The Beijer Institute of Ecological Economics

DISCUSSION PAPER

Beijer Discussion Paper Series No. 184

Replacement costs as economic values of environmental change: A review and an application to Swedish sea trout habitats

Sara Sundberg. 2004.

The Beijer Institute of Ecological Economics
The Royal Swedish Academy of Sciences
Box 50005 SE-104 05 Stockholm Sweden
Phone: +46 8 673 95 00 Fax: +46 8 15 24 64
E-mail: beijer@beijer.kva.se

Replacement costs as economic values of environmental change: A review and an application to Swedish sea trout habitats

by

Sara Sundberg*

*) Beijer International Institute of Ecological Economics, The Royal Swedish Academy of Sciences, Box 50005, SE-10405 Stockholm, Sweden.
E-mail: sara.sundberg@beijer.kva.se.

Contents

Executive Summary

The objective of this study was to analyse the replacement cost method. For this purpose a number of valuation studies based on replacement costs was reviewed and the method was also applied to value sea trout habitats in Swedish coastal areas.

The natural environment supplies goods and a flow of direct and indirect services to society. Economic activity can lead to changes in the flows of these services and the quality of these goods. The value of environmental goods and ecosystem services is not reflected in market prices. This is due to the fact that environmental goods typically are public goods, as for example air. The lack of market prices is often interpreted as if the environmental goods have no value, a fact that leads to overuse of the resource and environmental degradation. Different methods for defining a value of environmental resources have been developed. The principal motivation for environmental valuation is to make it possible to include environmental impacts in cost-benefit analysis. Valuation methods are usually divided into two different approaches: stated preferences and revealed preferences methods. The replacement cost method is an example of a revealed preferences method that could be applied to environmental quality valuation.

The replacement cost method assumes that it is possible to find substitutes for environmental goods and ecosystem services. The cost of replacing a function of an ecological system with a human engineered system is used as a measure of the economic value of the function itself. However, the validity of the method depends on the fulfilment of three conditions (Shabman & Batie, 1978). The conditions that must be met are the following:

1. The human engineered system provides functions that are equivalent in quality and magnitude to the ecosystem service.
2. The human engineered system is the least cost alternative way of replacing the ecosystem service.
3. Individuals in aggregate would in fact be willing to incur these costs if the ecosystem service was no longer available.

A number of replacement cost studies was examined. The examination was based on the three conditions explained above. A summary of the review is found in table I, where the studies are given a judgment with respect to how well the conditions are fulfilled.

Table I. Summary of replacement cost studies.

		1. Perfect substitute	2. Cost-effectiveness	3. WTP
Gunatilake & Vieth (2000)	**Erosion**	Completely*	Not at all	Not at all
Samarakoon & Abeygunawardena (1995)	**Erosion**	Completely*	Not at all	Not at all
Kim & Dixon (1986)	**Erosion**	Completely*	Not at all	Not at all
Xue & Tisdell (2001)	**Forest:**			
	1) water conservancy	Not at all	Not at all	Partially
	2) nutrient cycling	Not at all	Not at all	Partially
	3) pollutant decomposition	Not at all	Not at all	Partially
	4) pest control	Not at all	Not at all	Partially
Guo et al. (2001)	**Forest**	Partially	Not at all	Not at all
Niskanen (1998)	**Forest**	Not at all	Not at all	Not at all
Scott et al. (1998)	**Shrub-steppe**	Not at all	Not at all	Not at all
Folke (1990)	**Wetland**	Partially	Partially	Partially
Leschine et al. (1997)	**Wetland**	Partially	Not at all	Completely*
Thibodeau & Ostro (1981)	**Wetland**	Partially	Partially	Not at all
Gosselink et al. (1974)	**Wetland**	Not at all	Not at all	Not at all
Markandya et al. (1991)	**Drainage function of waterways**	Not at all	Not at all	Partially
Spurgeon (1992)	**Coral reefs**	Partially	Partially	Partially
Gibbons (1986)	**Water**	Partially	Partially	Not at all
Sousa-Poza et al. (2001)	**Housework**	Not at all	Not at all	Not at all

* = assumption

One conclusion from the examination of replacement cost studies is that it could be difficult to fulfil these conditions in a practical application of the method. Many studies discuss the first condition about perfect substitutes. However perfect substitutes for ecosystem services are difficult to identify and consequently many studies rely on close substitutes as an approximation. Also the third condition has shown difficult to meet. The second condition is perhaps the least controversial of the three conditions and this might be a reason to the fact that a majority of the studies do not discuss wheatear their replacement technique is cost-effective or not.

It was also examined how the replacement cost method could be used to value habitat of fish species. The Swedish coastal zone is severely affected by human activities. Damages such as eutrophication, industrial effluents and physical rearrangements can be seen. This of course affects the quality of marine habitats negatively. The fish habitats could be restored in different ways. Two examples of restoration efforts are removal of migration obstacles and increased access to spawning substrates. In a replacement cost study the value of the habitat is defined as the cost of restoration. In this paper the replacement cost method was applied to derive an economic value of sea trout habitats in Swedish coastal areas. Management projects in four Swedish streams were the aim was to enhance the abundance of sea trout, were studied. These projects are summarized in table II.

Table II. Summary of fishery management projects.

Watercourse	Type of management measure	Increase in yearly smolt production	Replacement cost (SEK, in 2002 prices)	Replacement cost per smolt
Kagghamraån	Restoration of streambed	A: 68 B: 260	327,000	12.6-157.1
Hammerstaån	Weir fishway	A: 8 B: 93	70,000	33.2
Solbergsån	Fishway	A: 1631 B: 1815	590,000	8.2-38.5
Kävlingeån	Fishway	1193	817,000	13.7

Based on the yearly increase in smolt production due to the management measure and the total replacement cost the replacement cost per smolt was calculated. The replacement cost based on the cost of the management measures was compared to the cost of stocking. This was a cheaper alternative, but stocking only replaces the number of fish in the stream and is not a prefect substitute to the habitat.

Acknowledgements

This paper describes work carried out in the research programme Sustainable Coastal Zone Management (SUCOZOMA). Funding from the Swedish Foundation for Strategic Environmental Research (MISTRA) is gratefully acknowledged. I am also very grateful to Tore Söderqvist at the Beijer International Institute of Ecological Economics for his invaluable advice and support. I would also like to thank those who have provided me with information to the sea trout case study.

1 Introduction

Economists have developed methods to reveal values in the presence of market failure. These methods could be applied to value environmental goods and services that rarely are exchanged through the market process. The replacement cost method is a valuation method based on cost estimates. The cost of a man-made substitute, that provides the same service as the ecosystem, is estimated to derive the economic value of that ecosystem service.

Gosselink, Odum and Pope made an early attempt to apply the replacement cost method to value the waste treatment function provided by wetlands. The value estimate was achieved by estimating the cost of sewage treatment as a replacement technique. Gosselink et al (1974) argued that this cost could be viewed as the value of the wetland's waste assimilation capacity. The study was, however, criticised by Shabman and Batie (1978). They claim that the replacement cost method can result in a conceptually correct approximation of the value if the method is properly applied. They also argue that Gosselink et al. (1974) failed to subject their value estimates to any of the needed important tests. The replacement cost method will only result in valid estimates of economic values if the following three conditions are met: (1) the human engineered system provides functions that are equivalent in quality and magnitude to the ecosystem service (2) the human engineered system is the least cost alternative way of replacing the ecosystem service. (3) individuals in aggregate would in fact be willing to incur these costs if the service was no longer available (Shabman & Batie, 1978).

More precisely, the criticism by Shabman and Batie goes as follows. Gosselink et al. (1974) compares the cost of sewage treatment with the wetlands' ability to remove and assimilate nutrients (BOD, Biochemical Oxygen Demand). The estimation of assimilation capacity is based on data from five wetlands. It is assumed in the study that all wetlands provide the same waste assimilation services. This is however not likely and information on the level of waste assimilation provided by particular acres of wetland is needed for a proper application of the method (Shabman & Batie, 1978). Gosselink et al. (1974) do not discuss whether the sewage treatment is a cost-effective replacement technology. Shabman and Batie (1974) suggest that a combination of land treatment, changes in production technologies and different waste treatment technologies may be less expensive in some areas. This option has not been taken into account by Gosselink et al. (1974). The third condition is also ignored in GOP's study. They implicitly assume that the demand for sewage treatment exists by concluding that: "without the treatment, accelerated pollution accumulation would soon exact payment, either through direct payment or indirect means, such as increased medical costs, loss of recreational areas, loss of fisheries, etc" (Gosselink et al. 1974, p.11). This argument, however, cannot be regarded as an evidence of the existence of WTP, since it is still possible that the benefit people derive from the ecosystem service provided by the wetland is lower than the cost of replacing the service.

Since the study made by Gosselink, Odum and Pope (1974) a number of replacement cost studies have been conducted. It is often argued that the replacement cost method is easy to apply and less time consuming than other valuation methods. It is also often claimed that the method results in an approximation of the value. This paper provides an examination of the replacement cost method for valuation of environmental quality and ecosystem services. A number of replacement cost studies is examined and the method is applied to value sea trout habitat. Different management alternatives, including restoration efforts, can be employed to counteract and obstruct habitat degradation and thus promote successful reproduction of different fish species. Restoration of a habitat made to compensate for degradation may be viewed as a replacement technique. The habitat provides a sustainable environment for the species living there and is thus a valuable resource. The value could be established with the use of a replacement cost study where the cost of habitat restoration is estimated.

This paper is partly based on my master's thesis: T*o value the environment with the use of replacement costs - an examination of the method and an application to sea trout habitats* (Sundberg, 2003).

1.1 Objective

The objective is to examine the replacement cost method for valuing environmental quality. The objective is further to illustrate how the method could be applied to value the habitat of a fish species. Sea trout is the fish species chosen for valuation.

1.2 Method and delimitations

The examination of the replacement cost method is based on the validity conditions established by Shabman and Batie (1978). A review of replacement cost studies is presented and it is examined if the validity conditions are met in each study. The literature review is based on papers where the replacement cost method has been applied and discussed. The main focus is on applications to value ecosystem goods and services, but also other fields are included. I have searched for valuation studies that have applied the replacement cost method in various literature databases and on the Internet. In addition to the literature review, the replacement cost method is also examined through a practical application of the method. The method is applied to value the service provided by a habitat of a fish species. An application to habitats of pike and perch is discussed. However, the case study concerns the value of sea trout habitat.

The review of replacement cost studies includes the applications of the method that I found and thus does not represent a selection of studies. The review does not claim to be fully comprehensive, since more studies may exist at least in the “grey” literature.

Initially my intention was to apply the replacement cost method to pike and perch in the Baltic Sea, since recruitment failure and decreasing fish stocks of pike and perch recently have been observed. However, few management projects have been carried out and consequently it was difficult to identify the cost of management measures. Moreover, the existing management projects had not yet been evaluated. Instead, the application of the replacement cost method is made to establish an economic value of sea trout habitats. An active management of the stocks of sea trout has been a part of the fisheries management in Sweden for a longer period and consequently more information about management projects targeting sea trout was available.

1.3 Outline

The paper is organised as follows. In chapter 2, the basic theory of economic valuation of environmental goods is presented. This is followed by a brief description of valuation methods where the replacement cost method is presented in more detail. Chapter 3 provides a literature review and an examination of replacement cost studies. In chapter 4 the application of the replacement cost method to habitats of a fish species is discussed and the case study of sea trout habitats is also presented. Final remarks are found in chapter 5.

2 Economic theory

In this section the theoretical background of environmental valuation is provided. Different valuation methods are briefly described and the replacement cost method is presented in detail.

2.1 Environmental goods

An ecosystem is the set of organisms living in an area, their physical environment, and the interaction between them (Daily, 1997, p. 2). Ecosystems have life-supporting functions and they also produce goods and services that are of great value to humans. Forage, timber and food are example of goods produced by different ecosystems, goods that often are considered as renewable resources. In addition to the production of goods, natural ecosystems produce services such as decomposition of wastes, renewal of soil fertility and translocation of nutrients[1]. Ecosystems also provide opportunities for recreation. These goods and services produced by ecosystems could be called environmental goods, environmental services or ecosystem services. In this paper ecosystem services and environmental goods will be used interchangeably to denote these kinds of goods. An improvement in environmental quality could be thought of as an increase in the supply of the environmental good or the ecosystem service.

In the past, humanity has drawn benefit from ecosystems without causing global environmental problems. The rapid deterioration of the environment we can see today gives an indication of a changing situation. Due to human activity many environmental goods are today scarce or deteriorating in quality. Ironically, the importance of ecosystem services is often only observed upon their loss.

2.2 Environmental valuation

"If the Earth's resources were available in infinite quantities, and if they could be deployed at zero cost, there would be no economic problem. Everyone could have everything they wanted without compromising each other's or later generations' wants and needs. It would not be necessary to choose (Pearce, 1993, p.1)". But they are not; resources are finite, and we do have to choose. But how and on what basis (Pearce, 1993)? The trade-offs people make are based on their preferences about the goods in question. If the good is a market good, the marginal value of the good is reflected in its market price. In a perfect economy markets allocate resources efficiently. However, many environmental goods are not transacted through

[1] These are example of ecosystem services and goods. See Daily (1997) for a thorough exposition.

the market process or they are exchanged in markets that are incomplete in some way. This is due to the fact that many environmental goods are public goods. The properties of a pure public good are non-rivalry and non-excludability. A good is non-rival if one individual's consumption does not reduce the amount available of the good to other individuals and it is non-excludable if people cannot be excluded from consumption of the good. Because of the public goods characteristics of environmental goods the market system fail to allocate and price the goods correctly (Perman et al., 1999). This often results in overuse of environmental goods, since every individual maximizes her or his utility from the good considering a price of zero. Economic valuation of environmental goods and services is an approach to make the value of the environment visible.

Putting prices on environmental goods and services has been questioned both by non-economists and economists (e.g. Foster, 1997, Sagoff, 1988). Although economic valuation of the environment has been, and in some sense still is, controversial, it seems like some consensus has been reached (Daily et al., 2000). Different methods for valuing non-marketed public goods, such as environmental quality, have been developed and the techniques are constantly refined. Various motives for environmental valuation can be found. The principal motivation for economic valuation of the environment is to make it possible to include environmental impacts in cost-benefit analysis, (CBA) (Perman et al., 1999). Brännlund and Kriström (1998) argue that environmental value estimates, expressed in monetary terms, are easy to compare and therefore useful in decision-making. Economic values of environmental quality can also be expressed through economic policy instruments. Then the purpose of environmental valuation is to set, for example, an efficient tax level. The national accounts could also be adjusted for changes in environmental quality based on environmental valuation estimates, in order to produce for example “green GDP” estimates (Brännlund & Kriström, 1998). Environmental valuation gives more complete economic information adjusted for changes in environmental quality, resulting in an improved basis for decision-making. However, economic valuation measures are only one component of the information basis available in evaluation of policy. Recognizing that economic values are derived from individual preferences and are based on an anthropocentric ethic, non-economic information is needed as a complement (Perman et al., 1999).

2.3 The concept of value

The economic concept of value is based on individuals’ preferences. People make trade-offs by choosing less of one good and more of some other good and these trade-offs reveal the economic values people place on the goods. Individuals might place such values on resources not only because of the use people make of them, but also as a result of altruistic concerns.

The latter can be the source of non-use or existence values (Freeman, 1993). In contrast to economic values, derived from individual preferences, there also exist non-anthropocentric definitions of values. Intrinsic values for example assume that the environment has a worth of its own regardless of human perception (Brännlund & Kriström, 1998).

The total economic value can thus be divided into use and non-use values (Pearce, 1993). Use values are derived from the direct individual use of a resource; a forest provides for example timber but also opportunities for outdoor recreation. Use values are not only placed on goods that are used directly, but also on goods that are used indirectly. Indirect use values can be derived from ecological functions, such as flood control provided by wetlands (Barbier, 1994). People also place monetary values on natural resources that are independent of their present use of those resources, which characterizes non-use values. People can for example gain utility from the knowledge that endangered species are preserved even though they never expect to see them (Freeman, 1993). Values might also be discussed in terms of option values, which refers to the price an individual is willing to pay to retain the availability of the resource for future use (Pearce, 1993).

A variety of valuation methods can be applied to capture different components of the total economic value. A brief description of valuation methods can be found in section 2.5, environmental valuation methods.

2.4 Welfare measures

Economic values are the result of individuals' preferences, which are communicated as people make trade-offs between goods. The willingness to pay (WTP) is the sum that an individual is willing and capable to pay for a good or service. In a perfect economy the price of a good gives information on the marginal willingness to pay for that good. However, for many environmental goods no market exists and the WTP is not expressed by a price. The fact that no price exists for many environmental goods should not be interpreted as if they have no value. Still, individuals might make trade-offs also between goods that are not traded on markets, which express that the goods actually have a value although it is not communicated as a market price.

The economic theory for measuring changes in individuals' well-being was developed for the purpose of interpreting changes in prices and quantities of goods purchased in markets. This theory has been extended and is now also used for measuring changes in individuals' well-being caused by changes in environmental quality (Freeman, 1993).

First, we examine how a change in an individual's utility, resulting from a change in the price of a private good, can be measured. Since individuals' utility cannot be observed, the most frequently used measure of welfare is consumer surplus (CS). The measure CS is defined as the difference between the maximum individuals are willing to pay for a good and what they actually pay (i.e. the market price). The change in CS can be treated as a monetary measure of the individual's utility change when the price of a good changes and it is possible to estimate CS with the knowledge of the ordinary Marshallian demand curve. CS is, however, only a valid measure of utility change under some restrictive assumptions, such as constant marginal utility of income (Freeman, 1993). The measures compensating variation, CV, and equivalent variation, EV, based on the Hicksian demand curve, does not require as restrictive assumptions as CS. Although CV and EV theoretically are the correct measures of changes in welfare, CS is the most used measure in empirical work, since the compensated demand curve is unobservable. With a price fall, CV is the amount of money, when taken from the individual, leaves the individual at her initial level of utility (Gravelle & Rees, 1992). EV is, with a price fall, the amount of money that would leave the individual at her initial level of utility, when given to the individual at the initial price level (Gravelle & Rees, 1992).

We now continue to examine how to find monetary measures of changes in welfare due to changes in environmental quality. In addition to the private good, *x*, a public environmental good, *z*, is also included in the utility function $U = U(x, z)$. By solving the maximisation problem and the minimization problem respectively the indirect utility function $v = v(p, y, z)$ and the expenditure function $e = e(p, z, u)$ are derived[2]. CV and EV can be defined with the use of the indirect utility function or with the use of the expenditure function.

CV is the amount of money that is needed for this equity to hold:

$$v(p, y - CV, z^1) = v(p, y, z^0)$$

where *v* denotes indirect utility, *p* price , *y* is money income and *z* is the environmental quality at the initial level z^0 and after the change to z^1. If the change is an improvement in environmental quality, CV is the quantity of money income, when taken from the individual, leaves the individual at her initial level of utility. That is the individual's willingness to pay (WTP) for the improvement in environmental quality. If instead deterioration in environmental quality is considered, CV is the compensation required by the individual to accept lower environmental quality (i.e. WTA).

EV can be defined in a similar way as CV, but instead the new level of utility is regarded as reference. EV is the amount of money such that the following equity holds:

$$v(p, y, z^1) = v(p, y + EV, z^0).$$

If environmental quality improves, EV is the minimum amount of money that must be given to the individual to make her as well of as she was before the change, if the improvement does not take place. In that case EV is the individual's willingness to accept compensation (WTA). If environmental quality instead deteriorates, EV is the maximum the individual is willing to pay, WTP, to prevent a deterioration of the environment.

CV and EV can be illustrated graphically in a simple case. In this case x is an aggregation of private goods and z is a public good, i.e. environmental quality. Figure 1 below illustrates CV and EV for an improvement in environmental quality.

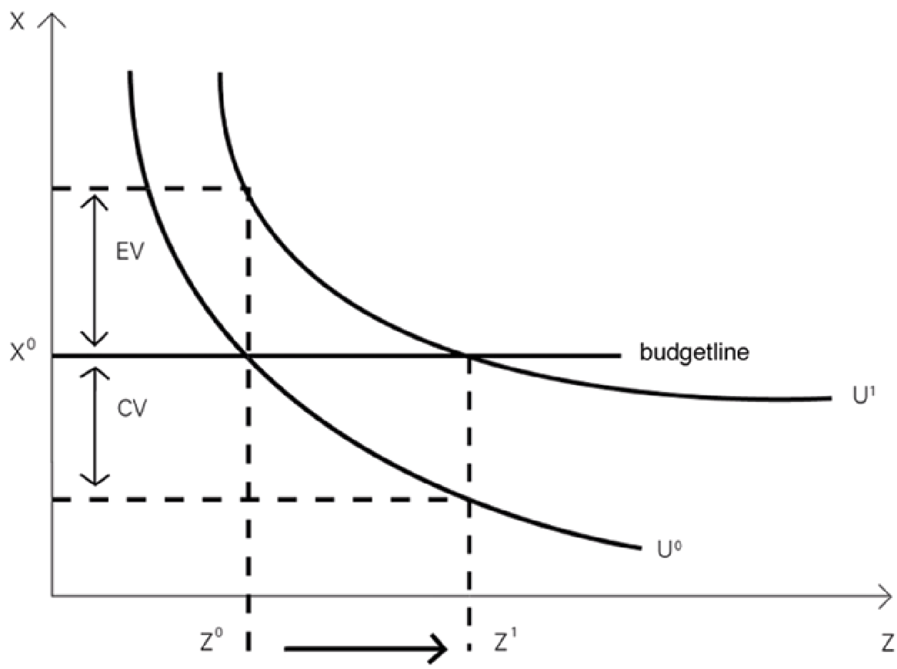

Figure 1. CV and EV adapted from Johansson (1993).

Since the environmental good is provided for free, the budget line is horizontal. If environmental quality improves, from z^0 to z^1, the individual will attain a higher level of utility than before, moving from the indifference curve U^0 to U^1 in the figure. In this case, EV is the minimum compensation required by the individual to stay at the initial indifference

[2] See for example Freeman (1993) or Gravelle & Rees (1992).

curve U^0 without the improvement. CV is the willingness to pay for the improvement, i.e. the maximum amount of money that can be taken from the individual and which makes her as well of as she was in the initial situation at the indifference curve U^0.

The choice between the two measures depends on the initial situation, i.e. if the individual has the right to a change or the right to keep the original quality level. If the property right is implied in the change, EV is the appropriate measure. Then the individual has to pay to avoid deterioration, but must be compensated if an improvement does not take place. If the property right instead is implied in the status quo the CV measure should be used. This implies that the individual must pay for an improvement in environmental quality, but must be compensated if environmental quality deteriorates (Freeman, 1993).

CV and EV, can also be defined by using the expenditure function for a change in environmental quality, $\Delta z = z^0 \to z^1$, the change is assumed to be an improvement, $\Delta z > 0$.

$$CV = e\left(p^0, z^0, u^0\right) - e\left(p^0, z^1, u^0\right) = -\int_{z^0}^{z^1} \frac{\partial e\left(p^0, z, u^0\right)}{\partial z} dz$$

$$EV = e\left(p^0, z^0, u^1\right) - e\left(p^0, z^1, u^1\right) = -\int_{z^0}^{z^1} \frac{\partial e\left(p^0, z, u^1\right)}{\partial z} dz$$

The marginal willingness to pay, MWTP, is the amount of money an individual is willing to pay for an improvement in environmental quality. By the use of the expenditure function, the marginal willingness to pay can be expressed as follows:

$$MWTP = -\frac{\partial e\left(p, z, u^0\right)}{\partial z}$$

(Freeman, 1993).

2.5 Environmental valuation methods

Methods for valuing environmental quality can roughly be divided into two different approaches, stated preferences (SP) and revealed preferences (RP) methods[3]. Freeman (1993) adds another dimension where hypothetical methods are separated from methods based on observed behaviour.

SP methods for measuring values are based on responses to hypothetical valuation questions. The most-well known is the contingent valuation method (CVM), where a sample of the relevant population answers questions about their WTA or WTP for a specified change in environmental quality.

RP methods for measuring environmental values use surrogate markets to perceive the value people implicitly put on the environmental good. Thus, RP methods are based on a relationship between a market good and the environmental good, whose value will be estimated. To estimate the value of the environmental good, behaviour on the related market is observed. The travel cost method, where the demand on trips to a certain recreational area is estimated and used as a value of the environmental quality of the area, is an example of an RP valuation method. Other examples of RP methods are the defensive expenditure method and the method examined in detail in this paper, the replacement cost method.

SP methods are often considered to be the only methods that can be used to estimate non-use values (Perman et al., 1999). However, Ledoux & Turner (2002) claim that also the replacement cost method under some circumstances can be used to estimate non-use values of ecosystem services, in their paper represented by ecosystem services provided by wetlands. They state that a perfect substitute might have the potential to provide the same non-use benefits as the original system (Ledoux & Turner, 2002). Several aspects may, however, limit the possibility of eliciting non-use values in a replacement cost study, such as cultural and historical aspects and a desire for authenticity (Ledoux & Turner, 2002).

2.6 Defensive expenditures and replacement costs

As already explained, RP methods are based on a relationship between some market good and an environmental good. The relationship between the market good and the environmental good can take different forms; the goods could be either complements or substitutes. Since both the defensive expenditure method and the replacement cost method rely on the perfect substitutability assumption, the relationship based on substitutes is examined below. In the defensive expenditure method it is studied how the demand of a perfect substitute to the environmental good is changed given a specified change in environmental quality. The replacement cost method instead uses the cost of the perfect substitute to estimate the value of the environmental good. Since the defensive expenditure method is to some extent similar to the replacement cost method an explanation of that method is also given.

The rest of this section is organised as follows. It starts with an examination of perfect substitutes. This is followed by an explanation of, first the defensive expenditure method and then the replacement cost method. In the end of the section the issue of validity of the replacement cost method is discussed.

2.6.1 Perfect Substitutes

If the z and x are perfect substitutes, a value of a change in environmental quality can be estimated by estimating the resulting change in the demand of x. The defensive expenditure method is based on this assumption.

Mäler (1974) shows that the marginal willingness to pay can be expressed as the marginal rate of substitution between the environmental good and the market good.

$$MWTPz = -\frac{\partial e(p,z,u)}{\partial z} = -pi\left(\frac{\partial u(.)/\partial z}{\partial u(.)/\partial xi}\right) = pi\left(-MRSzx_i\right)$$

The marginal rate of substitution (MRS) is not easily observed. Assuming a utility function that is weakly separable and of the following form, where x_1, x_2 and x_3 are three private goods: $u = \left[u_1(x_1), u_2(x_2), \left(C \cdot x_3^{-\alpha} + (1-C)z^{-\alpha}\right)^{-1/\alpha}\right]$, $MRSx_3z$ is independent of x_1 and x_2 and the marginal rate of substitution can be expressed as follows:

$$MRS_{zx_3} = \frac{C}{1-C} \times \left(\frac{z}{x_3}\right)^{1/\sigma}$$

where σ = elasticity of substitution. The elasticity of substitution between x_3 and z can be expressed as follows:

$$\sigma = -\frac{d\left(\frac{x_3}{z}\right)}{\left(\frac{x_3}{z}\right)} \cdot \frac{MRSx_3z}{dMRS}$$

[3] See Freeman (1993) for an exposition of the environmental valuation theory.

The elasticity of substitution is assumed to be constant, which yields the following expression of the marginal willingness to pay:

$$MWTP_z = P_3 \times \left(-S\left(\frac{z}{x_3}\right)^{1/\sigma} \right)$$

Where

$$S \equiv \frac{C}{1-C}$$

and S is interpreted as the rate of technical substitutability, which is computable from technical consumption data or from the household production function (Freeman, 1993).

It can be observed from the expression of MWTP that knowledge of both σ and C is needed in order to compute MWTP. If x_3 and z are perfect substitutes, the elasticity of substitution between them is infinite, and then the expression for MWTP reduces to a simple term:

$$MWTP_z = P_3 \times S$$

This can be shown graphically for a simple case where the technical substitutability, S, is assumed to be equal to one, see figure 2 below.

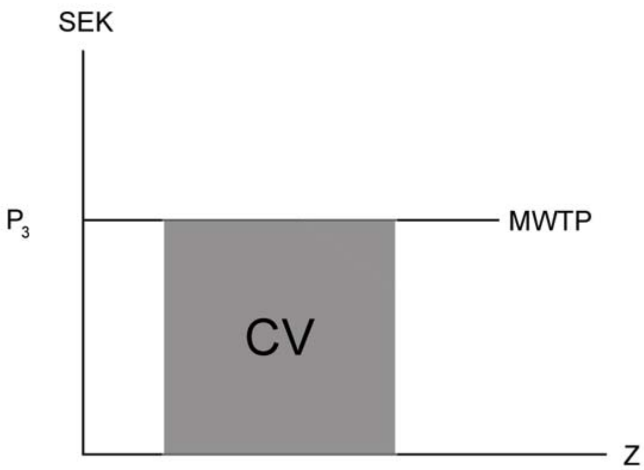

Figure 2. MWTP (Söderqvist, 2002).

2.6.2 Defensive expenditures

The defensive expenditure method is based on the assumption of perfect substitutability. Individuals' market behaviour and the cost incurred in mitigating the effects of reduced environmental quality are studied to get value estimates of the environmental good. By observing the demand of the defensive market good, conclusions about the demand of the environmental good are made. The defensive expenditure method gives information of the use value of the environmental good. People can for example install some kind of water purification filter to protect themselves from poor-quality water (Abrahams et al., 2000). The example illustrates market behaviour and the filters can be viewed as a substitute for high-quality water.

A marginal change in the spending on x_3, a perfect substitute for the environmental good, is a correct measure of the marginal willingness to pay for the change in environmental quality, z. The marginal value of an improvement in environmental quality, z, is equal to the reduction in spending on x_3, the private good. The defensive expenditure method is based on this link between expenditures on a private good and changes in environmental quality. From the example above, x_3 is the water purification filters and z is the water quality. To find a monetary value of a marginal improvement in water quality, the resulting decrease in the demand of water purification filters can be estimated. Freeman (1993), however, emphasizes that the link between the private good and the value of the environmental good only is valid for marginal changes in environmental quality. Due to the income- and substitution effects defensive expenditures will not reflect the value of the change correctly for a non-marginal change in environmental quality (Freeman, 1993). If for example a large improvement in environmental quality occurs, the resulting decrease in defensive expenditures will understate the value of this improvement.

2.6.3 Replacement costs

The replacement cost method is, as the defensive expenditure method, based on the assumption about perfect substitutes, but the replacement cost method is based on non-market behaviour. The cost of a potential or actual replacement technique is used to derive a value of a change in environmental quality.

The cost of replacing an ecosystem service with a man-made substitute is used in the replacement cost method as a measure of the economic value of the ecosystem service. Consequently, it must be possible to identify a substitute for the ecosystem service. The cost of investment and the maintenance cost should both be included in the replacement cost. The method could for example be applied to value the flood protection capacity of wetlands by estimating the cost of replacing this capacity with the use of a human made protection, i.e. some kind of artificial coastal defence such as breakwaters or sea walls. The method could also be used to estimate a value of soil fertility by looking at the cost of fertilizers needed to maintain a certain level of productivity.

The method is based on the possibility of finding perfect substitutes to ecosystem services. However, the validity of the method does not only depend on the possibility of finding perfect substitutes. Replacement costs can be a valid measure of economic value only if three conditions are met. Shabman and Batie (1978) define the conditions and these conditions are also discussed in Leschine et al. (1997), in Bocksteal et al. (2000) and in Freeman (2003). The conditions are the following:

1. The human engineered system provides functions that are equivalent in quality and magnitude to the ecosystem service.
2. The human engineered system is the least cost alternative way of replacing the ecosystem service.
3. Individuals in aggregate would in fact be willing to incur these costs if the ecosystem service was no longer available.

Compliance with these three conditions in a replacement cost study is needed to achieve a valid measure of economic value. An important topic is how these conditions can be taken into consideration in the practical work with a replacement cost study.

Perfect substitutes

The first condition, states that a perfect substitute should be used to replace the ecosystem service. It is obviously difficult to achieve compliance with this condition since perfect substitutes for ecosystem services or environmental goods rarely exist. However, in many cases “close” substitutes exist and they can be used to find an approximate value of the ecosystem service. The replacement cost method has been criticised by ecologists because of the difficulty to find perfect substitutes (Edwards-Jones et al., 2000). Winpenny (1991) also brings up this criticism and he states that the replacement cost method assumes that there is no uncompensated loss. Expressed in another way; it is, according to the replacement cost method, possible to find perfect substitutes for all environmental goods and ecosystem services. Today ecosystem services and environmental goods are subject to increasing scarcity due to severe exploitation. This can possibly lead to a situation where it is more and more complicated to find substitutes to replacing ecosystem services. According to this way of reasoning, the criticism about the possibility of finding perfect substitutes may be justified. Winpenny (1991) also discusses the problem of identifying all services produced by a certain ecosystem, which is essential if the objective is to estimate the value of the entire ecosystem. Ecosystems are complex systems and to identify all services they produce and substitutes for them might be difficult. As a consequence, all aspects of the ecosystem’s functions are not included when suitable replacement techniques are identified and the estimated replacement cost value will understate the true value of the ecosystem. Still, the replacement cost method can be used to establish an economic value of a single ecosystem service.

The replacement cost method may, under some conditions, also result in an overstatement of the value. It is possible that individuals derive secondary benefits from the substitute or the replacement technique (Pearce & Moran, 1994). The use of a certain replacement technique can obviously also cause negative effects, which decrease individuals' utility. The replacement cost does not, in these cases, reflect the true value of the environmental good replaced. This is similar to the problem of separating different components of defensive expenditures. Double-glazing for example can be viewed as a defensive measure and it will reduce the interior noise level as well as improve heat isolation.

The fact that natural resources and ecosystem services are not homogenous in quality must also be taken into consideration. Shabman and Batie (1978) bring up the example of waste assimilation provided by wetlands. The ecosystem service provided by a wetland will differ in quality according to the characteristics of the wetland area. The level of waste assimilation provided by specific areas of wetlands has to be known to facilitate a correct application of the replacement cost method. It is obvious that biological assessments are very important to obtain information about the ecosystem services. In addition, it must be possible to measure a change in quality of the ecosystem service.

Cost-effectiveness

The second condition states that the replacement technique used for valuation should be a cost-effective alternative. Therefore, different alternative replacement techniques have to be examined, which also has to include combination of techniques. In cases where many techniques for replacement are available, a substantial part of the work with a replacement cost study may be to find the least cost alternative technique. However, in a practical application of the method it is not likely that every existing replacement technique is examined. It is probably more reasonable to try to select some techniques that will be studied in detail. To get reliable cost estimates it is probably practical to choose techniques that are available at the time. The reasonable number of replacement techniques that are going to be compared has to be decided for every new application of the method.

The fact that the replacement cost method is based on cost estimates has been seen as an advantage, since cost information is easily obtained. Pearce state it: "If environmental damage is done it is often possible to find out quite easily the cost of restoring the damaged environment" (Pearce, 1993, p.107). Freeman (1993) does not share this view and he calls it a "naïve theory of cost". Those who claim costs are easy to measure ignore the fact that all costs causes utility losses to individuals, which creates symmetry between benefits and costs. Freeman (1993) concludes that it is therefore likely that costs are as difficult as benefits to measure. An additional aspect ignored in the naïve view of costs is that governmental regulations can affect people's welfare. Firms' pollution control costs cause firms to increase prices, which result in decreases in consumer surplus, i.e. a welfare loss to the individual. It is therefore not correct to equate pollution control expenditures to social costs (Freeman, 1993).

Willingness to pay

According to the third condition there should exist substantial evidence that the service would be demanded by society if it were provided by the least-cost alternative. This condition ensures that the replacement costs will not overstate the value of the ecosystem service. If individuals in aggregate are not willing to incur the costs of replacement, the estimated value of the environmental good is in fact going to be an overstatement of the true value.

To make certain that the replacement costs are not exceeding the amount people are willing to pay, the replacement cost study may be combined with some kind of survey using a SP method. An advantage of the replacement cost method, often mentioned, is that the data required are easy to generate and it is less time consuming than other valuation methods. Valuation by estimating replacement costs could therefore be viewed as a less costly alternative (Gunatilake & Vieth, 2000). If a combination with some kind of survey is needed to ensure that WTP is not overstated by the cost estimate, this advantage will be lost. Besides, the information needed for valuation could probably be derived from the survey itself.

Another option to get information about the relationship between the estimated costs and the actual WTP is to look at results from a past valuation study. It may be possible to obtain an estimate of economic value from a valuation study conducted in a similar area, what is usually called benefit transfer. Benefit transfer refers to the use of information from a past study in a new context. The use of benefit transfer is a highly debated subject within the area of environmental economics. In many cases the derived value is dependent on the original context and the value is therefore difficult to transfer to a new study setting. Despite the uncertainty connected with the method it is widely used for policy recommendations, e.g. the same emission standard is used within different a geographical area. If it is taken into consideration how the original study was conducted, benefit transfer may in some cases be possible. The use of benefit transfer is tempting, since it is a cost saving compared to the alternative of conducting a new study (Garrod &Willis, 1999). The use of benefit transfer could be one option to make sure that the replacement costs do not exceed individuals' actual willingness to pay.

A third alternative way to make sure that the replacement costs do not exceed WTP is to combine a replacement cost study with a study of "political willingness to pay", i.e. the cost of realizing decisions taken by governments or authorities (public bodies). Political decisions regarding environmental goods may under some circumstances reflect the society's willingness to pay for a change in environmental quality (Ledoux & Turner, 2002). However, it is not likely that this is valid for all political decisions, due to for example lobbying and compromises between political parties. But if the decision has support by the general public, the possibility that it reflects the society's willingness to pay correctly will increase (Söderqvist, 1996). The cost of realizing decisions taken by public bodies gives normally only a rough approximation of the theoretically correct measure of societal value, but may provide useful information that can complement the result of a replacement cost study. However, to get useful information it is important to identify cases where it is likely that the political willingness to pay and the sum of individual WTP coincide. It may, for example, be of use to study political willingness to pay, if the replacement of the environmental good or ecosystem service is needed to meet a certain environmental target that is supported by the society. Pearce and Moran (1994) suggest that replacement costs are correct measures of benefits when it is possible to argue that the replacement must take place due to some constraint, such as a water quality standard. By setting the standard it can be assumed that the society is willing to bear the expenses of reaching the standard level (Pearce & Moran, 1994).

When the result of a valuation study is analysed the median WTP value could be studied instead of the mean value. The cost of realizing public bodies' decisions could be compared to the median value of WTP. The WTP median value could be interpreted as the outcome of a referendum (Johansson et al., 1989). At the median value 50 per cent would vote for and 50 per cent against a proposed change and thus if absolute majority is required the will of the median voter is going to be the result of the referendum. Consequently, political willingness to pay could be viewed as the median WTP if absolute majority is required for a decision.

3 Replacement cost studies

The aim of this chapter is to provide a review of valuation studies where the replacement cost method has been used. A number of replacement cost studies will be examined, principally from the area of natural resource economics. The examination is based on the three conditions established by Shabman and Batie (1978). The purpose of the examination is to study if consideration has been taken to welfare economics when estimating monetary values with the use of the replacement cost method. The chapter is organized as follows. A division of the studies is made according to what topic is examined, for example forest or wetlands. How each study is carried out and its objective is described. The description of the study is followed by an analysis based on Shabman and Batie's validity conditions (see below). In the end of the section, a summary of the valuation studies examined can be found in table 1 together with a discussion.

1. The human engineered system provides functions that are equivalent in quality and magnitude to the ecosystem service.
2. The human engineered system is the least cost alternative way of replacing the ecosystem service.
3. Individuals in aggregate would in fact be willing to incur these costs if the ecosystem service was no longer available.

3.1 Erosion

Erosion is a severe problem in many countries, especially in the developing world. Three studies focusing on the on-site cost of soil erosion are examined below.

3.1.1 Soil erosion in the Upper Mahaweli Watershed of Sri Lanka

Gunatilake and Vieth (2000) present a comparison between the replacement cost method and the productivity change method. Both methods are applied to estimate the on-site cost of soil erosion in the study area, the upper Mahweli watershed of Sri Lanka. The objective of the study is to examine the reliability of the replacement cost method. The replacement cost method is viewed as a less expensive method, which could be of use in developing countries where more expensive methods cannot be afforded given their budget constraints. The on-site cost of erosion is defined as the value of lost future productivity due to current cultivation. To estimate the replacement cost information on nutrient loss per ton soil eroded, price of nutrients and the cost of labour spreading fertilizer are required. The cost of repair and maintenance of damages due to soil erosion is also included in the replacement cost. Information on nutrient levels in eroded soils was not available in this study and therefore nutrient levels in non-eroded soils were used, under the assumption that soil nutrient levels in eroded and non-eroded soils were the same. Also, the possibility of deposition of eroded soils in other farms was not considered in the study. Fertilizers generally used in Sri Lanka are identified and the cost of nutrient replacement is calculated from market prices assuming the use of these fertilizers. The estimated on-site cost value is also used in a cost-benefit analysis and compared to the cost of soil conservation practices. Stone terraces and spill drains are two examples of soil conservation measures evaluated in the study.

It is assumed that the productivity of soil can be maintained by replacing the lost nutrients and organic matters artificially. This assumption can be considered as an argument for the idea that the replacement, fertilizers, provides functions that are equivalent in quality and magnitude to the ecosystem service. The first condition is met if this assumption holds. However, it is not presented how organic matter lost due to soil erosion should be replaced. The second condition concerns cost-effectiveness of the replacement technique. Whether applying chemical fertilizer is the least cost replacement technique is not discussed in the paper. Therefore, it is difficult determine if the cost- effectiveness condition is met. From the information in the article it cannot be concluded if the least cost alternative has been used for valuation. A discussion about the connection between the replacement cost and the willingness to pay is also missing. The authors do not present any evidence that a willingness to pay for the service exists and consequently it could not be concluded if the third condition is met.

3.1.2 Soil erosion in Nuwara Eliya District of Sri Lanka

Samarakoon and Abeygunawardena (1995) have also applied the replacement cost method to value the on-site cost of soil erosion in an area of Sri Lanka, however not in the same study area as Gunatilake and Vieth (2000). Two different replacement techniques are examined in the study. The cost of material used and cost of labour make up the replacement cost. The replacement cost is also estimated for the two main rainy seasons in the area. A cost-benefit analysis is conducted where the replacement cost is compared to the cost of three alternative conservation measures that reduce soil erosion. According to this analysis, it is economically rational to adopt conservation measures that reduce the level of soil erosion.

In the first alternative the loss of soil is compensated by soil from fallow land. A rented truck is used to transport the soil from the fallow land to the field. To be able to calculate the cost of transportation it is assumed that the soil can be brought at certain distance from the field. Fertilizers suitable to the area are used to replace lost nutrients. Costs of repairing damaged field structures are also included in the replacement cost.

In the second alternative, ploughing of the field is the technique used to compensate the loss of soil. As in the first alternative lost nutrients are replaced by the use of fertilizers and the cost of field repair is also included in the replacement cost.

It is assumed that the productivity is maintained under the two replacement alternatives. If this assumption holds, the first condition about perfect substitutes is met. However, it is likely that the effect of the two alternatives would differ if they were compared at different levels of erosion. According to the second condition the valuation should be based on the least cost replacement technique. Two alternative replacement techniques are examined in this study. The first alternative is less costly and should therefore be used for replacement cost valuation, but in the study both alternatives are used in the cost-benefit analysis. Moreover, it is not discussed in the study why these two alternative replacement techniques are examined and if additional techniques exist. From this it is clear that compliance with the second condition is not achieved. The authors do not take up the third condition that requires evidence of people's willingness to pay for the service if it is no longer provided by the ecosystem. Hence, it is not proved in the study that people actually are willing to pay the replacement cost.

3.1.3 Soil erosion in Korea

The third replacement cost study focusing on soil erosion is from Korea (Kim and Dixon, 1986). Arable land is a scarce resource in Korea due to urbanisation and industrialisation and as a consequence upland areas are also used for farming. Inadequate soil management techniques have made erosion a severe problem in these upland areas. The productivity in the upland areas can be maintained either by physically replacing lost soil and nutrients or by adopting a management technique and this is compared in a cost-benefit analysis. The replacement costs are interpreted as a minimum estimate of the value of measures that will improve on site management practices and thereby prevent damages. A combination of straw mulching and vertical mulching is found to be the most efficient soil management approach in reducing erosion. For the analysis data on the amount of soil, nutrients and water lost due to erosion are needed. Then, the replacement costs are estimated by adding the cost of fertilizer, transport of organic matter, irrigation and the cost of repairing damaged field structures. Compensation payments for deposition of soil in lowland fields from upland farmers to lowland farmers are also included in the replacement cost. These are all annual costs. In addition to the estimation of the replacement cost and the cost of the soil management technique, an analysis of a status quo alternative is also provided.

It is assumed that the productivity in upland areas can be maintained by replacing lost soil nutrients with fertilizer. Moreover, lowland fields are also repaired, which means the damage caused by soil erosion in upland areas is compensated for. If this assumption holds the fist condition is met. It is not demonstrated in the paper if the replacement techniques, fertilizer, irrigation and supply of organic matter, are cost-effective alternatives. Other replacement techniques might exist and since this is not an issue brought up in the paper it is difficult to determine if the cost-effectiveness condition is met. The authors state that the willingness to pay for the new soil management technique does not seem to exist, despite the fact that it would be economically rational to use straw and vertical mulching as preventive measures. The low adoption rate of preventive measures can, according to the authors, be due to several factors. It can either be caused by the use of the, from the farmer perspective, wrong discount factor or farmers are constrained by the availability of cash. Another explanation is that farmers have not got the incentives to adopt soil conservation techniques because they do not own the land.

3.2 Forest

A forest ecosystem provides several ecosystem services. Two case studies from China are examined below.

3.2.1 Changbaishan Mountain Biosphere Reserve, a forest ecosystem

In this case study, the value of benefits derived from a forest ecosystem, the Changbaishan Mountain Biosphere Reserve located in Northeast China, is estimated (Xue & Tisdell, 2001). The replacement cost method is used to provide a monetary value of four of the ecosystem services identified. These services include water conservancy, nutrient cycling, pollutant decomposition and disease and pest control.

The function of water conservancy is displayed in different ways, e.g. reducing the water runoff, improving the water quality and increasing the quantity of water available. To find a monetary value of this ecosystem service the annual amount of conserved water is estimated and multiplied by a price per unit water. The latter is based on the cost of reservoir construction in China including the cost of maintenance. Whether the reservoir could be considered as a perfect substitute for the water capacity of the forest is not discussed in the article. The forest ecosystem has a positive impact on the water quality and it is not likely that the reservoir has the same positive impact. It has to be stressed that the reservoir is not a perfect substitute to the water conserving capacity of the forest if it cannot maintain this positive impact. Neither is it discussed in the article if reservoir construction is the least cost alternative way to replace the ecosystem service.

As a tree grows it absorbs nutrients, which is accumulated in the stem. Some of the accumulated nutrients will return to soil in the withering process and the remaining nutrients in the stem is the net conserved amount. To estimate the value of this ecosystem service the total net nutrient amount maintained in the standing forest is multiplied by the market price of nutrients, i.e. the market price of chemical fertilizers. The vegetation is divided into two main types based on the amount of nutrients maintained in different types of forest. This division is made to facilitate the calculation and take into consideration that the quality of the ecosystem service is not perfectly homogeneous. Whether the replacement technique is equivalent in quality to the natural ecosystem service is not discussed in the paper and nor do the authors discuss if it is a cost-effective substitute.

Decomposition of pollutants is the third ecosystem service, evaluated with the use of replacement costs. Forests absorb different harmful gases. In the study purification of SO_2 is considered as an example of this service provided by the ecosystem. The average absorption capacity is considered for two different types of forest and is multiplied to an alternative price, which is based on the cost of engineered control to SO_2 in China. What kind of engineered control they base their cost estimation on is not presented in detail, which makes it difficult to determine if the conditions concerning cost-effectiveness and perfect substitutability are met.

The forest ecosystem also provides natural disease and pest control. Due to control by natural enemies, there are almost no plant diseases or insect pests within the studied ecosystem. The value of this service is computed by estimating the cost of artificial control with chemicals. As for the other ecosystem services the perfect substitutability and the cost-effectiveness conditions are not discussed.

It is emphasized in the paper that the replacement cost method will result in an overstatement of the value of the ecosystem service if the willingness to pay for it is less than the cost of its replacement. However, whether the valuation of the Chinese forest's ecosystem services in this study leads to an overstatement of the value is not discussed.

3.2.2 A forest ecosystem in Xingshan County of China

Guo et al. (2001) estimates the value of forest ecosystem services in Xingshan County of China. The replacement cost method is in this study applied to estimate the value of one ecosystem service; soil conservation. The replacement cost is interpreted as the value of the benefit of restoring the asset. Forest has an ability to protect soil fertility by reducing soil erosion. Stalks and straw are usually used as fertilizer in Xingshan County but they are also used as fuel. Consequently if stalks and straw are used in the farms, the consumption of firewood will increase. In this study, the cost of firewood is therefore interpreted as the cost of replacing organic fertility. However, inorganic nutrients, such as nitrogen, phosphorus and potassium, are also lost due to soil erosion and to replace these nutrients chemical fertilizers are needed. The price of fertilizer is used to estimate this replacement cost.

None of the three conditions are discussed in the article (Guo et al., 2001). However, soil fertility loss is divided into two different types and different means of replacement are used. This may be viewed as an attempt to find a perfect substitute to soil fertility. The replacement used in the study might be a cost-effective solution, depending on the circumstances in the area. Still, from the information presented in the paper it cannot be concluded if the second condition is met.

3.2.3 Impacts of reforestation in Thailand

In this study the cost and benefits of reforestation in Thailand are assessed (Niskanen, 1998). The replacement cost method is used to estimate a monetary value of benefits derived from erosion control provided by the forest plantations. Soil erosion rates are estimated for different land management practices. Then the cost of commercial fetilizers needed to replace lost nutrients in eroded material is estimated as the replacement cost. In addition, the value of nutrient loss in harvesting is also based on replacement cost estimates. The amount of nutrients accumulated in stems is estimated, which is the amount of nutrients lost due to harvesting. The value of the amount of lost nutrients is interpreted as a cost of harvesting.

The validity of the derived replacement cost estimates is not examined in the study (Niskanen, 1998). Neither is any of the three conditions formulised by Shabman and Batie (1978) discussed in general terms.

3.3 Shrub-steppe habitat

Scott et al. (1998) identifies different ecosystem services provided by a shrub-steppe habitat in Washington state. Soil stabilisation, species maintenance and biological diversity are examples of functions provided by the shrub-steppe habitat. Different valuation methods are applied in the paper and the replacement cost method is used to value species maintenance, i.e. game habitat. Shrub-steppe land in the study region provides open space for a variety of recreational uses, including game hunting.

The estimate of recreational value of hunting on open space is based on the cost of replacing shrub steppe hunting sites using human analogues. In this study a game ranch is used as the substitute. The estimation of replacement costs is based on the sale of Barker Ranch, which is a property that has been used by private hunting clubs, in the Benton-Franklin county area. The sale price is viewed as a measure of hunters' willingness to pay for a game habitat after all other costs of hunting are paid. This should, according to the authors, be viewed as an upper-bound value of the willingness to pay for hunting, since there is a difference in quality between the shrub-steppe habitat area and the hunting ranch. Within the ranch the quality of the hunting experience could be improved for example by restricting access and increasing the population of game birds. The fact that the quality of the ranch is better than average shrub-steppe habitat means that the ranch could not be viewed as a perfect substitute. It is not clear from the paper whether the condition of cost-effectiveness is met. The objective with the purchase of the ranch is to use the property for hunting, which could be seen as an indication of an interest in hunting in the area. The objective of the purchase is however not to replace the study area and thus it is not proved that individuals in aggregate in fact would be willing to incur these costs if the game-hunting service was no longer available.

3.4 Wetlands

Wetlands are highly productive systems and they provide many services to society. An examination of four studies, where the objective is to estimate a total value of entire wetland ecosystems or a value of one service provided by the wetland, will follow.

3.4.1 Martebomire, Gotland

Folke (1990) identifies ecosystem services produced by a Swedish wetland system, the Martebomire on the island of Gotland in the Baltic Sea. In the middle of the nineteenth century mires covered about ten per cent of the island of Gotland. Due to extensive exploitation, primarily with the purpose of increasing the area of agricultural land, large parts of the wetlands have disappeared. In the study, exploitation effects and replacement techniques for lost services are identified. The purpose of the study is to evaluate the loss of the wetland's life-support capacity. This is made in terms of energy analysis, where the energy required by the wetland to produce and maintain ecosystem services is compared to the energy used to produce and maintain replacement techniques producing similar services. In addition, the cost of replacing these services provided by the wetland is estimated. Some of the replacement techniques identified are already in use, as for example the use of fertilizers to compensate for degraded soil fertility. Other replacement techniques will be introduced in the near future, such as a pipeline for transportation of drinking water and a sewage treatment plant for reduction of nitrogen.

The replacement technologies identified in the study do not maintain all services provided by the wetland and consequently they cannot be regarded as perfect substitutes. Therefore the first condition is not met and as a result the cost of replacement does not completely reflect the true value of the wetland's functions. When identifying replacement techniques Folke (1990) examine technologies already in use or ones that will be used in the near future. It is not discussed in the paper whether the identified substitutes are cost-effective replacements. If different replacement techniques exist, the cost-effective technique would probably be chosen, but this is not examined in the study. Moreover, some of the replacement technologies Folke (1990) lists are not actually used with the purpose of replacing a lost ecosystem service although they are in use. These technologies could, however, be viewed as potential substitutes. The third condition, that states that individuals in aggregate in fact must be willing to incur the costs of replacement if the ecosystem services were no longer available, is not discussed at all in the study. The fact that some of the replacement technologies actually are used with the purpose of replacing ecosystem services lost, could indicate the existence of a willingness to pay for some of the services. However, Folke (1990) does not take up this discussion.

3.4.2 Flood protection

The replacement cost method is also applied to estimate the economic value of wetlands' flood protection capacity in Western Washington (Leschine et al., 1997). The report was prepared for Washington State Department of Ecology, USA. It is claimed in the study that the replacement cost method could be used to derive an approximate value of the flood protection services provided by many wetlands. In this paper two case studies are presented.

The first case study describes North Scriber Creek Wetlands that are situated northeast of the City of Lynnwood, Washington. The city has proposed to enhance flood flow reduction through projects that would enhance the ability of the existing wetland to lower flood flows. The enhancement is accomplished via construction of a channel, which works as an interconnection between the wetland and a detention pond. Cost estimates of the engineered system are used to establish an economic value of the flood protection currently provided by the wetland. The effectiveness of the existing wetland and the increase in effectiveness due to the interconnecting channel are estimated. It is assumed that each acre of the wetland has an equal effect in reducing flood flows. To establish a value of the flood protection service provided by the existing wetland the cost of enhancement per percent reduction effect is multiplied by the existing reduction effect per acres of existing wetland. It is emphasized that the cost of replacing lost functions normally are used to provide willingness to pay estimates, not the cost of improving already existing ones as in this case study. However, it is also claimed that the North Scriber Wetland is more efficient than the planed channel between the wetland and the detention pond and therefore it is likely that the derived estimates are underestimates.

By assuming that each acre of the existing wetland has an equal effect in reducing flood flows only one substitute is needed. This assumption makes it easier to find a replacement technique that is a perfect substitute. However, the chosen replacement technique has a lower capacity to reduce flood flows than the existing wetland and thus cannot be viewed as a perfect substitute. The estimated economic value is for that reason regarded as a proxy measure.

The second case study examines the efforts of the City of Renton, another community in Western Washington. The city seeks to improve the flood flow protection capacity by reconnecting isolated wetlands to a main stem channel and by excavating a wetland area that was previously filled. As in the Lynnwood case, the cost of the enhancement project is used to estimate a value of the existing wetland.

The paper ends with a discussion of the result of the two case studies. In this analysis, the fact that the valuation approach is based on expected rather than actual expenditures is considered as a weakness of the study. However, a replacement cost valuation could be based on a potential substitute for which expected expenditures are estimated and it is not necessary a weakness of the study. Concerning the second condition about cost-effectiveness, it is said in the study that if additional capacity to reduce flows can be added in a cost-effective way the estimated value will in fact be an overstatement. Additional capacity may be added in the two case studies and thus the second condition is not met. In the study expected expenditures are assumed to equal the societal willingness to pay, but no evidence of this connection is presented. The cost of the enhancement project might be viewed as the “political willingness to pay” if the action plan for the area is a result of political decisions. A political decision to pay for a project (in this study flood flow enhancement) can under some circumstances be interpreted as an indication of a societal willingness to pay for the project.

3.4.3 Water supply

An additional example of a replacement cost study with the objective to estimate the value of services provided by a wetland is a presented by Thibodeau and Ostro (1981). The objective of the paper is to quantify some of economic benefits by wetlands in the Charles River Basin, Massachusetts, USA. The replacement cost method is used to establish a value of the water supply function provided by wetlands. The water supply value was calculated as the difference between the cost of wetland wells and the cost of providing water from the next best source. The next best source in this case is the Metropolitan District Commission, a regional agency that maintains reservoirs and sells water to municipalities. Gupta and Foster (1975) have also described this example.

If the alternative water source provides functions that are equivalent in quality and magnitude to the wetlands is not discussed in the paper. However, it is said that the replacement is the next best source, which could be interpreted as if the source is as close as possible to a perfect substitute and a cost-effective way of replacement. In the paper, no evidence of the existence of willingness to pay for the service if provided by the alternative source is presented.

3.4.3 Waste treatment work of a wetland

Gosselink et al. (1974) also applies the replacement cost method to measure the value of a service provided by a wetland. As discussed in the introduction of this paper, the service in focus for their replacement cost valuation is the wetland's ability to remove and assimilate nutrients (BOD, Biochemical Oxygen Demand). The cost of sewage treatment is used to find a measure of the economic value of the service provided by the wetland. The study has been criticised by Shabman and Batie (1978), since compliance with the three conditions they defined is not achieved.

3.5 Drainage functions of inland waterways

Markandya et al. (1991) presents six case studies from the United Kingdom, where benefit or damage estimation has been assessed. One of the case studies is a valuation of the drainage function of Britain's inland waterways (canals). The canals form an important part of the country's drainage system since they receive discharges from various sources. To identify the beneficiaries of the free drainage function and try to seek out their willingness to pay for it would be complicated and expensive, instead the replacement cost method is used to estimate the benefit of the drainage function. If the canals did not exist, alternative means of drainage have to be provided and the cost of replacing them is used for valuation.

It does not emerge from the study if the estimated replacement cost is the cost of constructing a new canal system or the cost of some alternative means of drainage. Therefore, it could not be determined whether compliance with the first and the second conditions is achieved. It has not been examined in this case study if individuals would be willing to incur the costs of replacement if the canals were no longer available. In the paper it is, however, emphasized that the replacement cost method in fact can lead to an overstatement of the benefits. This overstatement is due to the fact that some individuals benefiting from the free service would not be willing to pay for the same function if it the canals were replaced by the least cost alternative. But on the other hand, since the demand curve for the drainage function could be assumed to slope downward, some individuals will tend to value the function more highly than the cost of replacement (Markandya et al., 1991). The authors consider this as a possibility for the overstatement to be balanced out. Still, if this possibility of balancing out exists in the case of the country's waterways is not examined in the study.

3.6 Coral reefs

Despite the fact that coral reefs are ecosystems that provide a range of benefits valuable to humans, they are often damaged by over-exploitation and indirect impacts of human activity. Spurgeon (1992) discusses the value of ecosystem services and goods produced by coral reefs. To derive a monetary value of the services and goods produced by coral reefs different valuation methods are suggested and the replacement cost method is one of the proposed methods.

Coral reefs provide physical protection to coastlines. To establish a monetary measure of this protection benefit Spurgeon (1992) suggests that three different methods can be used; the percentage dependence technique, the change in productivity technique or the replacement cost technique. If the replacement cost technique is used for valuation, the cost of replacing the reefs protective function with artificial costal defences is estimated. This replacement cost is assumed to be equivalent to the value of the natural protective function of the coral reef.

Spurgeon discusses two studies where the cost of replacing the protection service has been estimated. Only little background information is given about the two studies and it is therefore difficult to determine if the three validity conditions are met. Spurgeon (1992) states that the replacement cost method usually gives a minimum value. Three different explanations are presented to explain this understatement of the value. The explanations given are the following: *first*, people may be restrained by ability to pay, *second*, the benefits of the measure taken may be far greater than the costs involved and *last*, renewing of the replacement is needed. The first explanation given in the paper shows that Spurgeon (1992) is not aware of the third condition. It has to be proved in a replacement cost study that there exists a willingness to pay for the service if it is provided by the artificial replacement. Compliance with this condition is needed to make sure that the study does not result in an overstatement of the value. The ecosystem service should also be replaced by a perfect substitute in a cost-effective way, which ensures that the artificial defence would provide the same service as the ecosystem at the lowest possible cost. Consequently, the benefits of the reefs natural function will be correctly reflected. Regarding Spurgeon's third argument, the cost of renewing the artificial defence should, as well as the cost of installing it, be included in the replacement cost. According to Spurgeon a replacement cost study can also result in an overstatement of the value. The use of the same substitute in a large area ignores the fact that the ecosystem service differs in quality. Again, the first condition that states that the ecosystem service should be replaced by a perfect substitute has to be considered. If the ecosystem service differs in quality, different substitutes or different levels of substitutes should be used for valuation.

3.7 Water

Gibbons (1986) discusses the value of different services provided by water. The value of wastewater assimilation and dilution is based on replacement costs. Pollutants impose various degrees of damage depending on the type of pollutant and what the intended use of the water is. The value of dilution water is calculated by estimating the cost of providing the same water quality without dilution through pre-treatment of the effluent. Information on the water quality in a given stream at different levels of dilution flow is needed. Gibbons discusses studies that have estimated the value of water for assimilation and dilution of BOD (Biochemical oxygen demand). Since the valuation studies Gibbons base her discussion on are not explained in depth, it is difficult to determine if the validity conditions are met. However, it is emphasized in the study that the function should be replaced by a perfect substitute in a cost-effective way.

3.8 Housework and child-care

Sousa-Poza et al. (2001) analyses the allocation and value of time assigned to housework and child-care in Switzerland. Two different valuation methods are applied to estimate the value of time spent on unpaid labour; the replacement cost method and the opportunity cost method. In the replacement cost method, the number of hours spent on housework is multiplied by the wage rate of a market substitute. Two versions of the replacement cost method are examined in the study. In the first version, called the generalist method, the wage rate of a professional housekeeper is used as a substitute to the unpaid housework. The second version is called the specialist method and there the housework is divided into different activities. Time spent on a specific activity is multiplied by the wage rate of a professional, who is a specialist. Thus, for example, time spent on the activity cooking is multiplied by the average wage rate of a cook.

The first condition is not discussed in the paper. In the specialist version of the replacement cost method the substitute is a specialist and the question is if that person produces a service that is equal in quality to the unpaid housework. A cook, for example, could probably produce a higher quality service than an average person cooking. The discussion whether the substitute could be considered to be cost-effective is not brought up in the paper. The third condition states that there must be substantial evidence that the service would be demanded by the society if it were provided by the least cost alternative substitute. Are people actually willing to pay for a professional to take care of the housework and child-care? This issue is not discussed in the paper. If the estimated value should be valid there must a willingness to pay for the services provided for free in the household.

3.9 Some other replacement cost studies

In addition to the examined replacement cost studies above there exist references that briefly take up the method and studies where the valuation is partly based on replacement costs. Since these studies do not provide enough information about for example the ecosystem service in focus for the valuation or the replacement technique used they are not included in the examination. However, a brief summary of some of the studies will follow.

Coastal protection provided by different ecosystems could be valued with the use of the replacement cost method. Spurgeon (1998) takes the example that the valuation of flood protection provided by coral reefs could be based on the cost of artificial coast protection structures. Moberg & Rönnbäck (2003) discuss the replacement cost for coastal protection provided by both coral reefs and mangroves. However, the aim of their paper is to examine technical substitutes for ecosystem services from a biological perspective and they do not argue that the value of the ecosystem service equals the replacement cost. Sathirathai (1998) presents a case study of economic valuation of mangroves. The study is from a village in Thailand and the replacement cost method is applied to derive a monetary estimate of the benefit of coastline protection provided by mangroves. The construction of dams is used as a replacement technique.

Valuation studies of ecosystem services provided by wetlands are included in the examination of replacement cost studies. Further examples are discussed as follows. Gren (1995) presents a paper in which the value of marginal investments in wetlands for nitrogen purification is estimated. Secondary benefits of wetlands are estimated with the use of replacement costs. These estimations are based on Folke (1990). Byström (2000) provides another Swedish application of the replacement cost method. The value of using wetlands for abatement of agricultural nitrogen load to the Baltic Sea, with regard to a reduction target of 50 per cent, is estimated. The replacement value is defined as the savings in total abatement costs that are made possible by using wetlands as an abatement measure in cost-effective reductions of nitrogen load to the Baltic Sea (Byström, 2000). McNeely (1988) refers to a replacement cost study where the value of waste treatment provided by marshes in Massachusetts has been estimated with the use of replacement costs. Dehnhardt (2002) presents a case study of the river Elbe, where the replacement cost method is applied to estimate the value of flood plains as nutrient sinks. Chichilnisky and Heal (1998) refer to the case of New York that takes its water from a watershed in the Catskill mountains. The water purification service provided by the watershed used to be sufficient to meet the required water quality standards, but have now been degraded due to for example the use of fertilizer and pesticides. Chichilnisky and Heal (1998) base their discussion about the value of the ecosystem service provided by a watershed on a replacement cost approach. To meet required standards of water quality the city could choose between building a filtration plant and restoring the Catskill ecosystem. It is found out that restoration definitely is the cheapest alternative despite the fact that only one ecosystem service provided by the watershed is considered. In addition to the water purification service the watershed provides other valuable services, such as carbon sequestration.

Erstein (1999) refers to several studies where the replacement cost method has been applied to value the on-site cost of soil erosion. In the referred studies the cost of replacing nutrients lost through soil erosion is estimated. The replacement technique used is chemical fertilizers.

Rudbeck Jepsen (2003) evaluates the damming of the Senegal River by applying cost-benefit analysis. The impact of dam management on aquifer recharges is based on replacement costs. Deep wells are used to substitute the shallow aquifers in the river valley. The replacement cost is based on the establishment and maintenance costs of wells assuming a total termination of aquifer recharge.

3. 10 Discussion

The replacement cost studies, examined in this chapter, are summarised in the table below. Each study is given a judgement based on whether compliance with the three conditions (Shabman & Batie, 1978) is achieved. The judgement *completely* means that compliance with that condition is achieved. The judgement *partially* is given when the authors have shown that they are aware of the validity condition, but the condition is not actually met in the study or at least not discussed for the valuation made in the study. The judgement *not at all* means that the condition is not discussed in any way in the study, not in general terms nor in the terms of the specific case examined.

Table 1. Summary of replacement cost studies.

		1. Perfect substitute	2. Cost-effectiveness	3. WTP
Gunatilake & Vieth (2000)	**Erosion**	Completely*	Not at all	Not at all
Samarakoon & Abeygunawardena (1995)	**Erosion**	Completely*	Not at all	Not at all
Kim & Dixon (1986)	**Erosion**	Completely*	Not at all	Not at all
Xue & Tisdell (2001)	**Forest:**			
	1) water conservancy	Not at all	Not at all	Partially
	2) nutrient cycling	Not at all	Not at all	Partially
	3) pollutant decomposition	Not at all	Not at all	Partially
	4) pest control	Not at all	Not at all	Partially
Guo et al. (2001)	**Forest**	Partially	Not at all	Not at all
Niskanen (1998)	**Forest**	Not at all	Not at all	Not at all
Scott et al. (1998)	**Shrub-steppe**	Not at all	Not at all	Not at all
Folke (1990)	**Wetland**	Partially	Partially	Partially
Leschine et al. (1997)	**Wetland**	Partially	Not at all	Completely*
Thibodeau & Ostro (1981)	**Wetland**	Partially	Partially	Not at all
Gosselink et al. (1974)	**Wetland**	Not at all	Not at all	Not at all
Markandya et al. (1991)	**Drainage function of waterways**	Not at all	Not at all	Partially
Spurgeon (1992)	**Coral reefs**	Partially	Partially	Partially
Gibbons (1986)	**Water**	Partially	Partially	Not at all
Sousa-Poza et al. (2001)	**Housework**	Not at all	Not at all	Not at all

* = assumption

From the review of replacement cost studies it is clear that full compliance with the conditions rarely is achieved. None of the reviewed studies achieve full compliance with all three conditions. The table suggests that a majority of the reviewed studies do not discuss the cost-effectiveness condition and this is also the case for the third condition. The table also shows that the first condition is discussed in half of the studies.

The fact that few of the reviewed studies fully meet any of the conditions can have different reasons. First, this may be due to the fact that it can be difficult to consider these conditions in a practical application of the method. In other words it may, in practice, be complicated to control if compliance is achieved, e.g. if the substitute is a perfect or just a close substitute. In the examined studies the three conditions are mainly discussed in general terms and not in relation to the specific case that is studied. This indicates that it may be difficult to take these conditions into consideration in a practical application of the replacement cost method. A general discussion, however, shows that the author is aware of what is required to reach a valid result according to welfare economics theory. Second, many of the reviewed studies do not discuss how to achieve compliance with the conditions. This may be due to the fact the authors are not aware of the conditions that have to be met to reach a valid result when applying the replacement cost method. A third explanation may be that the authors do not agree with welfare economics and therefore do not discuss the conditions.

We continue to look at how the studies generally perform in relation to each of the conditions. To find a perfect substitute is, if not impossible, at least very difficult. However, it might be possible to find substitutes that are close to perfect. The perfect substitutability condition is discussed in about 50 per cent of the studies examined in this section, which shows that a majority of the authors are aware of this condition. In several studies it is stressed that the replacement technique used for valuation cannot be viewed as a *perfect* substitute but as a *close* substitute and therefore can serve as an approximation (for example Leschine, 1997 and Folke, 1990). It is still possible that those who do not discuss the perfect substitutability condition are aware of it and have considered it in their study.

Few of the reviewed studies discuss the cost-effectiveness condition. A possible explanation is that it is regarded as obvious that the least cost alternative should be chosen. Since the cost-effectiveness condition is uncontroversial, it is possible that it has been considered in most of the reviewed studies. However, few authors explain the reasons why a certain replacement technique is used, which makes it difficult to determine whether or not they are aware of the cost-effectiveness criteria. As a result, many studies have got the judgement *not* with reference to this condition. An example could also be found where it is clear that the valuation not only was based on the least cost alternative replacement technique (Samarakoon and Abeygunawardena, 1995).

The most controversial condition is the third regarding individual's willingness to pay. According to the review of replacement cost studies it is very difficult to show that the replacement cost equals the willingness to pay. Only one of the examined studies provides support for the assumption that the individuals in the case study in fact are willing to pay the replacement cost (Leschine, 1997). A few studies also discuss the risk of overestimation of the derived value, but in most studies the third condition is not discussed at all. The condition is based on the theory of welfare economics and all authors may not agree with this theory. This may be one reason to the fact that few studies discuss this condition.

To conclude, a practical application of the replacement cost method is not as straightforward as it first may seem. The first condition is the most discussed of the three in the reviewed studies, but still perfect substitutes for ecosystem services are difficult to find in practice. Consequently close substitutes have to be used to estimate the replacement cost value, which then may be regarded as an approximate value. In a practical application of the method it is also difficult to achieve compliance with the third condition. There is a need for further development of how to ensure that the willingness to pay is not overestimated by the replacement cost.

4 Application of the method

In a replacement cost study the cost of replacing an ecosystem service or an environmental good is used to estimate the value of that service or good. A possible application of the replacement cost method is to use replacement costs to estimate the economic value of a fish species' habitat. Habitat refers to the natural conditions and environment in which a species live. In other words, the habitat provides a suitable environment for the species living there, which may be viewed as an ecosystem service. The cost of replacing the ecosystem service is studied to estimate the value of the service provided by the habitat.

In Sweden there is a broad interest in fishing. According to a survey from 2000, 55 per cent of the population expressed that they were interested in fishing (Bengtsson et al., 2000). Many are also interested in fisheries management; four per cent of the population said they were member of a fishery association and two per cent had participated in practical management work (Bengtsson et al., 2000). Pollution and physical change have implied a decreased fish recruitment capacity in many watercourses in the country and management of the fish stocks are therefore needed. The Swedish government grants SEK 20 million annually for fisheries management projects in the country (www.ab.lst.se).

In this section, pike and perch in the Baltic Sea are discussed, as well as sea trout in Swedish coastal watercourses. The need for restoration of recruitment areas for pike and perch in the coastal zone of the Baltic Sea has recently been stressed while habitat restoration and management of sea trout has been employed for many years. A brief ecological background about these fish species are given followed by a discussion about how the replacement cost method can be applied to establish an economic value of habitats for fish species. The section ends with a practical application of the replacement cost method to sea trout habitats in Swedish streams.

4.1 Ecological background

The coastal zone has been subject to human influence for a long time and as a result fish species habitats have been significantly affected. Many human activities, such as industries, are located in the coastal area due to strategic reasons, but the coastal zone is also important for recreational activities and fisheries. Rivers and small streams along the coast are important recruitment areas for many species. These watercourses have also been affected by anthropogenic activity. Different management alternatives, including restoration efforts, can be employed to counteract and obstruct habitat degradation and thus promote successful reproduction of different fish species.

4.1.1 Pike and perch

Pike and perch are two popular species within both the recreational and the commercial fisheries. The brackish water in the Baltic Sea makes it possible for freshwater fish species to live there. Pike and perch can be found in the entire Baltic Sea accept from the very southern parts where the salinity is too high. Pike and perch demand relatively high water temperature (20-25 °C) and consequently the best recruitment areas for freshwater fish are situated in the shallow areas near the coastal zone (Karås, 1996). The quality of the recruitment areas is decisive for the fish production in the area. However, the quality of the recruitment areas in the coastal zone is severely affected by human activities. The impact can be seen in the form of eutrophication, industrial effluents and physical rearrangements (Karås, 1996).

The interest in management of freshwater species such as pike and perch has been low compared to the broad interest in management of salmonid stocks in running water. However, an increasing interest in management of these types of freshwater fish species has been noticed lately (Sandström, 2003). The increasing interest may be due to the fact that attention has been drawn to recruitment failure of pike and perch. Decreasing stocks of pike and perch and poor fish recruitment have for example been observed in Kalmarsund along the Swedish coast of the Baltic Sea (Andersson et al., 2000). To solve the recruitment problems different restoration measures have been suggested to improve the habitats for pike and perch, such as increased access to spawning substrates, restoration of coastal wetlands and removal of migration obstacles (Sandström, 2003).

4.1.2 Sea trout

Sea trout is a migratory (anadromous) fish species, which is returning from the sea to fresh water to spawn. Many small coastal streams serve as nursery areas for sea trout. Sea trout need gravel streambeds for successful spawning (Degerman et al., 2001). Another important habitat requirement is the access to structural refuges for juveniles, providing protection from predators. In Sweden, the sea trout lives about 1-3 years in the streams with fresh water before smoltification and migration to the sea (Degerman et al., 1998). The age of smoltification differs both within the stream and between streams. After about 1-3 years at sea, they become sexually mature and return to their natal stream to spawn (Degerman et al., 2001).

Sea trout is an important species in the recreational fisheries and therefore different management measures have been implemented to enhance the abundance of sea trout in Swedish streams. Examples of management measures are removing migration obstacles, ensuring sufficient water supply, creating buffer zones between arable land and watercourses, and increasing access to spawning substrates (Degerman et al., 2001). Stocking of sea trout is another common measure. In the Stockholm region stocking of sea trout has been carried out since in the middle of 1970's (Lovén, personal communication).

4.2 Valuation

Fish habitats have been exposed to serious degradation due to effects of human activities, which also may result in a decline in fish production. To compensate for this loss different efforts to restore damaged habitats can be made or stocking of reared fish can be carried out. Restoration measures include for example increasing access to spawning substrates, restoring wetlands or removing barriers to migration. Restoration of a habitat made to compensate for degradation may be viewed as a replacement technique. The cost of such an improvement can be used in a replacement cost study to establish the economic value of the ecosystem service provided by the habitat.

To be able to conduct a replacement cost study as described above, it is important that the stream and the fish habitat have been studied from a biological perspective. The replacement cost should be related to a change in environmental quality and therefore it must be possible to quantify the ecosystem service in focus. Information about the change in quality of the ecosystem service is also needed. For an application to fish habitats, data on the fish production in the watercourse before a change occurs is needed, i.e. a reference point must be identified. From the knowledge about the natural ecosystem service a suitable replacement technique can be identified. In the case of fish habitats the replacement technique could either be restoration of habitats by the means of different management measures or stocking of reared fish. To find out if the replacement technique is a perfect substitute to the ecosystem service, it must be possible to estimate the effect it has on the fish recruitment. Electrofishing, for example, is used to quantify the fish stocks in many watercourses. Hence, it is possible to estimate the fish density in a certain watercourse. However, it is also necessary to relate the change in the stock to a specific fishery management effort, i.e. the replacement technique used. To relate the used replacement technique to the change in stock is often the most difficult part, since many factors affect the size of the stock (Armstrong et al., 2003).

From the discussion above it can be concluded that an important issue in a replacement cost study is to define the ecosystem service. This might seem simple, but often this can be done in different ways. In the application to sea trout in this paper at least two ways of defining the ecosystem service can be found. The fish recruitment opportunities provided by the marine habitat can be viewed as the ecosystem service. The habitat can be restored in different ways, such as increasing access of spawning substrates and providing structural refuges for juveniles. The objective of the restoration is to create a suitable environment for the sea trout and thereby increase the population to the initial level. If the ecosystem service is defined in this way stocking of sea trout cannot be regarded as a replacement technique. However, if the objective instead is to replace the number of catches of sea trout, stocking can be viewed as a replacement technique. Another central question in a replacement cost study is to define the initial or natural level of the ecosystem service. Again, the importance of biological assessments can be stressed. In an application of the replacement cost method the available amount of data is probably going to be the constraint and the natural level is then identified from what is known about the watercourse.

Pike and perch are stationary species, which makes an application of the replacement cost method to estimate a value of their habitat suitable. However, at present, it does not seem like enough information is available to apply the replacement cost method to value habitats for pike and perch. Since the recruitment failure recently have been discovered, few management projects have been implemented and as a result available data are insufficient for this kind of valuation study. Management of salmonid stocks in running water is more common and consequently more data from management efforts targeting sea trout can be found. For that reason sea trout is, in this paper, chosen to illustrate an application of the replacement cost method.

4.3 Case study: Sea trout

The case study illustrates how the replacement cost method can be applied to establish a value of improved habitats for sea trout reproduction in a stream. The case study is based on fishery management projects in four Swedish streams. The management projects include habitat restoration and construction of fishways to remove migration obstacles.

4.3.1 Method

In Sweden the fisheries management work is carried out on different levels and stakeholders involved are for example the National Board of Fisheries, The County Administrative Boards, communities, fishing management units (fiskevårdsområden) and sports fishing associations. The National Board of Fisheries distributes the yearly governmental grants (SEK 20 million in 2003) to the County Administrative Boards. The County Administrative Boards use the grants to fund own fisheries management projects, but they also issue grants to other organisations working with fisheries management in the county.

In this study it was central to find information about management projects where the effects had been evaluated for example by electrofishing. Besides, the total cost of the project must also be known. To find adequate management projects the County Administrative Boards in coastal counties (i.e. 14 out of 21) were contacted. The person responsible for fisheries management at the County Administrative boards was asked about the Board’s own projects as well as other projects within the county.

The main problem was to find projects where the effects had been evaluated. Especially many small-scale projects have been carried out without any evaluation of the effects, but this has also been the case for larger projects. However, there is a trend towards a more systematic evaluation of management projects. The National Board of Fisheries has by the government been assigned to develop a monitoring programme (Budgetpropositionen 1999/2000:1). The aim is a systematic evaluation of their and the County Administrative Boards’ fisheries management projects. As the work with national environmental objectives started the need for evaluation of management projects has also been emphasized. Another example is a project going on in the rivers Vindelälven and Piteälven, where the objective is to improve the knowledge about migration patterns of sea trout (http://oringracet.slu.se/). The effects of restoration will be studied and this is going to provide useful information for developing better management measures. The fact that many stakeholders typically are involved in fisheries management also made it difficult to gather information about the projects. It is common that the County Administrative Boards work together with local organisations or the municipality and often many enthusiasts are involved working on a voluntary basis. As a result the information had to be gathered from many sources.

4.3.2 Smolt production

Information about the cost of the management measure and the effects on fish recruitment was gathered for each project. All costs are given in the price level of 2002, adjusted according to CPI (Appendix 3). The effects on fish recruitment are in all cases but one captured from electrofishing data. From the electrofishing data the smolt production in the watercourse is estimated according to two different models. In the stream Kävlingeån smolt production is measured in a smolt trap in Håstad Mölla and data were obtained from the trap.

To get exact information about the smolt production the migrating fishes have to be captured in the stream and counted. This is an expensive method and based on electrofishing data an approximation of the smolt production can be made. Degerman et al. (2001) presents two simple models for this purpose. The two models are based on data from watercourses on the Swedish west coast. The first model (A) is the most conservative of the two and it is based on the assumption that the age of smoltification is 2 years. According to model A the smolt production is equal to 27 per cent of the sea trout older than yearlings (>0+). In the second model, B, it is assumed that 15 per cent of the yearlings (0+) are migrating.

Model A: $0.27 \times$ **the number of >0+**

Model B: $0.15 \times$ **the number of 0+**

The fact that the two models are based on data from the west coast makes an application of them on data from the east cost (i.e. the streams Kagghamraån and Hammerstaån) less reliable. Models to estimate smolt production in the Stockholm region and on the east coast have not yet been developed. However, the development of such a model, adapted to the conditions (the environment) in the Stockholm region, is going on. Since 2002, electrofishing is a part of the regional environmental monitoring programme in Sweden. In total, 25 watercourses are included in the programme and electrofishing will be carried out on a yearly basis in eight of them. In addition a smolt trap is installed in the stream Åvaån, in the Stockholm region, where electrofishing is carried out as well. This is going to facilitate the development of a model for estimation of smolt production in streams in the Stockholm region (Andersson, personal communication).

4.3.3 Kagghamraån – a stream in the Stockholm region

The watercourse Kagghamraån is located in the region of Stockholm and the stream drains into the Baltic Sea in Kaggfjärden, see figure 3. Kagghamraån is one of the most important sea trout recruitment areas along the Swedish east coast. The sea trout found in Kagghamraån is a wild stock. The stream has been heavily affected, above all from the surrounding farmland. Among the resulting problems insufficient water supply, increased levels of nutrients and migration obstacles in the form of culverts, can be found. As a consequence of the lack of buffer zones between the surrounding farmland and the watercourse, erosion has also become a serious problem. The erosion has caused accumulation of sediments on the streambed resulting in a lower quality of the reproduction area (Andersson, 1998).

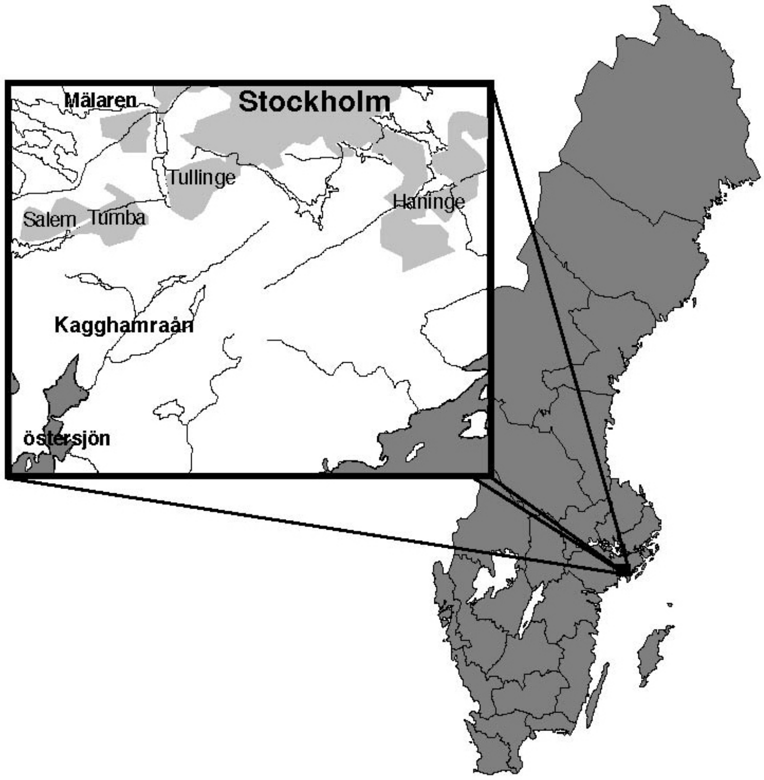

Figure 3. Location of the stream Kagghamraån (Andersson, 1998)

In 1989-1990 a study of the sea trout population in the watercourse was made with the purpose of formulating a management strategy to improve the conditions for sea trout reproduction in the stream (Andersson, 1990). The study resulted in a management plan that proposed different measures to restore the sea trout habitats in the watercourse. The restoration work in Kagghamraån and its tributaries started in 1991. The project was carried out in collaboration between the Stockholm County Administrative Board, Botkyrka municipality and the city of Stockholm. The Stockholm County Council funded the project.

Habitat restoration in Uringegrenen

In Uringegrenen, a tributary to Kagghamraån, restoration efforts were made in 1994 and 1995, putting gravel on the bottom of the stream. The aim of the restoration was to increase access to suitable spawning substrates and thereby promote successful reproduction. In addition to the gravel, stones and boulders were also put in the watercourse to create structural refuges for juveniles. Figure 4 shows the stream Kagghamraån and its tributaries.

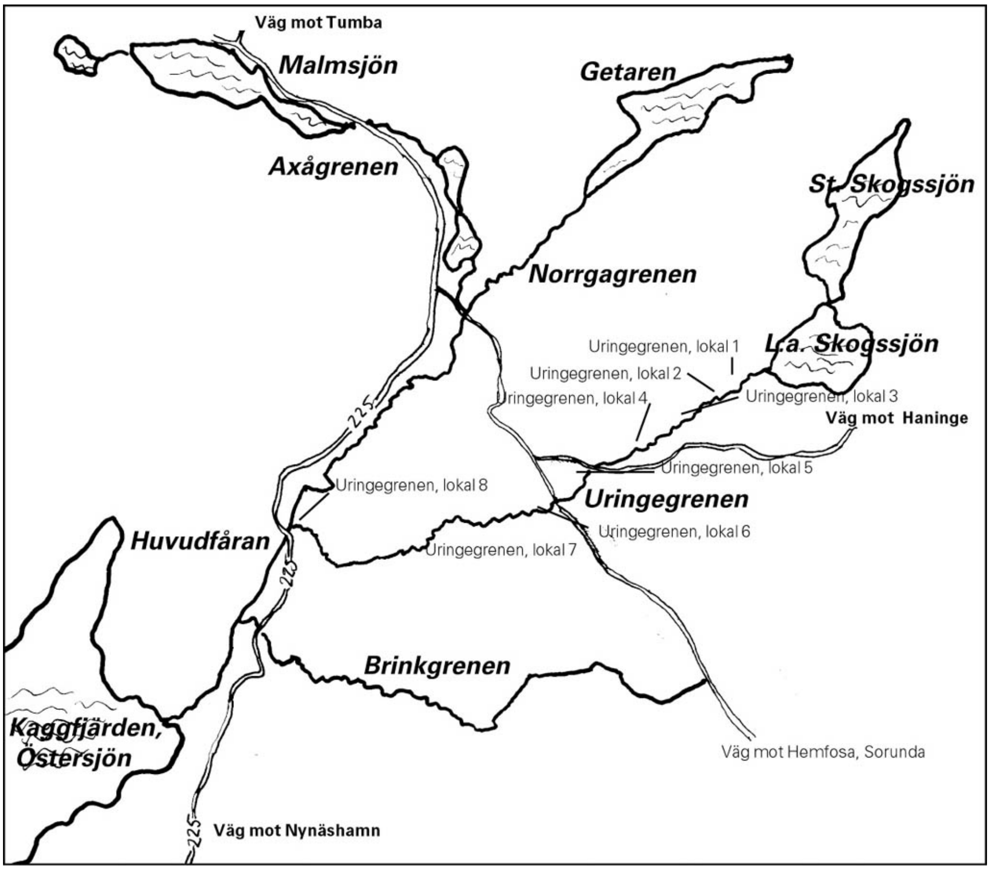

Figure 4. Kagghamraån, electrofishing zones (Andersson, 1998).

The restoration started in 1994 during the summer in the upstream part of Uringegrenen. The restoration work was completed in 1995 when additional stones and cleaned gravel were put on the streambed.

The cost of restoration in Uringegrenen amounted to SEK 326 866, given in the price level of 2002 (appendix 1). Cost items such as time for planning and contact with landowners, electrofishing to measure density and maintenance of the restored area are not included. Due to the fact that the restoration in the stream Uringegrenen is part of a larger project makes it difficult to estimate these cost items. The maintenance of the restored area is judged to be negligible. However, migration obstacles may be created and in that case they have to be removed to ensure that the sea trout can access the restored part of the stream. In 1995, for example, a migration obstacle was created when beaver established in the stream. The beaver dam stopped the sea trout from reaching the restored area, which is located upstream from the dam. To solve that problem a fishway was build. In addition, maintenance of the dam that regulates the water level in the watercourse may also be necessary. To conclude, maintenance of the restored area is probably not needed, but it has to be ensured that the sea trout is able to reach the restored section of the stream (Andersson, personal communication).

Andersson (1998) concludes that the restoration made has been successful, since it resulted in an increased density of sea trout in the restored part of the stream. Electrofishing is continuously carried out in Kagghamraån and its tributaries to measure the density of sea trout. Density was also measured both before and after the restoration took place, which gave an indication of the effects of the restoration. The highest density of sea trout was estimated in the upstream part of Uringegrenen and the density in 1997 had increased compared to the density in 1994 (Andersson, 1998). Andersson (1998) claims that the density changes were due to the restoration, that took place in 1994-1995, rather than to any other factor. Until 1986 there was a migration obstacle in the stream that prevented the sea trout from reaching the very upstream part of Uringegrenen. Thus, the population was established after removing the migration obstacle in 1986. The electrofishing zone U:3 is located within the restored area and electrofishing was carried out there in 1994. That was before the restoration started, and therefore the density estimation from 1994 could be viewed as a reference estimate. In 1994 the density of older fish was only approximately 5 per 100 m^2 and no yearlings at all were observed. Since 1997 the density of sea trout in the stream has increased even further and that is also due to the habitat restoration (Andersson, personal communication).

Since the development of a model for estimating smolt production adapted to the Stockholm region is not ready, the two models presented in Degerman et al. (2001) are applied. Due to the fact that the models are not adapted to the area, smolt production is estimated with the use of both models (appendix 1). The estimation is based on electrofishing data (density per 100 m^2 of river) from 6 years between 1996 and 2002. The mean value of sea trout per 100 m^2 is calculated based on data from different zones. The mean value is assumed to be a representative value for the restored area. From the years 2000, 2001 and 2002 data are only available from the zone U:4, where earlier the highest density of sea trout has been found. Thus, the value from zone U:4 is not representative for the whole area. To compensate for this higher value, an adjustment is made according to how much the specific site contributed to the density earlier years (appendix 1). The area of the restored section of the stream is about 2480 m^2. The smolt production is then estimated according to the two models, A and B, which were discussed above.

Table 2. Estimated smolt production in Kagghamraån according to model A and B.

Year	Model A	Model B
1996	45	62
1997	72	220
1999	110	177
2000	58	134
2001	37	435
2002	86	530
Total:	408	1559
Mean:	68	260

As seen in table 2, the two models give different result. Degerman et al. (2001) advocates model A, that gives a more conservative result. The results presented above can also be compared to the smolt production in the stream Åvaån, where the smolt production is about 200-1000 per year (Andersson, personal communication). The environment in Åvaån is similar to the environment in Kagghamraån and Uringegrenen. It is therefore likely that the smolt production in Uringegrenen reaches similar levels as the production in Åvaån (Andersson, personal communication). For that reason the estimate of smolt production from model B is used when calculating the replacement cost per smolt.

The cost of the restoration efforts made in the stream Uringegrenen amounted to SEK 326 866, which is the replacement cost. This cost is, according to the replacement cost method, viewed as the value of the service provided by the habitat. The estimations showed that, according to model B, 260 smolts on average migrate every year from the restored area. The restoration made is also assumed to be enduring, if no radical changes in the environment occur. According to Andersson (personal communication) the density estimate from zone U:4 is considered as the highest possible density in the area and thus it cannot be assumed that the increase in density will continue at the same rate. In this paper it is assumed that the smolt production in the stream also in the future will correspond to the estimated mean value. The value of the ecosystem service is expressed as the cost per smolt. Since it is not possible to exactly predict for how long the effects of the restoration will endure, the cost per smolt is calculated for five different scenarios (appendix 1). The value per smolt is SEK 157.1 if the most conservative scenario is assumed, that is if the effects of the restoration only are observed up to today. This value decreases if it can be assumed that the restored part of the stream also in the future is going to contribute to the smolt production, see appendix 1 for different scenarios.

4.3.4 Hammerstaån – a stream in the Stockholm region

Hammerstaån, or Muskån as the stream is also called, is located in the Stockholm region and the stream drains into the Baltic Sea south of Stockholm. The parts of the stream with gravel streambeds serve as spawning grounds for sea trout. The stream holds a wild stock of sea trout (Stockholm County Administrative Board, områdesbeskrivningar registerblad NRO01030). A constructed dam, Vretaforsdammen, stopped the sea trout from further migration in the stream. In 1998 a weir fishway was constructed to solve this problem. The weir fishway consists of a series of pools functioning like the steps of a ladder. It is made of concrete and stones from the watercourse, making it look more natural. This project was carried out by the City of Stockholm.

The constructed dam stopped the migration totally and therefore it is assumed that no sea trout could be found upstream from the dam. Electrofishing was carried out in the stream in 2002 and the result is used to estimate the smolt production (Electrofishing data, Swedish environmental monitoring programme www.fiskeriverket.se). Smolt production is estimated according to model A and B (Degerman et al., 2001), as in the case study of Kagghamraån.

Table 3. Estimated smolt production in Hammerstaån according to model A and B.

Year	A	B
2002	8	93

The fact that data on fish density only are available from one year makes the estimation of smolt production less reliable due to yearly fluctuations in production. The result from 2002 is however interpreted as the increase in production in the section upstream from the fishway. As in the previous case the estimation based on model B is used to compute the cost per smolt, since Hammerstaån as Kagghamraån is a stream in the Stockholm region.

Total cost of the construction of the fishway amounted to SEK 69 514 (appendix 1). In addition, yearly supervision is needed and the annual cost for that is SEK 500. The cost per smolt is calculated for four scenarios including the present value of the supervision (appendix 1). In the most conservative scenario, the cost per smolt is calculated assuming a time period of five year as the time the fishway has been in use. The value per smolt is then SEK 154.2. The fishway is a permanent construction and it is assumed that it will be in use for, at least, 25 years (Lovén, personal communication). If a time perspective of 25 years is assumed the cost per smolt is going to be SEK 33.2. Other scenarios are presented in appendix 1.

4.3.5 Solbergsån - a tributary to Göta Älv

Solbergsån drains into the river Göta Älv. Before 1986 a milldam at Solberg constituted a migration obstacle, which stopped sea trout and salmon from reaching the upstream parts in Solbergsån. In 1986 this problem was solved as a fishway was constructed through the milldam. This made it possible for sea trout and salmon to reach another 7 km of the stream (Höglind, 1992).

Electrofishing has been carried out in the stream on a yearly basis since 1981 (www.fiskeriverket.se). Since electrofishing data are available both from the period before and after the fishway was built, the change in density can be studied. An increase in the density has been observed. The smolt production is calculated according to model A and B (Degerman et al., 2001), as in the cases presented above (Table 4).

Table 4. Estimated total smolt production in Solbergsån in the upstream part from the fishway according to model A and B

	Model A	Model B
Before	1038	427
After	2669	2242
Increase	1631	1815

The two models give in this case similar results with a density about 10 smolts per 100 m^2, which corresponds with the County Administrative Board's density estimates (Höglind, personal communication). The cost per smolt is calculated based on model A, since this model is advocated in Degerman et al. (2001).

The construction work was carried out by a local sports fishing association (Sportfiskarna). Total cost of the fishway amounted to SEK 590,000 (appendix 1). In appendix 1, the cost per smolt is presented for four different scenarios. In the most conservative the cost per smolt is calculated assuming a time period of 16 years, which is the time the fishway has been in use. The cost per smolt is in that case SEK 34.6.

4.3.6 Kävlingeån – a stream in the south of Sweden

The river is one of the largest in the county of Skåne (Scania). The water has been used for many different purposes. In the Middle Ages many mills were built along the river and in the twentieth century large industries, such as spinning mills and tanneries, were established close to the river. The activities in and along the river affected the possibility for sea trout to migrate in the stream and had also major effects on the water quality. In the 1940's an association (Svenska Lax- och Laxöringföreningen) that worked for an improved environment for salmonids started their fisheries management work in Kävlingeån. They constructed a smolt trap, of the type called Wolf trap, in the stream. A smolt trap is a structure that spans a cross section of the stream and collects the smolts as they migrate to the sea. The purpose was to make it possible to evaluate management projects carried out in the stream by estimating the smolt production. The association's work continued until the beginning of the 1980's when it wound up. In 1997 the smolt trap was restored and since 1998 the number of out migrating smolts has been registered every day during April and May. The fishing management unit (Kävlingeåns – Löddeåns fvo), the County Administrative Board of Skåne, and the county council funded the restoration and the management of the trap.

Table 5. Number of captured sea trout smolts (Eklöv, 2003).

Year	Number of smolts
1998	411
1999	4369
2000	1653
2001	2326
2002	3883
2003	2882

A number of migration obstacles exist in the river. Two of them were removed when fishways were constructed at two locations in the river (Bösmöllan and Silverforsen). At Bösmöllan the migration obstacle consisted of a dam. The dam was a difficult obstacle for migrating fish and sea trout could only pass the dam during periods of high flows. The construction of a fishway at Bösmöllan started in 2000 and it was finished in 2001. The other migration obstacle, Silverforsen, was an old dam where a fishway already existed. However, the old fishway did not work satisfactory. A new fishway was built in 2001 in the part of the stream with the lowest height of fall. The fishway was constructed as natural rapids of stones and rocks. The fishing management unit and the County Administrative Board funded the two fishways. Total cost of the two fishways amounted to SEK 817 072 (appendix 1).

The smolt production is dependent on the number of fishes that migrate up in the river system to spawn two to three years before the smolt migration. The two fishways were built in 2000-2001 and consequently 2003 is the first year the effects of the fishways on the production of smolt can be seen. In addition to the registration of the number of migrating smolt, the number of trout that have returned to the river to spawn has been counted in the trap. The average number of sea trout that have returned to the river to spawn has increased after the construction of fishways in 2001. This result indicates that the fishways facilitate the migration and that they work satisfactory (Eklöv, 2003). The increase in smolt production after the construction of the two fishways is calculated as the difference in the average smolt production between 1998-2001 and 2002-2003 (appendix 1). The increase in smolt production is 1193 smolt per year. The cost per smolt is calculated for four different scenarios assuming an average smolt production of 1193 per year (appendix1). The two fishways are both permanent constructions and it is assumed that they will be in use for, at least, 50 years (Eklöv, personal communication). If a life span of 50 years is assumed, the cost per smolt is going to be SEK 13.7.

4.3.7 Summary of sea trout case study

Four different fisheries management projects in Swedish coastal streams have been studied in order to illustrate how the economic value of an ecosystem service could be based on replacement cost. These projects are summarized in the table below.

Table 6. Summary of fishery management projects.

Watercourse	Type of management measure	Increase in yearly smolt production	Replacement cost (SEK, in 2002 prices)	Replacement cost per smolt
Kagghamraån	Restoration of streambed	A: 68 B: 260	327,000	12.6-157.1
Hammerstaån	Weir fishway	A: 8 B: 93	70,000	33.2
Solbergsån	Fishway	A: 1631 B: 1815	590,000	8.2-38.5
Kävlingeån	Fishway	1193	817,000	13.7

Two of the streams are located in the Stockholm region, one in the south of Sweden and on the east coast. In three cases fishways were built to eliminate migration obstacles and in the fourth case the streambed was restored in order to attain habitat improvements. These management measures can be compared since the objective is to enhance the abundance of fish either by providing access to a larger area or improving the quality of the existing area.

The increase in smolt production caused by the management measure was calculated. The smolt production is in all cases but one based on electrofishing data and calculated according to two different models A and B in the table. In the stream Kävlingeån, data about smolt production are derived from a smolt trap. In Kagghamraån electrofishing data from 1994 were available, i.e. before the restoration efforts were made. In addition density was also measured after the restoration was made. This made it possible to relate the cost of the measure to the effects on density accomplished. The fact that density was measured both before and after the restoration took place gave strong indications that density changes were due to the restoration rather than to any other factor. Thus, it could be concluded that the replacement technique caused the improvement in environmental quality that resulted in higher density of sea trout in the stream. In Hammerstaån density was measured four years after the fishway was built. Since, the dam completely stopped the sea trout from migrating further up in the stream it is likely that the increase in density observed in 2002 is due to the fishway. In Solbergsån electrofishing was carried out both before the fishway was built in 1986 and after the construction. This made it possible to evaluate the change in density. In Kävlingeån the two fishways were completed in 2001. Data on smolt migration are available from both before and after the fishways were built and the result indicates that the fishways are working. However, since the smolt production is dependent on the number of fish returning to spawn in the stream about two years before the smolt migration, 2003 is the first year an increase in smolt production due to the fishways can be observed. The water quality has also been improved in the stream and most likely that has also had a positive effect on the smolt production.

The replacement cost was calculated as the total cost of the management project. All costs are expressed in the price level of 2002. Based on the total replacement cost the cost per smolt was calculated for different time scenarios. The construction in Hammerstaån is expected to be in use for at least 25 years and the constructions in Kävlingeån are expected to be in use for at least 50 years. In these two cases the cost per smolt is calculated based on the expected life span of the fishways. For the streams Kagghamraån and Solbergsån the life span of the restoration and the fishway is not known and therefore a cost interval is presented. The lowest cost in the interval is based on the number of years since the management project was carried out and the highest cost in the interval is based on a very long life span, 75 years.

4.4 Discussion

Have the three required conditions for a valid replacement cost study (Shabman & Batie, 1978) been met in this application? The replacement technique used must be a perfect substitute and a cost-effective solution. In addition, individuals must be willing to pay for the cost-effective replacement technique. Compliance with these conditions is required for a valid result.

The first condition states that the ecosystem service must be replaced by a perfect substitute. Hence, it is important to define the ecosystem service to make clear what is being replaced with the substitute. The main difficulty may be to define what is the initial or natural level of the ecosystem service. The examined management measures in the case study were: putting gravel on the streambed to improve the conditions for spawning and construction of fishways to make migration possible. The objective in all streams has been to restore the habitat, making it a suitable environment for the sea trout and thereby ensuring a certain level of fish recruitment. An alternative replacement technique could be stocking of sea trout. However, stocking does not replace the ecosystem service of the habitat. Instead, stocking of sea trout directly replaces the number of fish in the stream. It is also important to notice that management projects with the purpose of improving sea trout habitats also may have consequences for other species living in the watercourse, both positive and negative. Muotka et al. (2002) studied how in-stream restoration, with the ”single-goal” of enhancing salmonid fisheries, affects other stream biota. They examined a number of streams that had been channelized for water transport of timber and the recovery of habitat structure and macro invertebrate communities after the streams had been restored. Restoration causes a large disturbance in the stream, which has profound impacts also on stream organisms other than fish. It is also an unpredictable disturbance, for which stream biota cannot have any evolved responses (Muotka et al., 2002). In their study they conclude a relatively rapid recovery of habitat structure and macro invertebrate communities in the restored streams. The biodiversity of Kagghamraån has also been studied (Lundberg & Slotte, 2001). They observed an increase of biodiversity in the restored parts of Kagghamraån, which indicates that the restoration aiming at an enhancement of sea trout also has affected other species.

It is also necessary that the replacement technique used is a cost-effective replacement. The cost of the management measure can be compared to the cost of stocking hatchery-reared sea trout. Once again, emphasizing that stocking of sea trout only replaces the production level not the ecosystem service produced by the habitat. Sea trout is, for example, stocked annually in the Stockholm archipelago, an activity organised by the City of Stockholm. The annual cost of this activity amounts to SEK 1,2 million (Lovén, personal communication). Two methods for stocking are used, stocking of two-year old smolts and stocking of younger fish. The cost of the two-year old smolt is SEK 17,5 per fish and that includes the cost of hatchery rearing and transport to the archipelago (Lovén, personal communication). Cost items such as time for planning, work efforts to release the fish and electrofishing to measure the density are not included. Stocking of sea trout is also carried out in other parts of Sweden. At the National Board of Fisheries’ research station in Älvkarleby sea trout is produced for compensation stocking in the river Dalälven. The costs are SEK 17 for two-year old sea trout, with a weight less than 120 g and SEK 21 over that weight (Ragnarsson, personal communication). The cost of transport is not included. If a truck is used for transport the cost amounts to SEK 500 per hour and if a trailer is used the cost amounts to SEK 50 per 10 km. In addition, cost items such as time for planning, work efforts to release the fish and electrofishing to follow up have to be added as well. The cost of hatchery-reared smolts for stocking is in this paper assumed to be SEK 19, as the average cost of the two sizes of two-year old sea trout.

The cost of stocking sea trout is compared with the cost per smolt calculated for the examined streams. Stocking of hatchery-reared sea trout has in many cases shown poor survival rates (Degerman et al., 2001). Differences in mortality between hatchery-reared sea trout and wild populations are however not considered in this comparison. The present value of the cost of stocking is calculated and compared to the cost of the management projects (Appendix 2).

Table 7. Cost per smolt – stocking compared to management projects.

Number of years	Stocking, SEK per smolt	Kagghamraån, SEK per smolt	Hammerstaån, SEK per smolt	Solbergsån, SEK per smolt	Kävlingeån, SEK per smolt
5	17.5	-	154.2	-	-
10	15.9	125.7	79.0	-	68.5
25	12.0	50.3	33.2	24.6	27.4
50	8.1	25.1	17.1	12.3	13.7
75	5.9	16.8	11.5	8.2	9.1

Table 7 suggests that the cost of stocking in all cases (Kagghamraån, Hammerstaån, Solbergsån and Kävlingeån) is a less expensive replacement technique than the different management projects studied.

According to this calculation stocking of fish is thus a cheaper alternative than the restoration measures if the objective is to replace the production of fish. However, if the objective is to replace the ecosystem service produced by the habitat then stocking cannot be viewed as a replacement technique. Holmlund and Hammer (1999) state that fish populations provide human societies with a variety of ecosystem services. They also claim that stocked fish rarely compensate for the loss of all ecosystem services provided by wild populations. An artificial system dependent on continuous inputs of reared fish is created if stocking is used as replacement technique. An aspect of this is that irregularities in the ecosystem may not be discovered due to regular stocking practices (Holmlund & Hammer, 1999). In addition, it is also difficult to foresee the long-term effects of stocking practices in the ecosystem (Holmlund & Hammer, 1999). Stocking may also result in a loss of genetic variation, which may, for example, decrease the fish stocks' ability to adapt to changes in the environment (Degerman et al., 1998). Another aspect is the fact that anglers may not value stocked fish as highly as wild fish. Consequently they might have a higher willingness to pay for restoration measures that result in a self-sustaining wild population than for hatchery-reared fish.

The third condition concerns the existence of a willingness to pay for the replacement technique if it is introduced. Whether a willingness to pay for the restoration measures, examined in the case study, exist is difficult to confirm. However, some indications of a willingness to pay for the restoration projects may be referred to. To begin with some of the projects have partly been based on work of volunteers. Members of a local sports fishing association (Sportfiskarna) participated in the management projects in Kagghamarån and Hammerstaån. Secondly, restoration projects like the ones examined have also been carried out and funded on a voluntary basis by different organisations. For example members of a local sport fishing association carried out a restoration project in the stream Vitsån, in the Stockholm region (Andersson, personal communication). That has also been the case in the stream Åkers kanal where members of Österåkers sports fishing association have participated in restoration work on a voluntary basis. The association has also paid for parts of the restoration (Höglund, personal communication). The interest people show in voluntary work as well as raising funds for restoration projects may indicate that there exists a willingness to pay for this kind of projects. Lovén (personal communication) also mentions that the city of Stockholm receives money from individuals to fund fisheries management projects such as restoration or stocking.

An interesting thing to note in this application of the replacement cost method is how the cost per smolt is calculated. To be able to do this calculation different time perspectives for how long the effects would remain had to be assumed. Since this was not known in all cases the cost per smolt was calculated assuming different time scenarios. This shows that if a conservative time scenario is used in the calculations this will result in a high replacement cost value. If instead a longer time perspective is assumed the replacement cost value will be lower. Thus, the more successful measure the higher is the value, which is a very contradictory result. This shows how sensitive the result is for the assumptions made about the effects of the management measure.

Parts of the analysis could be improved with more available information. First of all, it was not possible to get information about all costs in this study. A model for estimating smolt production adapted to the conditions on the west coast, to get more reliable data, should be valuable. In this case study only limited time series of electrofishing data were available and as a result the projections of future production in the watercourse must be considered as rough estimations. The projections of future production may be improved if longer time series of electrofishing data were available.

5 Final remarks

This paper shows that the replacement cost method is not as straightforward as it first may seem. The method is not based on market behaviour and therefore an application of the method does not automatically result in valid estimates of economic value. The method may however result in valid estimates of economic value if compliance with three conditions is achieved: (1) the human engineered system provides functions that are equivalent in quality and magnitude to the ecosystem service, (2) the human engineered system is the least cost alternative way of replacing the ecosystem service and (3) Individuals in aggregate would in fact be willing to incur these costs if the ecosystem service was no longer available (Shabman & Batie, 1978).

The review of replacement cost studies made in this paper shows that these conditions rarely are fulfilled. It is of course difficult to identify perfect substitutes for complex ecosystem services, but this first condition is still discussed in many of the reviewed replacement cost studies. If no perfect substitute exists it is often possible to find a close substitute, which may be used in the calculations of replacement costs. A majority of the reviewed replacement cost studies has not discussed the cost-effectiveness condition. This is however considered an uncontroversial condition, since it is reasonable to believe that in most cases the least cost alternative technique is chosen as replacement. The third condition is perhaps the most neglected in the reviewed studies. This shows that it is difficult to handle the question about how to ensure that the estimated value does not overstate the individuals' willingness to pay for the ecosystem service. This was also true for the application of the method to sea trout habitats presented in this paper.

6 References

Abrahams, N.A., Hubbell, B.J. & Jordan J.L. 2000. Joint production and averting expenditure measures of willingness to pay: Do water expenditures really measure avoidance costs? *American journal of Agricultural Economics, 82,* 427-437.

Andersson, H. 1990. *Kagghamraån - Inventering av havsöringens reproduktionsmiljö. Förslag till förbättringar.* Municipality of Botkyrka, The Environmental Administration (Bokyrka kommun, miljöförvaltningen).

Andersson, H. 1998. *Havsöringen i Kagghamraån - Resultat från 1997 års kvantitativa elfisken.* Municipality of Botkyrka, The Environmental Administration, report 1998:3 (Botkyrka kommun, miljöförvaltningen).

Andersson, J., Dahl, J., Johansson, A., Karås, P., Nilsson, J. Sandström, O. & Svensson, A. 2000. *Utslagen fiskrekrytering och sviktande fiskbestånd i Kalmar läns kustvatten.* The National Board of Fisheries report 2000:5. Göteborg: The National Board of Fisheries.

Armstrong, J.D., Kemp, P.S., Kennedy, G.J.A., Ladle, M. & Milner, N.J. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research, 62,* 143-170.

Barbier, E. 1994. Valuing Environmental Functions: Tropical Wetlands. *Land Economics, 70,* 155-173.

Bengtsson, B, Lundgren, R. & Johansson, G (eds.). 2000. *Fiske 2000 - En undersökning om svenskarnas sport- och husbehovsfiske.* Finfo 2000:1. Göteborg: The National Board of Fisheries.

Bockstael, N.E, Freeman, A.M., Kopp, R.J., Portney, P.R. & Smith, V.K. 2000. On measuring Economic Values for Nature. *Environmental Science & Technology, 34,* 1384-1389.

Brännlund, R. & Kriström, B. 1998. *Miljöekonomi.* Lund: Studentlitteratur.

Budgetpropositionen 1999/2000:1, utgiftsområde 23 Fiske.

Byström, O. 2000. The replacement value of wetlands in Sweden. *Environmental and Resource Economics, 16,* 347-362.

Chichilnisky, G. & Heal, G. 1998. Economic returns from the biosphere. *Nature,* 391, 629-630.

Daily, G.C. (Ed.). 1997. *Nature's Services - Societal dependence on natural ecosystems*. Washington D.C.: Island Press.

Daily, G.C., Söderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A., Jansson, B-O., Kautsky, N., Levin, S., Lubchenco, J., Mäler, K-G., Simpson, D., Starrett, D. & Tilman, D. 2000. The Value of Nature and the Nature of Value. *Science, 289,* 395-396.

Degerman, E, Nyberg, P, Näslund, I & Johansson, D. 1998. *Ekologisk fiskevård*. Stockholm: Sportfiskarna - Sveriges Sportfiske- och Fiskevårdsförbund.

Degerman, E, Nyberg, P. & Sers, B. 2001. *Havsöringens ekologi*. Finfo 2001:10. The Göteborg: National Board of Fisheries.

Dehnhardt, A. 2002. The replacement value of flood plains as nutrient sinks: a case study of the river Elbe. Paper at the 2002 World Congress of Environmental and Resource Economists. Available: http://weber.ucsd.edu/~carsonvs/

Edwards-Jones, G., Davies, B. & Hussain, S. 2000. *Ecological economics - an introduction.* Oxford: Blackwell Science Ltd.

Eklöv, A. 2003. *Redovisning av fiskräkning i smoltfällan vid Håstad Mölla 1998-2003.* Kävlingeåns-Löddeåns fvo och Länsstyrelsen i Skåne. Eklövs Fiske och Fiskevård.

Erenstein, O.1999. *The economics of soil conservation in developing countries: The case of crop residue mulching*. Thesis. Wageningen: Wageningen University.

Folke, C. 1990. *Evaluation of Ecosystem Life-Support - in relation to Salmon and Wetland Exploitation.* Chapter V – The Societal Value of Wetland Life-Support. Stockholm university, Department of Systems Ecology.

Foster, J. 1997. *Valuing nature? Economics, ethics and environment.* London and New York: Routledge

Freeman, A.M. 1993. *The Measurement of Environmental and Resource Values -Theory and Methods.* Washington, D.C.: Resources for the Future.

Freeman, A.M. 2003. *The Measurement of Environmental and Resource Values – Theory and Methods*. 2nd Edition. Washington, D.C.: Resources for the Future.

Garrod, G. & Willis, K.G. 1999. *Economic Valuation of the Environment - Methods and Case Studies.* Cheltenham & Northampton: Edward Elgar.

Gibbons, D. 1986. *The economic value of water*. Washington, D.C.: Resources for the future.

Gosselink, J.G., Odum, E.P. & Pope, R.M. 1974. *The value of the tidal marsh.* LSU-SG-74-03. Center for Wetland Resources, Louisiana State University.

Gravelle, H. & Rees, R. 1992. *Microeconomics*. 2nd edition. London: Longman.

Gren, I-M. 1995. The value of investing in wetlands for nitrogen abatement. Beijer reprint series no. 47. Reprinted from: *European Review of Agricultural Economics*, 22, 157-172.

Gunatilake, H.M. & Vieth G.R. 2000. Estimation of on-site cost of soil erosion: A comparison of replacement and productivity change methods. *Journal of soil and water conservation, 55,* 197-204.

Guo, Z., Xiao, X., Gan, Y. & Zheng, Y. 2001. Ecosystem functions, services and their values – a case study in Xingshan County of China. *Ecological Economics, 38,* 141-154.

Gupta, T.R. & Foster J.H. 1975. Economic criteria for freshwater wetland policy in Massachusetts. *American Journal of Agricultural Economics, 57,* 40-45.

Holmlund, C.M. & Hammer, M. 1999. Ecosystem services generated by fish populations. *Ecological economics, 29,* 253-268.

Höglind, K. 1992. *Undersökningar i några av länets havsöringsförande vattendrag*. Miljövårdsrapport 1992:7, Miljövårdsenheten och Fiskeenheten, Länsstyrelsen Göteborgs och Bohus län.

Johansson, P-O. 1993. *Cost-Benefit Analysis of Environmental Change*, p. 24-45. Cambridge: Cambridge University Press.

Johansson, P-O., Kriström, B. & Mäler, K-G. 1989. Welfare evaluations in contingent valuation experiments with discrete response data: comment. *American Journal of Agricultural Economics 71*, 1054-1056.

Karås, P., 1996. *Rekryteringsmiljöer för kustbestånd av abborre, gädda och gös.* The National Board of Fisheries report 1996:6. Göteborg: The National Board of Fisheries.

Kim, S-H. & Dixon, J. 1986. Economic valuation of environmental quality aspects of upland agriculture projects in Korea. In: Dixon, J. & Hufschmidt, M. (Red.) 1986. *Economic valuation techniques for the environment - A case study workbook.* Baltimore, London: The Johns Hopkins university press.

Ledoux, L. & Turner, R. 2002. Valuing ocean and coastal resources: a review of practical examples and issues for further action. *Ocean & Coastal Management, 45*, 583-616.

Leschine, T. M., Wellman, K. & Green, T.H. 1997. *The economic value of wetlands - wetlands' role in flood protection in western Washington.* Washington State Department of Ecology. Ecology publication No. 97-100 (Available: www.ecy.wa.gov/ under publications 02-12-27)

Lundberg, S. & Slotte, H. 2001. Bottenfaunan i Kagghamraån – Resultat från 1998 års bottenfaunaundersökning. Municipality of Botkyrka, The Environmental Administration report 2001:1 (Miljöförvaltningen, Botkyrka kommun).

Markandya, A. Pearce, D. & Turner, R.K. 1991. Chapter 6: United Kingdom. In Barde, J. & Pearce, D. (eds). 1991. *Valuing the environment - six case studies*. London: Earthscan.

McNeely, J. 1988. Economics and biological diversity: Developing and using economic incentives to conserve biological resources. Gland: IUCN Publications Services.

Moberg, F. & Rönnbäck, P. 2003. Ecosystem services of the tropical seascape: interactions, substitutions and restoration. *Ocean & Coastal Management, 46*, 27-46.

Muotka, T, Paavola, R., Haapala, A., Novikmec, M. & Laasonen, P. 2002. Long-term recovery of stream habitat structure and benthic invertebrate communities from in-stream restoration. *Biological Conservation, 105*, 243-253.

Mäler, K-G. 1974. *Environmental economics: A Theoretical Inquiry*. Baltimore and London: The Johns Hopkins University Press.

Niskanen, A. 1998. Value of external environmental impacts of reforestation in Thailand. *Ecological Economics, 26*, 287-297.

Pearce, D.W.1993. *Economic Values and the Natural World*. Cambridge: The MIT Press.

Pearce, D. & Moran, D. 1994. *The economic value of biodiversity*. London: Earthscan Publications Ltd.

Perman, R., Ma, Y., McGilvray, J. & Common, M. 1999. *Natural resource and environmental economics* (2nd ed), Harlow: Pearson Education Limited.

Rudbeck Jepsen, M. 2003. Natural resource management in an ecological econometrics perspective – a modelling approach. *Danish Journal of Geography, 103,* 115-124.

Sagoff, M. 1988. The Economy of the Earth: Philosophy, Law, and the Environment. Cambridge: Cambridge Unversity Press.

Samarakoon, S. & Abeygunawardena, P. 1995. An economic assessment of on-site effects of soil erosion in potato lands in Nuwara Eliya district of Sri Lanka. *Journal of Sustainable Agriculture, 6,* 81-92.

Sandström, A. 2003. *Restaurering och bevarande av lek- och uppväxtområden för kustfiskbestånd*. Finfo 2003:3. Göteborg: The National Board of Fisheries.

Sathirathai, S. 1998. Economic valuation of mangroves and the roles of local communities in the conservation of natural resources: case study of Surat Thani, south of Thailand. EEPSEA Research reports series. Publications on coastal and marine resources, Economy and Environment Program for Southeast Asia.

Scott, M., Bilyard, G., Link, S., Ulibarro, C. & Westerdahl, H. 1998. Valuation of Ecological Resources and Functions. *Environmental management, 22,* 49-68.

Shabman, L.A. & Batie, S. 1978. Economic Value of Natural Coastal Wetlands: A Critique. *Coastal Zone Management Journal, 4,* 231-247.

Sousa-Poza, A., Schmid, H. & Widmer, R. 2001. The allocation and value of time assigned to housework and child-care: An analysis for Switzerland. *Journal of Population Economics, 14,* 599-618.

Spurgeon, J.P.G. 1992. The Economic Valuation of Coral Reefs. *Marine Pollution Bulletin 24* (11), 529-536.

Spurgeon, J. 1998. The socio-economic costs and benefits of coastal habitat rehabilitation and creation. *Marine Pollution Bulletin, 37*, 373-382.

Stockholm County Administrative Board, områdesbeskrivningar registerblad NRO01030. Available at www.ab.lst.se

Sundberg, S. 2003. *Att värdera miljön genom ersättningskostnader - en granskning av metoden och tillämpning på havsöringshabitat*. [To value the environment with the use of replacement costs - an examination of the method and an application to sea trout habitats]. Master thesis 306, Department of Economics, Swedish University of Agricultural Science, Uppsala.

Söderqvist, T. 1996. Ekonomisk värdering av miljön: Metoder och svenska erfarenheter, p. 5-73 in *Expertrapporter från Skatteväxlingskommittén*, SOU 1996:117. Ministry of Finance, Stockholm.

Söderqvist, T. 2002. Lecture on "Benefits of environmental regulation, economic valuation of environmental change" at the Swedish University of Agricultural Science.

Thibodeau, F. R & Ostro, B.D. 1981. An Economic Analysis of Wetland Protection. *Journal of Environmental Management, 12*, 19-30.

Winpenny, J.T. 1991. *Values for the environment - A guide to economic appraisal.* London: HMSO.

Xue, D. & Tisdell, C. 2001. Valuing ecological functions of biodiversity in Changbasin Mountain Biosphere Reserve in Northeast China. *Biodiversity and Conservation, 10,* 467-481.

Personal communication

Andersson, Henrik, The County Administrative Board of Stockholm.
Eklöv, Anders, Kävlingeån – Löddeåns fiskevårdsområde.
Höglind, Key, The County Administrative Board of Västra Götaland.
Höglund, Jan, Österåkers sportfiskeklubb (sports fishing association)
Lovén, Sverker, fisheries manager, Stockholms Stad.
Ragnarsson, Bjarne, The National Board of Fisheries, Research station, Älvkarleby

Internet resources

www.ab.lst.se (The county administrative board of Stockholm)
www.scb.se (Statistics Sweden)
www.fiskeriverket.se (The National Board of Fisheries)
www.rgk.se (The Swedish National Debt Office)
http://oringracet.slu.se/ (about sea trout in the rivers Vindelälven and Piteälven, only in Swedish)

Appendix 1

1.1 Kagghamraån

The calculations are based on electrofishing data from Uringegrenen. Electrofishing data were obtained from Henrik Andersson Stockholm County Administrative Board.

Zone U refers to Uringegrenen and all zones are located within the restored part of the stream.

The notation 0+ refers to the number of yearlings and the notation >0+ is the number of fish older than yearlings.

Density is measured as the number of fish per 100 m^2.

Electrofishing data from Uringegrenen.

Year	Zone	Fish	Density
1994	U:3	0+	
1994	U:3	>0+	5.4808
1996	U:2	0+	33.86908
1996	U:2	>0+	2.923977
1996	U:3	0+	18.81388
1996	U:3	>0+	3.928554
1996	U:4	0+	15.06645
1996	U:4	>0+	20.28345
1997	U:2	0+	13.17213
1997	U:2	>0+	9.690241
1997	U:3	0+	33.08898
1997	U:3	>0+	7.45675
1997	U:4	0+	131.235
1997	U:4	>0+	15.06645
1999	U:2	0+	24.93341
1999	U:2	>0+	12.52754
1999	U:4	0+	70.4015
1999	U:4	>0+	20.28345
2000	U:4	0+	57.36101
2000	U:4	>0+	13.85412
2001	U:4	0+	185.6871
2001	U:4	>0+	8.760951
2002	U:4	0+	226.45
2002	U:4	>0+	20.51452

Mean values of density are calculated for all years based on observations in different zones.

Mean values of density Uringegrenen per 100 m^2

Year	Density mean values 0+	Density mean values >0+
	0+	>0+
1994	0	5.4808
1996	16.93735	6.783995

1997	59.16539	10.73781
1999	47.66746	16.4055
2000	57.36101	13.85412
2001	185.6871	8.760951
2002	226.45	20.51452

The area of Uringegrenen is ca. 2479.5 m^2
To get total production in the stream the mean value per m^2 is multiplied by the area.

Estimation of total production in Uringegrenen

Total production in Uringegrenen			
Year	**Tot 0+**	**Tot >0+**	**Totalt**
1994	0	135.8964	135.8964
1996	419.9617	168.2092	588.1708
1997	1467.006	266.2441	1733.25
1999	1181.915	406.7743	1588.689
2000	1422.266	343.513	1765.779
2001	4604.111	217.2278	4821.338
2002	5614.828	508.6576	6123.485

Smolt production:

Model A: $0.27 \times$ the number of >0+
Model B: $0.15 \times$ the number of 0+

Adjusted: the production from year 2000-2002 is adjusted since it is only based on data from zone U:4. U:4 is the most optimal zone in the stream and contributed to 63 % of the total smolt production the first three years.

Smolt production in Uringegrenen according to the models presented above.

Year	**Modell A**	**ModellB**	**A-adjusted**	**B-adjusted**
1996	45.41647	62.99425	45.41647	62.99425
1997	71.8859	220.0509	71.8859	220.0509
1999	109.8291	177.2872	109.8291	177.2872
2000	92.74852	213.34	58.36932	134.261
2001	58.6515	690.6166	36.91108	434.625
2002	137.3375	842.2241	86.43048	530.036
Total:	515.869	2206.513	408.8423	1559.254
Mean:	85.97817	367.7522	68.14039	259.8757

Cost of the first part of the project, summer 1994, price level of 1994.

Cost of materials, freight included:	SEK
Boulders	2,040
Stones	6,970
Gravel	4,680
Cost of labour:	
Hours	120,000
Management	16,000

Travel allowance	15,600
Cost of machinery:	
Tractor	6,825
Crane truck	2,975
Total:	175,090

Cost of the last part of the project in 1995, price level of 1995.

Cost of materials, freight included:	SEK
Stones	10,725
Gravel	2,340
Cost of labour:	
Hours	96,000
Travel allowance	12,480
Cost of machinery:	
Tractor	4,225
Total:	125,770

In total, the cost of restoration in Uringegrenen amounted to SEK 326 866, given in the price level of 2002.

Cost per smolt, based on model B.

Number of years	**Number of smolts in total**	**SEK per smolt**
Today (8)	2080	157.1
10	2600	125.7
25	6500	50.3
50	13000	25.1
75	19500	16.8
100	26000	12.6

1.2 Hammerstaån

Electrofishing data were obtained from the Swedish environmental monitoring programme (www.fiskeriverket.se).

Electrofishing data, year 2002.

	0+	**>0+**
Nederfors	47.7	2.0
Prästtorpsbron	21.3	1.1
Mean	34.5	1.55

Area of the upstream part from the fishway is ca. 1800 m^2.
Smolt production is calculated according to model A and B.

Total production upstream from the fishway.

Total 0+	**Total >0+**	**Smolt A**	**Smolt B**
621	27.9	7.5	93.15

Cost of the fishway at Vretafors, prices given in the price level of 1998.

Cost of materials	8,672.5
Cost of labour:	
Sportfiskarna	19,990
Labour	10,125
Management	15,500
Travel allowance:	
Sportfiskarna	9,700
Manager	1,500
Total:	65,487.5

Total costs, in the price level of 2002: SEK 69514. In addition to the costs presented above the fishway is controlled annually at a cost of SEK 500 per year. The present value of the cost of the management of the fishway is included in the cost per smolt using the interest rate of 4.27%.

Cost per smolt, based on model B.

Number of years	**Number of smolts in total**	**SEK per smolt**
Today (5)	465	154.2
10	930	79
25	2325	33.2
50	4650	17.1
75	6975	11.5

1.3 Solbergsån

Electrofishing data were obtained from the Swedish environmental monitoring programme (www.fiskeriverket.se).

Density per 100 m^2 and smolt production per 100 m^2 according to model A and B respectively, before the fishway was constructed.

Year	**0+**	**>0+**	**A**	**B**
1981	1.5	6.1	1.647	0.225
1982	4.1	7.1	1.917	0.615
1983	3.7	14.9	4.023	0.555
1984	23	10.8	2.916	3.45
1985	22.6	26.4	7.128	3.39
1986	14.8	28.8	7.776	2.22
Total:	69.7	94.1	25.407	10.455
Mean:	11.61667	15.68333	4.2345	1.7425

The area upstream from the migration obstacle is ca. 24 500 m^2.

Total smolt production before the fishway was constructed:

Model A: $24500 \times (4.2345/100) = 1037.45$

Model B: $24500 \times (1.7425/100) = 426.9125$

Density per 100 m^2 and smolt production per 100 m^2 according to model A and B respectively, after the fishway was constructed.

Year	0+	>0+	A	B
1987	15.5	24.4	6.588	2.325
1988	51.1	21.9	5.913	7.665
1989	22.3	37.4	10.098	3.345
1990	31.8	39.9	10.773	4.77
1991	32.2	40.5	10.935	4.83
1992	73.5	30.8	8.316	11.025
1993	57.4	56.5	15.255	8.61
1994	41.3	58.2	15.714	6.195
1995	122	43.9	11.853	18.3
1996	16.9	46.3	12.501	2.535
1997	79.1	18.7	5.049	11.865
1998	56.4	48.7	13.149	8.46
1999	88.7	57.1	15.417	13.305
2000	97.1	35.6	9.612	14.565
2001	85.9	40.7	10.989	12.885
2002	105.1	44.9	12.123	15.765
Total:	976.3	645.5	174.285	146.445
Mean:	61.01875	40.34375	10.89281	9.152813

Total smolt production after the fishway was constructed:

Model A: $24500 \times (10.89281/100) = 2668.73845$

Model B: $24500 \times (9.152813/100) = 2242.44335$

Increase in average smolt production after 1986:

Model A: 2668.73845-1037.45=1631.28845
Model B: 2242.44335-426.9125= 1815.53085

Cost in SEK in price level of 1986:

Grants	295,000
Sportfiskarna (voluntary work)	295,000
Total:	590,000

Total cost in the price level of 2002, SEK 1, 004 067.4.

Cost per smolt, based on model A.

Number of years	Number of smolts in total	SEK per smolt
16	26101	38.5
25	40782	24.6
50	81564	12.3
75	122347	8.2

1.4 Kävlingeån

Number of captured sea trout smolts. (Eklöv, 2003)

Year	Number of smolts
1998	411
1999	4369
2000	1653
2001	2326
2002	3883
2003	2882

Increase in smolt production:

Mean value before the construction of the two fishways (1998-2001): 2189.75 smolts per year.
Mean value after the construction of the two fishways (2002-2003): 3382.5 smolts per year
Increase of smolts per year: 1192.75

Cost in SEK in price level of 2001:

Silverforsen	660,000
Bösmöllan	140,000
Total:	800,000

Total cost in the price level of 2002, SEK 817,072.

Cost per smolt

Number of years	Number of smolts in total	SEK per smolt
10	11930	68.5
25	29825	27.4
50	59650	13.7
75	89475	9.1

Appendix 2

2.1 Cost of Stocking

The cost of stocking two-year old sea trout is assumed to be SEK 19 per fish.
The present value of the cost of stocking is calculated assuming r = 4.27%, that is the average government borrowing rate during 2003 (www.rgk.se, August 2003).

Cost per smolt, in the price level of 2002.

Years	**SEK per smolt**
5	17.5
10	15.9
25	12.0
50	8.1
75	5.9

Appendix 3

Consumer Price Index (www.scb.se)

Year	Index	**Year**	Index
1980	100	**1992**	232.4
1981	112.1	**1993**	243.2
1982	121.7	**1994**	248.5
1983	132.6	**1995**	254.8
1984	143.2	**1996**	256
1985	153.8	**1997**	257.3
1986	160.3	**1998**	257
1987	167	**1999**	258.1
1988	176.7	**2000**	260.7
1989	188.1	**2001**	267.1
1990	207.8	**2002**	272.8
1991	227.2		