W. Nehlsen. 1995. Better roles for fish stocking in aquatic resources management. Pages 527–547 *in* J. H. L. Schramm, and R. G. Piper. (eds.), Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society, Bethesda, Maryland.

Wickström, H. 2001. Stocking as a sustainable measure to enhance eel populations. Doctoral dissertation. Stockholm University, Stockholm.

Wilson, J., B. Low, R. Costanza, and E. Ostrom. 1999. Scale misperceptions and the spatial dynamics of a social-ecological system. *Ecological Economics* 31:243–257.

Wirth, T., and L. Bernatchez. 2001. Genetic evidence against panmixia in the European eel. *Nature* 409:1037–1040.

Wonham, M. J., J. T. Carlton, G. M. Ruiz, and L. D. Smith. 2000. Fish and ships: Relating dispersal frequency to success in biological invasions. *Marine Biology* 136:1111–1121.

Wright, S. 1981. Contemporary Pacific salmon fisheries management. *North American Journal of Fisheries Management* 1:29–40.