Cost-benefit Analysis of Environmental Change: Linking Theory to Empirical Observations .

May 5, 2004

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Abstract We present a Cost-Benefit Analysis (CBA) of environmental change, in which theory and empirical work are closely knit together. The theoretical framework is used to derive a cost-benefit rule for projects that affect wild salmon survival. In contrast to many similar studies, we use this dynamic cost-benefit rule in structuring the contingent valuation study. Data comes from an ongoing project regarding a potential salmon passage-hydropower conflict in the northern Swedish river Umeälven and its largest salmon producing tributary Vindelälven. Daily water flow data are combined with daily data on the number of salmon (1974-2000) that pass the hydropower plant Stornorrfors. Detailed ecological studies are used to build the contingent valuation scenario and to study the opportunity costs of releasing more water to the potential benefit of salmon upstream migrants. We present results from pilot-studies on the value Swedes place on increasing the amount of wild salmon in this particular river.

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1 Introduction

This paper shows how theory and empirical work can be closely linked together in cost-benefit analysis of environmental change. The theory is based on dynamic cost-benefit analysis and focuses on hydropower - fish passage conflicts. Our approach is illustrated with data from an ongoing project regarding the salmon-hydropower conflict in a river in northern Sweden(Umeälven/ Vindelälven). Daily water flow data is combined with daily data on the number of salmon that pass the hydropower plant Stornorrfors, located about 40 km up-river. Data covers the period 1974 to 2000 and are used to structure the proper contingent valuation (CV) questions and to study the opportunity costs of releasing more water to the potential benefits of salmon upstream migrants.

In section 2 we detail the theoretical framework, including a cost-benefit rule (CBR) for the salmon-hydropower case. Section 3 provides background information about the wild salmon case under study. Section 4 has details on two pilot studies carried out to measure the benefits of increasing the salmon stock. Section 5 includes a preliminary assessment of the opportunity costs of diverting water from the hydropower plant to improve fish passage conditions. Section 6 presents concluding remarks.

2 CBA of the Salmon-Hydropower case

In this section we derive a simple dynamic cost-benefit rule that covers the salmon-hydropower case. Consider a society that values both its consumption of a numeraire good and its consumption of salmon. In addition society attributes a value to the stock of salmon. We interpret the stock of salmon as an indicator of an existence value. Abstracting from distributional concerns, the society under consideration aims at maximizing the present value utility of a representative individual:

$$\int_0^\infty u\left(c(t), c_L(t), s_L(t)\right) e^{-\delta t} dt \tag{1}$$

where $u(.)$ is an instantaneous utility function, $c(t)$ denotes consumption of the numeraire good at time t, $c_L(t)$ denotes consumption of salmon at time t, $s_L(t)$ denotes the stock of salmon at time t, and δ is a discount rate, for simplicity assumed to be constant across time.

For simplicity, we assume that the numeraire commodity is produced using electricity as the sole input. In turn, the amount of electricity is a function of the flow of water through the power station. Thus we have:

$$c(t) = f(\overset{\bullet}{s}_w(t)) \tag{2}$$

where $\overset{\bullet}{s}_w(t)$ is the time t flow of water through the power station (a dot refers to a time derivative). This flow is determined by natural conditions (precipitation, etc.), and the amount of water diverted from electricity production in order to promote the possibility of salmon to pass the power station and reach their spawning-grounds:

$$\overset{\bullet}{s}_w(t) = k(t) - A(t) \tag{3}$$

where $k(t)$ refers to the flow of water as determined by natural conditions, and $A(t)$ denotes the amount of water diverted from electricity production. The policy variable of our model is $A(t)$, because it directly controls the production of goods from water/electricity, and indirectly controls the amount of salmon.

The change of the stock of salmon is determined as follows:

$$\overset{\bullet}{s}_L(t) = g(s_L(t), A(t)) - c_L(t) \tag{4}$$

where $g(.)$ is a generic growth function. This formulation is based on the idea that $A(t)$, i.e. the amount of water diverted from electricity production, affects the number of salmon that makes it upstream through the power station. Thus the natural growth of the stock of salmon is a function of $A(t)$ and the size of the stock itself at time t. Equation 4 shows that the change of the salmon stock at time t is equal to the natural growth of the stock at time t less the catch of salmon at time t. For simplicity, it is assumed that the catch of salmon at time t is equal to consumption of salmon at time t.

Equations 3 and 4 make it clear that diversion of water from electricity production has two effects. First, there is an immediate impact on production of the numeraire good such that $c(t)$ is reduced. Second, there is an indirect impact on the growth of salmon such that the stock of salmon will be larger in the future (given the catch of salmon). The cost-benefit analysis looks at these benefits and costs. Thus we can use a change in $A(t)$ to generate the principal terms in a cost-benefit analysis of the salmon-hydropower conflict.

Given $A(t)$ society is assumed to maximize equation 1 with respect to $c_L(t)$ subject to equation 4 and some initial conditions and transversality conditions. Note that given $A(t)$ consumption of the numeraire good is completely determined by the flow of water as determined by natural conditions. This can be seen from equations 2 and 3.

The present value Hamiltonian of this problem can be written as follows:

$$H(t) = u(c(t), c_L(t), s_L(t))e^{-\delta t} + \lambda_L(t)(g(s_L(t), A(t)) - c_L(t)) \tag{5}$$

where $\lambda_L(t)$ is a present value costate variable.

First-order conditions for optimality can be summarized as follows:

$$\frac{\partial u(.)}{\partial c_L(t)} e^{-\delta t} = \lambda_L(t) \tag{6}$$

$$\overset{\bullet}{\lambda}_L(t) = -\frac{\partial u(.)}{\partial s_L(t)} e^{-\delta t} - \lambda_L(t) \frac{\partial g(.)}{\partial s_L(t)} \tag{7}$$

Equation 6 states that in optimum the present value marginal utility of consumption of salmon at time t is equal to the shadow price of the stock of salmon at that time. Equation 7 relates the change over time of the costate variable to the sum of the present value marginal utility of the stock of salmon plus the utility value (in present value terms) of a change in the growth rate of salmon caused by a marginal increase in the stock of salmon.

In order to arrive at a simple cost-benefit rule we assume that $A(t)$ is a parameter whose value is constant over the planning horizon; $A(t) = A, \forall t$. Consider then a small uniform increase in A. This can be interpreted as an increase of the water flow in the bypass channel at the power station. In turn, this increase causes an increase in the number of salmon that survive the passing of the power station. It is one of the technologies discussed in relation to the contingent valuation study presented in Section 4.

The total effect on the objective function, i.e. equation 1, of an infinitesimally small change in a parameter is obtained by taking the partial derivative of the present value Hamiltonian (or more generally the Lagrangean) with respect to the parameter and integrating along the optimal path over the planning horizon. Thus we obtain:

$$\int_0^\infty \frac{\partial H(t)}{\partial A(t)} = \int_0^\infty [-\frac{\partial u(.)}{\partial c(t)} \frac{\partial f(.)}{\partial A(t)} + \lambda_L^{c*}(t) \frac{\partial g(.)}{\partial A(t)}] e^{-\delta t} dt \tag{8}$$

where an asterisk refers to an optimal value, and $\lambda_L^{c*}(t)$ is a current value costate variable. The first term within brackets in the right-hand side expression of equation 7 reflects the marginal cost (in units of utility) of diverting marginally more water from electricity production. This cost is equal to the loss of consumption of the numeraire good, as less electricity for its production is available. Note that the magnitude of this cost might vary from year to year due to variations in k(t), the natural flow of water; recall that $f(.)$

in equation 7 is a function of the difference between $k(t)$ and $A(t)$. The second term within brackets yields the marginal benefit of divesting marginally more water from electricity production. This marginal benefit is equal to the optimal current value costate variable of the stock of salmon times the impact on the growth rate of the stock of salmon of diverting marginally more water from electricity production. It is here assumed that the last effect, i.e. $\partial g(.)/\partial A(t)$, is strictly positive. It can be shown that the current value costate variable $\lambda_L^{c*}(t)$ is equal to the present value sum (integral) from time t and onwards of the marginal utility of the stock of salmon plus the marginal utility of consuming salmon times the marginal effect on growth of the stock of salmon; see the appendix to this chapter for details. This fact indicates that existence values as well as use values should be accounted for in the valuation study.

Dividing through by the marginal utility of consumption of the numeraire good converts the expression in equation 7 from units of utility to monetary units. Thus the following expression represents a simple cost-benefit rule (CBR) for the project under consideration:

$$CBR = \int_0^\infty [\frac{\lambda_L^{c*}(t)}{\lambda_m^{c*}(t)} \frac{\partial g(.)}{\partial A(t)} - \frac{\partial f(.)}{\partial A(t)}] e^{-\delta t} dt \tag{9}$$

where $\lambda_m^{c*}(t) = \partial u(.)/\partial c(t)$ denotes the optimal current value marginal utility of consumption of the numeraire good at time t. The first term within brackets is equal to the time t marginal WTP for an increase in the stock of salmon times the impact on growth of salmon of a marginal increase in $A(t)$. The second term within brackets yields the marginal cost at time t in terms of the value of the loss of production of the numeraire good as marginally more water is used to "transport" salmon. The policy implication is that we should divert more water from electricity production as long as the present value of the sum of marginal benefits over the time horizon exceeds the present value of the sum of marginal costs over the time horizon.

Having outlined this framework, we now turn to our empirical application. We begin by presenting some useful biological background information and then turn to the benefits and costs.

3 Salmon and hydropower

Fish passage problems related to migrations through flow controlled areas in regulated rivers are global. In Sweden, these problems arise in larger rivers where fish spawn in upriver areas while critical migration passages such as bypass channels and fish ladders are situated in the downriver areas. In the completely flow-controlled Umeälven, and its natural largest tributary Vindelälven, Rivinoja et al. (2001) show that about 75 % of the salmon do not pass upriver through the flow controlled area around the Stornorrfors power station. [1]

Wild salmon undertake its spawning migration in the lower Umeälven in early summer and migrate upstream till early October. Daily and weekly control of the water flow through the hydropower station and over the dam in Norrfors have given rise to a concern that the salmon migration is hindered by low daily flow regimes during the spawning migration.[2]

Our study area is presented in figure 1. The salmon enters an area in which the water from the turbines and the bypass channel come together. The amount of water in each pathway depends on electricity generation (i.e. electricity demand) and stipulated flow in the bypass channel.

A salmon ladder, located 32 km from the estuary, generates detailed information on the hatchery (adipose fin cut)- and wild (adipose fin intact) salmon and sea trout stocks reaching the Vindelälven. About 70 % of all fish observed in the fish ladder is of wild origin (McKinnell et al. (1994)). Figure 2 presents data from the ladder, using observations on the yearly averages from 1974 to 2000. In Lundqvist et al (2002) Leonardsson et al. (2002)[3] present a growth function for the wild salmon that reaches the spawning places in the river Vindelälven. This growth function helps us to estimate with how much the amount of salmon that reaches the spawning places will increase over time due to a measure in the river such as an increase of the water flow in the bypass channel (Ferguson et al, 2002).

4 Measuring preferences for salmon

A pilot-study was carried out in May 2003 to obtain more information about Swede's sentiments towards the wild salmon in the river Vindelälven. Questionnaires were mailed to 250 randomly selected Swedes[4] and 200 were mailed

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[1] The river enters the Bothnian bay (63^{o}50'N 20^{o}05'E) just south of Umeå and stem from the mountain areas c. 450 km from the coast. The unexploited Vindelälven join the Umeälven c. 40 km from the estuary and c. 8 km upriver the dam in Norrfors. The wild salmon population in the Umeälven was destroyed during the 1950s by power exploitation while the Vindelälven still has wild salmon and trout. Releases of smolts from the Norrfors hatchery compensate the loss of naturally produced salmon from the Umeälven.

[2] See Perä & Karlström (1996), Rivinoja & Lundqvist (1998) and Rivinoja et al (2001) for detailed discussions about this issue.

[3] see Appendix 6

[4] 250 Swedes were randomly selected from the Swedish telephone directory.

to randomly selected Swedish anglers[5]. 28 percent returned the questionnaire. In this pilot study we identified a number of problems with the questionnaire and therefore a second pilot-study was carried out in March 2004. In the second pilot study 165 undergraduate students in Economics at the University of Umeåparticipated. Since the pilot-study was carried out in a classroom the respondent rate was 100 percent.

Both surveys were structured in a conventional manner. It initially provides general information about the current situation for wild salmon globally and specific information concerning the wild salmon in the river Vindelälven. The respondents were also made aware of the fact that increasing the number of wild salmon typically comes at an opportunity cost. In addition, the background part of the questionnaire included information about the present and future fishing situation in the river.

Different methods can be used to improve fish passage associated with the Stornorrfors Power Station in the Umeälven. One method, besides increasing the water flow in the bypass channel, is to build a fish ladder leading from the turbine discharge tunnel outlet to the bypass area so fish can migrate upstream and find the existing ladder leading the returning fish to approach the spawning areas in the river Vindelälven (Ferguson et al, 2002).

Our cost-benefit rule, equation 9, is based on the assumption that the fish passage is improved by diverting more water to the wild salmon and less to electricity production. However, in our questionnaires, the respondents were asked to state their willingness-to-pay (WTP) for increasing the migration of wild salmon with a new fish ladder, i.e no change in the division of water between salmon and hydropower production is involved. WTP might vary across the methods proposed to increase migration, therefore it is not given that our empirical findings from the questionnaires is directly linked to our cost-benefit rule. To straighten out this problem the following question was included in the questionnaire in the first pilot study:

> One way to increase the number of wild salmon that reach their spawning places, is to build a new fish ladder. A fish ladder already exists today, but a more efficient one could be constructed. Suppose that any method to increase migration of wild salmon is equally successful in terms of the number of migrating salmon and that the cost is the same. Does it then matter to you which method that is being used?

The respondents could answer 'yes', 'no' or 'do not know'. Space was also included for comments. 62 percent of the respondents did not care which

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[5] 200 Swedish anglers were randomly selected from the register of members of the largest Swedish angle association.

method was used, as long as the costs and the increase of wild salmon were the same for all methods. 9 percent answered 'do not know' and 29 percent of the respondents answered that it did matter for them which method was used, even if the costs and the increase of wild salmon were the same for all methods. The comments given by the yes-respondents indicate that it is of significance to this group whether or not the method increase the number of salmon in a natural way. An example of a non-natural increase would be to catch all salmon below the power station and then transport them to their spawning places above the power station. A new fish ladder and an increase of water flow in the old river basin are examples of methods that would increase the number of wild salmon in the river Vindelälven in a natural way.

The respondents answers suggest that reported WTP is quite independent of the method, as long as the method is considered as the "natural" one. Our working hypothesis is that these WTP estimates can be plugged in to our cost-benefit rule. To investigate this hypothesis further we extended the question in the second pilot-study. We told respondents to assume that the effects on the natural reproduction of salmon would be the same regardless of method. This had little effect on the response patterns; the proportions of people that answered 'yes', 'no' and 'do not know' to the "methods" question in the second pilot-study was essentially the same as in the first pilot-study. We will continue to explore preferences over different approaches in the main survey.

4.1 Willingness to pay over time

In recent years, a number of papers have inquired into WTP over time. This issue has several dimensions, including but not limited to; the difference between using lump-sum or by-period payments (see Johansson , 1987), implied discount rates (see Harrison et al, 2001) and the credibility of the payment vehicle. In our case, measures carried out "today" will have an impact on the number of salmon "tomorrow", via the growth function (see equation 4).

To be able to tie together the theoretical framework with the measurement method, we need to construct a valuation question that flows from the cost-benefit rule. The basic cost-benefit rule (CBR) for the project under consideration is given by equation 9:

$$CBR = \int_0^\infty [\frac{\lambda_L^{c*}(t)}{\lambda_m^{c*}(t)}\frac{\partial g(.)}{\partial A(t)} - \frac{\partial f(.)}{\partial A(t)}]e^{-\delta t}dt \tag{10}$$

The first term within brackets is equal to the time t marginal WTP for an increase in the stock of salmon times the impact on growth of salmon of a marginal increase in $A(t)$, i.e. this is the marginal benefit. Therefore, a proper WTP-question should, according to the cost-benefit rule, give information about both the direct effects of the salmon stock due to a change of water flow diverted to salmon and the impact on growth of salmon due to an increase of water flow. As stated in the previous section, we assume that the method used to increase the amount of salmon does not influence people's WTP, as long as it is considered a natural method (and the increase of salmon is the same regardless of the method). In our questionnaire the "natural method" is a new fish ladder.

Half of the number of responents in the pilot were asked the following question:[6]:

> During the last ten years, an average of 3000 wild salmon has reached the river Vindelälven each year. Assume that the number of wild salmon that reach the river increase to 4000 this year due to a new fish ladder. The new fish ladder will, together with the salmons' natural reproduction, result in approximately 6000 wild salmon reaching the spawning areas five years from now and approximately 9000 ten years from now. After ten years, the number of wild salmon in the river Vindelälven will stay at 9000 each year.
>
> Question(2): Would you be willing to pay the following lump-sum for this increase of the number of wild salmon in the river Vindelälven? (In the second pilot-study an open ended question was asked.)

The number of salmon referred to in question 2 is approximated by using Leonardsson et al.'s (2002) growth model, which is based on biological data form the river Vindelälven. The choice of a 10 year period is base on insights from earlier studies on discount rates.

To analyze if respondents were sensitive to different profiles of salmon development the other half of the sample (sample B) was asked about a case when the number of wild salmon was assumed to increase to 9000 already after five years, and was then held constant at that level. In summary, the difference between the scenarios for sample A and B is that 3000 additional salmon become available in year 5 in the case of sample B. We pictured the increase of wild salmon over time by using a diagram.

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[6] In the second pilot-study the same WTP-questions were asked, but the questions were distributed in another way among the respondents.

To make sure that the respondents distinguished between the different quantities of wild salmon, and between getting more wild salmon today and getting more wild salmon tomorrow, another WTP-question was asked before question 2 in the first pilot-study. 50 percent of the respondents were asked to reveal their WTP (lump sum) for an increase of salmon from 3000 to 4000 *this year*. The other 50 percent were asked to state their WTP (lump sum) for an increase of salmon from 3000 to 9000 *this year*.

The results suggest that people are willing to pay more for a larger increase of salmon than for a smaller. In other words, people seem to perceive the difference between quantities and do express an opinion about them. This is important, given the discussion about insensitivity to scope that has taken place in the literature on valuation, c.f. the discussion following the Exxon Valdez studies.[7]

Due small sample sizes and the low response rates in the first pilot study, little, if anything, can at this stage reliably be said about the size of the WTP for an increase of wild salmon over time.

5 Measuring opportunity costs

Our cost-benefit rule postulates that there is an opportunity cost of releasing water to the salmon. The relationship between flow and salmon passage is, however, an empirical question. This relationship is important to know to be able to make a complete cost-benefit analysis based on our cost-benefit rule. We have started to investigate this relationship in Hakansson et al, 2004.

Let us again turn back to our cost-benefit rule, equation 9:

$$CBR = \int_0^\infty [\frac{\lambda_L^{c*}(t)}{\lambda_m^{c*}(t)} \frac{\partial g(.)}{\partial A(t)} - \frac{\partial f(.)}{\partial A(t)}] e^{-\delta t} dt \tag{11}$$

The second term within brackets yields the marginal cost at time t in terms of the value of the loss of production of the numeraire good as marginally more water is used to "transport" salmon. In order to estimate the opportunity costs of diverting water from electricity production, we first need to estimate the value of production at the plant.

We do not yet have official data on output per day at the plant, neither any plant-specific economic data. However, we know that the Umeå municipality owns 26% of the revenues from the plant. In 2001, this was reported to

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[7] A recent summary of the literature on "scope" is in Veisten (2003).

be 118 MSEK, suggesting that the total revenues from the plant was about 453 MSEK.[8]

The current regulation at Stornorrfors during the salmon's migration season is that 20 m^3/s must be diverted from electricity production during weekdays, and 50 m^3/s must be diverted from electricity production during weekends. Given the data over Stornorrfors revenues from year 2001 we assume that the daily production of electricity generates a value of approximately 1 MSEK per day. The current regulation of a larger diversion in the weekends translates to a loss of roughly 5% of daily production, given that the average flow is about 600 m^3/s during June to September (SMHI, 2003). Further, the larger diversion in the weekends translates to about 0.05 MSEK loss per day. Suppose there are 30 days of loss in production in this way (i.e. 15 weekends, or roughly the salmon season). Hence, the yearly loss is 1.5 MSEK.

Since we chose a 10 year period when estimating the benefits of an increase of salmon, a 10 year period is also chosen for the costs. With a discount rate of 5 percent and a 10 year horizon, the present value is 12.2 MSEK. A change in current regulation to a larger diversion of water from electricity production would make this number even bigger. Again, these numbers are based on rudimentary calculations, but suggest the scale of the values involved in regulations of the water flow through the power station.

6 Conclusions

CV-studies typically focus the benefit side of a project. It is often of interest to also include the costs. The question addressed in this paper is how the theory of CBA can be linked to the practice of a CV-study. It is shown how theoretical and empirical findings can be linked in a cost-benefit analysis when the CV-method is being used. The approach has wider applicability than suggested here and should be useful in similar contexts as well.

We currently do not have sufficiently detailed data about people's preferences for salmon, but such data will soon be available from our main survey. On the costs side, we already have detailed data on water flow and soon over the electricity production. Finally, we have an unique biological data set which make it possible to deal with the intricate dynamic issues natural resources raise. We will present the results of the complete analysis in future work.

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[8] The source for this information is the yearly report from the Umeå municipality in 2001. See Umeå Kommun, 2003. The figure refers to total sales of electricity.

7 Appendix

The relationship between the present value and current value costate variables is as follows:

$$\lambda_L(t) = \lambda_L^c(t) \cdot e^{-\delta t} \tag{12}$$

Using this relationship and integrating forward along the optimal path yields:

$$\lambda_L^{c*}(t) = \int_t^{\infty} [-\frac{\partial u(.)}{\partial s_L(\tau)} + \frac{\partial u(.)}{\partial c_L(\tau)} \frac{\partial g(.)}{\partial s_L(\tau)}] e^{-\delta(\tau - t)} d\tau \tag{13}$$

Thus the current value costate variable $\lambda_L^{c*}(t)$ is equal to the present value sum (integral) from time t and onwards of the marginal utility of the stock of salmon plus the marginal utility of consuming salmon times the marginal effect on growth of the stock of salmon.

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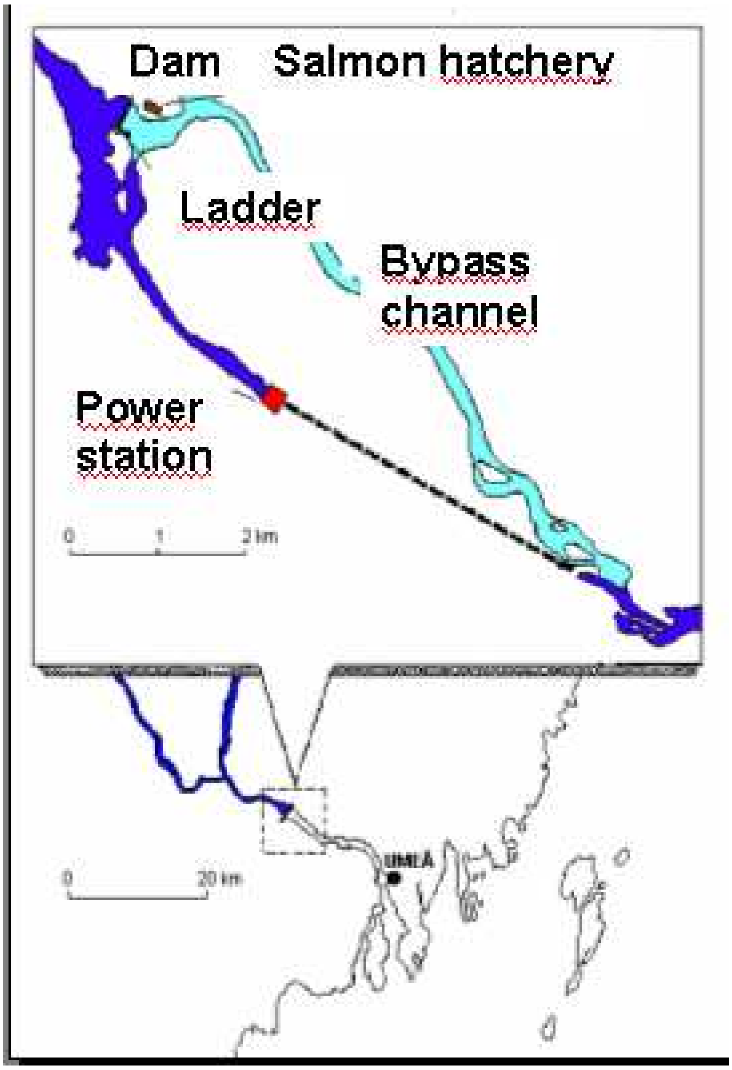

Figure 1: Study area

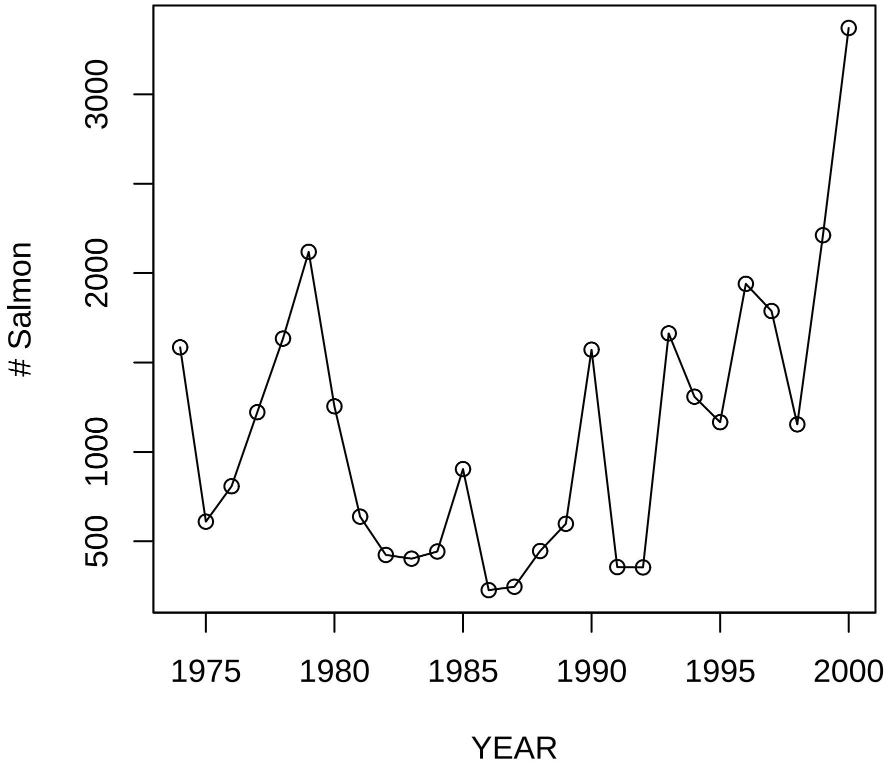

Figure 2: "Number of salmon in the Stornorrfors Ladder, yearly averages 1974-2000