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Samhällsekonomisk analys av alternativa åtgärder i flödespåverkade vattendrag: Emån och Ljusnan. Vetenskaplig slutrapport

Cost-Benefit Analysis of River Regulation: The case of Emån and Ljusnan. Scientific summary report

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1 Allmän information om slutrapportens uppläggning.

Rapporten sammanfattar arbetetet i Forskningsprojektet ”Samhällsekonomisk analys av alternativa åtgärder i flödespåverkade vattendrag: Emån och Ljusnan”, ett 3-årigt projekt med stöd från Elforsk, Energimyndigheten, Fiskerimyndigheten och Naturvårdsverket. Vi inleder med en fyllig sammanfattning på svenska. Rapportens huvuddel är dock på engelska. Avrapporteringen har två delar, dels denna vetenskapliga slutrapport, dels ett separat

2 Sammanfattning

Forskningsprojektet ”Samhällsekonomisk analys av alternativa åtgärder i flödespåverkade vattendrag: Emån och Ljusnan” fokuserar åtgärdsorienterad forskning i ett ekosystemperspektiv med beaktande av samhällsekonomiska aspekter. Arbetet utförs i ett nära samarbete med intressenter och finansiärer. Huvudsyftet är att utveckla generaliserbar teori och metodik för samhällsekonomisk lönsamhetsbedömning (cost-benefit analys, fortsättningsvis CBA) i reglerade vattendrag. Strategin består i huvudsak av att genomföra detaljerade naturvetenskapliga studier som grund för innovativa tillämpningar av CBA, där metoder för att behandla osäkerhet ingår som en viktig del. Projektet är en del av forskningsprogrammet Vattenkraft - miljöeffekter, åtgärder och kostnader i nu reglerade vatten}, ett samarbete mellan Fiskeriverket, Naturvårdsverket, Statens Energimyndighet och Elforsk.

I forskargruppen deltar ekonomer, naturvetare och statistiker från SLU-Umeå och Karlstad Universitet. Forskare från Handelshögskolan i Stockholm och Luleå Universitet medverkar också i projektet. Det leds av Professor Bengt Kriström, CERE (Center for Environmental and Resource Economics) och omsluter i storleksordningen 18 miljoner kr över 36 månader.

2.1 Projektets mål och syfte

I den ursprungliga ansökan angavs följande målsättningar:

- Utveckling av generellt utvecklingsbar teori och metodik av samhällsekonomisk lönsamhetsbedömning i reglerade vattendrag, med särskilt fokus på Emån och Ljusnan;
- genomförande av ett antal empiriska studier som ger den biologiska information som krävs för den samhällsekonomiska kalkylen; samt
- framtagande av metodik för att hantera osäkerhet såväl i de ekologiska som i de ekonomiska systemen.

Utöver dessa förslag till generellt användbara verktyg, pekade vi i ansökan på att detaljerad information kring Emån och Ljusnan tas fram som en värdefull biprodukt. Sålunda var närheten till beslutsfattare och andra intressenter en viktig utgångspunkt för vårt arbete; mer om hur detta samarbete lades upp och utvecklades nedan.

Huvudsyftet är att utveckla generaliserbar teori och metodik för samhällsekonomisk lönsamhetsbedömning i reglerade vattendrag. Existerande teori och metodik bör utvecklas för att ta hänsyn till det faktum att de ekonomiska och ekologiska systemen är såväl dynamiska som sammankopplade, ett faktum som är väldigt tydligt för de problemområden programmet behandlar. Parallellt pågår för övrigt det sk "PlusMinus" programmet, som stöds av SNV. Syftet med detta 3+2 åriga projekt (budget ca 20 Mkr) är att utveckla CBA generellt och explicit ta hänsyn till kopplingar mellan de dynamiska ekologiska/ekonomiska systemen i förslagen till utvecklad CBA metodik.

2.2 Projektets arkitektur

Vi har använt en potentiellt intressant arkitektur för tvärvetenskapligt samarbete. Ytligt sett består denna arkitektur av en vetenskaplig triplett, där de empiriska studierna behandlas i ordningsföljden Naturvetenskap → Statistik → Ekonomi. Vårt upplägg är dock i praktiken inte "linjärt"; i utförandet uppstår ett antal mer eller mindre komplicerade kopplingar mellan ämnesområden, där olika problem måste lösas gemensamt av forskare från olika discipliner, snarare än inom en viss vetenskapsgren. Exempelvis övergav vi analysen av ett föreslaget regleringsscenario för Dönje Krv (Bollnäs, Ljusnan), därför att det var för komplext (inom resursramen) för en adekvat samhällsekonomisk bedömning, trots att scenariot var mycket intressant ur ekologiska synpunkt. Till skillnad från liknande projekt på området står den samhällsekonomiska analysen i centrum. Utifrån ett samhällsekonomiskt ramverk som i princip hanterar såväl det ekonomiska som det ekologiska systemet, samt interaktioner däremellan, härleds s.k. Cost-benefit regler. Dessa ligger till grund för de empiriska studierna. I ramverket ligger även ett förslag till hur osäkerhet kan hanteras.

Stommen består av fyra "Workpackages" (WP) enligt följande;

- WP1. Ekonomi. Professor Bengt Kriström, CERE
- WP2. Statistik. Professor Bo Ranneby, Biostokastikum, SLU
- WP3. Emån. Professor Larry Greenberg, Karlstad Universitet
- WP4. Ljusnan. Docent Kjell Leonardsson, SLU-Umeå.

När vi utvecklat arkitekturen har vi tagit hänsyn till ett antal faktorer av särskild vikt för den vetenskapliga analysen. De naturvetenskapliga mätningarna är säsongsbundna. Ordningen Naturvetenskap → Statistik → Ekonomi kräver sålunda noggrann planering, inte minst därför att de ekonomiska värderingsstudierna är mycket tidskrävande. De kräver i sin tur information från statistikmodulen i projektet. I allt väsentligt har dock denna strategi fungerat väl.

Den ursprungliga programplanen framgår av följande tabell

2007	• Initiera konceptuellt arbete och modellformuleringar • Initiera biologiska undersökningar kring Ljusnan och Emån. • Leverera data till WP2.
2008	• Analysera data från fältförsök i WP2. Nyttja resultat som input till en första våg av värderingsstudier • Initiera den andra vågen av fältexperiment • Utföra statistiska analyser av data • Nyttja input från WP1 till den andra vågen av värderingsstudier
2009	• Utföra en tredje våg av fältstudier

	• Sammanställa och analysera genomförda studier • Påbörja den avslutande samhällsekonomiska lönsamhetsbedömningen
2010	• Avslutande rapport

Ansökan beviljades slutligen i juni 2007, varvid en fältsäsong försenades i Ljusnan och måste flyttas ett år framåt. Ett antal andra förändringar av den ursprungliga planen har gjorts. Exempelvis tillkom ett speciellt projekt kring värdet av reglerkraft (se Försund & Hjalmarssons (2010) rapport); ett nytt scenario tillkom och analyserades ("-2,+1") i Ljusnan samt att två internationella workshops (ett i Stockholm, ett i Arizona) med ledande ekonomer på området genomfördes.

En sammanfattning av projektet återfinns i följande tabell:

Bidrag	#	Mål	Kommentarer
Presentationer på konferenser, motsvarande	54	> 20	
Anordnande Workshops	5		1. Workshop on CBA in Regulated River Systems, October 24, 2007, Umeå. Organisatör:Kriström. 2. Workshop on nature-like design of fishways. September 8-9, Karlstad, 2008. Organisatör: Calles. 3. Workshop on CBA & Hydropower, August, 26, 2009, Stockholm. Organisatörer: Johansson, Kriström. 4. IISA Conference Jan 4-8, 2010, Visakhapatnam, (Andhra U., Waltair),Indien. Organisatör: Ranneby (session organizer) 5. Economic Evaluations of Water/Energy Interactions for Policy, 19-20 April, 2010, Phoenix, Arizona, USA. Organisatörer: Smith, Johansson, Kriström.
Forskningsrapp orter	22		
Uppsatser refeere tidskrift	7	> 10?	Flera uppsatser är under publicering
Böcker	2		Utgivare: 1. Johansson, P.-O. & B. Kriström (red) *Hydropower and Modern CBA*, Edward Elgar, Cheltenham, USA. 2. Johansson, P.-O. & B. Kriström (kommande) *Applied CBA and Hydropower conflicts*, Springer Verlag, New York (Under kontraktering)
Avh., Master-uppsatser	1		
Delprojekt	1		Specialprojekt kring reglerkraftsfrågor (se Försund Hjalmarsson (2010))
Avnämarmöten, press, media	Se separat rappor t		Avnämarmöten Emån, Ljusnan.

2.3 Huvudbidrag

Projektet har avkastat ett antal verktyg som vi anser vara värdefulla I den fortsatta diskussionen kring förvaltningen av våra rinnande vatten. Verktygen inkluderar två varianter av populationsmodeller som t.ex. kan användas för att analysera hur antal fiskvägar inklusive utrivning av dammar påverkar en fiskpopulation på lång sikt i en given älv. Den ena modellen är en enkel och lättanvänd jämviktsmodell med ett fåtal parametrar medan den andra modellen är konstruerad för detaljerade analyser av mer komplicerade scenarier. Vi har också utvecklat ett Excel-verktyg för analyser av sportfiskevärden. Förutom verktygen bidrar projektet med ett antal ansatser, eller mer allmänt angreppssätt, av särskilt intresse för konsekvensanalyser. Vi ger även ett antal förslag till nya (tekniska) lösningar på vissa problem inom våra vetenskapsområden. Det gäller t.ex. ett sätt att beskriva osäkerhet i samhällsekonomiska lönsamhetsbedömningar (en sk acceptability curve) samt estimatorer för intervalldata, när intervallen genereras på ett speciellt sätt. Vidare har vi initierat en mer detaljerad analys av reglerkraftproblematiken ur ett samhällsekonomiskt perspektiv. Projektet har även bidragit med att ta fram detaljerad naturvetenskaplig information om de vattendrag som varit huvudfokus för våra undersökningar. Därutöver har sammanställningar och analyser av naturvetenskapliga data från en stor mängd reglerade och oreglerade vattendrag möjliggjort prioriteringar vilka aspekter i de reglerade vattendragen som är mest angelägna för eventuella åtgärder och isåfall även i behov av samhällsekonomiska analyser.

2.3.1 Verktyg

En bärande tanke i arbetet har varit generaliserbarhet. Även om våra studier gäller två specifika vattendrag, är det viktigt att framhålla att de verktyg vi presenterar är generellt tillämpbara. Exakt vad som skall avses med ett verktyg i detta sammanhang är inte självklart, men vi har valt att skilja mellan ”verktyg” och ”angreppssätt”, där det senare betraktas som mer allmänt.

Följande verktyg beskrivs i mer detalj i de olika WP beskrivningarna nedan. I korthet är verktygen följande:

1. Ett verktyg för analys av sportfiskevärden (Anton Paulrud, WP1)
2. Två verktyg för analys av hur antalet vandringshinder påverkar möjligheten till återetablering av livskraftiga vandringsfisk populationer (Kjell Leonardsson, WP4)
3. Ett R-program för analys av själv-selekterade intervall data (Zhou Wenchao, WP1)

2.3.2 Ansatser

Vi har inom WP1 utvecklat en relativt omfattande modell för samhällsekonomisk lönsamhetsbedömning. Ramverket har anpassats till svenska förhållanden, men kan relativt enkelt anpassas till andra länder, liksom till framtida förändringar av gällande miljö- och energipolitiska förutsättningar, etc. Sålunda hanterar ramverket såväl utsläppsrättighetsmarknader och elcertifikat, som specifika ägarförhållande. Särskild vikt har lagts vid att kunna beskriva en förändring av ett givet tillstånd i ett existerande kraftverk. Exempelvis hanterar modellen såväl de (förändrade) miljövärden som förknippas med ett förändrat flöde lokalt som i andra delar av en älv. Vi har även skrivit ett antal uppsatser kring hur investeringar i vattenkraft skall värderas. Tillhopa betraktar vi detta som en ansats, i detta fall ett ramverk, med generell tillämpning. Ramverket har, tillsammans med de mätningar som gjorts i den naturvetenskapliga delen och analysen av osäkerhet, legat till grund för den empiriska analysen.

Scenariot som kallas ”-2,+1” är egentligen en del av en mer omfattande tankeram kring hur man kan närma sig miljö och energifrågor i reglerade vattendrag. Som beskrivs närmare nedan, innebär ”-2,+1” att de två nedersta kraftverken i Ljusnan rivs ut och att ytterligare turbiner installeras i det befintliga kraftverket Laforsen. På detta sätt garanteras att energiproduktionen inte påverkas, samtidigt som miljövärdena ökas avsevärt. Det gäller inte minst möjligheterna som skapas för att återigen få upp laxen i Ljusnan, vilket vi bedömt vara ogörligt utan den föreslagna utrivningen. Scenariot bidrar också till att minska isproblemen i MellanLjusnan. Ur ett mer allmänt perspektiv representerar ”-2,+1” en utbytbarhetstanke, eller, om man så vill, en helhetssyn på problemen. Denna helhetssyn överensstämmer med såväl Miljöbalkens intentioner som Vattendirektivets avrinningsområdesperspektiv. Synen harmonierar för övrigt med en mer allmän förändring av miljöregleringarna världen över, där flexibilitet och utbytbarhet blivit allt vanligare. Det yttersta exemplet på detta är det Europeiska systemet för handel med utsläppsrätter, som anger ramen för utsläppen, men överlåter och marknaden att allokera reningsinsatserna i rummet. Vi menar att det finns anledning att gå vidare och undersöka möjligheterna till en ökad flexibilitet i omprövningsärenden och exemplet ”-2,+1” är sålunda en del i en ansats för att angripa problemen i reglerade vattendrag.

Inom WP4 har vi sammanställt en stor mängd miljödata; flödesdata från oreglerade och reglerade vattendrag samt biologiska data (bottenfauna och fisk) för att kunna analysera hur stor den naturliga variationen är i oreglerade vattendrag jämfört med i reglerade. I de flesta undersökningar där man påvisat skillnader mellan reglerade och oreglerade vattendrag har ett fåtal vattendrag inkluderats i studierna. I sådana fall kan valet av vattendrag ha en avgörande betydelse för om skillnader påvisas eller inte samt huruvida eventuella skillnader egentligen befinner sig inom ramen för vad som är naturligt. Tanken med denna mera omfattande sammanställning och utvärdering har varit att få ett bra underlag för att avgöra vilken variation som ryms inom naturliga system för att kunna prioritera vid vilken nivå eller typ av reglering som åtgärdsförslag bör beaktas. Ansatsen har varit att analysera olika flödesaspekter med en stegvis ansats för att kunna identifiera om det finns några kritiska flödesparametrar som på ett otvetydigt skiljer reglerade vattenföringar från oreglerade och som samtidigt bedöms vara av stor betydelse för det akvatiska ekosystemet. Denna sammanställning utgör också ett bra underlag för att kunna definiera hur ett ”miljövänligt” flöde kan se ut för svenska förhållanden.

2.3.3 Tekniska lösningar

Under denna rubrik har vi valt att lägga arbeten inom projektet som ger förslag till lösningar av vissa mer eller mindre tekniska problem inom våra forskningsfält. Den s.k. ”cost acceptability curve” ger ett kompakt sätt att beskriva osäkerheten i en samhällsekonomisk kalkyl. Metoden tillämpas i fallstudien kring Dönje Kraftverk (Johansson & Kriström (2010)).

Vi har också utvecklat ett antal metoder för att hantera en viss typ av intervallosäkerhet, se vidare beskrivningen av WP2 nedan. Inom WP3 har förslag till konstruktioner för att underlätta nedströmsvandring tagits fram, se den mer detaljerade framställningen av denna del nedan. Inom WP4 har generella verktyg och underlag tagits fram för att kunna avgöra i vilka situationer tekniska lösningar, exv. byggande av fiskvägar, kan förväntas ge någon märkbart positiv effekt på miljön.

2.3.4 Avnämare

Vi har haft ett ofattande samarbete med olika intressenter, här kallade avnämare. Detta arbete beskrivs nedan.Se publikationslistan för fullständiga detaljer.

2.4 Sammanfattning av WP1-WP4

Som nämnts ovan sönderfaller projektet i fyra delar, vilka här kallas WP1-WP4. WP1 har tillhandahållit det teoretiska ramverket för olika tillämpningar av samhällsekonomisk lönsamhetsbedömning i Emån och Ljusnan; WP2 tillhandahåller nödvändig metodutveckling och stöd för den statistiska analysen; WP3 ansvarar för de naturvetenskapliga studierna i Emån och WP4 har haft ett motsvarande ansvar för Ljusnandelen.

2.4.1. WP1

Delprojektet har som nämnts ansvarat för den samhällsekonomiska metodutvecklingen och i samarbete med övriga forskare utvecklat de olika scenarier som analyserats. Till stöd för det empiriska arbetet har ett ramverk för samhällsekonomiska lönsamhetsbedömningar i reglerade vatten utarbetats. Detta har tillämpats på en fallstudie i Dönje, där vi beräknade om en värdet av en förändring av befintlig reglering till miljöns fromma och jämförde detta värde med den samhällsekonomiska kostnaden. Ramverket gav en s.k. cost-benefit regel som sedan användes för att strukturera de empiriska mätningarna, samt ge vägledning om hur intäkter och kostnader skall beräknas och summeras på ett korrekt sätt. Ramverket innehåller följande delar:

- Ett kontrakt mellan kraftverket och en annan part (I detta fall invånare i Bollnäs kommun) som utgångspunkt för den s.k. Cost-benefit regeln;
- Kontraktet är en hörnsten i vår tillämpning av scenariovärderingsmetoden (contingent valuation) ;
- skattesystemet i status quo;
- (delvis) utländskt ägande av kraftverket;
- Internationell handel med elektricitet;
- Handel med elcertifikat;
- Handel med utsläppsrätter (koldioxid);
- Externaliteter som genereras av ersättningskraft (som generats i andra länder)
- Värdet av förlust av reglerkraft och andra systemtjänster
- Överföring av el modellerad som ett naturligt monopol;
- Nedströms hydrologiska effekter samt miljövinster av skilda slag (tex estetiska)

Ramverket kan sålunda tillämpas på liknande problem i andra länder, med lämpliga modifieringar. Dönje-studien och ramverket beskrivs i en relativt omfattande rapport, Johansson & Kriström (2010) *A Blueprint for a Cost-Benefit Analysis of a Water Use Conflict*. *Hydroelectricity Versus Other Uses.* Denna rapport är fortfarande under revidering och vi planerar att ge ut den i bokform hos en internationell förläggare. Rapporten ligger till grund för flera andra uppsatser, exempelvis finns en förkortad version i boken *Modern Cost-*

Benefit Analysis of Hydropower Conflicts, som redigeras av Johansson och Kriström. Boken kommer ut på Edward Elgar 2011.

I Johansson, Kriström & Nyström (2009) "*On the Evaluation of Infrastructure Investments: the Case of Electricity Generation*" utvecklas en enkel allmän jämviktsmodell som används för att generera samhällsekonomiska utvärderingsregler för kraftverksinvesteringar. En typ av kraftverk ger inga utsläpp av klimatgaser. En andra typ av kraftverk genererar sådana utsläpp och måste därför köpa utsläppsrätter. Det visas att priset på en utsläppsrätt i allmänhet inte reflekterar klimatskadan utan värdet av den produktion som trängs undan när kraftverket införskaffar utsläppsrätten. En annan användare måste då reducera sin produktion så att en utsläppsrätt frigörs. Det visas också att möjligheten att välja investeringstidpunkt har ett options- eller flexibilitetsvärde också i frånvaro av osäkerhet om framtida priser och kostnader. Dessutom diskuteras hur man med hjälp av så kallade swithingmodeller kan skatta värdet av att ett kraftverk snabbt kan köras igång eller stängas av. Denna flexibilitetsegenskap har inte minst vattenkraftverk.

Johansson & Kriström (2010) *A note on how to undertake a cost-benefit analysis in monetary and environmental units*, diskuterar s.k. resursekvivalensmetoder, vilka allt oftare används i USA och inom EU för att fastställa krav på återställande åtgärder efter en miljöskada. Metoden bygger på att skadan skall ersättas i fysiska och inte, som i CBA, i monetära termer. Vi diskuterar under vilka antagande detta byte av metrik ger välfärdsrelevant information. Ett problem är delbarhet – i grova drag ersätts förlusten av en kollektiv med en annan kollektiv vara. Eftersom en kollektiv vara konsumeras av samma mängd av alla individer (ex. koncentration av växthusgaser i atmosfären) bygger resursekvivalensmetoderna väsentligen på att alla konsumenter har samma preferenser, vilket inte CBA gör. Slutsatsen är sålunda att metoden bygger på väsentligen starkare antaganden än vad CBA gör.

Johansson, P.-O. & B. Kriström (kommande) *Förslag till miljöförbättrande vattenkraftinvesteringar i Ljusnan: En enkätstudie*, redovisar resultaten av en webenkät rörande ett förslag till en omreglering av Ljusnan. Enkäten riktade sig till närmare 800 boende i kommunerna kring älven (Söderhamn, Bollnäs, Lusdal och Härjedalen). Den genomfördes i april-maj 2010. Respondenterna fick ta ställning till ett förslag som vi för enkelhetsskull kallar ('-2,+1'), därför att det innebär utrivning av de två nedersta kraftverken i Ljusnan (Ljusneströmmar och Ljusnefors) samt att nya turbiner installeras i det befintliga kraftverket Laforsen. En viktig punkt i förslaget är att energiproduktionen förblir oförändrad sett över hela Ljusnan. Förslaget ger också miljöförbättringar: Avledning av överskottsvatten via en tunnel från Laforsen till Forsänget (ca 20 km nedströms) förbättrar yngeluppväxtförhållandena i Mellanljusnan i och med att naturliga vinterflöden återskapas. Vinteröverlevnaden för lax- och havsöringsrom respektive yngel förväntas bli högre i och med att en lägre och stabilare vintervattenföring ger bättre förutsättningar för isbildning på vattenytan och ett skyddande lager av snö jämfört med idag. I nuläget uppstår ofta problem med issörja och bottenis i vissa partier av Mellanljusnan på grund av att vattnet blir underkylt under mycket kalla vinterdagar som en följd av nuvarande flödesreglering. Flödesregimen i (en huvuddel av) Mellanljusnan blir därför mer lik den som rådde före vattenkraftsutbyggnaden, med undantag av att vårfloden inte kommer att bli lika kraftig som tidigare eftersom även en del av vårfloden omdirigeras till tunneln. Sommarvattenföringen kvarstår som idag. Vi ger mer detaljer kring studien nedan.

Belyaev, Y & B. Kriström (2010) "*Approach to Analysis of Self-selected Interval Data*", Working Paper #3, www.cere.se. Utvecklar den statistiska teorin för intervalldata, där censoringen är endogen; existerande teori gäller främst exogen (eller slumpmässig) censorering. Den har presenterats på IISA konferensen i Matematisk statistik, Venkatachalam, Januari 2010. Den är också accepterad till *Annual Meeting of the Institute of Mathematical Statistics*, Göteborg, 2010.

I arbetet med de fritidsfiskerelaterade värdena inom projektet har stor vikt lagts till att vidareutveckla de modeller som tidigare tagits fram inom projektet (Paulrud & Laitila, 2010; Paulrud, 2010). Häri ingår framtagande av nytto- och besöksmodeller för såväl Ljusnan som Emån (samt Mörrum som referens). Ett arbete har även påbörjats med framtagandet av mer generella besöksfunktioner. Dessa har sedan använts i den ovan nämnda webbenkäten. Svaren analyseras tillsammans med de nyttofunktioner som tidigare tagits fram i projektet.

Det har även funnits ett behov av att titta djupare på de fritidsfiskerelaterade företagen (Paulrud and Waldo, 2010; Waldo & Paulrud, 2010a) för att få en bild av både efterfråge- och utbudssidan. De fritidsfiskerelaterade företagen ingår sålunda även som en komponent i de framtagna modellerna. Fritidsfiskarnas nytta av att fiska på en specifik plats påverkar deras besöksbenägenhet och därigenom efterfrågan på de fritidsfiskerelaterade företagens olika produkter. Om vattenkraften påverkar fritidsfiskarna påverkar den således även indirekt fritidsfiskeföretagen. I arbetet ingår även att se på hur olika fiskevårdande projekt skulle kunna påverka företagen. Åtgärder för att minska effekterna av vattenkraften är högt prioriterade enligt en enkätstudie av fritidsfiskeföretag presenterad i Laitila, Paulrud & Waldo (2010).

Kunskapen om fiskerättsägarna i Sverige är i det närmaste obefintlig. Det förs exempelvis inga register över fiskerättsägarna. Att sälja fiskekort och få avkastning av sin fiskerätt är en tänkbar målsättning för ägarna. Andra fiskerättsägare kan tänkas vilja nyttja sin resurs för vattenkraft eller att helt enkelt låta den vara orörd. Att analysera fiskerättsägarnas beteende i samband med vattenkraft är viktigt, då de delvis äger den resurs som kan påverkas av vattenkraftsproduktion. Projektet har aktivt deltagit i en större studie kring fiskerättsägarna i Sverige, vilken innefattade bl. a. en enkät som skickades ut till cirka 6 000 fastighetsägare. Studien avser att kartlägga fiskerättsägarna och deras verksamheter samt synen på förvaltningsansvar, vattenkraft och fiskevård. Studien kommer bl.a. belysa fiskerättsägarnas målsättningar och delaktighet i beslutsprocesser i förvaltning samt faktiska och framtida krav på avkastning. En första rapport kommer att färdigställas under senare delen av 2010.

2.4.2. WP2

Detta delprojekt har ansvar för de statistiska analyserna samt utveckling av metoder för att värdera och kvantifiera olika typer av osäkerhet.

Intervallsvar som ytterligare en källa till osäkerhet vid betalningsviljestudier.

Ett problem vid studier av betalningsviljan är att alltför ofta är svarsfrekvensen låg. Om de tillfrågade vid enkätundersökningen har möjlighet att istället för ett exakt värde ange ett intervall så har det visat sig att svarsfrekvensen ökar. Intervallsvaren medför dock vissa problem vid analysen och beräkningen av den genomsnittliga betalningsviljan. Ett angreppssätt för att hantera intervallsvaren är följande. På grund av olika anledningar känner respondenten sig osäker på vad han/hon skall svara och avger därför svaret i form av en stokastisk variabel med en viss fördelning. Respondenten kan naturligtvis inte ange en fördelning utan approximerar den genom att ange undre och övre gräns för sitt tänkbara svar. Den exakta formen på fördelningen får vi inte reda på men det finns några naturliga alternativ, vilka vi använder oss av. På detta sätt blir det enkelt att beräkna genomsnittlig betalningsvilja samtidigt som osäkerheten i den kan delas upp i två komponenter där den ena beror på urvalet och den andra på att vi tillåter intervall som svar. Metoden har illustrerats med den undersökning angående Klumpströmmen som gjordes för invånarna i Bollnäs kommun. Resultaten jämfördes även med en icke-parametrisk och en parametrisk skattningsmetod för intervall censurering. Det visar sig att dessa metoder inte fungerar så bra. De traditionella metoderna underskattar betalningsviljan. Detta beror förmodligen på att det sanna värdet för de som anger ett intervall har en tendens att ligga närmare den övre intervallpunkten. Metodik och resultat finns som ett kapitel i Johansson och Kriströms bok från den workshop som hölls i Stockholm i augusti 2009 samt som en rapport från Centre of Biostochastics.

Modell för elpriser har utvecklats i Kuljus & Ranneby (2010):Modelling Swedish electricity prices for 2000-2009.

Framtida elpriser är inte lätta att förutsäga. De beror naturligtvis på en mängd faktorer, men tillrinning och fyllnadsgrad i vattenmagasinen i både Sverige och Norge har stor inverkan på elpriset. Då det föreligger en betydande säsongvariation, men säsongerna inte återkommer på samma sätt varje år kan säsongvariationen inte modelleras med ett analytiskt uttryck. Vi har statistik för veckovis tillrinning och magasinsfyllnad för perioden 1995-2009. Genom att för varje vecka beräkna ett så kallat ”trimmat medelvärde” och sedan jämföra observerat veckovärde mot motsvarande medelvärde kringgår man problemet med säsongvariation. Fördelen med trimmat medelvärde är att inverkan av outliers elimineras samtidigt som i princip hela materialet kan användas. Konsumtion ingår också i modellen och behandlas på samma sätt som tillrinning. Självfallet finns även priset på utsläppsrätter med i modellen. För att ytterligare förbättra modellen har vi även med nettoexport. Genom att göra olika antaganden om de ingående variablerna kan veckovisa elpriser prognostiseras under olika scenarier. Låt oss exemplifiera med tillrinning. Då det är omöjligt att förutse vädret framöver används informationen om tillrinning mm för att ”korrigera” elpriset till normalväder. De prognoser som görs för de framtida elpriserna avser år med normala väderförhållanden. Detta angreppssätt, när elpriser jämförs med veckovis tillrinning, har fördelen att det också är möjligt att förutsäga elpriser för våtår och torrår om man så önskar. Klimatmodeller kan användas för att förutsäga framtida väder och elprisprognoser göras under olika scenarier. För att korrigera för den naturliga prisutvecklingen använder vi oss av nettoprisindex. När väl regressionsmodellen är klar har tidsserieanalys gjorts på residualerna. För perioden 2006-2009 (dvs. efter att handeln med utsläppsrätter) startat beskrivs residualerna utmärkt med hjälp av en autoregressiv process av ordning 1.

Felfortplantning

Den av Leonardsson utvecklade ”Populationsmodell för vandringsfisk” innehåller osäkerheter i flertalet av beräkningsstegen. Dessa osäkerheter samverkar och påverkar tillsammans tillförlitligheten i den slutliga skattningen. De årliga sannolikheterna för överlevnad varierar inom vissa intervall liksom passagesannolikheterna. För att få ett mått på den slutgiltiga osäkerheten kan man för varje sannolikhet använda sig av min- och maxvärden och utifrån detta uppskatta minimal respektive maximal förväntad populationsstorlek. Det erhållna intervallet kan då uppfattas som ett mått på osäkerheten. Detta mått är tyvärr inte så informativt. Genom att i varje steg låta sannolikheterna genereras från en stokastisk fördelning och sedan använda sig av dessa får man en mer realistisk sekvens av sannolikheter jämfört med när man använder sig av extremvärdena. Genom att upprepa denna procedur ett stort antal gånger och jämföra populationsstorlek vid varje upprepning får man ett mått på tillförlitligheten i uppskattningen av populationsstorleken. I analysen måste även osäkerheten i reproduktionsparametrar som antal honor, ägg och områdets storlek beaktas.

Konferens i Indien

Centre of Biostochastics (Bo Ranneby) fick erbjudande att arrangera en egen session vid en stor internationell konferens i matematisk statistik. Konferensen arrangerades av International Indian Statistical Association och ägde rum i Vishakhapatnam, Indien. Vi valde att fokusera på WTP och Bengt Kriström samt Magnus Ekström presenterade resultat och metodik relaterat till forskningsprojektet. Ekström presenterade resultat från sin artikel *"Nonparametric estimation for classic and interval open-ended data in contingent valuation"* Här beskrivs ytterligare en metod för att hantera intervallsvar. För att metoden skall fungera krävs att vissa anger både exakt värde och intervall.

2.4.3 WP3

Ett av målen för WP 3 var att utveckla en populationsmodell för öring i Emån, för att kunna kvantifiera de ekologiska effekterna av rehabiliteringsåtgärder. Mycket information stod att hitta i våra tidigare studier i Emån och i litteraturen, men kunskapsluckor som behövde fyllas genom nya studier var kvantifiering av smoltproduktionen i Emån, studera utlekta öringars (besor) beteende och passageframgång, samt utvärdera effektiviteten av avledning för att minska dödligheten hos öring vid nedströmspassage av vattenkraftverk. Ytterligare ett syfte för WP 3 var att undersöka effekterna av fragmentering på arter som inte hör till -laxfiskarna, med färna och ål som modellarter, med fokus på färna. Baserat på två års provtagning med hjälp av en s.k. screw-trap placerad i Emåns mynning, uppskattade vi att Emån producerade 1729 öringsmolt och 2688 laxsmolt per år. Åldersfördelningen för laxsmolt var 45% ettåringar (medellängd 118 mm) och 55% tvååringar (138 mm), medan 51% av öringsmolten var ett år (125 mm), 43% två år (159 mm) och 6% 3 år (191 mm). Dessutom fångade vi flera tusen laxfiskayngel (öring och / eller lax) i fällan som verkade vandra ut till Östersjön. Baserat på mätningar av förhållandet mellan strontium och kalcium i otoliter från vuxen öring, fann vi stöd för denna observation, eftersom 13% av de 23 fiskarna (dvs 3 fiskar) som studerades hade mer eller mindre simmat direkt ut till Östersjön efter de kläckts.

När det gäller nedströmsvandring av besor, så nådde 12 av 25 öringar (48%), som initierade migration från uppströms övre Finsjö, Östersjön. Mediantiden från migrationens början tills de nådde havet var 28 dagar (intervall: 4,0 till 44 dagar). En median total försening av 16,8 dagar (intervall: 1,95 till 39,6 dagar) vid de tre kraftverken observerades för de fiskar som övervintrade uppströms övre Finsjö, med största dröjsmål vid lägre Finsjö. Manuell pejlning visade att denna fördröjning verkar bero på att många besor hade svårt att hitta vägen forbi kraftverksdammar, eftersom vi observerade att besorna kunde simma upprepade gånger fram och tillbaka mellan kraftverksdammar. Under 2009, när studien genomfördes var många spill portar stängda. Vid Karlshammar betalade Gustaf Ulfsparre stiftelsen för att öka öppningen vid en av spill portar, och de flesta besorna som fanns i närheten av detta spill port lyckades simma förbi dammen. I motsats till detta, en öppningen av en spill porten vid lägre Finsjö, resulterade inte i en ökad passage framgång hos besorna

Nedströms vägledning testades med beteende- och mekaniska metoder för avledning. Beteendeavledning testades genom att placera en presenning ovanför turbinintaget vid övre Finsjö, för att försöka förstärka avledningsfunktionen hos en befintlig ytläns och isutskov (spillucka). Användningen av en presenning som ”overhead cover” resulterade i att 31% av smolten passerade isutskovet istället för genom turbinerna. I avsaknad av overhead cover simmade alla smolt genom turbinerna. Mekanisk avledning testades genom att installera ett galler med 18 mm spaltvidd och en låg vertikal lutning (35°) och ett bypasssystem vid ytan. Sammanlagt fångades 1043 fiskar av 17 arter i bypassfällan under våren 2009 och 2010. Passageframgång studerades i detalj för öringsmolt genom att följa radio-märkt fisk under 2009. Passageframgången för smolt var 84% (26 av 31 individer). För populationsmodellen modellerades fyra scenarier: 1. Dagens situation med fiskvägar vid Finsjö (uppströmspassage förbi 3 kraftverksdammar så att fiskarna kan nå Högsby), 2. Samma som scenario 1 fast med förbättrade möjligheter för nedströmspassage, 3. Fiskvägar förbi ytterligare 2 kraftverksdammar (d. v.s. 5 kraftverksdammar), samt 4. Samma som scenario 3 fast med förbättrade möjligheter för nedströmspassage. Utifrån dessa 4 scenarier fann vi att antalet lekmogen fisk varierade från 991för scenario 1 till 1715 lekmogen fisk för scenario 4.

När det gäller icke laxartade fiskar, fann vi att de två dammarna i Finsjö utgör ett vandringshinder för färna. Ingen av de 46 radiomärkta färnor som satts ut uppströms och nedströms övre och nedre Finsjö passerade båda dammarna under den 21 månader långa studieperioden från april 2008 - december 2009. Av de 30 kontrollfiskar, som släpptes ut uppströms och nedströms en naturligt forsande sträcka, passerade 43% detta område minst en gång under samma studieperiod (genomsnitt 1,4 passager). När det gäller ål visade vår beteendestudie på lab att ålar, till skillnad från de flesta andra arter, inte tvekar när de närmar sig ett hinder, utan de reagerar först efter att ha nått barriären. Dessutom tycks ål lockas till turbulens. Båda dessa beteendemässiga reaktioner från ål bör beaktas vid utformningen av framtida bypass-system för ål.

2.4.4 WP4

Detta delprojekt har haft ansvar för att ta fram metoder och verktyg för kvantifiering ev ekologiska effekter av de miljöåtgärder i reglerade vattendrag och då speciellt de åtgärder som hanterats i de olika fallstudierna.

Kvantifiering av förväntad mängd fisk vid olika flödesscenarier, med exempel från Klumströmmen vid Dönje

För att kunna genomföra en cost-benefit analys av olika scenarier med miljöåtgärder behövs någon typ av kvantifiering av de förväntade miljöeffekterna. I denna studie, Rivinoja *et al.* (2010) *Predicting populations sizes of European grayling and Brown trout at various flow scenarios in a regulated section of River Ljusnan, Sweden* som är under revidering, har vi utvecklat och tillämpat en metod som kan användas för att göra prognoser av mängden harr och öring innan förbättrade flödesregimer införs i en reglerad älvsträcka. Metoden bygger på att ytor med lämpliga fiskhabitat skattas vid olika flöden. Dessa ytor multipliceras med tätheter av fisk från snorkling och elfiske i oreglerade vattendrag för att erhålla den förväntade totalmängden fisk vid olika flöden i den reglerade älvsträckan. För ett av scenarierna beräknades mängden förväntade harrar att öka med ca 3-6 ggr jämfört med dagens nivå, där den övre gränsen är mer sannolik eftersom Klumpströmmen är en utloppsström. Se fallstudien för ytterligare beskrivning av denna studie.

Detaljerad populationsdynamisk modell för bedömning av komplexa scenarier för vandringsfisk i älvar med konnektivitetsproblem

Kostnaderna att bygga och använda fiskvägar är relativt höga vilket innebär att man vill ha någon slags garanti att etablering av nya fiskvägar möjliggör livskraftiga vandringsfiskpopulationer. Eftersom det inte funnits något verktyg att tillgå för den typen av utvärdering har vi utvecklat ett sådant inom projektet. Verktyget utgörs av en detaljerad populationsdynamisk modell som tar hänsyn till alla steg i den komplexa livshistorien för laxartade fiskar. Modellen kan användas till att utvärdera allt från enkla till komplexa scenarier med önskat antal fiskvägar för enskilda arter. Modellen har parameteriserat för lax (Ljusnan) och havsöring (Emån) för att ta kvantifiera den förväntade mängden lekfisk av dessa arter i de fallstudier som ingått i forskningsprogrammet. Vid generell utvärdering av vandringsproblematiken för lax framstår 6 vandringshinder som en övre gräns för att vara säker på att kunna erhålla en livskraftig laxpopulation. Modellen är skriven i Mathematica (WWW.Wolfram.com) kod och kräver denna programvara för att kunna användas. Programmet är skrivet så att parametrarna enkelt kan anpassas för andra vattendrag. Utförligare beskrivning av denna modell och nedanstående modell finns i den preliminära rapporten, Leonardsson 2010 *Environmental restoration in hydropower regulated rivers – where, when, and how can ecological improvements be expected?*som också ger utförligare beskrivning av de arbeten som utförts inom ramen för WP4 än vad som ges i denna slutrapport.

Förenklad populationsmodell, jämviktsmodell, för utvärdering av hur antalet fiskvägar förväntas påverka mängden vandringsfisk

Eftersom den detaljerade populationsmodellen är rätt krävande att parameterisera och modifiera för komplexa scenarier har vi insett att det finns behov av en betydligt enklare modell som ger samma genomsnittliga resultat. Vi har förenklat ovanstående modell till en enda ekvation med 5-7 parametrar beroende på vilken frågeställning man vill utvärdera. Den enkla modellen ger endast de förväntade jämviktstätheterna för vandringsfiskpopulationerna, dvs den ger inte någon information om populationsdynamiken. Vid jämförelse mellan den dynamiska modellen och jämviktsmodellen för Ljusnan-scenarierna erhölls samma resultat för det översta området. Områdena nedströms har en mer komplex dynamik till följd av att fisk som misslyckas att ta sig till hemområdet kan fortfarande leka i nedströmsliggande område om det finns lek och uppväxtplatser där. För sådana områden underskattar jämviktsmodellen den förväntade populationsnivån något. Jämviktsmodellen har också andra användningsområden. Till exempel kan ”The Salmon Action Plan” utvärderas, vilket ges som exempel i rapporten av Leonardsson (2010).

Bedömning av möjligheten till vandringsframgång vid nyetablering av fiskvägar

I Rivinoja *et al*. (2010). *Assessment of potential passage probabilities and reproduction areas for Atlantic salmon (Salmo salar L.) in the fragmented regulated River Ljusnan - A baseline of hypothetical scenarios for eco-eco analyses*, som är under revidering, presenteras underlaget till de delar av parameteriseringen av den detaljerade populationsmodellen för Ljusnanförhållanden. Metodbeskrivningen i den rapporten kan lämpligen utgöra en mall för hur motsvarande parameterisering kan göras för andra vattendrag. Generellt har expertbedömningen av den förväntade vandringsframgången bedömts som hög, se fallstudieavsnittet. Vi har nyligen påbörjat en jämförelse av hur dessa resultat förhåller sig till faktiska utvärderingar av befintliga fiskvägar världen över i relation till när anläggningarna byggdes.

Identifiering av skillnader mellan reglerade och oreglerade flöden som är av avgörande betydelse för miljökvaliteten

I Leonardsson (2010) redovisas de hittills genomförda utvärderingarna av jämförelser mellan oreglerade och reglerade vattenföringar. Dessa jämförelser visar bland annat att den omvända vattenföringen, som ibland används för att beskriva avvikelser mellan reglerad och oreglerad vattenföring, inte är speciellt användbar när det gäller att karakterisera avvikelser mellan reglerade och oreglerade vattenföringar i Sverige. Däremot är den naturliga vattenföringen norr om *Limes Norrlandicus* i stort omvänd jämfört med naturliga och reglerade flöden söder om denna gräns. Trots denna skillnad i naturliga flödesregimer mellan dessa regioner förekommer de typiska strömvattenarterna i båda regionerna. Tolkningen av det är att den omvända vattenföringen i sig inte torde utgöra något stort problem för faunan. IHA (Indicators of Hydrological Alteration) analyserna som gjordes för att undersöka eventuella skillnader i flödesregimer från 312 oreglerade och 512 reglerade vattendrag fördelade över hela Sverige gav inga signifikanta skillnader vare sig för den södra regionen eller den norra, vid användande av median differens-test för någon av de 74 parametrar som testades. Även om överlappet mellan reglerade och oreglerade var stort nog att undgå signifikans så framstod ett antal reglerade flödesregimer som kraftigt avvikande. En rekommendation baserat på det resultatet är att man bör prioritera de kraftigt avvikande områdena vid analys av eventuella åtgärder. I en undersökning av harrens tillväxt i vattendrag med alltifrån oreglerad flödesregim till korttidsreglering med 1 m regleringsamplitud per dygn visade det sig att harren växte snabbast där regleringen var som kraftigast.

I ett samarbete med LTU, se Minde *et al.*, 2010; *Applied Mechanics F-7015T: PIV measurements of bottom flow over half-cylinders motivated by river bed species*, har vi påbörjat en utvärdering av effekten av strömningsförhållandena nära botten (shear stress) på bottenlevande organismer. Denna aspekt har relevans för att förstå mekanismerna bakom utslagning av bottenfaunan i korttidsreglerade vattendrag med stora flödesvariationer, och därmed kunna ta ställning till vilka åtgärder som skulle kunna lindra de negativa effekterna på faunan.

Konferens i England
Vid en konferens om fisk och vattenflöden ur ett EU WFD perspektiv i England i januari 2010 presenterade Leonardsson bl. a. metoden för kvantifiering av förväntad mängd fisk (laxfiskar) i en sidofåra som en funktion av mängden vatten, och den detaljerade populationsmodellen för bedömning av komplexa scenarier för vandringsfisk i älvar med konnektivitetsproblem. Populationsmodellen rönte intresse och den tycks komma till användning där.

2.5 Fallstudier

Som nämnts ovan, fokuserar våra fallstudier Emån och Ljusnan, två vattendrag med väsentligt olka karakteristika,vad gäller miljöpåverkan, kraftnytta,etc. Nedan ges ytterligare information om de empiriska studier som gjorts kring Emån och Ljusnan

2.5.1 Dönje kraftverk i Ljusnan

Utöver vad som nämnts ovan angående Dönjestudien, kan det vara intressant att lägga till några detaljer kring undersökningen. De naturvetenskapliga analyserna genomfördes sommaren 2008 och beskrivs nedan i mer detalj. Som grund för den socioekonomiska studien inleddes arbetet med en serie fokusgrupper i Bollnäs, där 6 grupper a 6-7 personer diskuterade ett initiellt förslag till enkät. Denna studie samt ett större antal konsultationer med olika sakägare gav ett underlag för den webenkät som senare genomfördes i Bollnäs kommun under hösten 2009. Webenkäten innehåller den betalningsviljefråga som vi använder som underlag för att beräkna en del av nyttovinsten av att ändra vattenföringen i Dönje. Den baseras på att individen får välja ett fritt intervall om han eller hon så önskar. Den statistiska metodiken för denna frågemodell har utvecklats i programmet av Ekström (2010), Belyaev & Kriström (2010) samt Ju & Ranneby (2010).

I detta specifika fall studerades sex olika flödesnivåer mellan det minsta nuvarande lagstadgade vinterflödet på 0,25 m^3s^{-1} till det historiskt representativa sommarflödet av 41 m^3s^{-1} i den reglerade, men i avseende på bottenstruktur, unikt orörda älvsträckan Klumpströmmen i Ljusnan. Vid det rådande minimivinterflödet saknas lämpliga habitat för harr och öring. Med ett vinterflöde på 3 m^3s^{-1} skulle ca 3 ha vara lämpliga för lek- och yngel och ca 0,5 ha för vuxna fiskar. Den lagstadgade minimivattenföringen under sommaren är för närvarande 10 m^3s^{-1}. Vid detta flöde uppgår ytan av lämpliga fiskhabitat till 3 ha för yngel och 4 ha för vuxen fisk. Vid högre flöden ökade dessa ytor proportionellt sett mindre än flödet (21 m^3s^{-1}; yngel 4 ha, vuxna 5-6 ha and vid 41 m^3s^{-1}; yngel 6 ha, vuxna 8-9 ha). Jämfört med referensdata uppvisade snorkling i Klumpströmmen en låg täthet av harr, ett medel på 0,39 harrar per 100 m^2 skattades, medan ingen öring observerades. Genom elfiske skattades ett medel av 0,14 öringar per 100 m^2, vilket i förhållande till referensvärden indikerade en mycket låg täthet. Den samlade informationen tyder på att både harr- och öringpopulationen i älvsträckan hämmas avsevärt av nuvarande flödesreglering av Klumpströmmen. Med tidigarelagd sommartappning och vintertappning, ca 1.5 månader, i kombination med en ökad vintertappning från 0,25 till 3 m^3s^{-1} beräknades antalet harr och öring i sträckan kunna bli 3-6 gånger fler jämfört med den uppmätta mängden.

Vi tillämpade ovan beskrivna ramverk och sökte skatta de olika storheterna. En viktig del av analysen gäller prognosen på elpriserna, där vi använt olika angreppssätt och sökt belysa hur osäkerheten kring den framtida prisutveckling kan påverka resultatet. Två olika scenarier analyserades; i ”sommar och vinter” scenariet ökade vi vattenflödet under såväl sommar som vintersäsong, från 10 till 20 m^3/s respektive från 0.25 till 3 m^3/s i Klumpströmmen. Vinterscenariet innefattade endast ökningen från 0.25 till 3 m^3/s. Resultaten av betalningsviljeundersökningen gav att betalningsviljan inte skiljde sig åt mellan scenarierna. Resultatet är inte förvånande om man tänker på att de visuella effekterna av ”sommarscenariet” är mycket små, samt att den väsentliga miljöförbättringen erhålls när man undviker bottenfrysning. I så måtto är utfallet som förväntat.

Kalkylen gav följande resultat (se Johansson & Kriström (2010 a,b,c) för detaljer). I den engelska delen av denna rapport återfinns debilder som användes för att visualisera scenariot.

Tabell 2.5.1. Sammanfattning av Dönjestudiens samhällsekonomiska resultat. Miljoner kronor.

Post i kalkylen	Punktestimat sommarscenario	Punktestimat sommar och vinterscenario
Vinstförändring Kraftverksägaren	-66	-254
Betalningsvilja för lokal miljöförbättring	18	18
Betalningsvilja för föbättringar nedströms	0	0
Exteralitetskostnad av ersättningsel	-2	-7
Summa	-50	-243

Utfallet är beroende av vald diskonteringsränta, prisprognos och andra osäkerheter. Vår bedömning är dock att åtgärderna inte är samhällsekonomiskt lönsamma. Det kan, icke destomindre, existera ett frivilligt kontrakt mellan Fortum och Bollnäs Kommun, som både kan acceptera. Exempelvis skiljer sig ofta den diskonteringsränta som används i samhällsekonomisk kalkyl från den som nyttjas av privata företag. De senare använder alltsom oftast en högre diskonteringsfaktor. För övrigt presenterades scenariot med hänvisning till att det finns flera exempel på hur olika aktörer ”köpt vatten” av energiföretag. Tanken att Bollnäs Kommun skulle köpa den föreslagna förändringen av Fortum har således precedenter.

2.5.2. -2,+1. Förslag till omreglering av Ljusnan

Vi betraktar i Johansson & Kriström (2010) vattenreglering i perspektivet *samlad omprövning*, där vi tänker oss lösningar som satisfierar såväl ekologiska som ekonomiska önskemål. Tanken är i korthet att tillåta mer omfattande omregleringar av en älv, där man i ett och samma förslag t.ex. kan öka produktionen i en viss punkt och minska den i en annan. Vårt förslag innebär en relativt omfattande omreglering av Ljusnan, ett förslag som vi lät de boende i Ljusnandalen ge sina synpunkter på i en web-enkät. Enkäten riktade sig, mer precist, till boende i kommunerna kring älven (Söderhamn, Bollnäs, Ljusdal och Härjedalen). Undersökningen genomfördes under April-Maj 2010. Utöver detta har vi genomfört telefonintervjuer med ca 50 övriga deltagare i panelen. Respondenterna fick ta ställning till ett förslag som vi kallar ”-2,+1", därför att det innebär utrivning av de två nedersta kraftverken i Ljusnan (Ljusneströmmar och Ljusnefors) samt att nya turbiner installeras i det befintliga kraftverket Laforsen, ett naturligt vandringshinder ca 15 mil uppströms från havet.

Fröslaget har föregåtts av naturvetenskapliga studier, där vi utrett möjligheterna att få laxen upp till Laforsen. Utredningarna visar att en förutsättning för detta är att de två nedersta kraftverksdammarna tas bort, samt att fiskvägar ordnas. Respondenterna fick ta ställning till följande förslag (I den engelska delen av denna rapport återfinns de bilder som användes för att visualisera scenariot. Videon som användes kommer att bli tillgänglig på webplatsen)

- De två nedersta kraftverken Ljusneströmmar och Ljusnefors tas bort.

- En tunnel byggs från Laforsen till Forsänget och turbiner installeras vid det befintliga kraftverket Laforsen.
- Den nya tunneln innebär att vintervattenflödet i Mellanljusnan ungefärligen motsvarar flödet innan älven reglerades.
- Energiproduktionen förutsätts vara ungefär lika stor efter utrivning och nybyggnation som före.
- Fiskvägar etc ordnas så att laxen kan ta sig upp från havet till Laforsen (det naturliga vandringshindret). Idag kan laxen inte vandra upp i älven.
- Vi beräknar att den totala mängden vuxen lax som återvänder årligen för lek i Ljusnan kan uppgå till ca 5000 individer, med en genomsnittsvikt på ca 7-8 kg.
- Cirka 2500 av laxarna kommer att kunna nå lekområdena nedströms Laforsen, medan ca 300-500 laxar kommer att stanna för lek i vart och ett av områdena mellan nedströms liggande kraftverk, och ca 1200 laxar kommer att stanna för lek nedströms Höljebro.
- Projektkostnaden betalas av kraftverksägaren.
- Byggnadsarbetena beräknas ge åtminstone 1000 årsarbeten och ta flera år.

Konsultation med juridisk expertis ger vid handen att vårt förslag harmonierar med Miljöbalken (i vilken Vattenlagen sedermera infogades), i bemärkelsen att den premierar ett helhetsperspektiv. Dock kräver förslaget en lagändring, i och med att MellanLjusnan är starkt skyddad i gällande lag.

Webenkäten indikerade ett starkt lokalt stöd för projektet; som nämnts ovan har vi under den period vi utrett frågan egentligen inte funnit någon negativt inställd part. De få respondenter som var negativa till projektet var t.ex. negativa till att riva ”fungerande kraftverk”. Studien konkluderar att frågor kring flexibilitet i vattenregleringen bör utredas vidare, inte minst därför att det kan finnas liknande vattendrag som erbjuder möjligheter till ”dubbla vinster”.

2.5.3 Emån

Vi betraktar i Paulrud och Laitila (2010) sportfiskarnas värdering av olika egenskaper hos ett rinnande vatten med lax och havsöring (främst Emån och som referens även Mörrumsån). Värderingen av egenskaperna används till att modellera förväntad besöksfrekvens givet vattnets egenskaper.

Enkätstudier har genomförts i Emån och Mörrumsån i syfte att få kunskap om sportfiskarnas värdering av olika egenskaper hos åarna. Mer än 1 000 enkäter har skickats ut. Metoden som användes var s.k. Choice experiments. Metoden utgår från att man genom strukturerade intervjuer erhåller information som sedan kan nyttjas för att utreda sportfiskarens preferenser över olika alternativ, eller mer precist uttryckt, nyttofunktionens egenskaper. En teoretisk utgångspunkt för undersökningen är att en sportfiskare väljer att fiska vid den fiskeplats som ger henne/honom den största nyttan. Nyttan i sin tur bestäms av fiskeplatsens olika egenskaper.

För att få en ekonomisk värdering av en förbättring av egenskaperna hos en fiskeplats, jämförs den positiva effekten av förbättringen med en motsvarande kostnadsökning. Antag att fisket förändras så att förväntad fångst av stor fisk ökar med en fisk. Värdet av förändringen definieras som den höjning av kostnaden (ex.vis licensavgiften) som reducerar hela ökningen av nyttan till den nivå som förelåg före förbättringen av fisket. Detta ger sålunda individens maximala betalningsvilja och inte i största allmänhet ”vad man vill betala för en vara eller tjänst”.

Det värde som erhålls enligt denna definition gäller för en fisketur till platsen. För en total värdering måste hänsyn tas till totala antalet fisketurer. Ett enkelt sätt är att studera historiska data och beräkna antalet besök på platsen per säsong. En totalvärdering fås då genom att multiplicera värdet av förändringen per fisketur med totala antalet fisketurer. Denna ansats ger dock endast en nedre gräns av totalvärdet. Förbättringen av fiskeplatsen kommer antagligen att innebära att platsen väljs oftare framför andra fiskeplatser dvs., det totala antalet fisketurer kommer att öka. Om vi istället utgår ifrån antalet besök med förbättringen kan en övre gräns beräknas på motsvarande sätt. Orsaken är den att några av de som väljer att fiska vid platsen efter förändringen kommer från andra fiskeplatser med bättre egenskaper än de som fanns vid platsen före förändringen. Genom att i enkäten fråga om besöksfrekvenser för olika utformningar av fisket vid en viss plats kan sedan en relation mellan besöksfrekvens och fiskeplatsens nytta skattas. Denna relation används sedan för att uppskatta besöksfrekvenser före och efter en förändring.

I den ekonomiska analysen har följande scenarion analyserats:

1.Havsöringen når de fem nedre delarna av ån via tre fiskvägar vid lika många kraftverk, men utan åtgärder för förbättrad nedströmspassage. Detta motsvarar dagens situation. Mängden havsöringar som finns tillgängliga för vårfisket i det nedre området kvantifierades till ca 730 stycken för detta scenario.

2.Havsöringen når de fem nedre delarna av ån via tre fiskvägar och dessa kraftverk åtgärdas för förbättrad nedströmspassage. Mängden havsöringar som finns tillgängliga för vårfisket i det nedre området kvantifierades med hjälp av den populationsdynamiska modellen till ca 1110 stycken för detta scenario.

3.Havsöringen når de sju nedre delarna av ån via fem fiskvägar, men utan någon förbättrad nedströmspassage. Mängden havsöringar som finns tillgängliga för vårfisket i det nedre området kvantifierades med hjälp av den populationsdynamiska modellen till ca 1160 stycken för detta scenario.

4.Havsöringen når de sju nedre delarna av ån via fem fiskvägar och samtliga kraftverk åtgärdas för att åstadkomma 95 % vandringsframgång för samtliga vandringsstadier. Mängden havsöringar som finns tillgängliga för vårfisket i det nedre området kvantifierades med hjälp av den populationsdynamiska modellen till ca 1330 stycken för detta scenario.

Det ekonomiska nettoutfallet av ovanstående scenarion är, trots avsevärda förbättringar av Emåns egenskaper, såsom till exempel bättre förväntad fångst och nya fiskeplatser, negativt. Det ”specialist” fiske som bedrivs utförs av en mindre grupp människor som är relativt okänslig för förändringar och förändringen av besöksfrekvensen är relativt liten. En prishöjning för sportfisket på i storleksordningen 150 kr per dag för att finansiera förändringarna skulle dock vara tillräcklig.

Utifrån ett förvaltningsperspektiv är det viktigt att kunna se till och särskilja olika egenskaper hos de vatten som förvaltas. Sannolikheten att få fånga en fisk är en egenskap som värderas högt av de som fiskar. Att få ta med sig fisk hem från en fiskeplats är en annan egenskap som inte alltid har så stor betydelse relativt sett till att fånga fisken. I en aktiv förvaltning kan kunskap om värdet av vattnets egenskaper användas för att bestämma bag-limit och andra centrala egenskaper. Resultaten från studier av Emån och Ljusnan bidrar till att stärka kunskapen kring värdet av vattnens egenskaper.

3 Executive summary

This report summarizes a 3-year interdisciplinary program, in which economics, natural scientists and mathematical statisticians have worked together to shed some light on the costs and benefits of river regulation. It is financed by Elforsk, The Energy Agency, the Fishery Board and the Swedish Environmental Protection Agency. Our research program presents an integrated natural-social science approach to Cost-Benefit Analysis (CBA) of river regulation, with a primary focus on the Emån and Ljusnan watersheds. Each watershed requires a slightly different analytical focus: water flow considerations in the Ljusnan and fish passage in the Emån. We examine the ecological consequences of alternative environmental measures, develop values (e.g., costs and benefits) of these measures, characterize various measurement uncertainties, and, finally, subject the data to state-of-the-art welfare analysis. This is why the research program uses input from three groups of scientists. Importantly, we propose and apply an architecture for interdisciplinary work, that helps to effectively combine cutting edge research from each of our disciplines.

In this executive summary, we explain goals and objectives, the architecture developed to reach our goals and what we did deliver in terms of tools, approaches and technical solutions. In addition, we detail stakeholder interaction, which is an integral part of our general approach. Indeed, we deal with policy-relevant problems in two river systems and it is imperative that we can tap the substantial bodies of knowledge that exists among local stakeholders, industry experts and experts from the government. Finally, our case-studies are described here in detail, not only because they are interesting per se, but also because they have been used as our intellectual campfires. We have been involved in many similar large interdisciplinary projects and a key lesson learned in this program is that a focal point, in this case a set of clearly defined case-studies, is enormously useful.

The list of publications, seminars, workshops, stakeholder interactions and so on and so forth is collated into a separate file. Here is a summary table of the output.

Item	Delivered	Contracted
Presentations	54	> 20
Organized Workshops	5	1 Workshop on CBA in Regulated River Systems, October 24, 2007, Umeå. Organizer:Kriström. 2. Workshop on nature-like design of fishways. September 8-9, Karlstad, 2008. Organizer: Calles. 3. Workshop on CBA & Hydropower, August, 26, 2009, Stockholm. Organizers: Johansson, Kriström. 4. IISA Conference Jan 4-8, 2010, Visakhapatnam, (Andhra U., Waltair),Indien. Organizer: Ranneby (session organizer)

		5. 5. Economic Evaluations of Water/Energy Interactions for Policy, 19-20 April, 2010, Phoenix, Arizona, USA. Organizers: Smith, Johansson, Kriström
Reports	22	
Refereed journal	7	> 10?
Books	2	1. Johansson, P.-O. & B. Kriström (red) *Hydropower and Modern CBA*, Edward Elgar, Cheltenham, USA. 2. Johansson, P.-O. & B. Kriström (kommande) *Applied CBA and Hydropower conflicts*, Springer Verlag, New York (Under kontraktering)
Diss., Msc etc	1	
Stakeholder meetings, press, media	See separate report	

This is a snapshot of the current situation in July 2010, ie 3months before the formal ending of the project. There are several papers in the referee process and consequently the final output is not known with certainty at this point. Barring a very negative outcome in the referee process, the project will most likely reach the contracted goals. The contract does not stipulate number of workshops to be organized, nor number of scientific bools to be published.

3.1 Project goals and objectives

In the original application, we explained our goals and objectives in the following way:

"The ultimate goal of this program is to provide a framework for state-of-the-art CBA of river regulation. Our specific goals include:

- Developing generally applicable theory and methodology for CBA in regulated rivers, in particular with regard to Emån and Ljusnan;
- Carrying out empirical studies that supply the necessary biological background for innovative CBAs; and
- Generating methodologies to handle uncertainty in natural science and economic models and apply it in the empirical studies.
- Develop tools to be used to quantify the ecological effects of measures in hydropower regulated rivers

In addition to developing generally applicable methodologies, the project will also provide valuable site-specific information for the Emån and Ljusnan. Therefore, an important goal is to disseminate findings and provide decision-support to policy makers in these locations. Our general strategy is to construct policy-relevant scenarios and to subject these environmental measures to a carefully integrated conceptual and empirical analysis that draws upon natural sciences, mathematical statistics, and economics. These areas are linked together by the four work packages..."

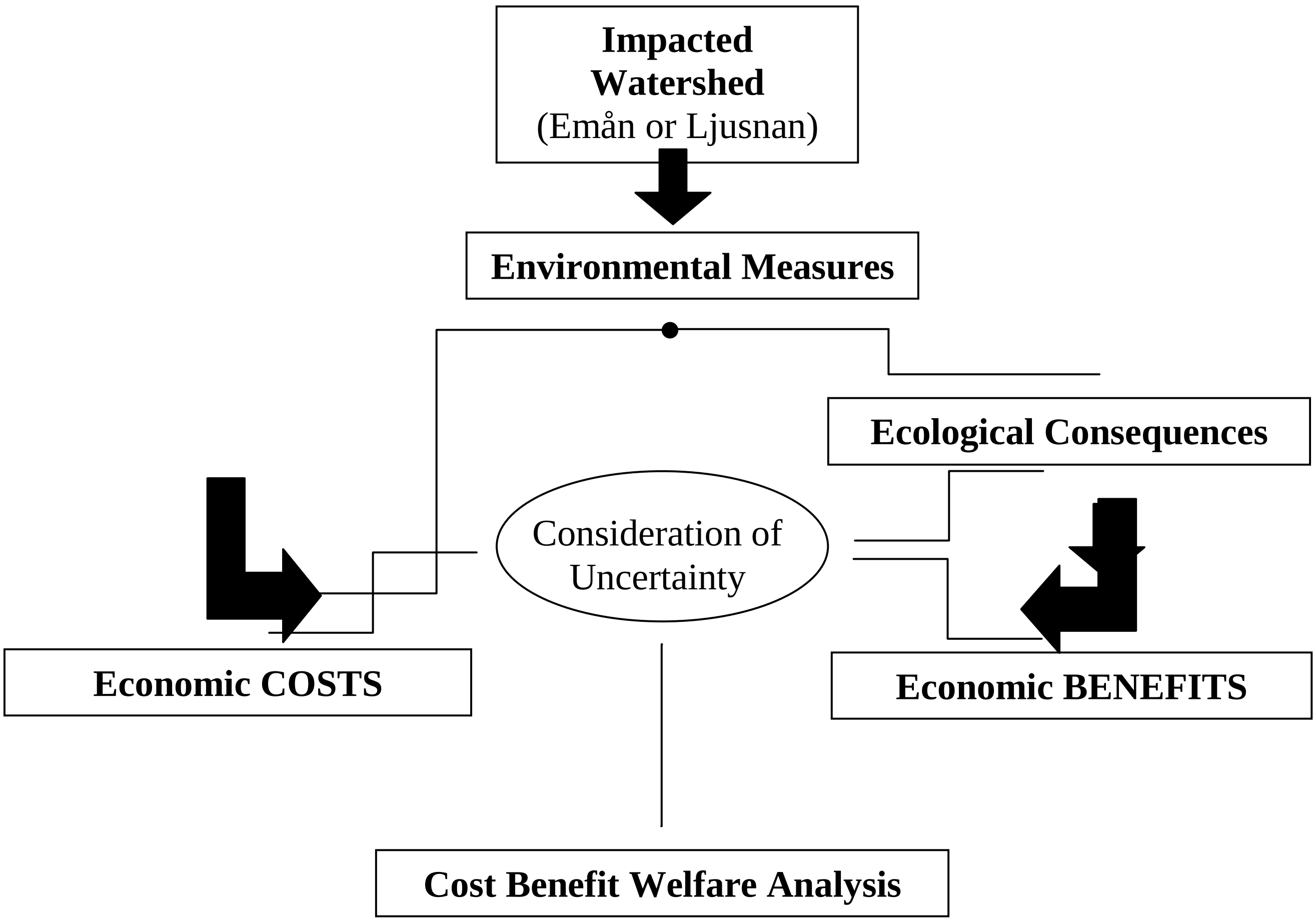
We proposed to carry out this research over 36 months with a budget of 18 million SEK.

3.2 Project architecture

We organized our work into four work-packages as follows:

WP	Objectives	Team-leader
1. Cost-benefit analysis	1. Provide a detailed welfare analysis of policy changes affecting selected river systems 2. Refine and extend existing methodologies for cost-benefit assessment in human-dominated ecosystems 3. Develop cost-benefit analysis with emphasis on handling uncertainty in input/output data	Bengt Kriström
2. Uncertainty	1. Develop methods for assessing error propagation (e.g., model quality, data, and CBA) 2. Develop strategies to handle survey non-responses in determination of WTP 3. Develop methods to handle preference uncertainty	Bo Ranneby
3. Emån	1. Quantify the function of natural fishways as a way of re-establishing upstream connectivity. 2. Identify downstream passage problems for fish migrating past hydroelectric facilities and evaluate remedial measures that increase downstream connectivity. 3. Predict the overall ecological effects of re-establishing longitudinal connectivity past the power plants in Högsby and Blankaström using population models.	Larry Greenberg
4. Ljusnan	1. Develop a framework for quantitative predictions of ecosystem restoration in dewatered channels, as a function of discharge and flow regimes - for use in CBA-analyses and in restoration processes in general, and for a case study in the research program in particular. 2. Develop a population model of migrating fish populations in rivers with connectivity issues. 3. Provide an analysis between regulated and unregulated flows in the framework of IHA (Indicators of Hydrological Alteration)	Kjell Leonardsson

The basic framework is explained in Figure 1



Broadly speaking, our work is based on the ordered triplette Natural Science – Statistics – Economics in the following manner. First, natural science measurements were carried out, given a proposed perturbation of the status quo in each of the two river systems. Second, the measurements were subject to uncertainty analysis. Thirdly, the economic valuations detailing the costs and the benefits of the perturbations. This, of course, is a rough charicature of the work. In an important sense, the economic analysis came first, because it developed the framework within which we analyzed each scenario. Economics, in particular applied welfare economics, is the workhorse of this program and all our measurement is based on a theoretical model. Furthermore, the development of the scenarios per se must be done in tandem; we spent a lot of time working together to develop the scenarios. In the Dönje case, described below, the scenario was based on an actual perturbation of the stream in question, thanks to fruitful co-operation with the power company Fortum. Perhaps uniquely, we developed a scenario based on on-site measurement of a regulatory change at the power plant. Given the perturbation, and its visulization, we then needed to map the measurement in to a credible and understandable scenario into a survey. This was truly a team-work effort, helped by focus groups at the site. In short, our empirical work in this program is a prime example of a joint effort.

As noted, the case-studies served several purposes and played a key role in focussing our joint efforts. In the application, we proposed a number of scenarios. These initial ideas were modified for various reasons, not the least because we learnt more about the underlying resource conflicts. The final scenarios analyzed were:

Scenario	Proposed change	Report
Ljusnan: The Dönje cases	1. Winter scenario. Increased flow in Klumpströmen from 0.25 to 3 m^3/s during winter season. 2. Summer-Winter scenario. From 10 to 20 m^3/s increased flow in Klumpströmmen in the summer season. Winter season as in scenario 1.	Johansson & Kriström (2010 a,b,c). Rivinoja et al. (2010)
Ljusnan: ”-2,+1”	Removal of two powerplants in Ljusnan, construction of new turbines at the existing powerplant Laforsen.	Johansson & Kriström (Forthcoming) Rivinoja et al. (2010), Leonardsson (2010), Paulrud (Forthcoming)
Emån:	1. The sea trout reach the five downstream sections via three fishways without measures (today’s situation). 2. The sea trout reach the five downstream sections via three fishways with measures to improve downstream passages. 3. The sea trout reach the seven downstream sections via five fishways. No improved downstream passages. 4. The sea trout reach the seven downstream sections via five fishways. All passages are improved to reach 95 % passage probabilities.	Paulrud (Forthcoming) Greenberg Calles

Table 2. The scenarios analyzed in the program.

3.3 Key deliverables

A list of publications and other outputs are collected into a separate file, included here as an appendix. Detailed presentations of our work are contained in separate chapters below, where each working package (WP) is described in more detail. In this executive summary, we summarize our work in terms of *tools*, approaches and technical solutions. We begin with the tools, i.e. a set of computer programs or simple equations that can directly be used in analyses of river regulation. We then turn to a description of a more general set of tools, that we here call *approaches*. Finally, a number of *technical solutions,* ranging from certain solutions to help downstream passage in at a particular plant to a certain way of dealing with uncertainty in cost-benefit analysis.

3.3.1 Tools

While our research targets two particular streams, a key idea is generalization. The tools we developed are, we hope, useful in other contexts. The difference between ”a tool”, ”an approach” and a ”technical solution” is sometimes subtle, but we still use these demarcations in the sequel.

The following tools are described in detail by WP1 and WP4 below:

1. An Excel-based tool for economic analysis of recreational sportfishing(Anton Paulrud, WP1)
2. A Mathematica based tool for detailed analysis of migrating fish populations in regulated rivers. (Kjell Leonardsson, WP4)
3. A simple equation based tool for preliminary analysis of migrating fish populations in regulated rivers. (Kjell Leonardsson, WP4)
4. An R-package for the statistical analysis of self-selected interval data (Wenchao Zhou, WP1).

3.3.2 Approaches

The program workhorse is an approach we have developed in WP1 for cost-benefit analysis of regulatory change in energy systems. The approach has been tailored to fit the particulars of Swedish environmental and energy legislation, but the approach is completely general. At present it includes permit markets, electricity certificate markets and many other dimensions as detailed in the description of WP1 below. We use it to generate cost-benefit rules that subsequently structure our empirical studies. Such rules are extremely helpful not only because they help avoid double-counting.

A second approach, made concrete within a particular scenario called ”-2,+1”, is part of a way of thinking about regulation flexibility. The approach is consistent with a general change of direction in environmental legislation in several countries, in which flexibility has become an important dimension of regulatory thinking. Basically, we target ways in which environmental improvements can be secured, without compromising energy generation. This, of course, goes directly to the heart of the dilemma and zooms in on the nexus of countless conflicts between development and preservation. The way out of these dilemmas is simple enough; just make sure that any change does not make anybody worse off. While theoretically appealing, such *Pareto-sanctioned* are rare in practice. Yet, by increasing regulafory flexibility, we stand a much better chance of finding such projects in practice.

In our application of this idea, we have analyzed a case in which we tear out two dams in the Ljusnan river and construct new turbines at an existing plant. We have chosen to call the scenario ”-2,+1” to reflect its generic structure. We describe in detail in the section on applications. It is sufficient here to note that this approach to river regulation is consistent with the Water Framework directive in terms of its focus on watersheds, as well as an underlying holistic principle of Swedish environmental legislation.

3.3.3 Technical solutions

We have chosen to call the third set of contributions ”technical solutions”. Again, there are subtle differences between a ”technical solution” and a ”tool”, but a technical solution is not anecessarily a computer program, or a software suite. Thus, the so-called *cost-benefit acceptability curve* developed in WP1 is a technical solution to the problem of describing the net benefits of a project. The *downstream passage solutions* detailed by WP3 below in Emån are technical solutions in their own right. In WP4, general tools and results have been developed that can be used to assess when technical solutions, e.g. constructing fishways, can be expected to be successful with the desired positive effects on the environment.

3.3.4 Stakeholder interaction

We have had rather intensive interaction with a broad set of stakeholders. This interaction is especially useful in this project, because we propose and analyze real world solutions to real world problems. One example is the extensive analysis of the “-2,+1” scenario. Together with the relevant municipalities, the County Board and Fortum, we essentially “travelled” Ljusnan, from the coast (where the dams are to be torn out), to Laforsen, the location of the new turbines (to be inserted 150 m below ground). This “travel” was enormously helpful in understanding the possible consequences of the proposal. Furthermore, in the course of this program we have elicited sentiments from at least 700 locals only in the Ljusnan Valley, mostly via web-questionnaires, but also by phone calls and their participation in our focus groups. To put this in perspective, it is tantamount to contacting about 80000 Swedes, should our project have had a national scale. Consequently, we submit that we have a reasonably good idea of how the population of the Ljusnan valley considers our proposals. In Emån, our target group is slightly different, because the focus is on recreational fishing. But also in this case, we have interacted closely with stakeholders. In short, stakeholder interaction has been a lively and tremendously important part of our research.

3.4 Additional deliveries

Over and above the tools, the approaches and the technical solutions described above, there are a number of deliveries that do not fit snugly in these categories. As we noted in the application, the project will generate a substantial amount of in-depth information about the watersheds under scrutiny. For further details about these reports, see the descriptions of the individual work packages 3 and 4 below. There are also a number of deliveries that were not contained in the original plan. The most important of these is an added sub-project on balancing power, reported in Försund & Hjalmarsson (2010). Hydropower is an ideal regulatory service in an electricity system and with the massive expansion of windpower that is under way, such services are expected to become increasingly more important. A reference group of designated experts were attached to this sub-project, to provide comments and guidance.

While contributions to scientific seminars, workshops and conferences are mandatory ingredients in any scientific project, and certainly not an additional delivery here, we did make a point of presenting our research at meetings targeting a wide audience. A complete listing of those presentations are available in the separate file that collates our deliveries.

4 Introduction and overview

This report summarizes a 3-year interdisciplinary program, in which economics, natural scientists and mathematical statisticians have worked together to shed some light on the costs and benefits of river regulation. The project is financed by Elforsk, The Energy Agency, the Fishery Board and the Swedish Environmental Protection Agency. Our research program presents an integrated natural-social science approach to Cost-Benefit Analysis (CBA) of river regulation, with a primary focus on the Emån and Ljusnan watersheds. Each watershed requires a slightly different analytical focus: water flow considerations in the Ljusnan and fish passage in the Emån. We examine the ecological consequences of alternative environmental measures, develop values (e.g., costs and benefits) of these measures, characterize various measurement uncertainties, and, finally, subject the data to state-of-the-art welfare analysis. This is why the research program uses input from three groups of scientists. Importantly, we propose and apply an architecture for interdisciplinary work, that helps to effectively combine cutting edge research from each of our disciplines.

In the sequel we provide a detailed account of what has been achieved in this project. We begin by outlining goals and objectives and our general approach to interdisciplinary work, i.e. the project architecture. We then turn to each of the four working packages and explain the contributions contained in each. Three major case studies are then described, which necessarily involves some amount of overlap with the working package descriptions. Indeed, the case studies are focal points of the whole project and they serve several purposes, beyond giving potentially useful policy information about how to proceed in the cases considered. The report is concluded in a separate appendix with information about publications, stakeholder meetings and so on and so forth.

4.2 Objectives, goals and initial plans

In the original application, we explained our goals and objectives in the following way:

"The ultimate goal of this program is to provide a framework for state-of-the-art CBA of river regulation. Our specific goals include:

- Developing generally applicable theory and methodology for CBA in regulated rivers, in particular with regard to Emån and Ljusnan;
- Carrying out empirical studies that supply the necessary biological background for innovative CBAs; and
- Generating methodologies to handle uncertainty in natural science and economic models and apply it in the empirical studies.

In addition to developing generally applicable methodologies, the project will also provide valuable site-specific information for the Emån and Ljusnan. Therefore, an important goal is to disseminate findings and provide decision-support to policy makers in these locations. Our general strategy is to construct policy-relevant scenarios and to subject these environmental measures to a carefully integrated conceptual and empirical analysis that draws upon natural sciences, mathematical statistics, and economics. These areas are linked together by the four work packages..."

We proposed to carry out this research over 36 months with a budget of 18 million SEK.

Initially, we focused on a set of case studies, as outlined in the following table:

Analytic Scenario	Environmental Measures considered[1]	Valuation Approach	Focal points
Scenario #1: Emån	Upstream migration measures	Choice experiments/ Contingent Valuation/ Travel Cost/Benefits transfer	Sport fishing, local communities, general population, salmonids (trout), eels and cyprinids
Scenario #2: Emån	Downstream migration measures	Choice experiments/ Contingent Valuation/ Travel Cost/Benefits transfer	Sport fishing, local communities, general population, salmonids (trout), eels & cyprinids
Scenario #3: Emån	Removal of dams	Cost assessment	Heuristic benchmark
Scenario #4: Ljusnan	Restoration of dewatered "channels"	Choice experiments/ Contingent valuation/ Benefits transfer	Local communities, tourism Ecological status (WFD), brown trout, grayling
Scenario #5: Ljusnan	Dynamic flow regimes	Choice experiments/ Contingent Valuation/ Benefits transfer	Local communities, tourism Ecological status (WFD), brown trout, grayling
Scenario #6: Ljusnan	Removal of dams	Cost assessment	Heuristic benchmark

Table 3. The scenarios proposed in the application

For a number of reasons we re-focused our work slightly, even though our final choice of case studies are very similar to the ones envisaged in the application.

Scenario	Proposed change	Report
Ljusnan: The Dönje cases	1. Winter scenario. Increased flow in Klumpströmen from 0.25 to 3 m^3/s during winter season. 2. Summer-Winter scenario. From 10 to 20 m^3/s increased flow in Klumpströmmen in the summer season. Winter season as in scenario 1.	Johansson & Kriström (2010 a,b,c), Rivinoja et al. (2010)
Ljusnan: "-2,+1"	Removal of two powerplants in Ljusnan, construction of new turbines at the existing powerplant Laforsen.	Johansson & Kriström (Forthcoming) Rivinoja et al. (2010), Leonardsson (2010)... Paulrud (Forthcoming)
Emån: Anton	1. The sea trout reach the five downstream sections via three fishways without measures (today's situation). 2. The sea trout reach the five downstream sections via three fishways with measures to	Paulrud (Forthcoming) Greenberg Calles

	improve downstream passages. 3. The sea trout reach the seven downstream sections via five fishways. No improved downstream passages. 4. The sea trout reach the seven downstream sections via five fishways. All passages are improved to reach 95 % passage probabilities.	

Table 4. The scenarios analyzed in the project.

In the case of Ljusnan, scenario #4 and #5 in Table 3 correspond to the Dönje cases in Table 4. The correspondence is not exact, because there is no dewatered channel at Dönje (but the current winter minimum flow regime generates problems that are similar, i.e. bottom freezing). In the Emån case, the scenarios actually analyzed are similar in spirit to scenario #1 and # 2 in Table 3. In both river systems, we discarded the most extreme scenarios, i.e. #3 and #6, the removal of dams. Initially, our idea was to provide cases that illustrate both the small-scale and the large scale, not the least because one aim was to keep consistency with the water basin focus of the Water Framework Directive. We maintained this basin perspective by analyzing a slightly different large scale scenario in Ljusnan, the so-called "-2, +1" scenario. As noted above, it entails tearing out two dams at the mouth of the river, and adding turbines at an exisiting plant above 150 km upstreams.

The re-focusing of the case studies reflect several dynamic processes, the most important of these presumably being the process of learning. At the outset, we simply had not thought about the possibility of finding a scenario that was potentially Pareto improving, i.e. a perturbation that makes at least one person better off, without impairing the welfare of anyone else. Indeed, the leitmotif of CBA is to generate information that is useful when addressing trade-offs, and this is the way we thought about the case studies in Emån and Ljusnan initially; in order to secure environmental improvements, something has to give – in this case electricity generation. As demonstrated, we believe, by "-2,+1" it is possible to have the best of both worlds and then, fortuitously, no CBA is needed because there are no trade-offs involved.

4.3 General approach and philosophy

This project is interdisciplinary in the sense that researchers from three disciplines have worked together to address the problems under scrutiny. There is little doubt that problems involving changing regulations of hydropower systems requires, at a minimum; natural science, statistical analysis of uncertainty and economics.

What separates this program from many similar interdisciplinary "eco-eco" projects is the fact that welfare economic principles are used to generate the scenarios. Thus, the workhorse is a general equilibrium model that, at least in principle, includes both the economic and the ecological systems, as well as their interactions. Because this framework is basic to this project and our research, it is prudent to motive it in some detail.

In our set-up, a scenario means perturbing the status quo, e.g. changing the current water regulation regimes at a particular plant. Such perturbations creates ripple-effects throughout both the economic and the ecological systems. For example, reducing power generation at a particular plant by diverting additional water to the fishways, necessarily means that electricity consumption must be reduced, if the loss of electricity is not compensated at another plant. If, as in Sweden, electricity is taxed, tax revenues are lost with an implied subsequent reduction of public services, pending any increase of a compensatory tax increase (or public borrowing). Evidently, the ripple-effects of these two direct economic effects quickly outstrip the imagination of even the most patient economist. On the ecological side, the improved possibilities of fish migration will impact the whole ecosystem, the details being different at each considered site. For example, in our Dönje-case, the proposed increase of the winter flow in the fish pathway has positive consequences for many other organisms that today struggle with the bottom freezing river. In turn, these positive ecological effects will find their way into the economic system, as sport fishing increases (the implied re-allocation of spending patterns among the sport fishers must also be accounted for). This rudimentary sketch gives an idea of the complexities involved and why an organizing framework is so useful for our work.

Now, the analysis is complicated by a sobering fact of economic and ecological life; uncertainty. Many, if not all, relevant processes in the analysis are not known exactly; there are elements of uncertainty both in the natural science analysis as well as in the economic analysis. Therefore, we find it very natural to give statistics, or the analysis of uncertainty, a key role in the program. One of the challenges is to provide information about benefit and costs of policy alternatives, given uncertainties in both systems under scrutiny. Thus, we have analyzed how uncertainty propagates in the fish population model that we use as an input to our scenarios. Furthermore, we have spent considerable effort also in developing methods that can usefully address respondents uncertainty about willingness to pay.

To sum up: our work is based on the ordered triplette Natural Science – Statistics – Economics in the following manner. First, natural science measurements and quantitative predictions were carried out, given a proposed perturbation of the status quo in each of the two river systems. Second, the measurements were subject to uncertainty analysis. Thirdly, the economic valuations detailing the costs and the benefits of the perturbations. This, of course, is a rough charicature of the work. In an important sense, the economic analysis came first, because it developed the framework within which we analyzed each scenario.

In the Dönje case, described below, the scenario was based on an actual perturbation of the stream in question, thanks to fruitful co-operation with the power company Fortum. Perhaps uniquely, we developed a scenario based on on-site measurement of a regulatory change at the power plant. Given the perturbation, and its visualization, we then needed to map the measurement in to a credible and understandable scenario into a survey. This was truly a team-work effort, helped by focus groups at the site. In short, our empirical work in this program is a prime example of a joint effort.

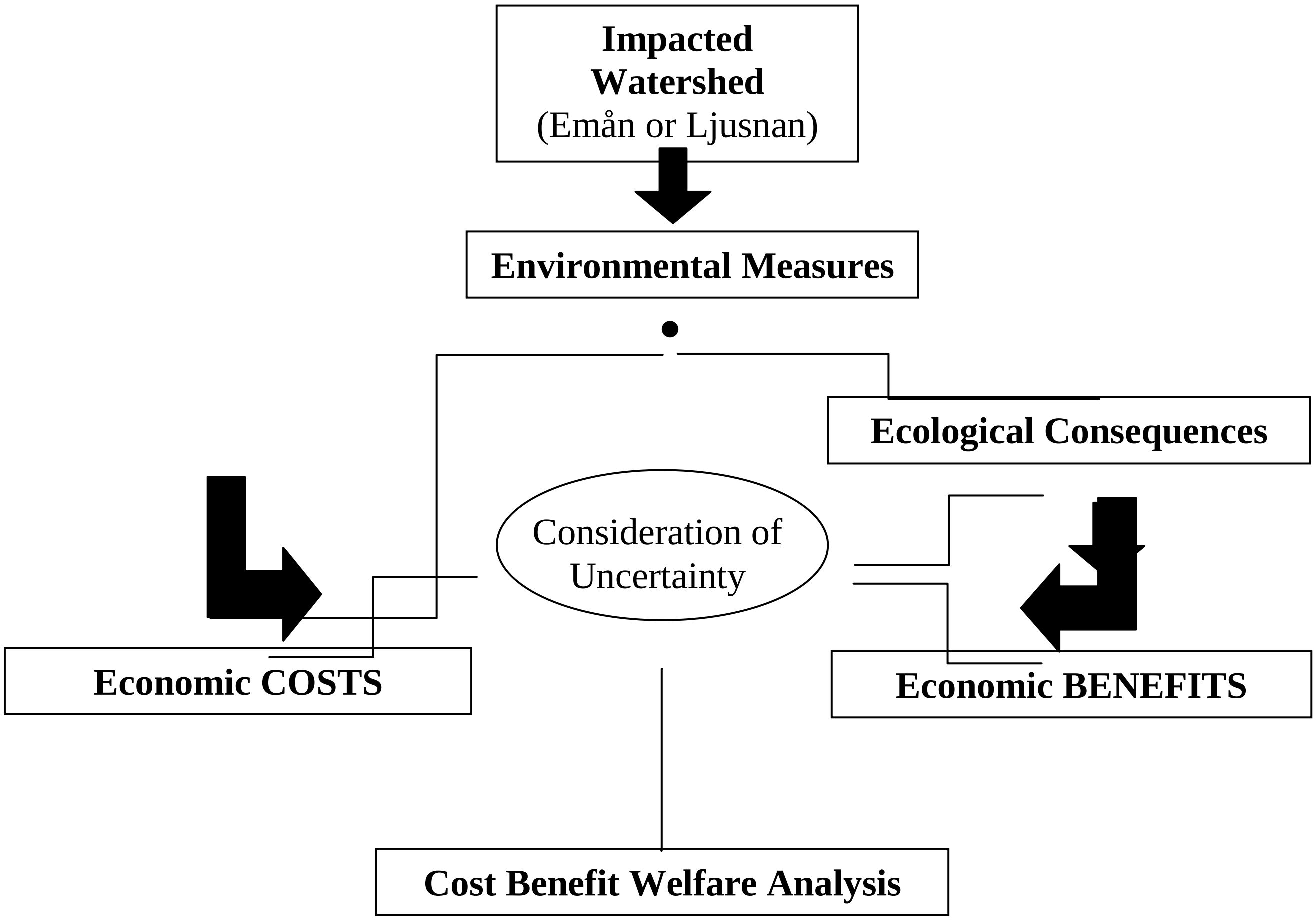
4.4 Architecture

We organized our work into four work-packages as follows:

WP	Objectives	Team-leader
1. Cost-benefit analysis	1. Provide a detailed welfare analysis of policy changes affecting selected river systems 2. Refine and extend existing methodologies for cost-benefit assessment in human-dominated ecosystems 3. Develop cost-benefit analysis with emphasis on handling uncertainty in input/output data	Bengt Kriström
2. Uncertainty	1. Develop methods for assessing error propagation (e.g., model quality, data, and CBA) 2. Develop strategies to handle survey non-responses in determination of WTP 3. Develop methods to handle preference uncertainty	Bo Ranneby
3. Emån	1. Quantify the function of natural fishways as a way of re-establishing upstream connectivity. 2. Identify downstream passage problems for fish migrating past hydroelectric facilities and evaluate remedial measures that increase downstream connectivity. 3. Predict the overall ecological effects of re-establishing longitudinal connectivity past the power plants in Högsby and Blankaström using population models.	Larry Greenberg
4. Ljusnan	1. Develop a framework for quantitative predictions of ecosystem restoration in dewatered channels, as a function of discharge and flow regimes - for use in CBA-analyses and in restoration processes in general, and for a case study in the research program in particular. 2. Develop a population model of migrating fish populations in rivers with connectivity issues. 3. Provide an analysis between regulated and unregulated flows in the framework of IHA (Indicators of Hydrological Alteration)	Kjell Leonardsson

As explained above, we did some changes in the basic scenario analysis, which then meant certain changes in our work plan. For example, while analysis has been carried out pertaining to upper Ljusnan, the focus became the Middle part of the river and a particular plant downstream (Dönje). Also, the focus of WP4 was initially on quantitative methods for predicting ecological effects of measures, not related to connectivity issues, in regulated rivers regarding changes in flow or other measures. However, the shift in focus in the research program to study the large case “-2,+1” in Ljusnan made it necessary to develop and apply a tool for quantifying population effects on migrating fish of establishing new fishways.

The basic framework is explained in Figure 1



Given the discussion about our general approach, there is not much to add to the figure. It describes the essential logic of our project workflow. Instead, we turn now to how we integrated the parts.

4.4.1 Integrating the scientific parts

As noted, project members have substantial experience in working with interdisciplinary research. This fact facilitated our work here, not the least because it was understood that each member brings the best from his speciality to the joint project. The challenge was rather how to combine the parts into an effective whole. Essentially, our approach to integration was the ”intellectual campfires”, i.e. our case studies. Currently, large interdisciplinary projects are in the vogue and research foundations support a substantial number of them, as witnessed by e.g. The MISTRA project portfolio and those of similar large-scale research foundations. An advantage with the program of which this project is a part is its sharp focus on case studies. At least we have found that this works much better than having a broadly based research outline within a large interdisciplinary group. The reason is partly psychological, partly practical; if a group has a clearly delianated goal well understood by group members, this is beneficial to group output not only because the organization of the practical work becomes so much easier.

Furthermore, the cost-benefit framework gave us a clear idea about what we wanted to measure and it was fairly straightforward to get everyone on board in carrying out the necessary measurements.

At a practical level, the routine work was mainly held together by monthly telephone meetings, scheduled to be a certain day of each month. Along the way, we were much helped by the stakeholder and similar meetings. In addition, the meetings with the board were instrumental as a soundboard, because we could get a quick response on whether or not our research plan was on the right track.

4.4.2 Involving the stakeholders

As already mentioned, the stakeholder meetings were a boon to our research, not the least because the stakeholders involved comprised a diverse set of competencies, all of them useful in the development of our ideas and various measurements. Again, the usefulness of having the case studies were effectively displayed. Rather than discussing problems at a more genereal level, we could go right at the heart of the matter by discussing the case studies. What is more, more general problems could be lifted in a more natural way, by using the case studies as vehicles for the discussions.

In the Dönje case, the municipality of Bollnäs organized a particular meeting, where we discussed river regulation at several levels, including the case at hand. This was useful in several ways, not the least because we used a web-questionnaire to elicit the sentiments of the those living in the municipality. Web questionnaires create obvious problems in sampling, because it is not obvious that the sample obtained provides a good picture of the underlying population. The discussions with the municipality representatives were comforting, in that they buttressed other ways of controlling the received sample in terms of its representativeness.

In short, involving the stakeholders was a significant boon to our research project.

4.4.3 Reaching the Research community

Our project did not engage in an particularly novel ways to reach our peers, rather we tried to reach them in the traditional ways. According to our contract, a number of conference presentations was promised. As is evident from the appendix, we had no trouble fulfilling this goal; the number of presentations at scientific meetings are much larger than the contracted number. What is more, we organized several targeted workshops, e.g. three workshops for economists specializing in the field. This has resulted in one contracted book and several other outputs (available on the net, as detailed in the appendix).

It is important to realize that publishing the results takes time. We have a lot of work that is currently under review and the final result will not be visible until after at least a year or two. We are confident that most of our results will be published in quality journals.

Finally, the tools developed in the project are also meant for the scientific commnuity and time will tell how well our tools will be received.

4.4.4 Engaging the Program Board

Almost all large research programs have a program board, in this case representatives from the various financiers. As already mentioned, we have had lively and fruitful meetings with the Board and it has been instrumental in re-shaping our scenarios, sometimes pointing out that what is theoretically pleasing might not be very practical (c.f. Scenarios #3 and #6 above). The Board represents bodies that have, at least according to common perception, symmetrically different interests in the matter; there is no reason why a private power company should have the same goals as the environmental protection agency, let alone the fishery Board. In all, the Board provided substantive and important criticism and much help in all sorts of ways that help our project forward.

4.5 What we planned to deliver and what we did and did not deliver: some reflections

Before turning to the details, we reflect briefly on ex ante and ex post, i.e. our expectations about output before we started the work and how it did turn out in the end. We re-iterate that it is really too early to draw a final line, because our results are still being published in scientific journals and so on. In fact, there is still three months left of the project time when this final report was delivered. As indicated, we submitted an initial plan of six scenarios; these six scenarios, 3 for each river systems, were then modified for reasons explained in detail in each of the yearly reports. Thus, while we were planning to present scenarios that covered the whole spectrum, from the minute detail at a small plant to the removal of all powerplants and dams, we came to choose a path that was, in some ways less travelled, yet in other ways a safer route. The original plans were, in a certain sense, modular; progressively larger perturbations were to be assessed through the lens of cost-benefit analysis. The final product has the small scale and the large scale, but the “massive sccenarios” were replaced (or discarded completely in the Emån case) by a scenario with a different profile, i.e “-2,+1”. In addition, we did less than we expected in the upper parts of Ljusnan, not the least because of the re-focussing.

Our self-assessment, which may or may not be of interest, is on the whole positive. Self assessments are naturally plagued by cognitive dissonance; negatives are more easily filtered out than positives by the self-assessor. Even so, we can point to concrete advancements that took us further than we predicted at the outset. We now turn to the details of each working package.

5 WP1 Economics

5.1 Objectives

- Provide a detailed welfare analysis of policy changes affecting selected river systems;
- Refine and extend existing methodologies for cost-benefit assessment in human-dominated ecosystems; and
- Develop cost-benefit analysis with emphasis on handling uncertainty in input/output data.

5.2 Analytical contributions

A major output from the project is the paper *A Blueprint for a Cost-Benefit Analysis of a Water Use Conflict*. Hydroelectricity Versus Other Uses. This paper is still under development and our target is to get a slightly enlarged version published as a book by an international publishing company (specifically, we have an invitation from Springer Verlag, in a series edited by Ian Bateman). In the paper we develop a simple general equilibrium model of a small open economy which is used to derive a cost-benefit rule that can be used to assess projects that diverts water from electricity generation to recreational and other uses. The cost-benefit rule is used to evaluate a proposed change at a Swedish hydropower plant. Most importantly, we present a framework for assessing the costs and benefits of small perturbations of current hydropower regulatory regimes. This framework integrates several key issues, including, but not limited to:

- a contract between the hydro power plant and another party (local residents) generating the general equilibrium cost-benefit rule;

- the contract is a corner stone of our referendum-style contingent valuation study;

- the tax system in the status quo;
- (partial) foreign ownership of the plant;
- trade in electricity;
- trade in renewable energy certificates;
- trade in carbon emission permits;

- externalities of replacement power (generated in other countries);
- value of loss of regulating (balancing power) and other system services;
- transmission of electricity modeled as provided by natural monopolies;
- downstream hydrological externalities and environmental benefits (aesthetic and otherwise).

The particular water use conflict under analysis in the paper relates to Fortum's hydropower plant at Dönje on the Ljusnan river in central Sweden. According to the proposal under study water is diverted from electricity generation to the natural river channel (dryway) creating environmental and recreational benefits. Two scenarios were developed according to which water was diverted from hydropower generation to increase the flow in a part known as Klumpströmmen. According to one scenario the winter flow of water was increased while the summer flow was left unchanged at its current level. In the second scenario also the summer flow was increased. From an ecological point of view the optimal flow mimics the natural flow. A "natural flow" scenario was considered but not implemented in our study due to its complexity. We used a contingent valuation study where local residents participate in a hypothetical referendum about the proposals. The web-based questionnaire has some novel features with respect to the format of the valuation question since we introduce an open-ended willingness to pay question plus an interval question within a hypothetical local referendum. We also put some numbers on the remaining items of the cost-benefit rule just in order to illustrate possible magnitudes of different benefits and costs. For details, see the section on case studies below.

The cost-benefit analysis is subjected to a sensitivity analysis. Among other things, it is shown that an almost infinitesimal increase in the consumer price might cause demand to fall by an amount similar to the loss of electricity output at Dönje. Due to the large distortionary taxes on electricity consumption the cost of undertaking the proposal increases considerably. A simple stochastic sensitivity analysis is also undertaken where we make assumptions about the joint density functions for the loss of profits at Dönje and the willingness-to-pay for the proposals. In particular we introduce what is termed a cost-benefit acceptability curve. This curve (reflecting the survivor function) yields the probability that the outcome of the cost-benefit analysis exceeds a particular number. We think that this approach is useful for a decision-maker since it provides some information about the probability that the project is profitable from a societal point of view.

Finally, the paper provides a brief discussion about the possibility for the local residents to "buy out" or "bribe" Fortum to undertake one or both of the scenarios under consideration. The question, however, is if it would be tempting for the local community to sell back the water and earn a considerable amount of money that could be used to improve the services of the local government, for example.

The paper has been used to generate several other papers. In particular a shortened version is included in the book *Modern Cost-Benefit Analysis of Hydropower Conflicts* edited by Johansson and Kriström. This book sheds some light on how current tools of welfare economics can be used to assess the benefits and costs of resource conflicts involving hydropower. We have attempted to garner a set of chapters that paint a fairly broad picture of the issues involved. Consequently, we have tried to solicit papers from authors on both side of the Atlantic, which inter alia means that we have been able to tap into the significant body of experience that already exists in the U.S. There is also a body of relevant knowledge in the hydropower intensive countries of Europe, which are dominated by the Nordic countries. As these countries were electrified, resource conflicts surfaced and had to be resolved in some fashion. Along with decision makers need for comprehensive background information, methods and approaches were developed to meet this demand. Perhaps the most extensive investigations in this regard were carried out in Norway in the 1970s, when large investigativebodies were commissioned to look at hydropower investments using tools from a wide array of scientific disciplines. We also tried to attract papers that shed some light on key methodological issues in our context, ranging from the intersection between CBA and behavioral economics to appropriate statistical methodology for interval data with a particular form of censoring. In addition, hydropower supplies several different services into the electricity grid, including balancing power. Hydropower can conveniently be turned on and off on a time-scale that is unparalleled among the set of currently available technologies. Hence, when countries with substantial hydropower in the energy portfolio plans to expand its wind power share, balancing services become more valuable. Because electricity grids become increasingly interconnected, such as in Europe, this issue is not without interest even in countries that lack hydropower.

In a cost-benefit analysis of a public sector project one has to address the question how to handle taxes. This might seem straightforward although possibly complicated due to a lack of data and estimates of relevant price and income elasticities. However, the literature give slightly confused and contradicting recommendations or guidelines. In *A Note on Cost-Benefit Analysis, the Marginal Cost of Public Funds, and the Marginal Excess Burden of taxes* Johansson and Kriström presents a simple cost-benefit rule; this CERE working Paper is produced jointly with PlusMinus. They then ask how the treatment of taxes according to this rule are related to the concepts of the marginal cost of public funds (MCPF) and the marginal excess burden of taxes (MEB). These two concepts have been digested in an almost infinite number of contributions. We are able to show that the treatment of taxes in our cost-benefit rule captures the MCPF or the monetary welfare cost of raising an additional Euro by increasing a particular tax rate. Several prominent researchers have argued that the MEB concept represents a completely different thought experiment from the MCPF. It constitutes a hypothetical lump-sum payment instead of an increase in a distortive tax, often an income tax. However, we argue that the relevant comparison is between the MCPF and the *marginal* MEB. Then it can be shown that one plus this marginal MEB is equal to the MCPF. This equality holds for any tax instrument. This result opens up for the possibility to use computable general equilibrium models (CGE) to estimate one plus the marginal MEB, i.e. the MCPF, for a number of different tax instruments. In turn a "vector" of MCPF's can be used in a discussion how different ways of financing a project affects its social profitability.

A drawback of this "conventional" approach is that the project in itself also might affect the economy's tax wedges. It seems extremely difficult to estimate such effects. Moreover, they are probably project specific. There seem to be no reason to believe that a national park has the same impact on private consumption and labor supply as a project aimed at reducing air pollution. Therefore, we propose an alternative treatment of taxes, an approach that provides rough upper and lower bounds for the project's social costs. This approach captures the effects of the project's impact on tax wedges as well as the MCPF.

In Johansson & Kriström (2010), currently available only in Swedish, we consider a more extensive re-regulation of the Ljusnan river. We consider changes that may satisfy both energy generation and ecological goals. In our application of this idea, we have analyzed a case in which we tear out two dams in the Ljusnan river and construct new turbines at an existing plant. We have chosen to call the scenario ”-2,+1” to reflect its generic structure. It is, in spirit, consistent with the Water Framework directive in terms of its focus on watersheds, as well as an underlying holistic principle of Swedish environmental legislation. For details, see the section on case studies below.

Emån

In the analytical work with the values related to the recreational fishing significant effort has expended to develop different models (Paulrud & Laitila, 2010; Paulrud, 2010). This work included models for willingness to pay as well as models for visitation frequency. In addition, we have tried to make existing models and new models more general and suited for benefit transfer. This has included making the models more practically applicable so that they can be used by stake holders in normal computer software packages like Excel.

To increase the knowledge of factors influencing consumer surplus of the fisher´s, the utility and the visitation frequency, a mail-survey was performed targeting recreational fishers that had fished salmon and/or Sea Trout, using Choice Experiments (CE).The CE-method is an economic method to elicit individual's marginal valuation of a goods different quality attributes. In this case the goods is a day of fishing and the quality attributes by others the expected catch of fish in different size classes. The method is built on the idea that the respondent chooses the preferred alternative out of two or more presented hypothetical alternatives. Each alternative is described by a number of quality attributes. The choice situation is repeated with the quality attributes altered in a systematic way (design). Each CE-question is followed by a frequency question where the respondent reveals how many days he or she would have visited the site if it had existed in real life. The results is analyzed in a cost and benefit perspective where the utility of a day's fishing for the recreational fisher is based on the quality attributes of the site and in turn affects the visitation frequency that finally will create the total utility (see further Paulrud and Laitila, 2010).

The mail-survey of recreational fishing also provided knowledge about the producer surplus of the companies with activities connected to the fishing. There has also been some need for a detailed study using an old data set from an earlier project targeting the recreational fishing companies (Paulrud and Waldo, 2010; Waldo & Paulrud, 2010a; and Laitila, Paulrud & Waldo, 2010). The effects on the supply of fishing services are naturally important in the CBA context.

Little is known about fishing rights ownership in Sweden. There, are for example, no computerised registers covering Swedish fishing right owners. Their goals for owning and managing fishing waters are unknown. One exception is the fishing owner associations. These associations have goals stipulated by law, namely to supply fishing opportunities etc. WP1 has actively taken part in a larger survey of Swedish fishing rights owners. That survey is aimed to describe the Swedish fishing rights owners, their goals, attitudes, management etc. A questionnaire has been sent to a sample of over 6 000 (presumed) fishing right owners in Sweden. Even if the results from this survey (autumn of 2010) will come a bit late for this project, this knowledge will beuseful for future work (Paulrud, Waldo, Olofsson and Laitila, 2010).

6 WP2 Statistics

6.1 Objectives

- Develop methods for evaluation of quality in models, data and the final CBA.
- Develop a strategy to handle the problem with nonresponses in the determination of WTP
- Develop methods to handle uncertainty in preferences

6.2 Analytical contributions

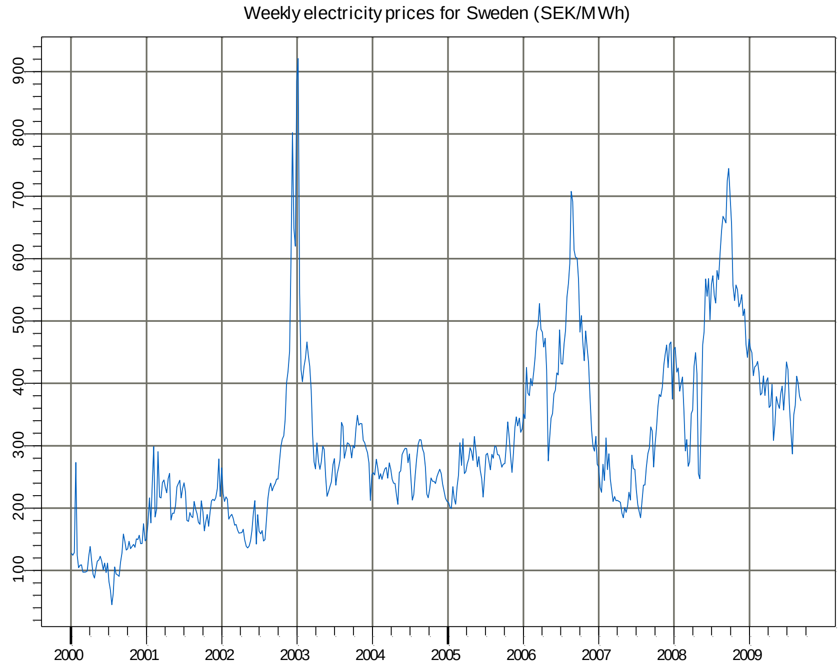
6.2.1 Electricity prices

Although the modeling of competitive electricity markets is still in the beginning a small but increasing literature has considered electricity prices using advanced econometric models. Both univariate and multivariate models exist. A natural approach when modeling electricity prices is to model the returns or more generally to describe the prices by an autoregressive process of order p. If the interest is in forecasting the prices far in the future or to investigate how different scenarios affect the prices it is less appropriate to use older prices to predict future prices. In Kuljus & Ranneby (2010) the approach is to model the prices without using previous prices. The deterministic part is modeled by regression techniques and then the residuals are described by a time series model. Changes of prices in one market may impact prices in several markets. For a detailed analysis it is necessary to have information also for gas and coal prices. Unfortunately, it has not been possible to get data for all markets.

We will model weekly electricity prices for Sweden during 2000-2009 using data from week 1, 2000 to week 37, 2009 (506 weeks in total). Below information are given about the response variable and the explanatory variables. Several variables are strongly affected by seasonal variation. One possibility is to try to fit some periodic function. It has shown to be quite difficult to get satisfactory descriptions of the seasonal variation. We have chosen an empirical approach. For every week we calculate an average value and use the deviation from that average as our variable. By using the arithmetic mean the influence from extreme years may be too high and by using the median the average may be imprecise. We have chosen a compromise and use a truncated mean where high and small values are not used.

Response variable: weekly area prices for Sweden (SEK/MWh)

Min	1st Qu	Median	Mean	3rd Qu	Max	Std
45	212	273	303	382	921	138



Explanatory variables:

I. **Water variables** (Svensk Energi, Folke Sjöbohm),
weekly data for week 1, 1995 – week 37, 2009

1) inflow to the Swedish and Norwegian hydropower reservoirs (GWh/week),
2) water reservoir content for Sweden and Norway (GWh).

To take into account seasonality in the water variables, we transform these variables. We calculate a truncated mean for every week $i, i = 1, \ldots, 52,$ by taking

away the two smallest and largest values for every week. For weeks 1 – 37 we have data for 15 years; for weeks 38 – 52 we have data for 14 years. For week 53 we take the mean of the values in 1998 and 2004.
Thereafter we form the standardized variables st.inflow.sweden, st.inflow.norway, st.res.sweden and st.res.norway in the following way:

$$st.water.country_t = water.country_t - trunc.mean(water.country)_t, \quad t = 1,...,53.$$

For every transformed water variable we consider separately the positive and negative part of it. For example:

inflow.pos.sweden = st.inflow.sweden, when st.inflow.sweden > 0 and 0 else;
inflow.neg.sweden = - st.inflow.sweden, when st.inflow.sweden < 0 and 0 else.

II. **Consumption** (Nord Pool Spot AB, Kristina Remec). We have data for daily consumption (MWh/day) in Sweden for 1/1/1996 – 25/11/2009. At first we summarize these as consumption per week (GWh/week). Since consumption has also seasonality effect, we consider again standardized (transformed) weekly values:

$$st.cons_t = consumption_t - trunc.mean(consumption)_t, \qquad t = 1,...,53.$$

For the truncated mean: we calculate again the mean without the two smallest and two largest values for every week. For weeks 1 – 37 we have data for 14, for weeks 38 – 52 for 13 years. In the model we look again separately at positive and negative part of the transformed consumption: cons.pos and cons.neg.

III. **Net price index (NPI)** (SCB´s homepage)
NPI (Net price index) - measures the fluctuations of consumer prices with indirect taxes deducted and subsidies added. NPI is currently presented on an index reference base of 1980=100.

IV. **EUA** – European Union Allowances (Pontus Ripstrand, NASDAQ OMX)
We have daily spot prices (EUR/ton) for 25/10/05 - 15/12/09. The prices exist only for weekdays. We calculate weekly prices by taking the mean of weekday prices and converting these into Swedish crowns. We use exchange rates from the Swedish Riksbank.

V. **Electricity export and import** from and to Sweden in GWh/week (Svensk Energi, Folke Sjöbohm). In the model we consider net exports

netexports = export – import

VI. **Nuclear power production** in Sweden (Svensk Energi, Folke Sjöbohm), weekly data (GWh/week) for 1995-2009. Because nuclear power production depends also on season, we use nuclear.pos and nuclear.neg (obtained in the same way as the positive and negative water and consumption variables) in modeling.

The variables used in modeling:

Variables	Unit
Elprice	SEK/MWh
res.norway.pos, res.norway.neg, res.sweden.pos, res.sweden.neg	GWh
inflow.norway.pos, inflow.norway.neg, inflow.sweden.pos, inflow.sweden.neg	GWh/week
cons.pos, cons.neg	GWh/week
nuclear.pos, nuclear.neg	GWh/week
NPI	
Netexports	GWh/week
EUA	SEK/ton

We use a time series regression modeling approach to describe the relationship between the response and explanatory variables. To take into account that the residuals are heteroscedastic and serially correlated, we use the Newey-West Heteroscedasticity and Autocorrelation Consistent (HAC) covariance matrix to compute the standard errors for the least squares estimates of the regression coefficients. By taking the serial correlation into account the standard errors of the coefficients increase which may reduce the number of variables that are significant.

The selected regression model is

$$elprice \sim npi + res.norway.pos + res.norway.neg + res.norway.neg^2 + inflow.norway.pos + netexports + eua$$

A test of the residuals shows that they are stationary but auto-correlated. For the whole period 2000-2009 an ARMA(1,2) or ARMA(1,4) gives a good description of the residuals. If we split the data into two periods 2000-2005 and 2006-2009 based on the introduction of EUA prices the residuals for period 1 is given by an ARMA(1,4) while for the second period it is sufficient to use an AR(1).

6.2.2 Uncertainty in preferences

The development of methods to measure willingness to pay (WTP) has renewed interest in cost-benefit analysis (CBA) for the economic evaluation of health care programs and environmental issues. We may ask how much people are willing to pay for changes in environmental quality. It depends of course on the individuals' preferences and their income. The preferences are summarized in a utility function *u* and the willingness to pay is defined as

$$u(y_0, z) = u(y_1, z - WTP). \qquad (1)$$

Here y_0 denotes current environmental quality, y_1 improved environmental quality, z income, and WTP the amount the individual is willing to pay for improving environmental quality from y_0 to y_1.

Usually in contingent valuation (CV) studies regarding willingness to pay the respondents give an exact value as his/her WTP-value. Unfortunately, the non-response rate has a tendency to be quite high. As an attempt to reduce that rate the respondents will have a possibility to give a self-selected interval instead of a fixed value as their WTP.

The concept of self-selected interval is closely related to interval-censored failure time data in survival analysis. Censoring mechanisms can be quite complicated and thus necessitate special methods of treatment. Different types of interval-censored data have been studied. Huang (1999) and Zhao et al. (2008) considered the partly interval-censored failure time data where observed data include both exact and interval-censored observations on the survival time of interest. Jammalamadaka and Mangalam (2003) introduced the concept of “middle censoring” which occurs when an observation becomes unobservable if it falls inside a random interval. However, standard methods for analyzing interval-censored and middle-censored data assume, implicitly or explicitly, that the censoring intervals are independent of the exact values. This is an assumption that may be questioned.

As a consequence we have developed and investigated some new methods to estimate mean WTP for the situation when self-selected intervals are allowed.

We propose (in Belyaev & Kriström (2010)), therefore, a different approach, arguing that there are two different probabilities involved. One probability is related to the conditional probability of finding WTP in a given interval; the second probability is related to the probability of choosing a particular interval. Here it is assumed that the censoring intervals follow a bivariate distribution with finitely many support points. Assuming that the respondents tend to state rounded intervals from a finite set this is a reasonable assumption. In this paper it is furthermore assumed that all respondents give self-selected intervals and consistency is proved.

In Ekström (2010) a slightly different situation is considered. Here it is assumed that some respondents give exact answers, some intervals and a third group answer both an exact value and an interval. It is assumed that the censoring intervals follow a bivariate distribution with finitely many support points. For this situation he derives a non-parametric maximum likelihood estimator. In a simulation study he compare that estimator with the Jammalamadaka & Mangalam estimator and finds that the latter has a tendency to give biased estimates if the respondents has a tendency to let the exact value be close to one of the endpoints. The proposed estimators by Ekström do not seem to share this problem.

In the paper by Ranneby & Yu (2010) three different approaches to estimate the mean willingness to pay are studied. It is assumed that some respondents give an exact value and that some give a self-selected interval. First we consider the nonparametric (the Jammalamadaka & Mangalam estimator) and a parametric approach (assuming a Weibull distribution) where the intervals are treated as if the respondent gives an exact value but we cannot observe it. Next we will give a different interpretation of the intervals: Included in the respondent’s answer is information about his/her uncertainty about what would be a reasonable value of WTP. For illustration purposes we will use data from the Dönje study (see Section 9.2)

To have a possibility to evaluate the extra uncertainty introduced by the fact that some respondents give an interval instead of an exact value we have to give a different interpretation of interval answers. We assume that, because of a number of uncertainties, instead of giving an exact value the answer is given by a random variable having a certain distribution, i.e. the WTP in equation (1) for individual *i* is given by W_i having mean value X_i. (Of course the expected value is a constant but randomness occurs depending on the selection of individuals to the panel). Certainly the respondent cannot give the answer as a distribution but has to approximate it by giving the lower and upper value of the interval and it is default what kind of distribution the respondent has in mind. The natural choices are a uniform distribution or a triangular distribution. Although symmetric distributions may be most natural we will also consider triangular distributions with mode in the left or right end of the interval.

For an interval observation $[L_i, R_i]$, the triangular distributions with L_i as the lower limit, R_i as the upper limit, and modes at $L_i, \frac{L_i+R_i}{2}$ and R_i (denoted as mode at 0, 0.5, and 1 in the tables in Section 9.2) respectively, or a uniform distribution are analyzed.

Suppose that the WTP for the ith respondent is W_i. After rearranging the data, we have the following observed data:

$$W_i = \begin{cases} X_i, & for\ exact\ responses\ \ i = 1, \dots, n_1 \\ X_i + \varepsilon_i, & for\ interval\ responses\ \ i = n_1 + 1, \dots, n_1 + n_2 (= n) \end{cases}$$

where X_i is the ``true" or expected WTP for the respondent and ε_i is a random variable, independent of X_i, that indicates the uncertainty in the answer.

As mentioned before, we assume that ε_i has a triangular distribution (with different modes) or a uniform distribution. Intuitively, the wider an interval one answers, the greater uncertainty a respondent has. In fact, for an interval observation $[L_i, R_i]$, the variances for ε_i are $\frac{(R_i-L_i)^2}{18}, \frac{(R_i-L_i)^2}{24}, \frac{(R_i-L_i)^2}{18}$, and $\frac{(R_i-L_i)^2}{12}$ for a triangular distribution with mode at 0, 0.5, and 1,or a uniform distribution, respectively.

Taking the interval uncertainty into account, we can estimate the variance of mean WTP by

$$\widehat{Var}(\overline{W}) = \frac{S_X^2}{n} + \frac{1}{n^2} \sum_{i=n_1+1}^{n} \frac{(R_i - L_i)^2}{c},$$

where S_X^2 is the sample variance of $\{X_i\}$ and

$$c = \begin{cases} 12, & \text{for uniform distribution;} \\ 18, & \text{for triangular distribution with mode at 0 or 1;} \\ 24, & \text{for triangular distribution with mode at 0.5.} \end{cases}$$

6.2.3 Error propagation

Different types of models and data will serve as input to the CBA. From a user point of view the quality of the different steps in the CBA, as well as the final CBA needs to be defined / declared. This will require not only well defined methods for assessing and describing the models and measurements themselves, but also methods that take into consideration the data used in the models and error propagation along the analysis.

Quality measures for each source/model have to be calculated together with a specification of the variability for each component and the interaction between the different components. Depending on the type of models and calculations leading to the final results different methods are employed to determine the propagation of uncertainties. If the model is not too complicated exact analysis or Taylor expansions can be used. However, if the model is large and consists of several steps or if it is a simulation model then Monte Carlo methods have to be used. Then for each level where we have uncertainties a distribution is specified. In the simplest case we can assume independence between the distributions but quite frequently the situation is more complicated and interaction between the different components must be taken into consideration.

How this can be done is illustrated by the population model developed in WP4.

The model consists of a large number of steps with uncertainty in each step. The population size is denoted by $N(t)$ and the construction of the model implies that the process $N(t)$ is ergodic and of Markovian type. That implies that when t tends to infinity then the marginal distribution of the process will be given by the stationary distribution. As a consequence the expected population size in the future can be estimated as a mean over time (calculated when stationarity is achieved). In the specification of the model there are a large number of parameters, where some are estimated from measurements and others are specified from expert knowledge and the literature. For the latter it is natural to assume a triangular distribution while for those estimated from measurements a normal distribution is the natural choice. However, to avoid a number of technical problems in the computer program the distribution for these parameters are also given by a triangular distribution (which we can view as an approximation of the normal distribution). For some parameters it is natural to assume independence between the distributions while it for others (e.g. related to weather conditions a specific year) the dependence between the distributions must be modeled.

The error analysis is included in the program developed by WP4, where also some numerical results are illustrated.

6.3 Empirical contributions

A. Modeling electricity prices

The Regression model

$$elprice \sim npi + res.norway.pos + res.norway.neg + res.norway.neg^2 + inflow.norway.pos + netexports + eua$$

has the following summary statistics

	Value	Std. error	t-value	Pr(>|t|)
Intercept	-1384.1537	170.3112	-8.1272	0.0000
NPI	7.0283	0.7303	9.6238	0.0000
res.norway.pos	-0.0070	0.0017	-4.2094	0.0000
res.norway.neg	-0.0180	0.0049	-3.7000	0.0002
res.norway.neg^2	1.70E-006	3.93E-007	4.3164	0.0000
inflow.norway.pos	-0.0176	0.0053	-3.3394	0.0009
Netexports	-0.1072	0.0209	-5.1332	0.0000
EUA	0.5692	0.0841	6.7673	0.0000

R-Squared 0.8218, Adjusted R-Squared 0.8193
Durbin-Watson Stat 0.3964
Residual standard error: 58.67 on 498 degrees of freedom

Remarks: The Durbin-Watson statistic for the innovation process in the time series model takes the value 2.04.

B. Scenarios

The estimated the regression function $f(t)$ can be used to estimate the effect of the explanatory variables in the model to the mean electricity price over a number of weeks. In the table below we consider nine different scenarios, i.e. nine combinations for the mean values of the explanatory variables. The number of weeks does not affect the estimated mean electricity price $\bar{f}$ or its standard deviation directly. But we have to take the number of weeks and the period of the year into account when we fix a certain mean for an explanatory variable – this value has to be reasonable.

The scenarios in the table:

1 – "standard" period according to our model

2, 3 – the EUA price increases

4 – import is higher than export

5 – export is higher than import during a number of weeks

6, 7 – correspond to a period when the value of the water reservoir content is lower than its mean (water scarcity). In our data set there is a period of 31 weeks at the end of 2002 – beginning of 2003 when the water reservoir content in Norway was more than 10000 GWh/week below its mean value. Another such a long period occurred in the second half of 2006. For scenario 6 import-export is in balance, in the case of 7 there is lack of electricity, i.e. a need to import.

8, 9 – correspond to a period when the inflow to the Norwegian hydropower reservoirs is above its mean value for several weeks. In our data set for example the inflow was more than 1000 GWh/week above its mean value during weeks 17-21 in 2000. The water reservoir content level in Norway during these weeks was more than 6000 GWh/week above its mean value. In the case of scenario 9 there is overflow of electricity in Sweden, thus the export from Sweden exceeds the import to Sweden.

Scenarios	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
NPI	250	250	250	250	250	250	250	250	250
res.norway.pos	0	0	0	0	0	0	0	6000	6000
res.norway.neg	0	0	0	0	0	13000	13000	0	0
inflow.norway.pos	0	0	0	0	0	0	0	1000	1000
Netexports	0	0	0	-400	400	0	-400	0	400
EUA	150	300	600	150	150	150	150	150	150
$\bar{f}$	458	544	714	501	415	510	553	398	356
standard error	13.9	20.4	42.7	16.6	15.8	17.0	18.4	12.6	16.1
95% CI	[431, 485]	[504, 594]	[631, 798]	[469, 534]	[384, 446]	[477, 544]	[517, 589]	[374, 423]	[324, 387]

6.4 Reflections on projects goals and achievements

One of the project goals was to develop methods to evaluate the uncertainty for the whole chain including the uncertainty in the final CBA. Within WP2 we have developed some general methods for evaluation of uncertainties. The Monte Carlo technique used for uncertainty evaluation of the population model can be tailored to get estimates for the final CBA. However, we have not tried to do that. Instead WP1 has introduced the “cost acceptable curve” to judge the uncertainty in the analysis.

The model developed for electricity prices has a high coefficient of determination and the residuals are stationary and can for the period 2006-2009 be described by an autoregressive process of order 1. Tests (both Durbin-Watson and Ljung-Box) show that the random variables in the innovation-process are uncorrelated. This is very satisfactory although it is expected that the model can be further improved if additional explanatory variables are available. The scenarios described are included to illustrate what can be done. A deeper scenario analysis requires a detailed examination of which values should be given to the different explanatory variables.

In the project it was planned to investigate if the non-respondents acted differently than respondents. However by asking a consulting company to conduct the survey (see Section 11.2) this study has to be cancelled. Fortunately, the results about self-selected intervals show that the additional uncertainty because of interval-answers is not so high and a slightly larger sample size compensates for that (see Section 9.2). If the introduction of the possibility to give self-selected intervals gives a much higher response rate the extra sample for checking the behavior of the non-respondents may be unnecessary.

Estimation of WTP when self-selected intervals are allowed has been investigated thoroughly. We have shown that traditional methods are not appropriate. Belyaev & Kriström shows consistency of a non-parametric estimator when all respondents answer intervals. However, it should be rather straightforward to show consistency for their estimator also for the situation with answers both as exact values and intervals. The results of the Dönje-study indicates that the SCE (Self-Consistent Estimator) by Jammalamadaka & Mangalam underestimates the WTP, which indicates that the respondents given an interval has a tendency to be closer to the upper bound of the interval. If that is really the case when evaluating the uncertainty introduced by the interval answers the triangular distribution with mode at the right endpoint should be used.

7 WP3 Emån

7.1 Objectives

The objectives in the original application were to study both upstream and downstream passage problems, but due to budget constraints, a shift in focus was requested by the Program Board. Given that we had investigated upstream passage in the previous phases of this program, we agreed to remove all proposed work dealing with upstream passage and remove most work associated with eels. Instead, focus was placed on the other objectives of WP 3, and we reformulated our objectives as described below:

1. Obtain additional information about the different life stages of the trout population in the River Emån, to be used in the population model:
    a. Smolt production and age at smoltification
    b. Kelt downstream migration
    c. Design, install and evaluate guidance measures for reducing mortality of trout during downstream passage at hydroelectric plants (HEP) (assuming additional funding could be obtained)
2. Population model
    a. Modify a salmon model developed by Kjell Leonardsson to make it suitable for anadromous trout in the River Emån (Leonardsson, 2009).
    b. Parameterize the model with data from our River Emån studies, conducted since 2000, and from the literature.
3. Examine the effects of fragmentation on non-salmonids, using chub and eel as model species, with focus on the chub. This is because we received separate funding from E.ON for studying passage problems in eel.
    a. Chub: investigate the impact of hydropower dams on chub movements in the River Emån
    b. Eels: investigate behavior of eels during downstream passage of obstacles.

7.2 Methods

Study site

The study was conducted from May 2007 to June 2010 in the River Emån (57°07’59’’N; 16°30’00’’E), a river that has been regulated for approximately 100 years and has a long history of supporting a recreational and commercial fishery (Trybom, 1890; Klippinge, 1999). At present, the first definitive obstacle for anadromous species in the river Emån is located at Högsby, about 54 km upstream of the Baltic Sea. For fish to get that far, however, they first have to pass the gates at the dam at Emsfors (HEP 0, no turbines in operation), which are always kept open and thus allow fish to pass freely, a vertical slot fishway at the hydropower plant in Karlshammar (HEP 1), followed by the two nature-like fishways at Finsjö (HEPs 2–3), which were constructed in 2000 (Figure 1A). HEP 3 is separated from HEP 2 by an 800 m long stretch of slow-flowing, deep water. At HEP 2, the entrance of the fishway is located at the tail-race of the power plant (Figure 1C, no. 2). Water from the power plant and the former channel conjoin approximately 350 m downstream of the power plant (Figure 1C, no. 1). At HEP 3 the entrance to the fishway is located in the former channel, approximately 250 m upstream of the tail-race, and fish have to pass a small waterfall (Figure 1B, no. 3) to reach the fishway (Figure 1B, no. 4). Results from phase 1 and 2 of this research program (2000-2006) showed that the relative discharge along the different migration routes past the power plants varied with flow conditions and power plant operation and influenced passage success of upstream migrants (Calles and Greenberg 2005, 2009).

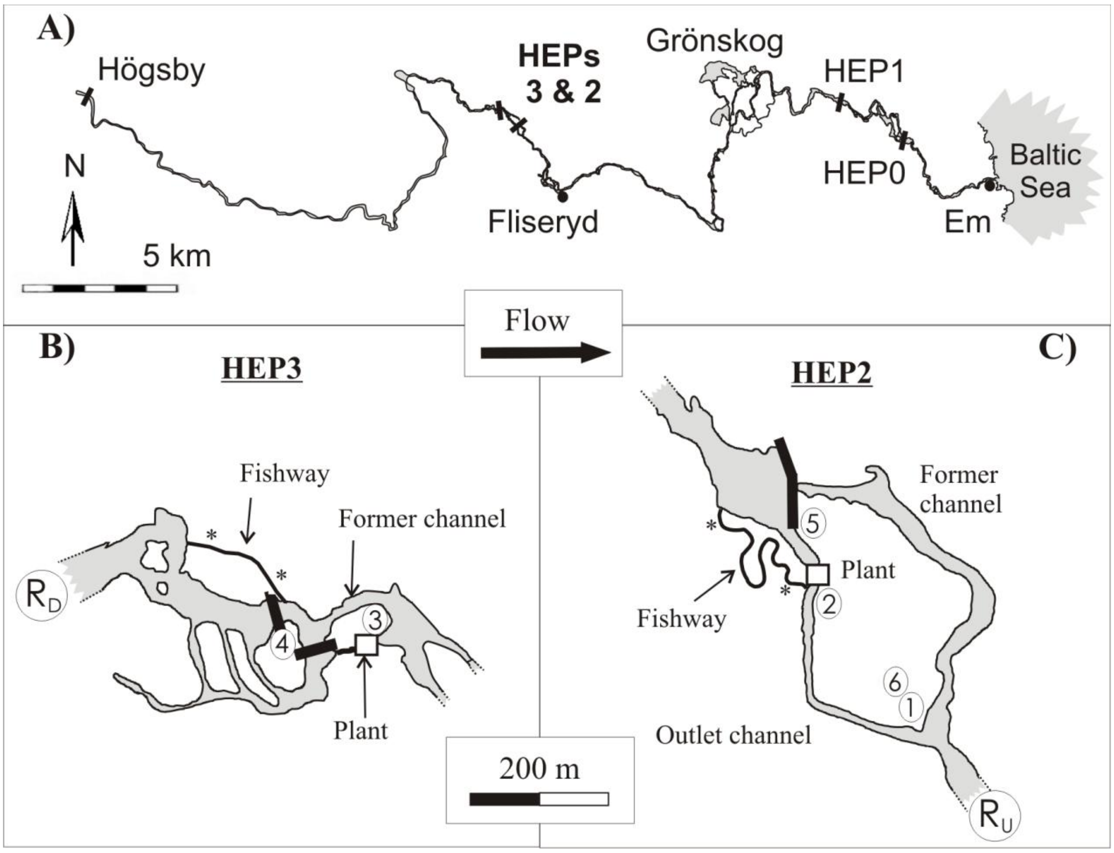


Figure 1. (A) Map showing the lower 54 km of the river Emån, with fishways at the former hydroelectric plant (HEP) in Emsfors (HEP 0, 5.3km from sea), and the operating HEPs at Karlshammar (HEP 1, 8.8 km), and lower (HEP 2, 28.8 km) and upper Finsjö (HEP 3, 29.6 km). (B) Map of area around HEP 3 and (C) Map of area around HEP 2. Circled numbers refer to different locations in the river.

The power plant at HEP 3 has a total capacity of 14 $m^3 s^{-1}$ and is equipped with two twin-Francis units from 1919 (i.e. four runners, Table I). The power plant at HEP 2 has twice that capacity, using one large Kaplan runner. HEP 1 is equipped with one Kaplan and one Francis runner, whereas HEP 0 has been inoperational for several years. Trash racks are present at all power plants, with 20 and 30 mm spacing at HEPs 3 and 2, respectively. Before 2009, there were no devices guiding downstream-moving fish, but there were 1m deep trash deflectors at both power plants in Finsjö and these could potentially be used to lead fish to the trash gates adjacent to the turbine intakes. If fish were to swim through the trash gates at both plants, they would fall several meters before striking a hard concrete surface. To evaluate the capacity of the trash deflectors as fish guiding devices, and to decrease the risk of injury for fish, wolf traps were constructed at the trash gates of HEP 3 (Figure 1B, no. 3, 2007), HEP 2 (Figure 1C, no. 2, 2007-2009) and HEP 1 (Figure 1A, 2009). More information about the river Emån and the hydropower plants in the lower parts of the river can be found in Calles and Greenberg (2005; 2007; 2009). For information on the river and its long history of recreational fishing see Sjöstrand (1999) and Klippinge (1999).

Trout life-stage studies

Smolt production and age at smoltification

Smolt production of the River Emån was estimated in cooperation with the National Fisheries Board (Lars Karlsson) by installing two screw-traps with leader arms, near the mouth of the river (Fig. 1A). The trap was checked daily, and all fish were counted and measured (total length, TL, mm). All trout and salmon smolts were individually marked with external streamer tags (TL < 120 mm) or Carlin tags (TL > 120 mm), moved one km upstream of the traps and released into the river. The proportion of individuals that were recaptured was used to estimate the total smolt production of the river. In addition, the age/size distribution of smolts was described. The traps were operative from mid-April to late May in 2007 and 2008.

Otoliths were removed from 23 brown trout kelts that were captured at in the River Emån, primarily during the years 2007-2009. Most individuals were captured near the river mouth in Em but a few were also captured at Emsfors. The fish ranged from 1.8 kg to 9.7 kg. Otoliths were ground and polished to expose the core. They were then analyzed with micro-PIXE across each otolith at distances of 6 microns. Spatial maps of strontium and calcium were obtained for each fish, which were then used to identify when the fish were in salt vs. freshwater. A high ratio of strontium to calcium concentrations indicates life in saltwater and a low ratio, freshwater. Maps were even obtained for zinc and manganese for those otoliths with detectable levels.

Kelt downstream migration

For the post-spawner study, sea trout (N=26) and salmon (N=5) spawners were caught in the fishway at HEP 1 in autumn 2008. The fish were held in a large tank (about 800 L), which was constantly flushed with river water. Captured fish, without visible injuries, were anaesthetized using benzocaine (5-14 min), measured, weighed and tagged following the standard procedure for surgical implants of trailing-whip antenna radio-transmitters (Jepsen et al., 2002). A 25 mm long incision was made on the ventral body surface, between the pectoral and pelvic fins, into which a radio-transmitter was inserted (model F1835, 14 g, Advanced Telemetry Systems (ATS), USA). The tagging procedure lasted 3-6.5 min. After tagging, the fish were put in a large tank and transported to HEP 4 (Högsby, Fig. 1), the first definitive obstacle in Emån, where they were released about 200 m downstream of the tail-race. The reason for releasing the fish at HEP 4 was to ensure that the fish would be forced to pass all three HEPs (1-3) on their way back to sea and thereby maximise the number of observations per HEP.

Downstream guidance

Overhead cover: A 1 m-deep, angled trash deflector was used to lead fish to the trash gate adjacent to the turbine intake at upper Finsjö. The trash deflector was used in combination with studying the effect of overhead cover. This was accomplished by mounting a tarpaulin over the canal, immediately upstream of the turbine intake. The tarpaulin was mounted using rope and clamps, attaching it to the trash deflector and the rack. The tarpaulin was set up and removed approximately every two days from 26 April until 23 May, so that 47% the time the tarpaulin was in place, the remaining 53% of the time it was not. To evaluate the functionality of the trash deflector used in combination with overhead cover as a fish guidance device, wolf traps, constructed immediately downstream of the trash gate, were used to capture the fish.

Bypass system: Our previous studies of downstream passage in the River Emån have shown that downstream moving fish run a high risk of getting injured at the hydroelectric facility at upper Finsjö (Calles & Greenberg, 2009). Large individuals cannot pass through the 20 mm trash rack and many of them spend a long time swimming, apparently looking for a way out. Small individuals and weak swimming species have three options when encountering the dams: they may become impinged and die on the rack, they may be consumed by predators or they may pass through the rack and turbines. The turbine-induced mortality at upper Finsjö is 30-70% (Engqvist, 2009; Olson, 2005; Calles & Greenberg, 2009). To reduce mortality associated with passage of upper Finsjö, additional funding from the Swedish Environmental Protection Agency (Naturvårdsverkets Havsmiljöanslag) was obtained to replace the 20 mm rack, with a 75° vertical inclination, that was currently in place. It was replaced with 18 mm rack, with a 35° vertical inclination that included a surface bypass system (Fig. 2, designed by Olle Calles and Johan Tielman, E.ON, after meeting with and consulting world leading experts in the field: Michel Larinier och Francois Travade, EDF, France; Ed Meyer, John Ferguson and John Williams, NOOA, U.S. and Dave Scruton, Fisheries and Oceans, Canada). The bypass systems in the River Emån and the River Ätran (companion project) are the first of their kind to be built in Sweden.

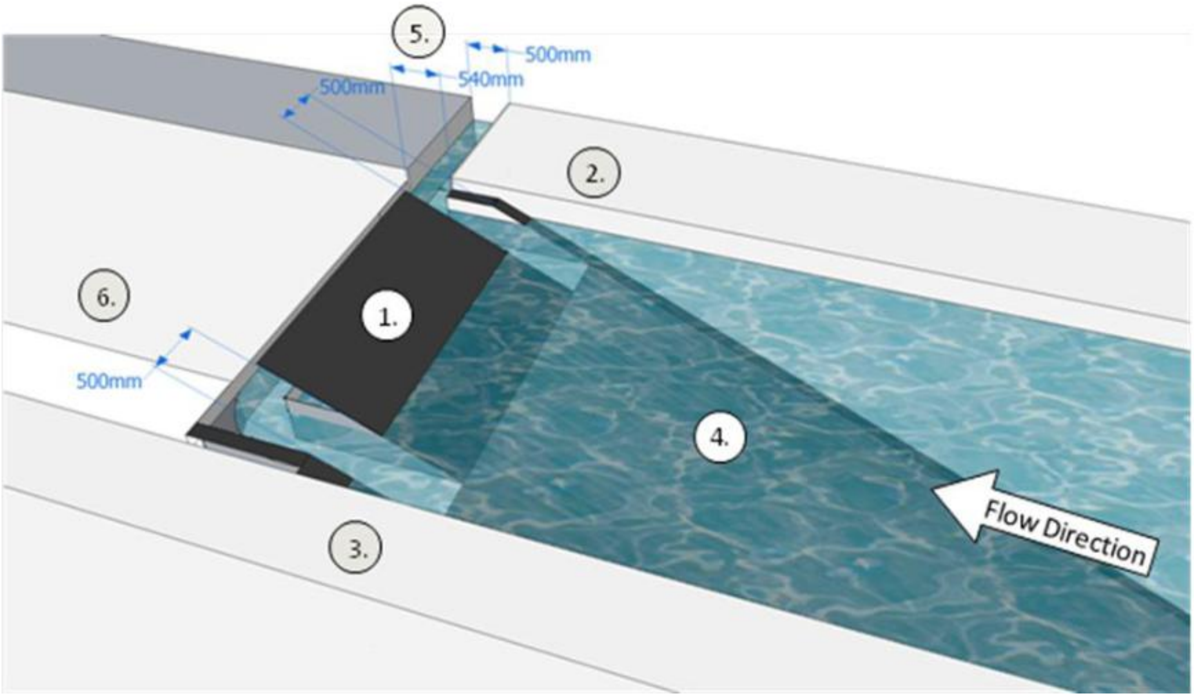


Figure 2. Angled view from above of the new low-sloping rack and surface bypass at HEP 3 (upper Finsjö) in the River Emån Sweden. Figure was drawn by Simon Karlsson, University of Southampton. Fish are expected to arrive via no. 4 and then choose one of the bypass openings (no. 2 or 3) and go with the flow to the chute (downstream no. 5).

The guiding device was evaluated during spring 2009 and 2010. Evaluation consisted of (1) a description of all fish (number of individuals and species) that were caught in the trap at the end of the chute of the surface bypass system (April 29 – May 28, 2009; 23 April – 3 June, 2010), (2) radio-telemetry on smolt released upstream of the bypass device in 2009, (N=32) and PIT-telemetry in 2010 (N=36), and (3) camera recordings of fish behaviour at the rack and entrance of the surface bypass system. To test for the influence of hydraulics in the bypass system on the number of fish caught, different situations were tested and the hydraulic conditions mapped using a flow meter or an ADV (acoustic doppler velocimeter). In 2009, the discharge was altered between high (150 L s^{-1}) and low flow (121 L s^{-1}), whereas in 2010 only the north opening was kept open with a constant discharge. The test in 2010 consisted of modifying the bypass entrance by smoothing out the corners to try to minimise turbulence, and this modification is referred to as the “the turbulence modification”. When only the north entrance was kept open the maximum discharge was 153 L s^{-1}, and when the turbulence modification was implemented the maximum discharge was 144 L s^{-1}.

Population model

The original model was developed for Atlantic salmon populations (Leonardsson, 2009), and as a part of this project it was modified to fit an anadromous trout population. A detailed description of the model can be found in Leonardsson (2010). The main objective, as described above, was to investigate the ecological effects of different remedial measures on the anadromous trout population in the River Emån. These data were then used in the economic analysis carried out by Anton Paulrud. Four different scenarios were tested (see Figs. 1 and 2 for details):

1. Today's situation: Sea trout have access to the five lowermost sections of the river (sections A-E, Fig. 3) via fishways at HEPs 1-3, but without any measures for improved downstream passage.
2. Sea trout have access to the five lowermost sections of the river (sections A-E, Fig. 3,) via fishways at HEPs 1-3, and with measures for improved downstream passage at all three HEPs.
3. Sea trout have access to the seven lowermost parts of the river (sections A-G; Fig. 3) via fishways at HEPs 1-5, but without any measures for improved downstream passage.
4. Sea trout have access to the seven lowermost parts of the river (sections A-G; Fig. 3) via fishways at HEPs 1-5, and with measures for improved downstream passage at all five HEPs.

Fragmentation and non-salmonids

Chub

A pilot-study was carried out on radio-tagged chub (N=21, model F1540, ATS, USA) that were tracked during spring 2007 to study the extent of their movements and the feasibility of radio-tagging. A full-scale study was initiated in 2008, and adult chub were caught by means of rod and line fishing (N=79) in April-June 2008. The fish were kept in "cyprinid bags" while fishing and were then brought to upper Finsjö where they were kept in tanks until tagging. Water from the river was pumped from the river into the tanks. Captured fish, without visible injuries, were anaesthetized using benzocaine, measured, weighed and tagged following the standard procedure for surgical implants of trailing-whip antenna radio-transmitters (Jepsen et al., 2002). A 10-20 mm long incision was made on the ventral body surface, between the pectoral and pelvic fins, into which a radio-transmitter was inserted (model F1820, N=20, 8 g and 1835, N=59, 14 g; ATS, USA). After tagging, the fish were released into an open, perforated container, which allowed the fish to continue their journey when they were ready. Scales (N=35) were sampled for age determination.

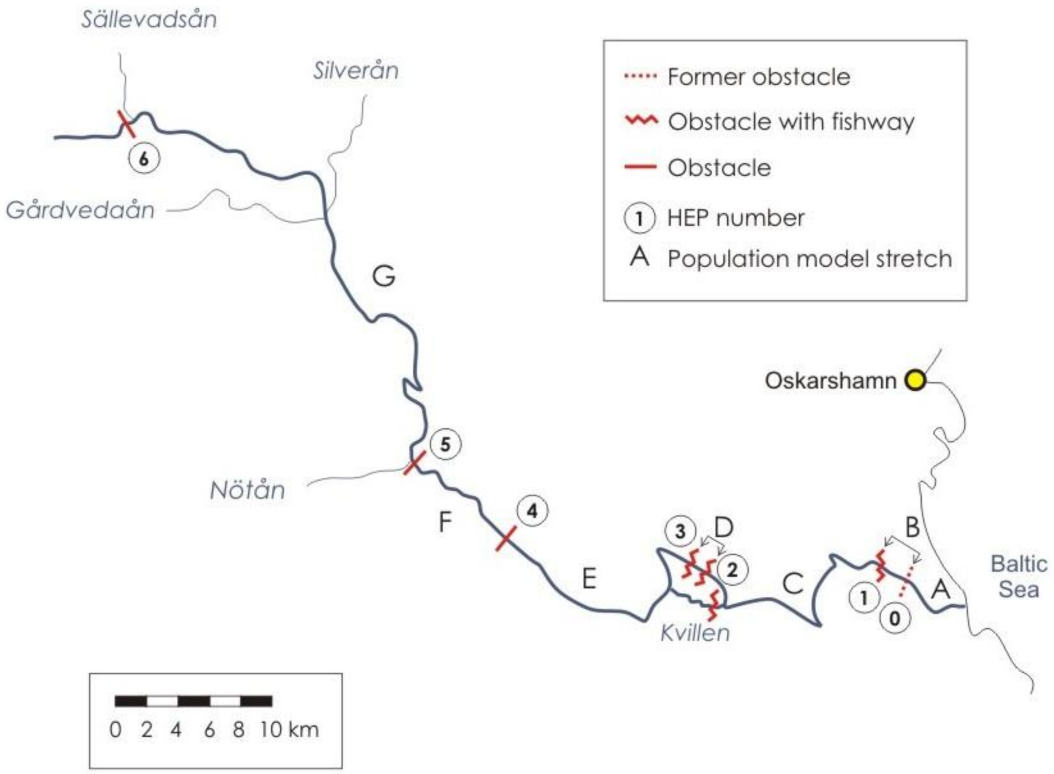


Figure 3. The lower portion of the River Emån, showing the seven sections used in the population model. The five most downstream sections, sections A-E, are currently accessible for anadromous fish. Sections F and G are not accessible today. The seven sections are: 1) Baltic Sea – Emsfors, 2) Emsfors – Karlshammar, 3) Karlshammar – lower Finsjö, 4) lower Finsjö-upper Finsjö, 5) upper Finsjö - Högsby including Kvillen, 6) Högsby - Blankaström, 7) Blankaström -Järnforsen including the tributaries Rivers Nötån, Gårdvedaån, Silverån and Sällevadsån.

The study of chubs entailed four study groups, an upper (N= 25) and a lower treatment group (N= 24) and an upper (N=15) and a lower (N=15) control group. The lower treatment group was released downstream of lower Finsjö, and the upper treatment group was released upstream of upper Finsjö, i.e. separated by the two hydroelectric facilities in Finsjö, which are passable via spill gates (for downstream migrants) and the two nature-like fishways (Calles & Greenberg, 2005, 2007, 2009). The two control groups were released about 7 km downstream of lower Finsjö, but instead of being separated from each other by two dams, they were separated by the presence of a large rapids area. The distance between the release sites for the two treatment groups and for the two control groups was the same, i.e. 1.3 km. The average size of the fish belonging to the upper and lower treatment groups was 963 g/427 mm (N=25) and 953 g/433 mm (N=24), respectively. The average size for the upper and lower control groups was 929 g/424 mm (N=15) and 910 g/ 426 mm (N=15), respectively.

The fish were tracked more or less continuously using permanently-mounted automatic stations strategically placed along the 1.3 km long sections, separating the two treatment and two control groups from one another. This enabled us to detect individuals passing the dams (treatment groups) or the rapids area (control groups). In addition, manual tracking was conducted monthly, except during the peak migration period in spring when tracking was performed more often. On four occasions the actual holding position of each located individual was identified and measured in terms of water depth, water velocity and substrate composition.

Eel

Downstream passage of eels in Ätran, including evaluation of a newly-designed and installed surface bypass system, was studied in a separate E.ON-financed project and is thus not reported here (see Calles & Bergdahl, 2009; Calles et *al*. 2010). For this project, we limited our research on eel to a single study, conducted in collaboration with researchers at the University of Southampton, on the behavioral response of downstream migrating eels to hydraulic conditions in a laboratory environment (Russon et al. 2010). Specifically, we studied the response of downstream migrating adult eels to bar racks (12 mm bar spacing) with different angles on the vertical and horizontal planes under different flow regimes and during periods of darkness. This was studied in a 21.4 m long (1.37 m wide, 0.6 m deep), glass-walled recirculatory flume at the University of Southampton. Eel behavior was recorded using a combination of overhead and side-mounted cameras, capable of filming under low light with infra-red illumination.

Results and discussion

Trout life stage studies

Smolt production and age at smoltification

The age distribution and production of smolts in the River Emån was estimated using the screw-trap data. Based on the two years of sampling, Emån produced 1729 (± 660) brown trout smolts and 2688 salmon smolts per year. In addition, several thousand salmonid fry (trout and/or salmon) were caught migrating to the Baltic Sea. For salmon smolts, 45% were one year of age (118 mm) and 55% were two years of age (138 mm). For brown trout smolts, 51% of the smolts were one year of age (125 mm), 43% were two years of age (159 mm) and 6% were 3 years of age (191 mm), which contrasts with previous data from the River Emån in which two-year-old smolts always dominated (Svärdsson, 1967; Klippinge, 1999). Now it appears that one-year-old smolts are slightly more numerous than two-year-old smolts. On top of that, based on the ratio of strontium to calcium, we found that 13% of the 23 fish (i. e., 3 fish) studied had more or less moved directly out to the Baltic Sea (Fig. 4). The remaining 20 fish spent varying amounts of time in freshwater before leaving for the sea. The results from Limburg et al. (2001) indicated a much higher degree of precociously-emigrant spawners (71%) from Emån, but the sample-size in that study was very limited. Even if the exact fraction of precociously-emigrant spawners is uncertain, the fact remains that a portion of today's trout spawning population in the River Emån is made up of individuals with very limited time spent in freshwater as juveniles, which will also have an effect on our estimates of recruits to the spawner population. The occurrence of precociously emigrant spawners has previously been reported from small ephemeral trout streams on the island of Gotland (Limburg et al., 2001).

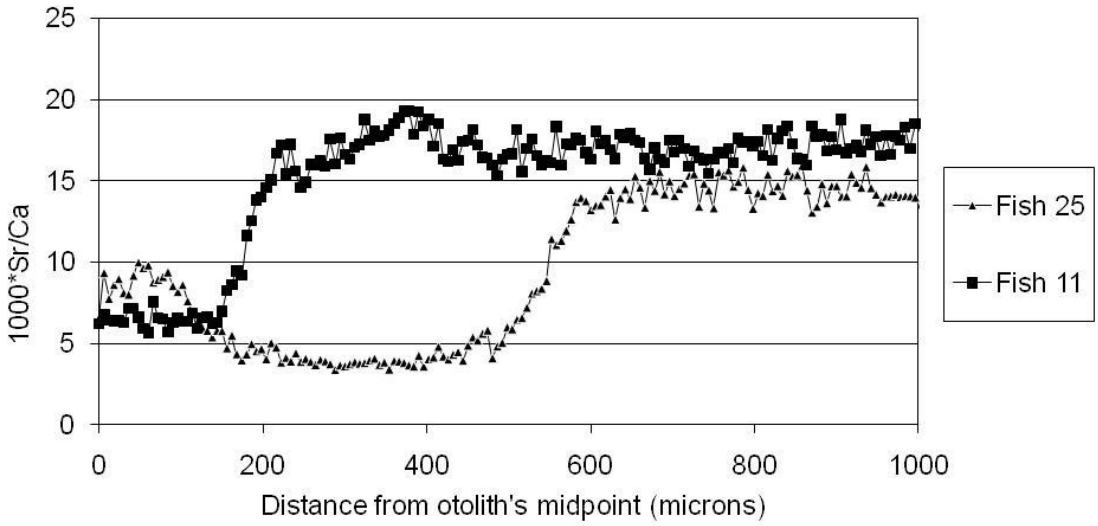


Figure 4. Otolith microchemistry for 2 trout caught in the River Emån. The Sr/Ca (x 1000) is plotted as measured from the otolith's origin (from egg stage) to its edge (at death) at intervals of 6 microns. Fish 11 represents a precociously emigrant spawner, with signs of entering marine waters early in life (Sr/Ca values of 15-20), whereas fish 25 has undergone the more commonly observed freshwater phase (Sr/Ca values < 5) before entering the sea.

Kelt downstream migration

All spawners were released at HEP 4 in fall 2008, and 84% of them remained near HEP 4 throughout the fall and winter, although a couple of individuals moved as far downstream as HEP 2. In addition, males were more mobile than females. All radio-tagged trout (N=26) survived winter, whereas two radio-tagged salmon died (40% mortality).

The median start for spring migration was 13 April (range: 2-27 April), and this was independent of sex and size of fish. In total, 12 of 25 trout (48 %) that initiated migration upstream of HEP 3 reached the Baltic Sea between 10 April and 27 May. Median time from migration start until they reached the sea was 28 days (range: 4.0-44 days). A median total delay of 16.8 days (range: 1.95-39.6 days) at the three power plants was observed for those fish that overwintered upstream of HEP 3. The median delay was longest at HEP 2, 16 days (range: 1 h-30 days), and manual tracking at HEP 2 showed that the fish moved back and forth between power stations. The median delay was brief at HEP 3 (28 minutes; range: 7 min-1.8 days), since the spill gates were open while the bypass system was being installed. The median delay at HEP 3 was 2.0 days (range: 6 min-20 days). Most dam passages for the three HEPS occurred during the morning.

Mortality during migration was low as only two fish could be confirmed dead. One was consumed by a predator and one died due to handling by us at HEP 3. The following winter (December 2009), we estimated that 50% of the 12 fish that never reached the Baltic Sea had died in the river. In December, we also noted that three of the fish that had migrated to the Baltic Sea had returned to Emån. Two were found upstream of HEP 3 and one upstream of HEP 1.

Downstream guidance

Overhead Cover: The use of a tarpaulin as overhead cover resulted in a larger percentage of smolts passing through the trash gate rather than through the turbines. Specifically 31% passed through the trash gate instead of the turbine when the tarpaulin was present, whereas all fish passed through the turbine in the absence of the tarpaulin ($X^2 = 4.57$, df = 1, P = 0.033). For the 17 passages for which time of passage could be identified, 10 of these occurred during daylight hours (59%). Four of six occurred during the day when the tarpaulin was in place and six of 11 occurred during the day when there was no tarpaulin in place.

Without more detailed behavioural studies, it is difficult to understand how overhead cover affects route selection. It is unclear whether the trout were reacting to a change in light climate associated with the overhead cover or to the physical presence of overhead structure. Whatever the mechanism, several studies have reported a reluctance by fish to enter covered or darkened structures (Glass & Wardle 1995, Welton et al. 2002), and this fact may be used in designing diversionary structures for smolts. Our results show that upper Finsjö, and presumably other power plants with Francis turbines, are in need of a functioning guidance system. Use of overhead cover and trash deflectors represents an inexpensive measure that could be used if channel flows are not too high, so that fish have the possibility to choose alternative routes. Nevertheless, such measures alone may not be sufficient, given that 69% of the smolts in our study still passed the dam via the turbines. At best this method could be used as a complement to other remedial measures.

Bypass system: A total of 1043 individuals belonging to 17 species were caught in the bypass facility in spring 2009 and 2010. The most commonly caught species were rudd (N=361), brown trout (N=137), roach (N=142), bleak (N=103), Atlantic salmon (N=49) and chub (N=31). Rudd and Atlantic salmon were only caught in 2010. Other species, such as pike (N=12), perch (N=10), white bream (N=9), common bream (N=9), tench (N=7), zander (N=4), ruffe (N=1), rainbow trout (N=1) and lamprey (N=1) were not caught as frequently.

Flow conditions differed between 2009 and 2010 in Emån. The magnitude of the spring flood was higher and the duration longer in 2010 than in 2009. Of the tagged individuals released upstream in 2009, 16 of 35 trout smolts (46%) were recaptured in the bypass, and the overall passage success was 84% (26 of 31 fish). The radio-tagged individuals that successfully passed the HEP without moving into the bypass did so by swimming through spill gates into the former channel. In 2010, fish were tagged with streamers and not radio-tags. Of the streamer-tagged individuals released upstream of HEP 3 in 2010, 10 of 42 trout smolts (24%) and three of 26 salmon smolts (12%) were recaptured in the bypass system. Since radio-telemetry was not used in 2010, no information is available as to what happened to the individuals that were not recaptured in the bypass system.

In 2010, the turbulence modification device at the entrance to the bypass resulted in a higher total catch when the device was in use (51% of time and 66% of catch), then when it was not in use (49% of time, 34% of total catch). The result was observed for Atlantic salmon (65:35), chub (75:25), bleak (73:27), roach (62:38) and rudd (73:27), but the opposite result was observed for brown trout (71:29). Hydraulic measurements showed that the turbulence modification device successfully reduced turbulence and that velocity increased more evenly in the entrance than without the device (Fig. 5).

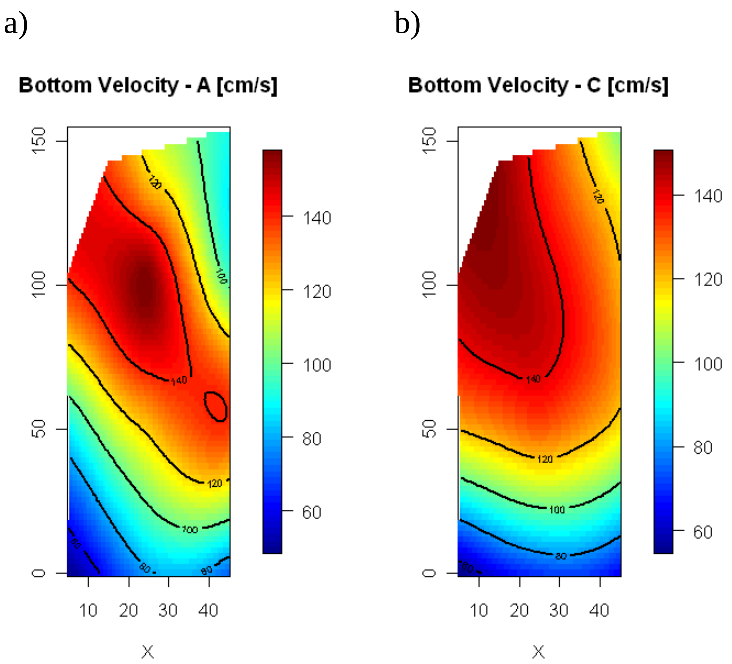


Figure 5. The flow patterns in the north bypass entrance in upper Finsjö 2010 at full discharge without (a) and with (b) the turbulence modification device.

Population model

The parameters used in the population model are presented in Table I. A more detailed description of the parameterization of the model can be found in Leonardsson, Calles & Greenberg (2010).

Table I. Parameters used in the population model for anadromous trout in the River Emån.

Parameter	Description
AntalOmr	No. of river areas used in model
Bb	No. of YOY that survived from hatching until after summer
MaxSmoltAge	Maximum smolt age
pSmoltAge	Probablitity of smoltifying at a given age
pSurv	Probablitiy of survival for different age classes in the river
pNonPrecocious	Proportion of fish that migrate to the sea
pPostSmoltSurv	Post-smolt survival
pSeaSurv	Survival at sea per year
pFisherySW1	Proportion of fish that captured by fishing during their first winter at sea
pFishery	Proportion of fish that captured by fishing per year after their first winter at sea
pSW	Proportion of male and female fish that return to the river for spawning at a given age
SmoltPerHektar	The maximum smolt production that can be achieved in the river
K	Carrying capacity – per area
Dist	Predation loss for smolts
pSmoltPassage	Proportion of smolt that successfully passes each power station during downstream migration
pKeltPassage	Proportion of kelt/large adults that successfully passes each power station

	during downstream migration
pHoming	Probability of homing for spawners
pReturnMigr	Proportion of spawners that successfully passes each power station during upstream migration
pReturnFishing	Probabliity for spawners to be caught by fishing during upstream migration
pKeltFishing	Probability for kelt to be caught by fishing during migration back to the sea
pKeltRiverSurvival	Probability for kelt to survive winter in the river
pKeltSeaSurvival1	Probability for kelt to survive the first summer/first year at sea.
pKelt1yr	Probability for kelt to return for spawning after one year at sea

The results of the model are described elsewhere in the report. In short, the number of spawners varied, from 991 spawners in scenario 1, 1380 spawners in scenario 2, 1537 spawners in scenario 3 and 1715 spawners in scenario 4.

Fragmentation and non-salmonids

Chub

The chub scales that have been analysed so far (N=18) show a close correlation between size and age, with the smallest individual (340 mm/ 420 g) being about 6 years old and the largest individual (590 mm/2340 g) being about 13 years old. Data from the pilot-study in 2007 revealed that the chub spawned in late May, and the fish occupied areas about 0.5 m in depth, with intermediate current velocities and vegetated substrates (Månsson, 2007).

Of the 79 radio-tagged chubs, three were confirmed dead. Two of the individuals released upstream of HEP 3 (Treatment-upstream) were found dead on the intake rack at HEP 2, 17 and 23 days after release. A third individual (treatment-downstream) was caught and killed by a fisherman 44 days after release. None of the remaining 46 radio-tagged chubs released at HEPs 2 and 3 (treatment fish) passed both of the HEPs during the 21 month long study period from April 2008 – December 2009. Among the control fish (N=30), 43% passed the rapids area at least once during the same period (average 1.4 passages). It was more common for a control fish released upstream of the rapids area to pass the rapids (8 of 15 = 53%, average = 2.3 passages) than for control fish released downstream of the rapids (5 of 15 = 33%, average = 0.5 passages). We even have data on the presence of fish in the vicinity of the HEPs or rapid areas. We found that 25% (12 of 49) of the treatment fish and 30% (nine of 30) of the control fish approached a HEP (treatment fish) or the rapids (control fish) without passage. Again, the individuals released upstream of the study reach were most prone to approach the HEP or rapids, with 40% of the treatment fish doing so (10 of 25) and 47% of the control group (7 of 15). We believe the lack of passage of HEP 2 by the chubs reflects poor attraction efficiency of the fishway and not poor passage efficiency as passage efficiency, which was measured in Calles & Greenberg (2007), was 86%. However, this is somewhat speculative on our part as passage efficiency was measured for HEP 3 and not for HEP 2 (Calles & Greenberg, 2009).

Eel

Results from the behavioral study of eels showed that eels predominantly moved along the channel floor and wall of the flume, tending to follow routes where turbulence intensity was high. Time taken to approach the rack was greater than expected if fish had moved passively with the flow. Eels did not exhibit clear avoidance behavior prior to encountering the rack, instead marked changes in behavior occurred only after physical contact was made with the structure. No impingement or passage through the rack occurred, and passes per approach were high (98.3%), when a vertical rack was angled 15^{o}, 30^{o} or 45^{o} relative to the flow. Impingement and passage through the rack only occurred when a horizontally inclined rack was placed perpendicular to the flow. The time eels were impinged on the rack was negatively related to discharge when angled at 30^{o} relative to the channel floor, and positively related when upright. Frequency of impingement was higher under low discharge (133 L/sec). Impinged eels escaped from the rack at approach velocities of 0.90 ± 0.05 m/sec. Passage through the upright rack was common under high discharge (279 L/sec). The results of this study can potentially be used to improve current fish passage criteria for European eels, so that more effective fish passage facilities can be built.

7.5 Reflections on projects goals and achievements

Trout life stage studies
Kelt downstream migration
Relatively few studies have looked at downstream passage success of kelts. While turbine-induced mortality was non-existent in the River Emån, due to the presence trash racks, the kelts experienced problems, with 48% reaching the Baltic Sea. We saw them frequently moving back and forth between dams, unable to find a way to proceed past them. In 2009, many spill gates were closed, forcing fish to use the fishways, which are not constructed for downstream passage, and which proved to be difficult to find. At Karlshammar, the Gustaf Ulfsparre Foundation paid to increase the opening at one of the spill gates, and most of the kelts that were in the vicinity of this spill gate managed to swim past the dam upon its opening. In contrast, opening the spill gate at lower Finsjö, albeit not to the same extent as at Kalrshammar, did not increase passage success. Thus, we recommend that appropriate authorities consider what paths are available past dams during kelt outmigration, check that the fish use them and ensure that the appropriate pathways are available to the fish during the outmigration period.

Downstream guidance
We examined the possibilities of using the trash deflectors, with and without overhead cover, to guide trout away from turbine intakes. The use of overhead cover in 2007 proved to have a statistically significant effect, with 30% of the trout exiting via the trash gate rather than entering the turbine intake at upper Finsjö as compared to 0% guidance in the absence of overhead cover. In phase 2 of the Elforsk program, we also tested the use of trash deflectors, albeit in the absence of overhead cover, in guiding trout into the trash gates, and we found variable effects, depending on year and power plant, guiding from 4-40% of the smolts and 0-76% of the kelts. Thus, our use of behavioral methods to guide trout away from turbine intakes was successful but inconsistent. As such we do not recommend the use of these methods alone, although they may prove useful in combination with other methods. This conclusion is well supported by many studies of behavioral guidance found in the literature. Our test of the low-sloping rack with surface bypass outlets, a mechanical guidance method, appeared promising as we were able to lead 84% of the smolts past the turbine intake (guidance was not measured for kelts- see Materials & Methods). We also captured 17 of Emån's 33 species in the bypass trap, suggesting that many species were able to use the system. Nevertheless, based on our camera observations, we observed that trout, both smolts and kelts, often hesitated, in many cases for considerable amounts of time, before passing through the bypass outlets. We attributed this to turbulence at the outlet openings. This led us to modify the openings in 2010 in an attempt to reduce turbulence. The results of this

manipulation are not fully analyzed yet. Nevertheless, our results for the bypass system look promising, and with additional testing and refinement we are hopeful that such a system can be implemented in many rivers in Sweden.

Population model

Since 2000, we have quantified passage success, for both upstream and downstream migrating trout, and these values have been used in the population model (presented in a separate appendix). During phase 3 of this program, additional quantification was necessary to obtain additional input values for the population model. Thus, we spent two years measuring smolt production at the mouth of Emån. In our sampling of fish in the screw traps we discovered that several thousand salmonid fry (trout and/or salmon) migrated to the Baltic Sea, which prompted our otolith analysis of kelts. A previous pilot study of trout otolith microchemistry by Limburg *et al*. (2001) reported that 5 of 7 trout kelts from Emån had spent little time in the river, before migrating to sea. Our study, based on 23 fish, also provided evidence for fish moving more or less directly out to sea, skipping the freshwater phase, but in our case it was 13% of the fish that did this. This number, albeit much lower than Limburg's, was still somewhat surprising as we are only aware of one published study (plus an unpublished study in for a stream emptying into Lake Vättern), showing direct migration to sea and this was conducted in Gotland, where streams typically dry up during summer.

Fragmentation and non-salmonids

Relatively little work has been done on dam passage by cyprinid fishes. Our rather long study (21 months) of chub was an attempt to determine how much of a barrier the dams represented for the chubs, despite the fact that passage facilities, developed for salmonids, were in place. None of the radio-tagged chubs, when moving upstream, passed the nature-like fishways, which compares to the 33% that passed the rapids area in the control reach. In fact, few chubs even approached the fishway, only 2 of the 24 radio-tagged chubs approached it. This might indicate that the chubs do not use the same cues as salmonids when migrating upstream, but it might also reflect a weaker willingness or interest to migrate.

Even for downstream passage no chubs passed the dam, which contrasts to the situation for the control reach, where 53% of the chubs passed the rapids area. In contrast to lower Finsjö, a relatively large number of chubs approached the fishway, 10 of 25 fish. We even caught a modest number of chubs in the bypass trap, 31 fish, although these fish were considerably smaller (average of 10 cm) than those marked with radio-transmitters. Thus, the dams at Finsjö represent a barrier for the chub, and we have no solution as to how to improve passage for this species.

Another non-salmonid, the eel, has recently received considerable attention within the EU due to its declining populations. Our laboratory study of eel has shed some light on how to design bypass systems for eels (see even Calles & Bergdahl (2009) for an evaluation of surface bypass system tested for eel in the River Ätran). We found that eels do not hesitate when approaching a barrier; instead they react after reaching the barrier. Moreover, the eels seem to be attracted to turbulence. Both of these behavioral reactions by eel should be considered when designing future bypass systems for eels.

8 WP4 Ljusnan

8.1 Objectives

- Develop a framework for quantitative predictions of ecosystem restoration in dewatered channels, as a function of discharge and flow regimes - for use in CBA-analyses and in restoration processes in general, and for a case study in the research program in particular.
- Develop a population model of migrating fish populations in rivers with connectivity issues.
- Provide an analysis between regulated and unregulated flows in the framework of IHA (Indicators of Hydrological Alteration)

The second objective was added after the project started, when there was a need for quantitative predictions of number of migrating fish as a function of numer of fishways (Case ”-2,+1”).

8.2 Analytical contributions

It is costly to build new fishways and there is also a cost of the water needed for these fishways. Implementing new fishways will certainly guide more fish than previously. But, the main question is – does it guarantee viable populations? With the tools and knowledge available to ecologists today, the best option is to use population dynamic modelling to resolve these issues. The issue focused on in this project made it necessary to include details that are beyond the scope of most of the available models. The approach required formulation and parameterization of a model for a specific species in a specific river that needs to be assessed. Nevertheless the developed model builds on a framework that allows the user to modify the settings in order to assess any migratory fish population in any river. The number of fishways or obstacles as well as the number and sizes of the spawning and juvenile rearing habitats are likely to differ between rivers, but the general ecological parameter setting will be almost the same among rivers as long as the same species is in focus. The model was constructed and parameterized with Atlantic salmon in mind, and for this species there may be slight differences in smolt ages or sea ages between strains from different rivers. Also, the type of density dependence as well as the life stage at which it acts may differ between rivers.

In this research project, two types of population models were developed to predict the outcome, in terms of population sizes, of constructing or improving fishways for migrating fish populations (parameterized for salmon and sea trout). The detailed population dynamic model is built on the complete life history, and this model was collapsed into a much simpler model that allows the same predictions of the equilibrium population size but without the possibility to investigate the expected dynamics. The models can also be used to evaluate quantitative effects on population size following habitat restorations. One question of general interest has been - how many fishways can a viable Atlantic salmon stock cope with? I analyse this more general question by using a case based on Atlantic salmon in the Swedish river Ljusnan. There is no migrating salmon left in this river and the question is if it is possible to have a viable salmon population back in Ljusnan merely by constructing fishways. Despite river specific parameterization of the model it is possible to gain some insight into this issue.

8.2.1 Population dynamic model

The population dynamic model is based on Markov chains with a matrix describing the transition probabilities for the individuals throughout their lives (Figure 8.2.1.1). This matrix becomes large and complex due to the long life cycle in combination with the complex life history of the salmonids. Since the complexity increase with the number of fishpasses, or other types of migration obstacles, the model is formulated as a mixture of a matrix model and an individual based model. The matrix generates the transition probabilities from the egg stage to the state where the survivals from these eggs return to the river mouth for spawning a number of years later. From there each individual is followed through each state for the rest of its life. The model keeps track of the individual such as where it is heading for spawning (homing behaviour), and whether it will reach there or not depending on migration success at each problematic passage or whether it suffers from fishing mortality or background mortality. The adult will spawn in the river section where it ends up and the recruitment success of the offspring follows a simple stock-recruitment function like a Ricker or Beverton-Holt function (Table 8.2.2.1). The maximum recruitment is river section specific, and is defined as the maximum number of 0+ for each river section in the model. This definition allows electro-fishing data to be used for estimation of production potential. The female fecundity is based on her sea age when returning to the river for spawning. After spawning the spent adults continue with repeated spawning one or two years later if the life history strategy of the species, and survival, admits so. The transition probabilities for downstream passage of smolt and kelt at each fishpassage is also included in the model. The model only deals with one species, but can still be used if the carrying capacity of this species can be defined in the presence of competing species. Dynamic feedbacks with predators cannot be dealt with in this model. The Mathematica software Mathematica (ver.7, WWW.Wolfram.com), was used for this model and it is a simulation model. The model has so far not been given any specific name.

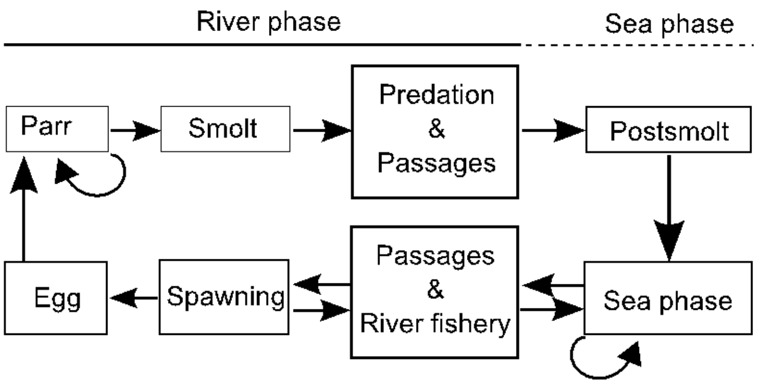


Figure 8.2.1.1 Schematic illustration of the states (boxes) and possible pathways (arrows) in the population model based on the life history of Atlantic salmon. For smolt the passage box includes the number of passages from the birth section to the sea. For the returning adults the passage box includes to the number of passages from the sea to the home section, or if failing to reach there to the section where it ends up. For kelts (after spawning), the passage box includes the number of passages from the section where it ended up during the return migration, to the sea. Predation or fishery may occur in some, or each, section during the migration. The loop arrows indicate that an individual may stay more than one year in that state. Each arrow indicates that the individual may reach the next state with some given probability.

A few results are shown here, but there are more results presented in the description of the case “-2,+1”. When analyzing the potential for restoring the salmon population in Ljusnan merely by building fishways, eight fishways required, it was found that very high (90-100 %)

fish passage efficiencies were necessary in order to re-establish the salmon at the most upstream area. The largest spawning grounds and rearing habitats are in this area. Relaxing the high passage efficiencies by some 10 % should result in just a few spawners to reach the uppermost area, and the larges number of spawners, ca 150 individuals, are expected for the most downstream section (Figure 8.2.1.2.).

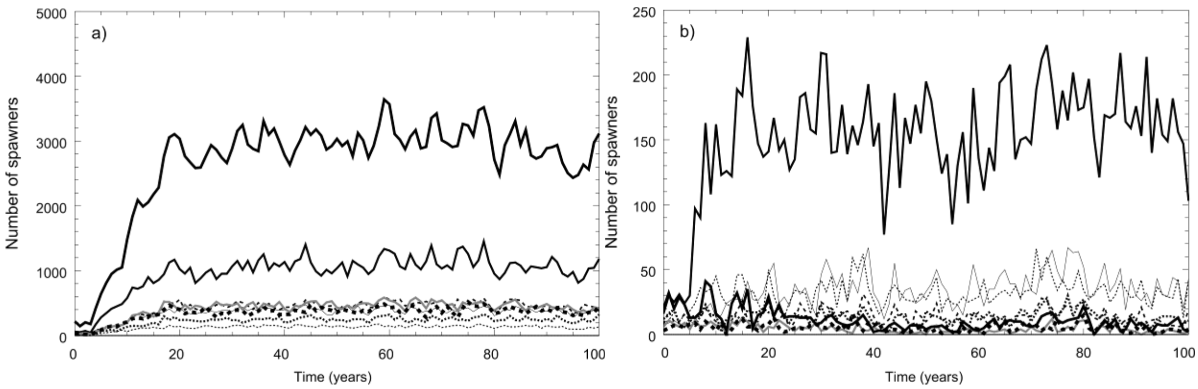


Figure 8.2.1.2. Predicted number of spawning adults of Atlantic salmon at different sections in the river Ljusnan at two levels of passage probabilities. The results are for the scenario with construction of fishways at all eight dams, with geometric mean fish guidance efficiency (FGE) of 0.98 for smolt, 0.93 for returns, and 0.90 for kelt (a), and 0.88 for smolt, 0.83 for returns, and 0.81 for kelt (b). Each line denotes the result for a specific river section.

More detailed description of the model and results from various scenarios are presented in the preliminary report by Leonardsson (2010) *Environmental restoration in hydropower regulated rivers – where, when, and how can ecological improvements be expected?*

8.2.2 Equilibrium population model

The population dynamic model is useful to study the outcome of more complex restoration or improvement scenarios, and allowing for detailed studies of uncertainty. A much simpler but still reliable model would be desired for use by managers for preliminary evaluations of whether improvements or constructions of additional fishways might gain migrating populations. The reduction of the full population dynamic model to an equilibrium model with a few parameters could be achieved by simplifying the life history, i.e. ignoring repeated spawners. The equilibrium model was derived by taking the product of all the probabilities except for the passage probabilities for each possible life history path in figure 8.2.1.1., thereafter summing up these products. This single probability is multiplied by a density dependent function to prevent the population from growing to infinity. The density dependence was applied for the egg-parr transition. Both the Ricker and the Beverton-Holt stock-recruitment functions yield tractable analytical solutions of the model. The density dependent recruitment function can be parameterized to give the number of 0+ parr at the end of the summer, i.e. at a time when there are plenty of data available through electrofishing monitoring programs. Dividing the single life history probability by two now covers the probabilities of a 0+ parr to become a spawning female. Finally, the product of all the passage probabilities are multiplied separately to the equilibrium model to allow analyses of passage issues. The final model is presented in Table 8.2.2.1.

The equilibrium model is useful since it can provide simple analytical solutions that may be explored for various aspects. Although the model only deals explicitly with the equilibrium density of adult females, the results can be rescaled to cover all adults. Pieces of the model can also be evaluated separately e.g. for calibration with observed parr or smolt production.

Table 8.2.2.1 Stock recruit functions and their corresponding functions for equilibrium population sizes. p_0 is the density independent survival at low densities and K is carrying capacity in terms of number of 0+ parr. *Fec* is the mean fecundity of all females, p_1 is the survival from the 0+ stage to the first spawning, p_S and p_R denote probability of migration success for the smolt and the returning adults respectively, and *FP* denotes the number of fish passes in the river. When *FP* is greater than 1 the probabilities of migration success denote geometric means.

Stock-recruitment type	Number of recruiters (0+ parr), N_{0+}	Number of adult females, N_F
Beverton-Holt	$\frac{U * K}{K + U}$	$\frac{K(V * Q - 2)}{2 * p_0 * Fec}$
Ricker	$U * e^{-\frac{U}{e * K}}$	$\frac{e * K * \mathrm{Log}[V * Q/2]}{p_0 * Fec}$
Exponential	$K * \left(1 - e^{-\frac{U}{K}}\right)$	$K\left(\frac{p_1 Q}{2} + \frac{\mathrm{ProductLog}[-V * Q/2 * e^{-V*Q/2}]}{p_0 * Fec}\right)$
Definitions:	$U = p_0 * N_F * Fec$	$Q = (p_S * p_R)^{FP}, \quad V = p_1 * p_0 * Fec$

Note: ProductLog[$x * \mathbf{e}^{x}$] =x.

The equilibrium model was used to create a figure that should correspond to the Ljusnan scenarios (Figure 8.2.2.1.). The similarity with the result from the population dynamic model verifies that it is straightforward to use the equilibrium model to make predictions on how the number of fishways and their passage probabilities affect the number of spawners of migrating salmon, at least for the river section upstream the ”last” hyropower station. The curves in the figure can also be used to evaluate the expected number of spawners at any number of fishways and at any functionality from the sea to the uppermost spawning area in Ljusnan. The geometric mean of the passage probabilities can be calculated by $Q^{(1/\text{number of fishways})}$.

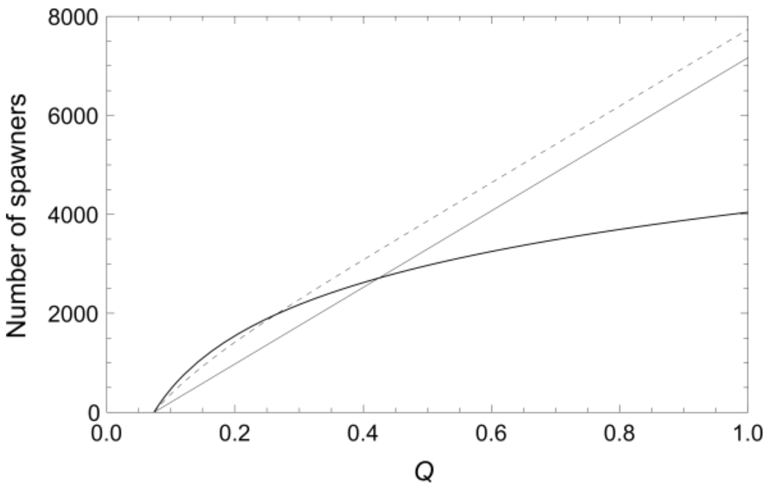


Figure 8.2.2.1. Predicted number of spawners as a function of the product of all passage probabilities, *Q*, for smolt and returns. *K*=1 430 000 corresponding to MellanLjusnan-Laforsen, p_1=0.0039 (only for the river section downstream Laforsen in Ljusnan due to predation during smolt migration since downstream areas have shorter migration distances in the river), p_0=0.7. Thick line denotes the result using the Ricker stock-recruit function, thin line denotes results using the Beverton-Holt stock-recruit function, and the dashed line denotes results using the exponential stock-recruit function.

The equations in Table 8.2.2.1 can be solved for the joint passage probability *Q* in order to analyse various questions. For example, in order to fulfill the requirements of the Salmon Action Plan, stating that the populations should recover to at least 50 % of the production potential in the rivers, the lower *Q*-value becomes;

$Q \geq 4/(p_0*Fec*p_1)$ (Beverton-Holt)

Almost equallly simple equations can be derived for the critical Q-value at the border of population extinction. Setting the critical limit to the situation when 100 females can make it to the spawning will give an estimate that should provide a basis for a viable population. For this example we solve the functions that defines the number of spawning females for *Q* when N_F=100. The critical *Q*-value becomes:

$Q=2(K+100*Fec*p_0)/(Fec*K*p_0*p_1)$ (Beverton-Holt)

For the uppermost section in the river Ljusnan (downstream Laforsen), the critical *Q*-value becomes 0.11. Since there are eight passages $Q^{1/8}$ gives the geometric mean 0.76 of each joint passage probability for smolt and returns. Since the smolt passages often are easier to solve with high passage probabilities, say ca 0.95, the probabilities for each upstream passage for returning adults need to be at least 0.80. Probably many years of improvements will be needed to reach such high guidance efficiencies at all passages. On the other hand, if the number of passages will be six rather than eight, the corresponding probability for the adults will be 0.73. For the Ljusnan case this scenario also added spawning grounds to downstream areas upon removal of dams, which will facilitate the upstream population by strayers from downstream areas. Therefore, for this more complicated scenario the population dynamic model is more appropriate.

8.3 Empirical contributions

8.3.1 Klumpströmmen

Rivinoja, P., Gyllenhammar, A. and K. Leonardsson. 2010. *Predicting populations sizes of European grayling and Brown trout at various flow scenarios in a regulated section of River Ljusnan, Sweden*. - This work aimed to develop and apply a method to quantify the outcome of improved flow regulations for grayling and brown trout populations in a regulated river section. The approach includes estimating suitable habitat areas for the species at various river flows. From these results, in combination with fish densities estimates from snorkelling and electro-fishing in unregulated rivers, we could calculate the total expected future fish stocks at various flow scenarios in the regulated section. The results can be used to evaluate flow scenarios to improve conditions for the fish fauna and thereby also for the ecological status of the regulated section.

In this specific investigation, six various flow regimes ranging from the present minimum legislated winter flow of 0.25 m^3s^{-1} to pristine low summer flows of 41 m^3s^{-1} were evaluated at the regulated, but riverbed wise uniquely pristine stretch Klumpströmmen in River Ljusnan. Compared to the minimum winter flow, with no suitable habitats for grayling and brown trout, the area of suitable spawning and juvenile habitats at 3 m^3s^{-1} were estimated to 3 ha, and 0.5 ha for adults. At the present legislated minimum summer flow of 10 m^3s^{-1} the suitable habitats covered an area of about 3 ha for juveniles and 4 ha for adults. At higher flows these areas increased proportionally less than the corresponding increase in the flow (21 m^3s^{-1}; juveniles 4 ha, adults 5-6 ha and 41 m^3s^{-1}; juveniles 6 ha, adults 8-9 ha). In relation to reference data (Table 8.3.1.1.), snorkelling in the river section indicated low fish densities, averaging 0.39 grayling per 100 m^2, while no brown trout was observed. By electro-fishing, an average of 0.14 brown trout per 100 m^2 was estimated, which in relation to references indicated a very low density. Based on all collected information the current flow regulations in the section seem to impair both the grayling and brown populations. With environmentally adapted flows implying c. 1.5 month earlier start and ending of minimum summer flow and increasing the minimum winter flow from 0.25 to 3 m^3s^{-1}, the salmonid density was predicted to increase by a factor of 3-6 compared to that estimated in the field (Figure 8.3.1.1.).

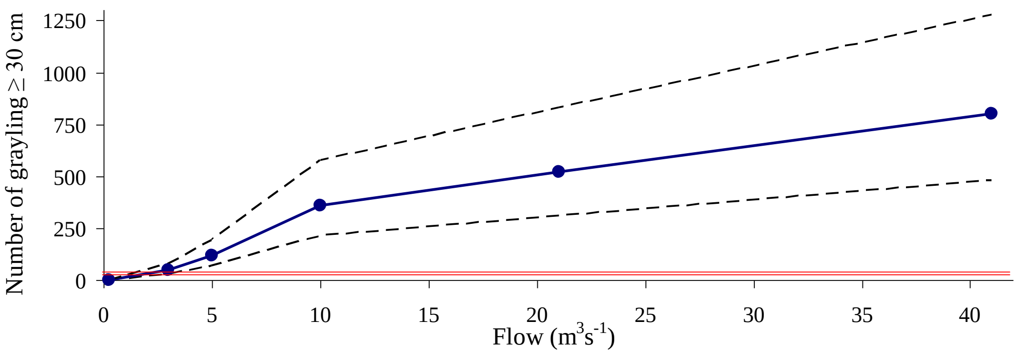


Figure 8.3.1.1. Predicted total number of adult grayling in relation to flows in Klumpströmmen. The solid line indicates the expected mean value while the dashed lines show the 95 % confidence intervals. The horizontal lines show the number of adult grayling estimated by the snorkelling, 26 and 42, respectively.

Table 8.3.1.1. Snorkelling counts from Klumpströmmen and data from reference rivers with the number of size classes of grayling and brown trout shown.

Species	Size class (cm)	Fish per 100m^2 Klumpströmmen Mean	Reference rivers 5th percentile	Median	95th percentile
Grayling	<30	0.30	0.41	0.63	1.16
	>30	0.09	0.16	0.32	0.46
	All	0.39	0.57	1.03	1.62
Grayling & Brown trout	<30	0.30	0.56	0.79	1.75
	>30	0.09	0.23	0.42	0.58
	All	0.39	0.82	1.36	2.38

8.3.2 Predicting fish passage probabilities

Rivinoja, P., Calles, O., Thorfve, S., Lundqvist, H. & Leonardsson, K. 2010. *Assessment of potential passage probabilities and reproduction areas for Atlantic salmon (Salmo salar L.) in the fragmented regulated River Ljusnan - A baseline of hypothetical scenarios for eco-eco analyses*, (under revision) - The potential to recover migration routes and reproduction areas for Atlantic salmon in the regulated and fragmented River Ljusnan was investigated. Hypothetical efficiency of possible fish passes at the nine power stations forecasted a maximum cumulative upstream migration success of 50% of adult spawners from the river mouth to main salmonid reproduction areas about 150 km upstream of the coast. The subsequent passage survival of downstream migrating smolts and kelts was estimated to 80% and 50%, respectively (Table 8.3.2.1.). Based on visual and GIS mapping of habitats, focusing on hydrological patterns and bottom composition a total of 357 ha in the river main stem was found as potential for salmon reproduction. This area could be increased with 36 ha by future river rehabilitation (river-bed restoration) and environmental flow adaptations (increased spill in residual river sections), while a total of 173 ha of potential reproduction areas could be gained by removing the current hydro schemes. To generate a future viable salmon stock, in the magnitude of the pristine one (c. 4000 adult female spawners), the success rates for possible fish passes should be maximised for both up- and downstream migrations, indicating the need of site specific fish pass adaptations.

Table 8.3.2.1. Details of the nine powers stations in the lower part of River Ljusnan, numbered from downstream to upstream. *Signify power stations with reduced flow sections in the main river branch. Turbine types and number of units are symbolized by K=Kaplan and F=Francis. The upstream success rate (Min-Max) refers to predicted passage possibilities for adult salmon, while kelt and smolt bypass success rates refer to the predicted passage rates for downstream migrants. Reproduction areas show the potential achievable sizes of spawning and juvenile habitats after river restoration (Restore) and power station removal (Remove) at connected sections up- and downstream each site, respectively. Technical data from the power station owner Fortum.

Power station (HP)	**1**	**2**	**3***	**4**	**5***	**6***	**7**	**8***	**9**
Distance from sea (km)	0.9	3.3	8.8	19.8	42.0	54.0	60.0	73.3	105.0
Head (m)	6.8	16.0	14.0	8.0	5.6	34.0	7.0	21.0	4.0
Flow (m^3s^{-1})	300	264	300	240	300	250	265	300	20
Effect (MW)	14.5	37.0	39.0	16.6	11.2	75.5	14.0	46.0	0.9
Turbines (K=Kaplan, F=Francis)	1K	2K	2K	2K	1K	3K	2K,3F	2K	2K
Adults, upstream									
Min success	0.70	0.75	0.70	0.85	0.70	0.70	0.60	0.70	0.90
Max success	0.95	0.85	0.98	0.95	0.90	0.95	0.88	0.90	1.00
Adults, downstream									

Kelt turbine survival		0.50	0.45	0.05	0.50	0.45	0.10	0.20	0.35	0.00
Kelt bypass success		0.95	0.90	0.80	0.98	0.95	0.80	0.80	0.95	1.00
Kelt max success		0.98	0.95	0.81	0.99	0.97	0.82	0.84	0.97	1.00
Smolt, downstream										
Smolt turbine survival		0.93	0.93	0.93	0.93	0.93	0.75	0.75	0.93	0.50
Smolt bypass success		0.90	0.80	0.80	0.95	0.95	0.80	0.80	0.80	1.00
Smolt max success		0.99	0.99	0.99	1.00	1.00	0.95	0.95	0.99	1.00
Reproduction areas										
Scenario	River section									
Restore	upriver (ha)	0	0	0.4	0	0	0.02	0.2	0.2	0.5
	downriver (ha)	0	6.7	2.5	0	0.6	13.4	0	7.0	4.8
Remove	upriver (ha)	1.1	3.2	1.2	3.1	20.5	7.9	6.9	18.8	2.1
	downriver (ha)	1.8	16.8	9.9	9.4	7.6	31.4	4.3	21.2	6.2

8.3.3 Comparisons between unregulated and regulated river flows

For these analyses we collected all data on flows (daily means) from Swedish rivers (data from SMHI). Each year in the time series was classified as regulated or not regulated depending on if the measurement site was affected by water regulation or not. For this classification we used Kuhlins database (www.kuhlins.com) with data on 1440 hydropower stations, SMHI:s “Vattendragsregister”, SMHI:s dam register, and SMHI:s reports on flow statistics in Swedish rivers (Svenskt Vattenarkiv 1993-1995) in a GIS environment. For consistency we also inspected the time series data visually before the final classification. We only included time series with mean flow exceeding 1 m^3/s in the analyses. In total we obtained 512 time series with more or less regulated flow regimes, and 375 time series with unregulated flow regimes.

Since the natural flow regime is shaped by the climate, the data was split between a northern region that characterize winter conditions with long snow cover and a southern region with more temporary snow conditions. Data on winter flow from normalized unregulated time series in combination with the number of was used for this classification. The two groups were split by means of the average number of below zero degree (°C) days that created a natural separation in the January flow data. Data on air temperatures, 30 year averages, from 653 stations (SMHI) were compiled to calculate the upstream catchment area weighted mean number of below zero degree days per year for each flow measurement site. The separation between the two regions was also consistent for the IHA-variables; ”Date of mimimum”, ”Date of maximum”, ” High flow timing”, ” Small Flood timing” and ”Large flood timing”, see Appendix 1 for a list of the IHA-parameters and their relation to influences on ecosystem functioning. The flow measurement sites are geographically distributed among the two regions, and the limit between the two regions seems to coincide with the “Limes Norrlandicus”. The number of time series in each of the region separated between regulated and unregulates periods or sites are given in **Fel! Hittar inte referenskälla.**. For the IHA-analyses we used the Nature Conservancy’s (rPurview LLC - Ted Rybicki Totten Software Design, Smythe Scientific Software) IHA software, ver. 7.1, available at http://www.nature.org.

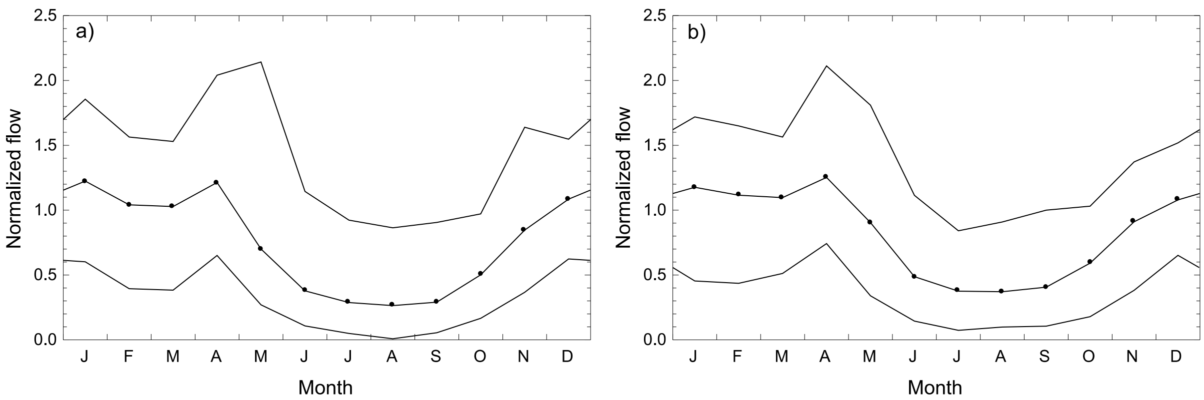
Table 8.3.3.1. Number of time series with flow data within each category regulated versus unregulated sites and less than 140 days with below zero mean air temperature or more than 140 days with below zero mean temperature.

Num. of days <0 °C	Unregulated	Regulated
≤140	62	197
>140	313	315

Biological data from regulated rivers are sparse, and it was therefore not possible to perform a large scale comparison between biological data from unregulated and regulated rivers. There is also a lack of coordinated collection of flow data and biological data in unregulated rivers in Sweden. We therefore analysed the natural variation of the seasonal pattern in unregulated rivers on a national basis and compared this with the spatial distribution of stream living benthic invertebrates and fish. For this purpose we compiled as much data as possible on stream living benthic invertebrates and fish. Data on the benthic invertebrates comes from national and regional monitoring programs (www.slu.se and Local County administrations), and the fish data comes from the Swedish Electro-fishing database (www.fiskeriverket.se).

Reversed flow regime

In the northern region there is normally a low water period during the winter, followed by a sharp rise during the spring flood (Figure 8.3.3.1.). Especially the low flow during the winter period has been replaced by much higher flows in the northern regulated rivers since the energy demand is much higher during winter than during the rest of the year. Consequently, the spring peak and the summer flow are lower in the northern regulated rivers. Thus, the annual flow regime is more stabilized in the northern regulated rivers than in the northern unregulated rivers. However, the so called reversed flow regime is not apparent in these data. It rather seems that the reversed flow regime is what characterizes the difference between northern and southern unregulated rivers. There seems to be almost no difference in the annual flow regime between the southern unregulated and the southern regulated rivers. Thus if the reversed flow regime have a major influence of the stream living fauna it should be apparent in the geographic distribution of stream living animals and plants.



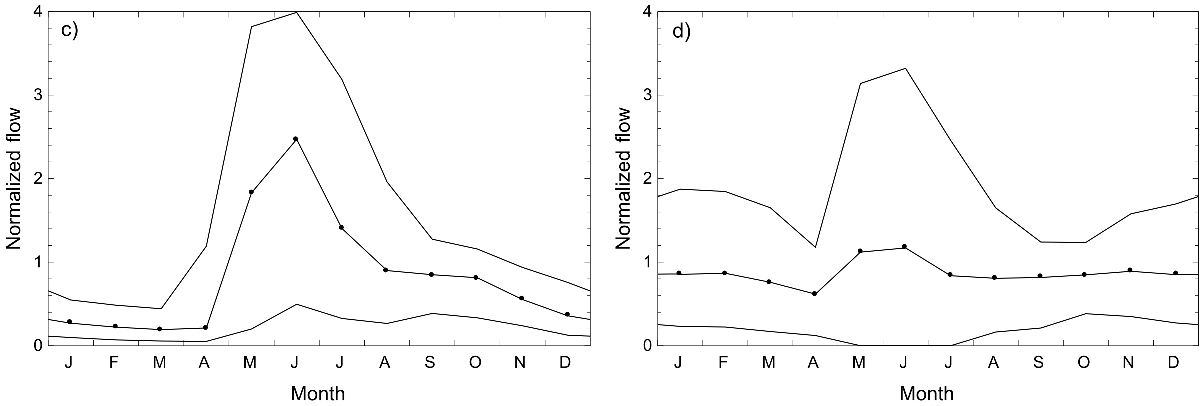


Figure 8.3.3.1. Mean normalized flow in a) unregulated rivers in the southern region, b) regulated rivers in the southern region, c) unregulated rivers in the northern region, and d) regulated rivers in the northern region.

The geographical distribution of three typical stream living benthic invertebrate taxa (Baetis spp., *Heptagenia* spp., and Simuliidae) (Figure 8.3.3.2.) and three fish species (Brown trout, *Salmo trutta* L.; Atlantic salmon, *Salmo salar* L.; Eurasian minnow, *Phoxinus phoxinus* (L.))(Figure 8.3.3.3.) indicates that the reversed flow regime between the northern and the southern region does not affect the viability of these taxa. These invertebrate taxa were just a few examples, but many other typical stream living taxa also showed similar whole range distributions. The differences in temperature regime between the regions might complicate this type of comparison, but the productive season is during the summer period in both regions, although the productive season is somewhat longer in the southern region. We had no data on plants for a similar comparison. The most conspicuous distribution pattern was that of the salmon. This species restricted distribution clearly shows where there still are sufficient with connectivity in the rivers to allow viable populations.

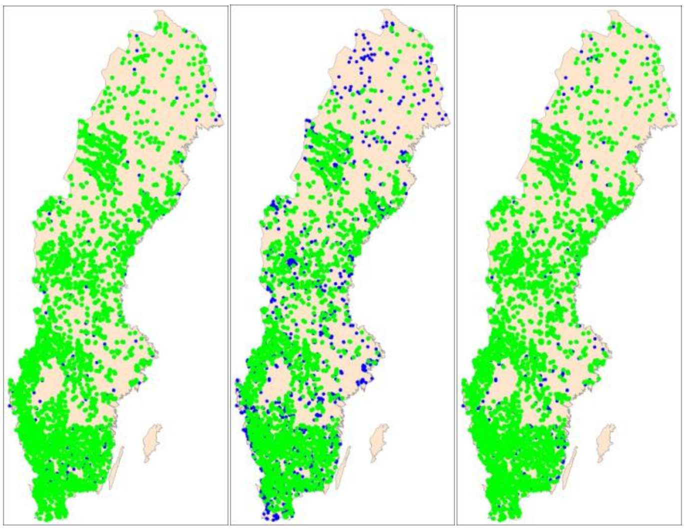


Figure 8.3.3.2. Geographic distribution of sampling locations of benthic invertebrates with presence of the taxon marked by a green dot and absence by a blue dot. The tree taxa are from the left; *Baetis* spp., *Heptagenia* spp., and Simuliidae.

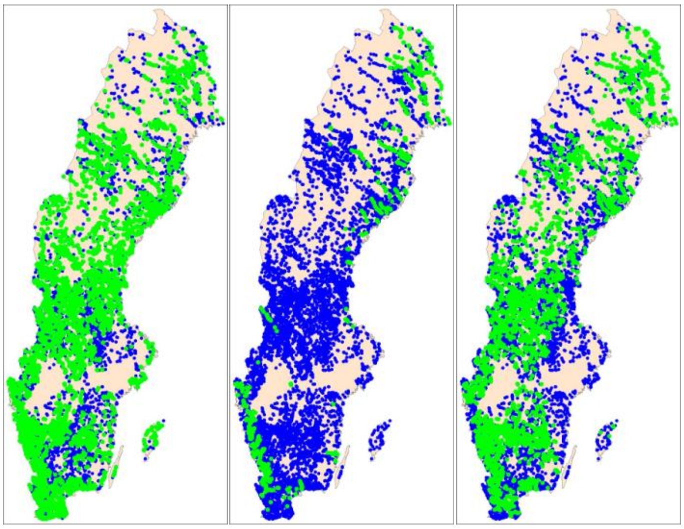


Figure 8.3.3.3. Geographic distribution of electro-fishing locations for investigation of stream living fish, with presence of the taxon marked by a green dot and absence by a blue dot. The tree taxa are from the left; Brown trout, Atlantic salmon, and Eurasian minnow.

Results from the IHA-analyses

Overall there was a large overlap between the IHA parameter values from unregulated and regulated rivers both in the sourthern and in the northern region (see Appendix 1 in Leonardsson 2010). The differences in the results between unregulated and regulated flow regimes were not significant when applying median difference tests (Figure 8.3.3.4.). The group of parameters that were responsible for the somewhat lower p-values in the northern region consisted of winter flows, 1-90 day maximum flows, annual CV, date of minimum, low pulse duration as well as date of minimum and 90 day minimum. Most of these deviations could be observed in the annual flow regimes depicted in Figure 8.3.3.1.

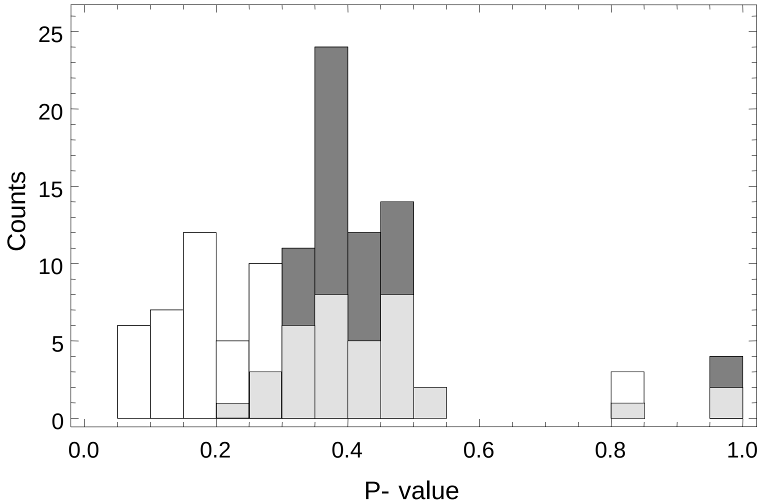


Figure 8.3.3.4. Variation in p-values from median difference tests of all IHA parameter values. The dark gray bars denote results from the difference between unregulated and regulated rivers in the southern region. The white bars denote results from the difference

between unregulated and unregulated rivers in the northern region. The light gray bars denote overlap between the two groups.

Even if the overlap beween regulated and unregulated flow regimes was sufficiently large to prevent significant differences, there were a number of regulated flow regimes that deviated much from the unregulated ones for some of the parameters (see e.g. Figure 8.3.3.5.). One recommendation that can be made from these results is that heavily deviating river sections should be given priority for analysis of possible measures or mitigations.

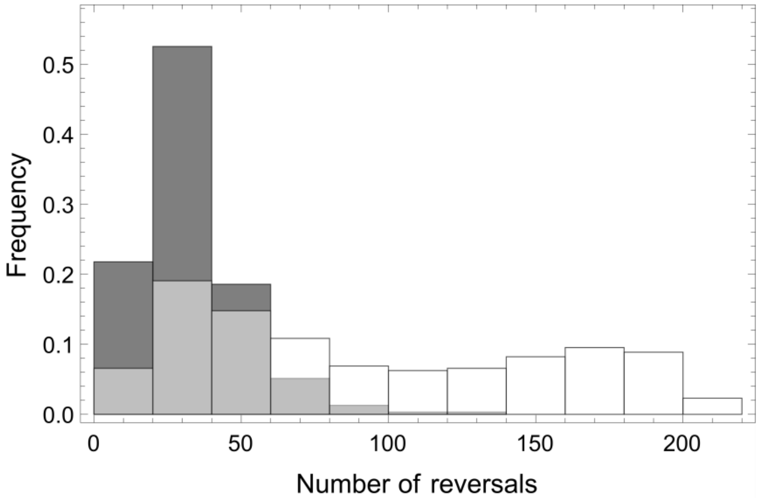


Figure 8.3.3.5. Distribution of mean number of reversals per year for unregulated (dark bars) and unregulated (white bars) river flows in the northern region. The light gray region denotes overlap between the two flow types.

There are analyses and interpretations of regulated versus unregulated flow regimes that remains to done before a final report can be presented. There is also an ongoing collaboration with researchers at LTU that relates to the flow questions (Minde *et al*., 2010; *Applied Mechanics F-7015T: PIV measurements of bottom flow over half-cylinders motivated by river bed species*). In this collaboration we investigate the effect of the flow conditions near the bottom (velocity and shear stress) for the benthic organisms. It is important to understand the mechanisms behind the deterioration of the benthic invertebrate communities in regulated rivers with large flow variations in order to define proper measures or mitigations to lessen the negative impact on the fauna. We also have results from an investigation of grayling growth that needs to be written. Growth data in that investigation comes on from seven rivers of various degree of flow regulation, from unregulated to short term regulation with ca 1 m daily amplitude changes. The results from that study showed that the grayling from the most heavily short term regulated system had the highest growth rate.

8.4 Reflections on projects goals and achievements

The data collection and compilation of the flow data and the benthic invertebrate data took longer time than expected, for various reasons. Consequently the analyses started late in the project period. Even if we have managed to produce a large amount of results within this workpackage, we suffer from not having finalized the reports and publications. However, this will be given highest priority during the remaining three months of the project. Still, we feel that the population models should be a significant contribution to the possibilities to evaluate the potential for fishways before any decisions are taken for such measures. Also, the somewhat surprising result about the large natural flow variation in unregulated rivers may contribute to a focus on identifying which regulated river sections that should be given priority for analysis of possible measures or mitigations.

9 Case study example 1. Dönje Powerplant

Dönje power station is a 67 megawatt (normal annual production is 340 gigawatt hours) hydroelectric facility on the Ljusnan river close to the small city of Bollnäs in central Sweden. Its The city of Bollnäs has around 13 000 inhabitants and the municipality of Bollnäs has around 26 000 inhabitants. The power plant is part of a 28 power plant system spread out over the Ljusnan and its small tributary Voxnan. Ljusnan, in mid/northern Sweden, is regulated at most of its length for hydropower production. The river originates from the mountains at the Norwegian border and has a catchment area of 19 800 km^2. It is 440 km long and has an annual mean flow of 226 m^3s^{-1} at the mouth

The plant and the catchment area is depicted below:

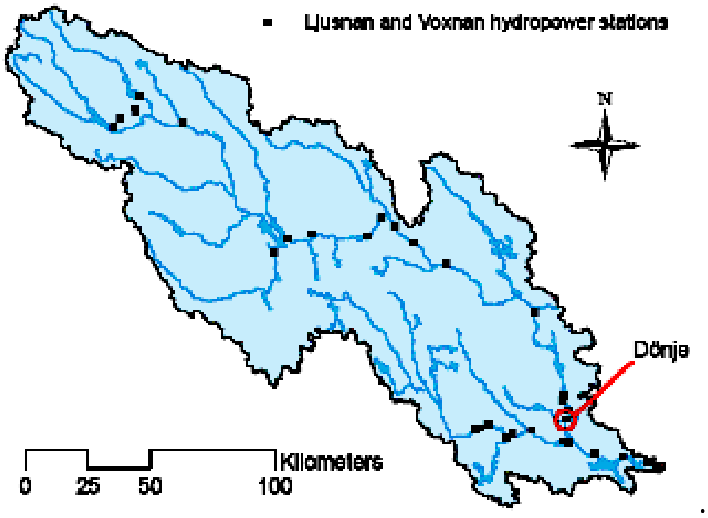


Figure 9.1 The Catchment area

Figure 9.2 The Dönje Plant

The river section Bollnäsströmmarna, c. 6.5 km in length, is located between power-station five and six in order from the river mouth, about 53 km upstream of the sea. Generally most of the water reaching this section is utilized by the power-station Dönje that has a maximum capacity of 250 m^3s^{-1}. Here the hydraulic head is created by 34 m deep intake tubes to turbines after which the water is lead via a tunnel to the outlet in the downstream Lake Varpen.

Since water is diverted from the natural river stretch this result in reduced flows in Bollnäsströmmarna. According to the hydropower licence conditions the minimum flow in the original stretch is to be 10 m^3s^{-1} from May 15 to October 21, after which the spill is gradually decreased to 0.5 m^3s^{-1} for the winter period (October 31 to May 14). In summer most of the water is spilled into the 1.3 km long eastern river branch, Klumpströmmen, that gains 0.25 m^3s^{-1} in winter, while the western branch is more or less dry for most of the year. Both scenarios target Klumpstrommen, see the figure for a map.

Figure 9.3.Klumpströmmen.

Historically about one third of the total flow amount in Bollnäsströmmarna passed at the Klumpströmmen section, while the remaining 2/3 passed the western river branch. The natural flow regimes before regulation of Klumpströmmen showed the typical patterns for rivers in northern Sweden; the highest flow events occurred in spring (peaking c. 740 m^3s^{-1}, with decreasing and stabilizing flows in the summer (normally c. 15-70 m^3s^{-1}), occasionally with an increase in autumn, and relatively low constant flows during the ice-period in winter (averages around 10 m^3s^{-1}). In practice this means that the dryway is more or less bottom frozen during winter, and that the downstream stocks of fishes that are valuable for fishing are small. The scenic view when the river channel is dry is far from overwhelming. Also recreational activities other than fishing such as canoing and ice skating are adversely affected by the regulation.

9.1 Natural science study

The approach and main results from WP4 that served as ecological and environmental base information to this particular case study are described in section 8.3.1. Here we make some reflections on the reliability of the predictions, and under what conditions the Klumpströmmen case can be generalized to other systems. First of all, Klumpströmmen is unusual compared to many other rivers and river sections. It has not been cleaned for timber floating. Therefore the riverbed is more heterogenous than the average river, even when compared to unregulated rivers. This aspect has a positive influence on the potential for the productivity in the river section. In addition, Klumpströmmen is an outlet stream which also contributes to high productivity, both concerning the fish fauna and the benthic fauna. However, the outlet effect is not unique to Klumströmmen. In fact, many bypass channels are close to dams, which mean that the potential for outlet effects should be common in these types of systems. That is to say, if water is added continuously to the river section.

Another aspect that may need explanation is the proposed a traditional constant flow regime, with a low winter flow and a higher summer flow, instead of suggesting a variable flow to mimic a more natural flow regime. The power station in Dönje has a maximum capacity that is exceeded at high flows. Therefore, the flow in Klumpströmmen is expected to become variable even in the absence of a legislated variable flow as could be seen in the time series from Dönje (Figure 9.1.1.). But, perhaps the most important aspect that makes this scenario work is that Klumströmmen is a natural side channel (or bypass channel). Before the damming, Klumpströmmen had about 25 % of the total flow. This means that there is a main channel into which the excess water during extreme highflows can be spilled to protect the smaller Klumpströmmen from severe disturbance during extreme high flow events for this size of river.

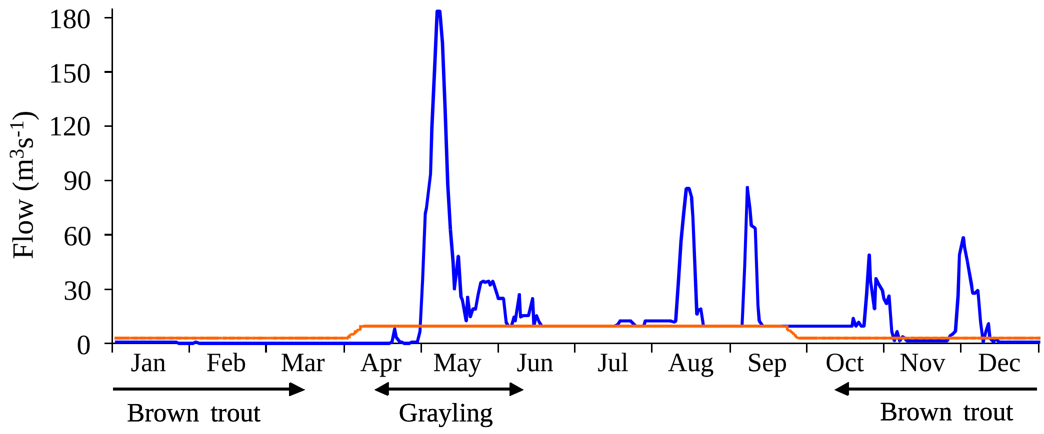


Figure 9.4 Example of high flow events in Klumpströmmen 2003-2008 (blue line, data from Fortum) and adapted future flow regimes (red line). The general spawning and egg periods of grayling and brown trout indicated by arrows.

9.2 Statistical analysis

As noted, the WTP-question was formulated as a referendum in the Bollnäs municipality. This follows a long-standing tradition of local referenda in some countries/states (e.g. Switzerland/California) in general and on water issues in particular. We use, as indicated, a type of question in surveys that includes many currently popular variants as special cases. Rather than asking the individual to state a point estimate or select between given brackets, the individual can self-select any interval of choice. A disadvantage with common bracketing approach is the possibility of starting point bias, or "bracketing effect", a phenomena that has been extensively studied and documented. Briefly, in split-samples one often finds significant differences between responses depending on the chosen bracket structure.

Our objective is to estimate the distribution of WTP. The most popular non-parametric maximum likelihood estimators are based on Turnbull (1976). A Turnbull-type likelihood is based on the assumption that the censoring mechanism is random from the individual's point of view. Thus, each interval is viewed as if the individual choose that particular interval among other presented intervals.

A different approach, based on so-called middle censoring, has been suggested by Jammaladaka & Mangalam. This estimator, the SCE (self-consistent estimator), needs both the point and the interval data, the intervals being viewed as randomly censored points. It was used for example by Håkansson (2008).

Survey data from Bollnäs municipality on willingness-to-pay for improvements in Bollnäs river are collected, where respondents have the opportunity to give an interval answer. In a web survey with 135 responses, 36 gave point numbers, 47 selected interval-answers, and the rest was zero-responses. The mean of point data is 482.25 and the mean of middle point of intervals is 495.09 (assuming positive WTP).

Table 1 presents the estimation results for mean WTP and it standard error, using the three different methods: the nonparametric one based on SCE, parametric based on Weibull distribution, and our method based on uncertainty measure. The Weibull distribution is chosen because of its flexibility. It can mimic the behavior of other statistical distributions such as the normal and the exponential. We observe that the Weibull method has the lowest standard error but the estimated WTP is also smallest, even less than the one that assuming all the interval answers having the mode at the lower limits. So the WTP seems to be underestimated. Whereas the WTP estimates with SCE, the triangular distribution with mode at middle, and the uniform distribution look reasonable, the triangular is favorable with its lower standard error.

Results for zero-responses are easily obtained by multiplying the corresponding information in Table 1 by a factor 83/135.

Table 9.1: The estimates of mean WTP and their standard errors by the three different methods without Zero-responses: nonparametric (SCE), parametric (Weibull), and our method

	SCE	Weibull	Triangular dist. with mode at 0	0.5	1	Uniform distribution
WTP	464.9	420.6	436.5	489.5	542.5	489.5
s.e.	72.48	53.79	63.32	68.08	75.73	70.03

Table 9.2: The estimates of the standard errors for the two extreme cases

	Triangular dist. with mode at 0	0.5	1	Uniform distribution
s.e.(I)	60.41	66.07	73.32	66.07
s.e.(II)	65.45	69.58	77.52	72.9

To investigate the behavior of uncertainty in our WTP estimation, it would be interesting to know how the standard error changes in the following two extreme cases:

(I) The interval answers were replaced by their middle point so that we pretend that we had only observed exact points.
(II) Opposite to Case I, we pretend that we had only observed intervals.

The standard errors estimated corresponding to these two cases are shown in Table 2. The changing rate seems quite small, which implied that our estimate of uncertainty is stable.

The Weibull approach has the lowest relative standard error but at the same time the estimate of mean willingness to pay is remarkably smaller compared to the other methods. In fact it is even smaller than when we assume that the individual's uncertainty is given by triangular distribution with mode at the left end of the reported interval. Thus there is an evident risk that the Weibull distribution does not give a good distribution of the data and leads to biased estimates. Assuming a parametric model gives more structure to the problem and often also to lower standard errors of the estimates. Unfortunately if there is no underlying knowledge about the chosen parametric model but it is chosen by other reasons e.g. flexibility the risk for biased estimates is obvious.

The mean WTP estimate using the SCE approach (464.9) is lower than the one based on symmetric distributions (triangular and uniform). It is also worth noting that it is clearly lower than the mean WTP obtained from those exact responses, which is 482.3. This indicates that the SCE approach tend to underestimate the mean WTP. The findings by Ekström indicate that if this is the case then the respondents giving an interval have a tendency to be closer to the upper bound of the interval.

The relative standard errors when we assume different triangular distributions are all around 14%, which is lower than that obtained from the SCE approach. It was interesting to compare the situation where it is assumed that all respondents give an exact value or all give an interval. When interval uncertainty is included to standard errors increases form 5% (symmetric triangular distribution) to 10% (uniform distribution) or with another interpretation. To obtain the same precision the number of respondents has to increase with 10 to 21%. One of the reasons to allow self-selected intervals was to reduce the non-response rate. Usually, the non-respondents have other preferences so to avoid bias a second small sample from the non-respondents should be included in the study. Thus by increasing the sample size slightly and allow self-selected intervals we guarantee a higher precision and may also avoid the need of a second sample.

The estimates based on uniform or symmetric triangular distributions are used in the economic analysis in the following section.

9.3 Economic analysis

As explained above, we develop a simple general equilibrium model and derived so called cost-benefit rules. In our case, it reads:

dW=profit change+WTP (local improvement)+WTP(downstream improvement}-WTA^{Externality cost for replacement electricity}+tax term

Each of these terms has then been subject to empirical analysis, given the two scenarios under scrutiny.

Table 9.3 Results of the CBA in the Dönje case

Item	Pointestimate winterscenario (0.25 → 3 m^3s^-1)	Pointestimate summer and winterscenario (0.25 → 3 m^3s^-1 and 10 → 20 m^3s^-1)
Profit change	-66	-254
WTP local improvement	18	18
WTP downstream	0	0

improvements		
Externality cost of replacement electricity	-2	-7
Sum	-50	-243

Thus, the bottom-line is that the proposed changes do not pass a simple benefit-cost test. This, of course, does not mean that the change is unprofitable at all parameter configurations. Yet, the overall conclusion is fairly robust.

In Johansson & Kriström (2010a) we go through the estimations in detail and only a brief summary is given here. The first term is the change in the present value profits given an implied horizon of 30 years. Fortum has kindly provided us with estimates of the annual loss of revenue if water is diverted from electricity according to our scenarios. For ease of replication, we calculated the profit loss using standard formulas (and the differences turned out to be insignificant).Using Nordpool data and estimates from Eurelectric we develop two price scenarios, that we believe give reasonable lower and upper bounds on electricity price developments. For additional details regarding how we estimated change in net profits, we refer to Johansson & Kriström (2010a).

The second term is the local improvement as perceived by inhabitants in the Bollnäs municipality. As mentioned above, we carried out a contingent valuation study to estimate this term. It was preceded by the focus groups analysis described below and the on-site ecological assessment described above. In July 2008 the economics team in the project held six focus groups (meeting with a total of 39 individuals) in the city of Bollnäs. The focus groups of three to seven people were moderated by two researchers from SLU and lasted approximately 75 minutes. Respondents received a cash payment of SEK 250 to compensate for their time. Respondents were asked to answer all survey questions and to write notes, questions or comments in the margin to indicate confusion or misunderstanding. At designed places in the survey, respondents were asked to stop and discuss their reaction to the questions. The moderators asked probing questions to determine whether respondents understood the key aspects of the valuation scenario. The ensuing discussion resulted in valuable insights into how the survey was interpreted and provided useful information for revisions.

Given the insights obtained from the focus-groups, we then proceeded to revise our survey instrument. A web-based sample was obtained providing 136 completed surveys for the Bollnäs municipality, and 200 completed surveys in total. The 200-136 = 64 questionnaires not from the Bollnäs municipality came from households in neighboring municipalities. We compared various statistics obtained from the sample with official data on income, demographics and so on. This analysis suggested that the sample was not unbalanced in the dimensions we could study.

The WTP-question was introduced in the following manner:

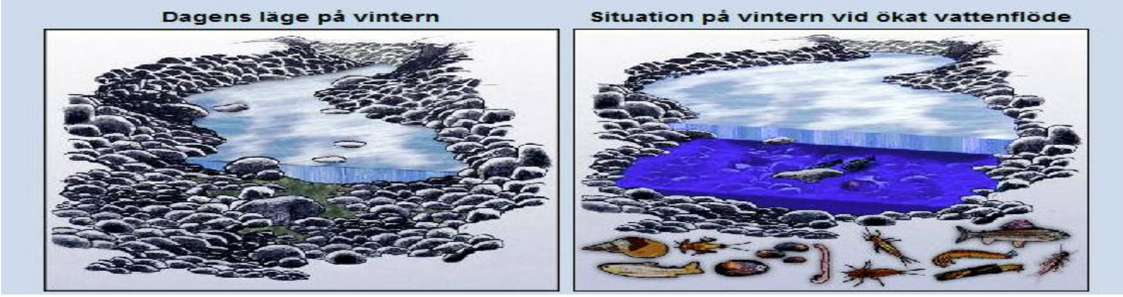
It has become more common in Sweden that those who are affected by local environmental issues are able to vote in local referendums. The following proposal can be viewed as such a local referendum. It is thought to be held among inhabitants of Bollnäs municipality.

The purpose of this question is to shed some light on how the average citizen of Bollnäs values a potential change of the water flow in the Bollnäs streams. The change will improve fishing conditions, water ecology and landscape aesthetics. At present, the water rights are owned by the Fortum company. This means that Fortum has the right to produce electricity at the Dönje plant. Suppose that the only possible way to increase the water flow in the Bollnäs streams is to buy back those water rights, by means of a joint action among Bollnäs citizens. The [winter] ***Proposal*** *entails an increase of the winter season water flow from 0.25 m^3s^-1 to 3 m^3s^-1. There will be no change in the summer season water flow. This means that the water flow will increase from the power station to Varpen (note: this was described in a map not included here) The proposal is depicted in a series of pictures in the sequel. The total costs for the* ***Proposal*** *is not known with certainty at the present time. Suppose that the referendum is held when the cost has become known. If a majority supports the proposal, it will be undertaken. A "yes" entails each household paying a given sum over a period of 5 years.*

A series of pictures were introduced in order to depict, see Figures below. The drawing was necessary, because we have no photographs of the change during the ice-period. For the summer-winter scenario, a picture was added showing the summer season change. The difference (10 → 20) is quite small. Consequently, we expect rather similar valuations of the two scenarios, an expectation that was fulfilled.

Table 9.4 Dönje scenarios

 Summer 10 (status quo and scenario 1)	 Summer 20 (Scenario 2)
	 Winter 3 (scenario 1 & 2)



Status quo and scenario 1& 2

For the estimations, see WP2 above. For ease of replication we thus use the inerval midpoints, rounded up to 300 SEK. The next term in the cost-benefit rule relates to possible donstream improvements, such as smoother flow. We approximate this term to zero, given that small perturbations proposed. Next, we considered the possible environmental impacts of any replacement eletricity. We obtained an upper bound by assuming that all electricity lost is replaced by Danish coal-fired plants. Observe that carbon dioxide is not included, because of the European permit system. The calculations of externality cost were done via literature studies and using information from a German research project.

Finally, assuming a constant electricity demand, the tax term is unaffected. In the sensitivity, we explain why the tax term is very important, if there is a demand response; the reason is that electricity is heavily taxed and the lost revenues must somehow be replaced, given constant public consumption. The sensitivity of demand gives added information about the project's profitability. The bottom-line is that the suggested scenarios do not pass a simple cost-benefit test over a fairly large region of the parameter space.

10 Case study example 2. Emån CBA

10.1 Natural science study

The population dynamic model developed within WP4 was used to make quantitative predictions for the three scenarios in this Case. For reliable predictions, the model was re-parameterized for sea trout, the main species of interest in in the river Emån. The re-parameterization was necessary for the biological parameters and also for the Emån specific environmental parameters such as recruitment areas, fish passage probabilities for each passage, predation risk for smolt, etc.

10.2 Economics study

A mail-survey was performed targeting recreational fishers that had fished salmon and/or Sea Trout, using Choice Experiments (CE). As explained above, the goods include a day of fishing and the expected catch of fish in different size classes. Preliminary results of the CBA that looks at the scenarios detailed above are in Laitila & Paulrud (2010). We need to buttress these results further, before we can send them off for publication.

11 Case study example 3. 'Flexicurity' and the -2,+1 Ljusnan case

The peculiarities of the current regulation in Ljusnan is a key to our proposal. Following extensive, sometimes even bitter, conflicts in the 1970s, a part of the river called MellanLjusnan, was protected by law. The upshot of this protection is hydropower generation upriver and downriver, leaving a ”hole in the middle” – an 80 km stretch free from dams. Because electricity generation is significantly much higher during the winter season, MellanLjusnan is subject to a kind of stream reversal. Under natural conditions, MellanLjusnan will carry perhaps 50 m^3/s during the winter season; the current regulation rarely leaves the flow under 200 m^3/s. The reversal during the summer season is not quite as dramatic. The basic point is that the ”excess flow” in the winter can be redirected in a new tunnel and the associated power conveniently harnessed at the existing plant Laforsen, if new turbines are inserted below ground. The ecological improvements secured by reverting MellanLjusnan to a state more similar to natural conditions is explained below.[1]

11.1 Natural science study

The population dynamic model was developed to make predictions for this case, see section 8.2.1. The most difficult part has been the parameter estimation, especially since there are no fishways in Ljusnan to estimate the passage probabilities from. There are also difficulties in estimating the expected predation losses of smolt during downstream migration since there are no salmon parr and smolt in Ljusnan. Data for parameterization therefore comes from other rivers in the northern Sweden, or elsewhere, when data from these rivers were lacking. Due to the uncertainty in the parameter estimates we applied sensitivity analyses as a first approach, and later on the model was modified to allow analysis of uncertainty in the way described by WP2 (Figure 11.1).

There is, however, one type of uncertainty that can not be dealt with using error propagation and that is when it comes to the type of density dependent recruitment function. For that reason analyses were made with each the two common types, Beverton-Holt and Ricker functions, separately (Figure 11.2.). For a large range of parameter values both recruitment types gave approximately the same average population size of spawners. But, the population dynamics is predicted to become more fluctuating, almost cyclic, with a Ricker Recruitment. The Beverton-Holt recruitment function is used by ICES (WGBAST) for the assessment of the salmon in the Baltic, but their recruitment data indicates that some of the rivers have tendencies of a humped-shaped Ricker function.

Another aspect is that when we developed this case in the first place, the model predictions differed somewhat from the most recent version of the model. The reason for this change in predictions is that there has been an ongoing activity in refining the parameter values. The

1 Because the tunnel ends at Forsänget, leaving a stretch of MellanLjusnan that will be unaffected by our proposal, it is not strictly correct to say that our proposal benefits the whole of MellanLjusnan.

results that may serve as the most present and robust predictions are those in Figure 11.2 and for the total number of spawners in Figure 11.1.

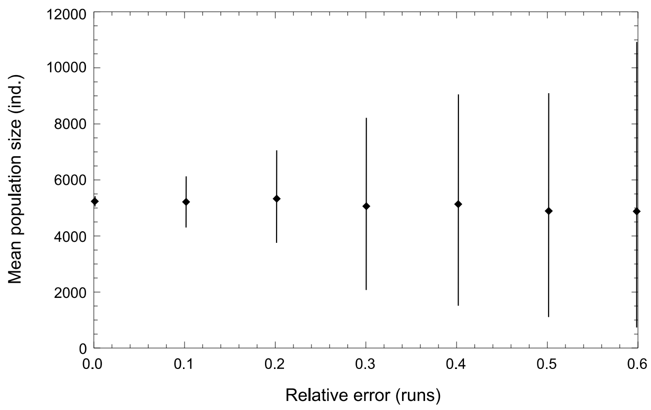


Figure 11.1 Influence of uncertainty of the parameter mean values on the predicted mean population size of spawners. The uncertainty is expressed as the relative error of the parameter mean. The relative error was randomly drawn from a triangular distribution that was centred around 1.0 and then multiplied by the parameter mean. The error bars denote 95 % confidence intervals.

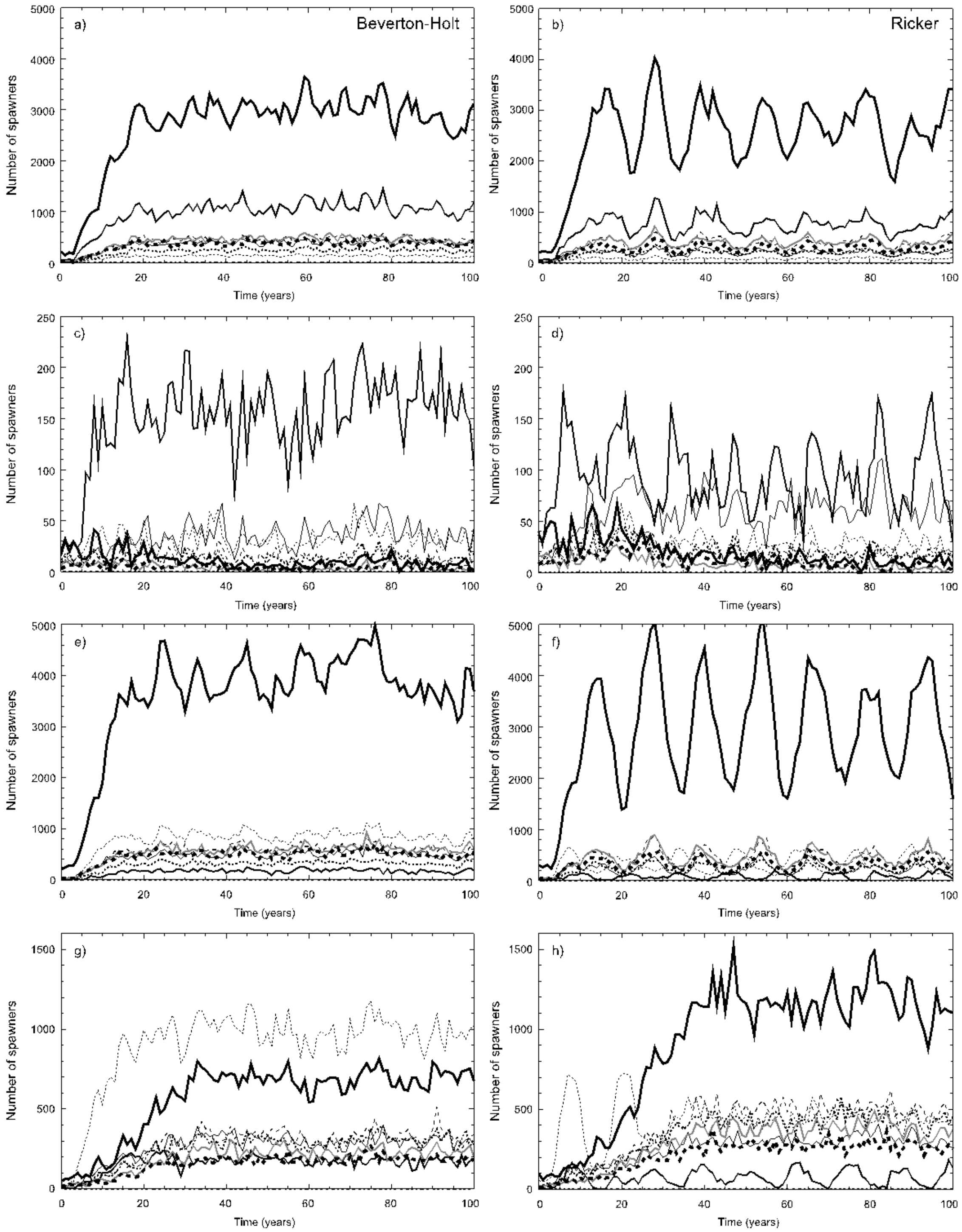


Figure 11.2. Predicted number of spawning adults of Atlantic salmon at different sections in the River Ljusnan depending on which stock-recruitment relationship the population will follow. The scenarios include; a-d) construction of fishways at all eight dams with geometric mean fish guidance efficiency (FGE) of 0.98 for smolt, 0.93 for returns, and 0.90 for kelt (a, b), with geometric mean FGE of 0.88 for smolt, 0.83 for returns, and 0.81 for kelt (c, d). The scenarios (e-h) implies removal of the two dams closest to the sea and construction of fishways at the remaining six dams with geometric mean FGE of 0.98 for smolt, 0.95 for returns, and 0.92 for kelt (e, f), and with geometric mean FGE of 0.89 for smolt, 0.86 for returns, and 0.82 for kelt (g, h). all hydropower stations and dams left represents removal of the two hydropower stations/dams closest to the sea.

11.2 Statistical analysis

To get an idea about the support for the project "-2+1" a survey was planned covering people living in the municipalities Söderhamn, Ljusdal, Bollnäs, and Härjedalen having an age of 18 years and older. The size of the survey was decided to be 800 with proportional allocation for the four municipalities. With this approach there was a guarantee getting a sufficient number in each municipality and at the same time each individual had the same probability of being selected facilitating the analysis.

The task to conduct the survey was given to a consulting company. Unfortunately, they were not able to do that properly. Instead of a sample size of 800 they got a sample size of 878 and the selection was not done by proportional allocation. For example, the obtained proportions for Söderhamn and Ljusdal were 37% and 18%, respectively instead of 31.7% and 23.3%. According to their reporting the response rate was 51% for the whole sample as well as for Söderhamn. A follow up study was planned for Söderhamn in order to analyze if the non-respondents had other preferences. About 50 respondents were telephone-interviewed. Of those almost all (except 2 or 3) declared that they had not got any questionnaire to answer. Consequently, there was no surprise that they had the same preferences as the others and any further analysis was meaningless.

11.3 Analysis of preferences

As explained above, analysis with the fish population model suggested that to get the salmon back up to Laforsen, a natural stop for the salmon runs some 150km from the coast, it was essential to tear out the first two dams in the river. To buttress the popular support for our proposal we used a web questionnaire, followed-up by a small-scale telephone interview. In addition, we discussed the idea with the stakeholders at a designated workshop. The questionnaire targeted those living in the municipalities along the river (Söderhamn, Bollnäs, Ljusdal och Härjedalen). Söderhamn is located at the mouth of the river and hence will benefit from the dam removal and the subsequent improvements of marine life. Those living in Bollnäs will be able to enjoy the salmon runs, while the most apparent impact in Ljusdal will be the extensive construction work. At the existing power plant, Laforsen, we propose to insert new turbines below ground (at some 150m below the surface). A 20km long tunnel will transport the water from the plant to the outlet at Forsänget.

The web-survey was carried out during April-May 2010, resulting in 445 completed questionnaires. In addition, we telephone-interviewed about 50 respondents.

The proposal was presented to the respondents as follows:

- The powerplants Ljusneströmmar och Ljusnefors are revomed (these are the two powerplants closest to the coast)
- A tunnel is constructed from the exisiting powerplant at Laforsen to Forsänget. New turbines are installed at Laforsen.
- The new tunnel implies that the winter waterflow in MellanLjusnan will be approximatedly equal to what it was before regulation of the river.
- Energy generation will be about the same before and after construction.

- Fish patways are constructed such that the salmon can travel from the Sea up to Laforsen (a natural passage block). Salmon cannot travel up the river today.
- We estimate that the total number of grown salmon that returns year to spawn in Ljusnan is about 5000, with an average weight of 7-8 kg.
- About 2500 of the salmon will reach spawning grounds downstream of Laforsen, 300-500 will remain at each of the areas between the remaning powerplants downstream. About 1200 salmon will spwan downstream the Höljebro power plant.
- The cost for the project is absorbed by the onwer of the plants.
- Construction work is estimated to give at least 1000 an years and take several years.

We visualized this description by photographs and an optional video. The video contained the same information as in the text provided, except that the text had optional additional details about the proposal.

The Figures below describes the proposal. The video is available on the project homepage.

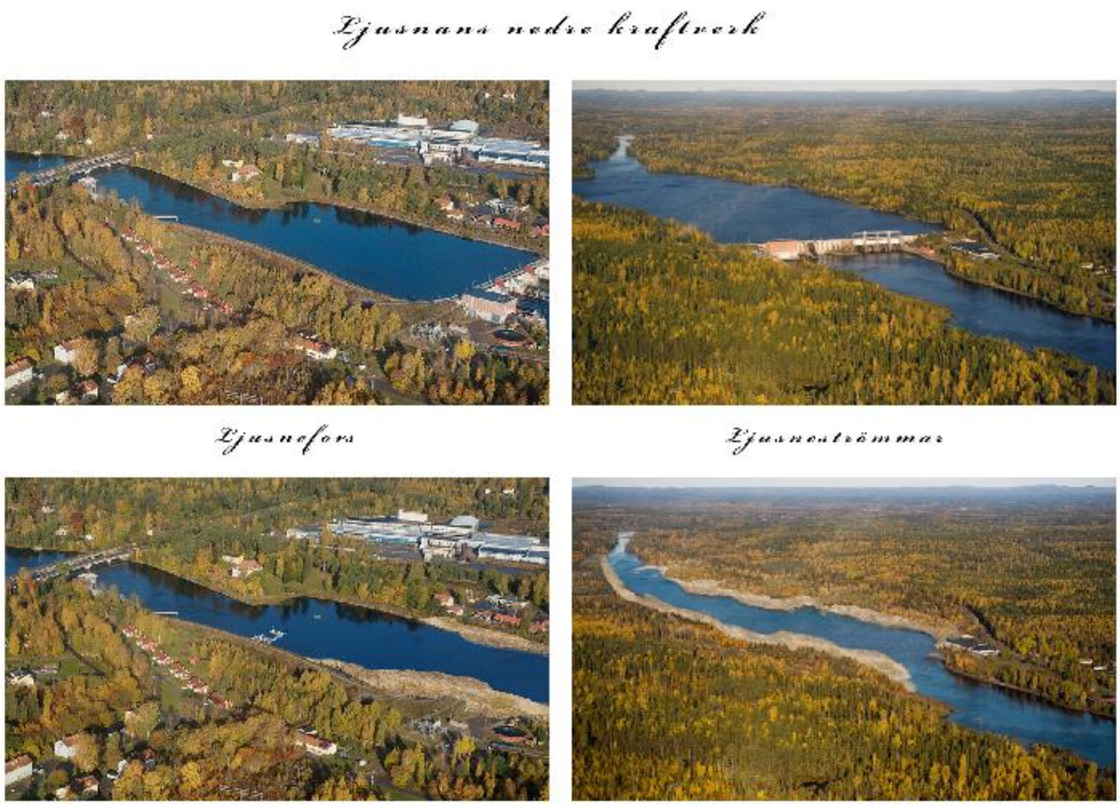


Figure 11.3 . “-2,+1” Short run

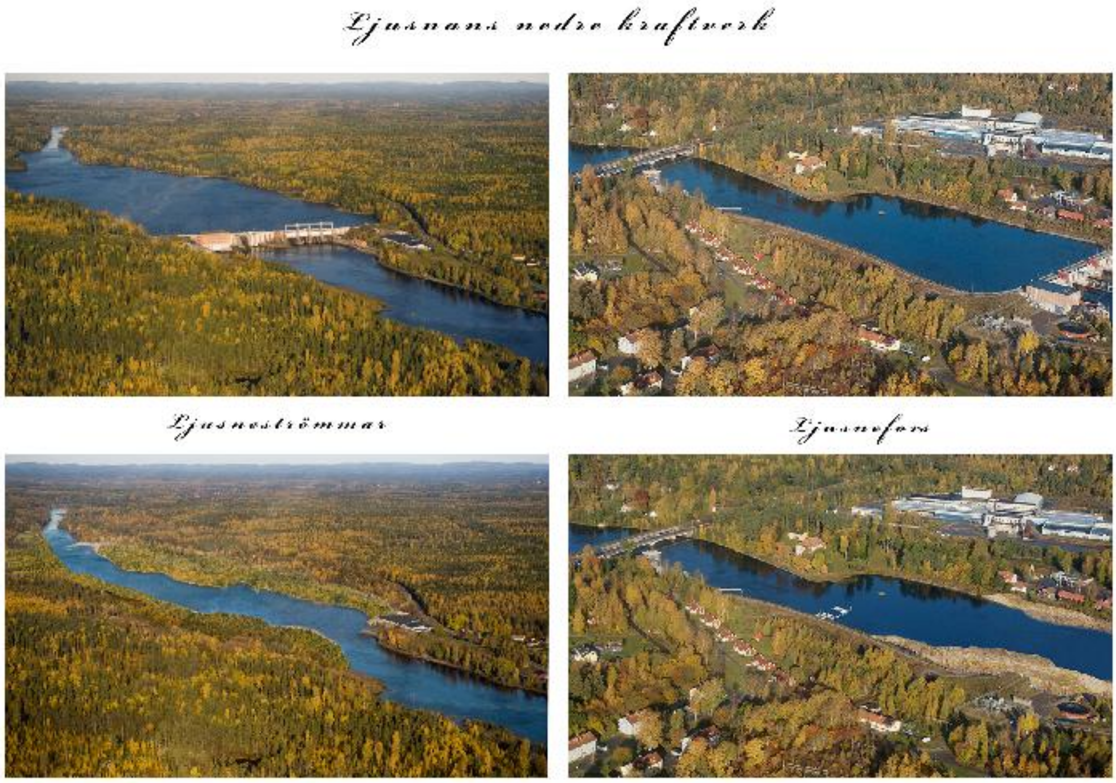


Figure 11.4 Scenario "-2,+1" Long run.

The displays above were used to visualize the proposed scenario;we explained and pictured the difference between the short- and long run, as can be seenin the pictures.. After having absorbed the information about the scenario, we asked the respondents for their sentiments. There were 5 different options, ranging from ”Definitely an improvement” to ”Definitely worse”, there were also a ”don't know option”.

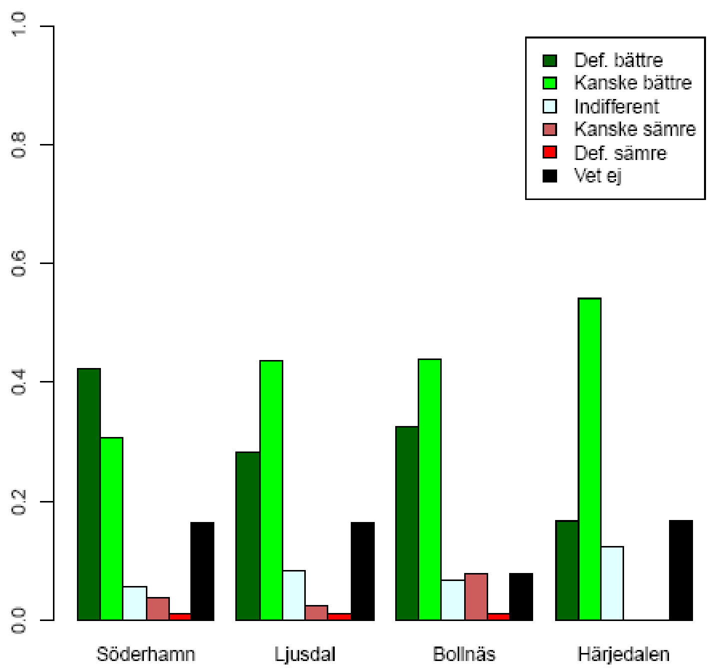


Figure 11.5.Results of the “local referendum” in the 4 municipalities

Thus, there seems to be a significant majority in favor of the project. At this point, there is no need to overstate these results. Our empirical analysis does indicate that our scenario has some popular support. In addition, because the scenario has not met with resistance from several key stakeholders, we feel that this study can serve as a starting point for further investigation into “flexicurity” type scenarios. The term flexicurity is a combination of “flexibility” and “security”, here combining two ideas. First, we look for scenarios that, at the minimum, maintains both ecological integrity as well as energy generation at the status quo levels. “-2,+1” implies an environmental improvement (while keeping energy generation constant). Second, flexibility is used here in the sense of alerting the policy maker about the potential existence of comprehensive regulatory changes, if a holistic perspective on regulation is maintained. As argued above, this perspective is consistent with the Water Framework Directive as well as Swedish environmental law.

The broader question is, of course, if “-2,+1” just happened to be a lucky shot, or if the broader perspective we are suggesting is beneficial to further creative thinking about regulatory problems in other water systems? We remain confident that the holistic perspective provides useful food for thought and should open the scope for much interesting research in the future.