Cost-Benefit Analysis of continuous cover forestry and buffer zones as Nature Based Solutions to preserve water quality level in Lake Puruvesi and in its sub-catchment area.

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Abstract

Mitigation from the perceived risks of climate change is urgent issue in many fields. This research focuses on providing information to support decision making in mitigation of hydro-meteorological risks that climate change causes to the water quality in Lake Puruvesi. This study reviews continuous cover forestry (CCF) and buffer zones as possible nature-based solutions (NBS) that could achieve the goal of keeping the water quality level in study site on current level or improve it. The main research question of this research is: Is it economically feasible to implement continuous cover forestry and buffer zones as nature-based solutions to mitigate nutrient loading in research area so that the water quality will stay at least at the current level in the future?

Previous research has shown that CCF can be economically feasible way to manage forests. In addition to this, continuous cover forestry and buffer zones can reduce nutrient loading from forests to nearby waters. These solutions are evaluated in the framework of cost-benefit analysis which is the main method in this study. The aim is to monetize costs and benefits that NBS implementation will cause. If the net social benefits after analysis are positive, the project should be recommended. In this study recreation values from the study site were obtained by utilizing pre-existing valuation studies made by Finnish Natural Resource Center. Costs on the other hand were derived by using size-structured forest optimization model. The economic loss for forest owners is the difference between their optimal forest management choice, and the optimized solution, where clearcutting is restricted. In the buffer zone case optimization was similar but the costs from buffer zones are directly the maximized profits from forest as the buffer zone is completely left out from any forestry.

In both cases CCF was the optimal forest management regime for the sample forests. When these costs were compared to the benefits this study produced positive net social benefits and hence CCF and buffer zones should be recommended as NBS in the study site. However, there are quite large assumptions made in this study, and further modeling of nutrient flow in study site is required as the quantified impacts of nutrient run-off are still unclear. For this reason, further research is required for more precise analysis regarding quantified impacts.

Keywords

Cost-Benefit-Analysis, Buffer zone, Continuous cover forestry, Nature based solution

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Väinö Nurmi, Marko Lindroos

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Tiivistelmä

Ilmastonmuutoksen aiheuttamien riskien hallinta on nyt ja tulevaisuudessa tärkeää. Tämä tutkielma keskittyy antamaan tietoa päätöksenteon tueksi ilmastonmuutoksen aiheuttamien hydrometeorologisten riskien hallintaan, joita ilmastonmuutos aiheuttaa vedenlaadussa Puruvedellä. Tutkimuksen tarkoituksena on arvioida jatkuvapeitteisen metsän kasvatuksen (CCF) ja suojavyöhykkeiden soveltuvuutta luontopohjaisiksi ratkaisuiksi (NBS), joilla saadaan pidettyä järven vedenlaatu nykyisellään tai parantamaan sitä. Tutkimuskysymys on: ”Onko taloudellisesti järkevää käyttää jatkuvapeitteistä metsän kasvatusta ja suojavyöhykkeitä ravinnekuormituksen vähentämiseen tutkimusalueella, jotta vedenlaatu alueella säilyy vähintään nykyisellä tasolla”

Aiempi tutkimus on osoittanut jatkuvapeitteisen metsänkasvatuksen olevan taloudellisesti varteenotettava vaihtoehto kasvattaa metsää. Lisäksi tutkimus on osoittanut, että CCF ja suojavyöhykkeillä voidaan vähentää vesistöihin kohdistuvaa ravinnekuormitusta metsämailta. Näistä NBS:istä aiheutuvia kustannuksia ja hyötyjä arvioidaan tutkielmassa kustannus-hyötyanalyysin keinoin, jossa tarkoituksena on laskea projektista johtuvat hyödyt ja kustannukset ja verrata näiden nettonykyarvoa. Mikäli projektista seuraava yhteiskunnan nettohyöty on positiivinen, tulisi projektia suositella.

Tutkimusalueen virkistysarvo arvioitiin käyttämällä hyödyksi Luonnonvarakeskuksen aiempia arvottamistutkimuksia. Virkistysarvoja verrattiin NBS:stä aiheutuviin taloudellisiin menetyksiin metsänomistajille. Kustannukset saatiin hyödyntämällä kokoluokka-rakenteista metsän optimointimallia. Tavoitteena oli selvittää, mikä on metsästä saatava maksimoitu tuotto metsänomistajille ja verrata sitä optimointitulokseen, jossa päätehakkuu on rajoitettu. Tämän lisäksi suojavyöhykkeillä olevan metsän maksimoitu arvo laskettiin, josta saadaan suoraan metsänomistajille aiheutuva menetys, koska alueet poistuvat kokonaan metsätalouden piiristä.

Jatkuvapeitteinen metsänkasvatus oli kummassakin tapauksessa taloudellisesti optimaalinen tapa kasvattaa metsää. Tämän lisäksi arvioitu yhteiskunnan nettohyöty projektista on positiivinen, joten NBS:iä voidaan tältä perusteelta suositella keinoiksi vedenlaadun säilyttämiseksi tutkimusalueella. Tutkimuksen tuloksiin on kuitenkin suhtauduttava varauksella, koska analyysiä tehtäessä tutkimusalueen ravinteiden huuhtoutumismallit ovat vielä tekeillä, joiden valmistuttua tarkempi tieto NBS:ien vaikutuksista on saatavilla.

Avainsanat

Kustannus-hyötyanalyysi, Suojavyöhyke, Jatkuvapeitteinen metsänkasvatus, Luontopohjaiset ratkaisut

Ohjaajat

Väinö Nurmi, Marko Lindroos

Säilytyspaikka

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Muita tietoja

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INTRODUCTION

Climate change has already caused hazards such as extreme weather and various climate change related risks have already observed to be increasing. If the temperature rises, the probability of the materialization of these risks will increase as well. European Union is funding a project named OPERANDUM through its H2020 program, which is European Union’s research and innovation program (European Commission, 2013). The main task of OPERANDUM is to find nature-based solutions which can mitigate damages caused by hydro-meteorological risks that are emerging due climate change. Such risks can be for example flooding, extreme precipitation, draughts, coastal erosion and potential storm surges. (OPERANDUM, 2019c; Sahani et al., 2019) This research is part of OPERANDUM, and although nature-based solutions are developed and reviewed in twelve different countries, this research focuses only to Finland and lake Puruvesi and its sub-catchment area of Kuonanjoki. In this research the author conducts a cost-benefit Analysis to review if the nature-based solutions for nutrient load mitigation in Kuonanjoki sub-catchment area are economically feasible solutions. The chosen nature-based solutions in this OPERANUM project are continuous cover forestry (CCF) and buffer zones and are therefore studied in this thesis as well.

Current situation in the research area is that Lake Puruvesi has generally excellent water quality. However, the water quality in Kuonanjoki sub-catchment area and in Savonlahti inlet are significantly worse compared to the overall situation in Lake Puruvesi. The main reason for this is the nutrient loading from the surrounding forest area which causes water quality degrading. The target of OPERANDUM is to develop nature-based solutions and implement them to the extent that will keep the water quality level on the same level as it is now, or in the best case, improve it. The plan is to do this first in Kuonanjoki sub-catchment area and in future in the whole Lake Puruvesi region as well.

This topic is significant because climate change will have an impact on the environment and increases the frequency and the severity of the risks mentioned earlier. Developing and studying new nature-based solutions for risk management and mitigation of damages caused by climate change provides valuable information for wider cooperation as well, where similar solutions may be implemented in other vulnerable areas. OPERANDUM project provides an opportunity to study different scenarios in many countries and it is possible, or at least one of the targets of this project, to use the results in the future to mitigate hydro-meteorological risks in other contexts as well. From a purely academic point of view the topic is significant for a thesis as it combines most of the important theorems and subjects of the environmental economics such as cost-benefit analysis and environmental valuation and their microeconomic backgrounds, and economic models that study the optimal use of natural resources - a switch to continuous cover forestry from rotation forestry in this case. Continuous cover forestry is especially interesting subject as it has been in the center of discussion (Hutinen, 2018; Juntti, 2019; Oinaala, 2018) as resent research has been able to prove that it might be a more profitable solution for forest management compared to rotation forestry in some situations. (Assmuth, Rämö, & Tahvonen, 2018; Rämö & Tahvonen, 2015; Rämö & Tahvonen, 2016) However, the empiric evidences from the field studies regarding continuous cover forestry are yet quite scarce as the findings of these studies are largely based on models.

Main research question in this thesis is: Is it economically feasible to implement continuous cover forestry and buffer zones as nature-based solutions to mitigate nutrient loading in research area so that the water quality will stay at least at the current level in the future? Research question is answered by construction a cost-benefit analysis of these nature-based solutions. In addition to this, the aim of this research is to provide information for OPERANDUM project and future research it holds. This can mean for example transferable cost-benefit scenarios for other locations, more accurate and thorough cost-benefit analysis from the study site or provide supporting evidence for the stakeholders. This cost-benefit analysis is considering only one sub-catchment area of Lake Puruvesi and its characteristics. In the future it is possible that the results from this thesis could be implemented to whole Puruvesi-region by transferring the models used in this work.

This thesis includes three separate parts. The first part, section 1, of this thesis is focusing on OPERANDUM, Lake Puruvesi and the sub-catchment area of Kuonanjoki. This part focuses on explaining the research context and provides the overview for the characteristics of the research site. This is a necessary step for the justification of the nature-based solutions, assumptions behind the benefit and cost items in the cost-benefit Analysis and provides an overview of the project and the research area for the reader.

In the second part, sections 2-4, the author explains key concepts behind cost-benefit analysis, environmental valuation, natural resource economics and briefly the key microeconomic theories behind these methods. The last part, sections 5-7, concentrates on the empirical research and how the cost-benefit analysis was conducted and what are the results. The last part includes also an interpretation of the results and provides conclusions.

The main methodology that the author is using in this research is cost-benefit analysis and utilizes the nine steps approach developed by Boardman (2014). This is the base of the theoretical framework in this thesis. The benefits of recreation use in the research area are derived from two studies done by Finnish Natural Resource Institute (Pouta & Tienhaara, 2018; Tienhaara, Pouta, & Lankia, 2018). The methodology used to derive the results in both of the papers is a combination of Travel Cost and Contingent Behavior valuation methods. These studies were conducted to evaluate what is the recreational value of Lake Puruvesi with the current water quality and to estimate how the recreational value changes in different hypothetical water quality scenarios. Travel cost method is a suitable method to be used when observable behavior is being assessed. However, this method was not sufficient alone to study the interaction between different water quality levels and their corresponding recreational values, next to the current value. Hence, a combination of travel cost method and contingent behavior method were used to obtain estimated recreational value in the hypothetical water quality scenarios.

To obtain the recreational value from the study site, the benefit side of the cost-benefit analysis, the results of these valuation studies are transferred to the study site. This step requires estimation of number of residents and visitors in the study area by utilizing population data from the Population Register Centre of Finland (Population Register Center, 2018) and Central Statistical Office of Finland (Tilastokeskus, 2019). After this, the benefits from the previous valuation studies are estimated by this population data, which in turn provides estimate for different water quality scenarios in the study.

These benefits are then compared to the costs that the implementation of the nature-based solutions would impose to the forest owners. These costs are derived by using forest optimization models developed by the Economic-ecological optimization group lead by professor Olli Tahvonen from University of Helsinki. The underlining idea here is to construct a forest owners profit maximization problem for the forest-owners, compare the optimal solution to the CCF-solution, and assess the economic value that is lost due to turning some of the forest into buffer zones. This methodology is applied to a sample forest and a sample buffer zone in the study site. These two samples are modelled from open source data from Finnish Forest Center. (Finnish Forest Centre, 2017) After this, the collected forest data is used as an input for the forest optimization model (Parkatti, Assmuth, Rämö, & Tahvonen, 2019) and the forest owner's profit is maximized. In the CCF case, this solution is then compared to optimization result, where clear-cutting is constrained in the model and forest is "forced" to CCF-regime. Comparing the difference between these two solutions yields the economic loss of a forest owner from implementing the CCF. The cost of turning some forest area into buffer zone is modelled with the same optimization model. Profits from the sample forest is maximized, and the maximized profit is used as a proxy for the economic loss as it is assumed that the forest turned into buffer zone area is left completely outside of forestry activities. The optimization calculations for this research were made by Vesa-Pekka Parkatti from University of Helsinki and the stem distribution for the sample forests were simulated by Sakari Sarkkola from Finnish Natural Resources Institute. After finding estimates of the cost and benefit items, Monte Carlo-simulation is constructed so that uncertainty of the cost-benefit analysis can be assessed. The resulting distribution yields the estimated net social benefit value of the project as well as the distribution for the NPV. Finally, recommendations for the implementation of nature-based solutions are made based on these results.

1. RESEARCH CONTEXT

This section focuses on explaining the framework of this study and the characteristics of the study area in Puruvesi as it is necessary to understand the context of the study. The main focus in here is the OPERANDUM project and how this study, Puruvesi and Finnish Meteorological Institute (FMI) are linked to it. It is also an opportunity to provide background knowledge from Lake Puruvesi, its characteristics and why it has been chosen to be the site of research.

1.1 OPERANDUM

This research is part of EU project OPERANDUM which has 26 different partners from 12 different countries. Finnish partners are Finnish Meteorological Institute (FMI) and Natural Resources Institute (LUKE). The objective of OPERANDUM is to find solutions to mitigate the hydro-meteorological risks that are emerging due climate change.

Proposed solutions for the risk mitigation are *nature-based solutions* (NBS). This concept is defined in EU as following; *"(NBS are) inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience."* (OPERANDUM, 2019b) The idea is to mitigate risks by working with nature instead of building against it and finding the *"natural way"* (Kalantari, Ferreira, Deal, & Destouni, 2019) for problem solving. Such methods may vary a lot in practice and are dependent on-site characteristics.

Another key-concept of OPERANDUM is the concept of Open-Air Laboratories (OALS). Following description provides an explanation what these study sites are: *"Open-Air Laboratories (OALs) cover a wide range of hazards, with different levels of climate projections, land use, socio-economic characterization, existing monitoring activities and NBS acceptance."*(OPERANDUM, 2019c) There are several study sites all around the world, where these proposed NBS's are studied and which have been selected to be as OAL.

However, this study focuses only on the Finnish OAL which is Lake Puruvesi and its sub-catchment area of Kuonanjärvi. This site has been chosen to be OAL as it is facing flooding and extreme precipitation, (OPERANDUM, 2019c) which are expected to get more severe due to climate change. The hazards that are emerging because of these increasing risks are nutrient loading and eutrophication which are both degrading the water quality of the lake.

1.2 PURUVESI OPEN AIR LABORATORY

Lake Puruvesi is part of Lake Saimaa and it is located in the eastern part of Finland between Southern Savonia and North Karelia as shown below figure. From a governmental point of view, Lake Puruvesi belongs to the cities of Savonlinna and Kitee.

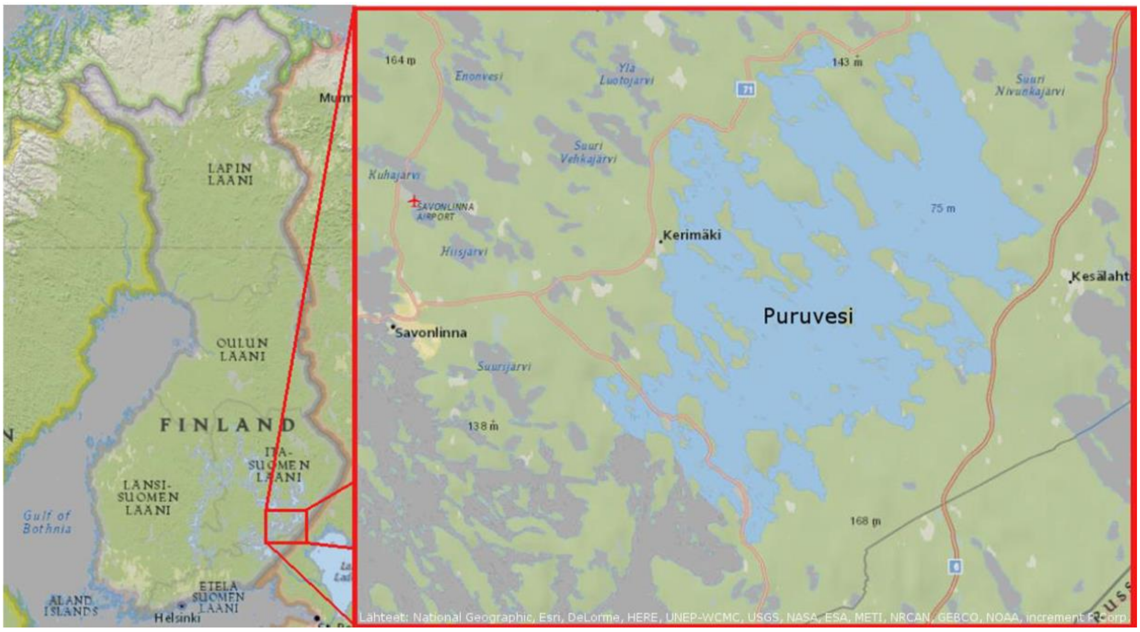

Figure 1.2.1 Map of Lake Puruvesi. (Tienhaara et al., 2018)

Lake Puruvesi has over 850 islands and has a very complex morphology. Over 77% of the lake belongs to Natura 2000 program. (Tienhaara et al., 2018, p. 4) One of the main characteristics of the lake is its good water quality. The water is pure, and the underwater visibility is excellent, because part of the water originates from the groundwater supply. In addition to this, oxygen situation in the lake is good and it does not contain humus. (Tienhaara et al., 2018, p. 4)

Despite these characteristics, Lake Puruvesi has showed increase in eutrophication, especially in its shallow parts. Main effects of this increased eutrophication are sliminess of rocks on shore, thick eutrophic bottom sediment in some locations and blue green algal blooms. (Tienhaara et al., 2018, p. 4) The main reason for the eutrophication is the forest industry with forest cuttings and drainage of peatlands. (Pouta & Tienhaara, 2018; Tienhaara et al., 2018) Agricultural activity also has an increasing effect on the eutrophication. However, only 8% of the catchment area are used for agriculture (Suomen Metsäkeskus et al., 2013) and therefore NBS's to mitigate eutrophication from agricultural activities are not considered in this cost-benefit analysis (CBA).

Nutrient load that Lake Puruvesi faces can be categorized into four different categories: Forestry, agriculture, settlement/point sources and natural run-off/fallout. According to the research of Metsäkeskus (2013), most of the nutrient load from forests comes as natural run-off. The share of the forest industry run-off is only 20% of solid particle/phosphorus load and 12% from nitrogen load. The main active cause for nutrient load from forestry are logging, the surface erosion it causes, and peatland trenching. (Suomen Metsäkeskus et al., 2013, p. 11) The nutrient load from agriculture is caused by erosion which increases solid particle run-off and the rate of nutrient pressure is much dependent on the characteristics of field and production methods that are used in the area. Settlement nutrient load comes mainly from two conurbations of Kerimäki and Punkaharju, but this loading does not have a big impact compared to other categories. (Suomen Metsäkeskus et al., 2013, p. 12)

In this study we are focusing on sub-catchment area of Kuonajärvi and Savonlahti areas, as this area has shown already sings of degrading water quality because of the eutrophication and the water quality is described to be average/poor which is significantly lower compared to the overall excellent water quality of the lake. (Suomen Metsäkeskus et al., 2013, p. 26). The sub-catchment area of Kuonanjärvi is not part of the Lake Puruvesi. However, waters from this catchment area flow to the Savonlahti inlet and hence has a direct impact to the water quality of Puruvesi as well. Reasons for the water quality difference is that the run-off area of Kuonanjoki is the largest one in Puruvesi and the average load per area unit is among the highest. Proportion of the agricultural land is only 6.2 %, which is also a big reason that in this study the author is not focusing on agricultural activities. One distinctive characteristic that is worth to mention is that large proportion of the run-off area is covered by peatlands and from this peatland significant proportion is trenched, (Suomen Metsäkeskus et al., 2013, p.26) which means that nutrients are able to flow more easily to the surrounding waterbodies.

1.3 OTHER PROJECTS IN LAKE PURUVESI AREA

There are couple of other stakeholders acting in the Puruvesi region to improve its state in addition of OPERANDUM. The most significant are FRESHABIT project and Pro Puruvesi organization as they are also working in cooperation with OPERANDUM workgroup. Object of FRESHHABIT is to preserve natural, cultural and recreational values of water heritage. (Metsähallitus, 2019) According to The Finnish Forest Administration (Metsähallitus), the current and the past actions of humans such as agriculture and forestry has caused degraded water ecosystems and FRESHABIT project targets to mitigate these problems with Puruvesi being one of their location for corrective actions. FRESHABIT project has already started and its projected timeline is 2016-2022. (Metsähallitus, 2019) This means that unlike in OPERANDUM, some of the concrete actions have already been implemented such as restoration fishing and reaping of water plants. (Pro Puruvesi, 2019a)

Pro Puruvesi is a non-profit citizen organization that was founded in 2010 to work towards clean future of Lake Puruvesi. It has had wide range of different projects in cooperation with municipalities and regional governments already. (Pro Puruvesi, 2019b) Currently it organizes water quality data gathering from the Puruvesi region. From the OPERANDUM point of view, Pro Puruvesi provides the support and connections to work in cooperation with stakeholders, which is one of the focus points in this project: To encourage stakeholders to cooperate with co-creation and implementation of NBS's.

2. COST-BENEFIT ANALYSIS

In this chapter the author reviews the main method used in this thesis, which is cost-benefit analysis. The aim of this chapter is to explain what this analysis is, what kind of steps it consists of, and in what kind of situations and how it can be used. This includes a description of the basic microeconomic background that is behind this method such as a compensating and an equivalent variation and a Pareto efficiency. The author focuses on introducing the nine steps developed by Boardman (2014), as the empirical part of the thesis is largely structured based on these steps. In addition to this, the author will point-out some of the key weaknesses of the method, including the neglect of distributional issues and the inherent uncertainties that CBA has, and how to address these issues.

Instead of thinking CBA as one rigid method, it is instead like a guideline for decision-making, or a process flow. This interpretation is illustrated the fact that, in its simplest form, CBA is only a subtraction calculation, where the person conducting the CBA calculates the difference between the social benefits (B) and the social costs (C). This is an overly simplified example, but the principle still holds despite CBA's can be extremely intricate.

1. $NSB = B - C$

If the net social benefits (NSB) are positive, the decision maker should recommend the project. If the CBA is conducted after the project has finished and the NSB is positive, the analyst can provide supporting evidence for similar projects in the future and evaluate the effectiveness of the implemented measures. (Boardman, 2014, p. 2),

2.1 BACKGROUND OF CBA

A Key element behind CBA regarding environmental project is the idea of externality. (OECD, 2006, p.31) Externality is a key concept in environmental economics as well. Both positive and normative theories are linked to externalities. In normative application the theory related to externalities is applied in a normative way, like in this thesis, so that decision makers can get recommendations, how to mitigate these externalities, which would not be taken care without intervention to markets. Externality can be defined as *"(externality)…is a present whenever the well-being of a consumer or the production possibilities of a firm are directly affected by the actions of another agent in the economy"*

(Mas-Colell, Green, & Whinston, 1995, p. 352) Eutrophication of waterbodies caused by agricultural activities is a good example of a negative externality. Even though CBA is used to mitigate issues rising from externalities, it is good to note that CBA does not tell what is good or bad, as it is only a tool. (Bateman, Ian, Brainard, & Lovett, 2003, p. 4) This means that integrity, judgement and knowledge of a person conducting CBA are crucial to get the best possible output for decision making.

2.2 DIFFERENT TYPES OF CBA

According to Boardman et al,(2014), there are four different types of CBAs: *ex ante, ex post, in medias res* and comparative CBA. Each of these corresponds the timing, when the analysis is made in relation to the implementation of the project/policy change. *Ex ante* analysis is conducted before a planned project or a policy change have been implemented. *Ex post* is the counter part of the *Ex ante*, as the CBA is conducted after the project / policy change. *In medias res* falls in the middle ground of the two former ones: The analysis is conducted whilst the implementation of project / policy change is ongoing. The fourth and the last method is the comparative CBA, where *ex ante* and *ex post* or *in medias res* analysis of the same project are compared. It is critical to point out that ex post and in medias res are the only methods that can affect to the output of the particular project they are analyzing and thus they are the most useful for deciding whether resources should be allocated to a particular project or program. Ex post offers best tools to contribute on the implementation decisions of future projects which share similarities with the implemented one. (Boardman, 2014, pp. 2-3)

There are alternative tools available to predict outcomes of projects and their feasibility, which are like CBA. Two good examples are Cost-Effectiveness Analysis (CEA) and Cost-Impact-Analysis (CIA). Difference between CEA and CBA is that CEA compares only projects with exactly the same type of benefits. (Nyborg, 2012, p. 15) CEA focuses only on the cost side of the proposed project and the researcher is trying to find out the project which gives the desired outcome with the least costs, i.e. the most efficient solution.

CIA can be described as a list where different projects yield different outcomes. This is practical, when assessing the benefits in monetary terms is impossible for some reason. However, the costs are measured in monetary figures for all possible choices. However, it is mandatory to provide benefits in monetary terms to evaluate the net present value of different proposals, and if this is done, the analysis turns into CBA.

In addition to these different types of CBA's described, there are other alternative tools for the impact assessment of projects such as Environmental Impact Assessment, Strategic Environmental Assessment, Life Cycle Analysis, Risk Assessment, Comparative Risk Assessment, Risk-Benefit Analysis, Risk-Risk Analysis, Health-Health Analysis and Multi-Criteria Analysis. (OECD, 2006) However, in this research we are only considering CBA and utilize it as a framework to compute the net present values of the proposed project for Lake Puruvesi.

2.3 NINE STEPS OF CBA

Table 2.3.1 shows the process steps that Boardman (2014, pp. 6-15) has developed to describe the whole process of CBA. These steps are also followed in this thesis as they provide a solid guideline to conduct a CBA.

1. Specify the set of alternative projects.
2. Decide whose benefits and costs count
3.Identify the impact categories, catalogue them and select measurement indicators
4.Predict the impacts quantitatively over the life of the project
5.Monetize all impacts
6.Discount benefits and costs to obtain present value
7.Compute the net present value of each alternative
8.Perform sensitivity analysis
9.Make recommendation

Table 2.3.1 The major steps in CBA (Boardman, 2014)

In this section the author focuses on elaborating the steps of CBA that Boardman (2014, p. 6-16) has created to guide a researcher through CBA. However, this is a general overview. Empiric part of this study, sections 5-7, focuses on more deeply into these steps and answers which, and why the chosen, decisions were made.

The first step of the CBA requires to specify all the possible different alternative projects. In the case of this project this means assessing every possible NBS combinations which could be implemented and picking those for research that are most feasible and meaningful to pick. This means plausible projects that are realistic, and their probable impacts are significant. This also brings out a challenge: For example, the possible range of different NBS sets are huge as one can alter the level of required buffer zone size and make different assumptions about the required forest management practices. It is also good to point out the normative aspect of the first stage: Reaching some goal that has been set. (OECD, 2006, p. 53) In the case of OPERANDUM project, the set goal is to mitigate the hazards that eutrophication might cause in Lake Puruvesi and maintain the water quality on the current level in the future.

The second step is to decide whose benefits and costs count and are significant to take into consideration in the CBA. OECD (2006, p. 56) provides following instruction for CBA author: *"The basic rule is that benefits and costs to all nationals should be included, whilst benefits and costs to non-nationals should be included if a) the policy relates to an international context in which there is a treaty of some kind (acid rain, global warming), or b) there is some accepted ethical reason for counting benefits and costs to non-nationals."* This step brings up similar difficulties as the first one. In the case of Lake Puruvesi there are costs and benefits to the residents and forest owners at regional level, but the lake offers recreational value also up to national level. Hence, it is important to critically think, which costs, and benefits are taken in consideration as project might have vast amounts of minor cumulative effects which could be calculated but it might not be a realistic task to do so within the boundaries of the project.

The third step is to identify the impact categories, catalogue them, and to select the measurement indicators. In the third category one must recognize the impacts that the project might cause. It is necessary that impact categories have clear causal relationship with the project e.g. in the case Puruvesi, the degrading water quality caused by eutrophication decreases recreation value for ecosystem service users of that lake, and vice versa, NBS are implemented to prevent the decrease. This step requires careful analysis as the impacts can have complex pathways (OECD, 2006, p. 57) as some of the impacts might be indirect or happen after a long time period. In some cases, the initially predicted impact might not happen at all**.** These uncertainties of possible impacts are, especially in the case of ex ante CBA, a large challenge for researcher to mitigate, which leads to the fourth step of Bateman's CBA process flow.

The fourth step is predicting the impacts quantitatively over the life of the project. In this step author of the CBA needs to quantify the impact categories. As already mentioned, predicting the impacts can be very complex especially if the project has long time frame, is unique (i.e. justifying predictions as previous research/results does not exist) or if the causal relationship with the project and its impacts are complex. During the early days of CBA, the time frame for quantifying the impacts was the life cycle of the chosen project. (OECD, 2006, p. 57) This is logical and rather easy task to be done, if the project is a tangible project like a building, a road or other infrastructure. But if the researcher is trying to assess the change in total economic value caused by a more complex project with various impact categories, the impact prediction becomes a more difficult task. This is because timeline of different impacts can be much longer.[1] As the timeframe gets longer, the impact prediction becomes more difficult and unprecise.[2]

The fifth step in CBA is monetizing all impacts. This is from the environmental economic point of view one of the most complex steps in the CBA process and it will be explained further on section 2 as the environmental valuation is its own field of study inside the environmental economics and a crucial part of this study. The objective of this step is to get a monetary value for each impact, whether it is a cost or a benefit. For some of the impacts this can be quite simple, if the pre-existing data is available from impact or impact causes changes in the consumption of market goods. However, as neither from the previous situations rarely applies to the case of ecosystem services, environmental valuation (i.e. monetizing the value that ecosystem services provide) is a tricky task.

The baseline in this step is to assess the change caused by an impact in monetary terms, e.g. how recreation site users' willingness to pay changes if environmental quality of the recreation site changes. (OECD, 2006, p. 58)

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[1] Good example for elaborate the matter is the impacts of perseverance of biodiversity. How to choose right time horizon for this as it could be "infinite" impact. On the other hand, if in the future climate is changing naturally without help from humans, it could be seen that the change of the biodiversity would be natural event and one could argue that human interference to preserve biodiversity would impact harmfully to this natural event. This is of course only hypothetical situation but puts the task number four into perspective.

[2] A Gruesome example regarding human interference is the "perverse incentive", which illustrates how surprising effects human interference can have. (Flynn, 2009)

As the timeline of the project and its estimated impacts gets longer, the more careful work is needed to discount the effects of the impacts. The sixth step in a CBA is to discount benefits and costs to obtain present values. For projects which impact a long period, it is necessary to aggregate and discount benefits and costs that are derived from these impacts. Need for discounting according OECD (2006, p. 59) rises from three different time-related concepts: Pure time preference, inflation and relative price changes. Pure time preference is based on welfare-economic assumption that individuals prefers consumption that happens now rather than later. Inflation refers to overall price increase in general and relative price means that some costs and benefits that are compounded from project may attract higher valuation overtime relative to the general price level. Another, more precise, definition for discounting follows Ramsey equation (Ramsey, 1928) where interest rate is the function of pure time preference, product growth rate of consumption and consumption elasticity of marginal utility. (Traeger, 2009)

By discounting CBA author can find the present value (PV) of costs and benefits. Present value of cost PV(C) and benefits PV (B) can be derived with following equations:

2. $PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$
3. $PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$

Where s corresponds to the social discount rate and B_t and C_t denote the benefits and costs in year t.

The seventh step is to compute the net present value (NPV) of each alternative. NPV is derived from following formula.

4. $NPV = PV(B) - PV(C)$

If PV(B) > PV(C), the analyst should recommend the project. However, if there are more possible outcomes than one and status quo, the analyst should choose a project bundle which has the largest NPV.

The eighth step of the CBA according to Boardman (2014) is a sensitivity analysis. To mitigate the uncertainties that are profoundly part of CBA, sensitivity analysis must be conducted to determine the robustness of the NPV estimates that have been derived for each project in the seventh step. This analysis could be for example a worst/best-scenario-analysis, a partial sensitivity analysis or a Monte Carlo simulation depending which one suits the studied case best. According to Boardman (2014, p.178) partial sensitivity analysis is a good choice, when analysists believes that one or several assumptions are the key uncertainty elements. Worst- and best-case analysis aims to answer what happens when the most conservative assumptions are made and how it affects to the output result and whether the effect is positive or negative. In a Monte Carlo simulation, the parameter values related to the key assumptions are randomly sampled based on a pre-determined distribution and the resulting net-benefit distribution is then assessed to obtain information about the riskiness of the project and the Expected Net Present Value.

The ninth and the last step is making the recommendation based on the findings of the CBA. Finally, analyst should make a recommendation for the decision maker based on the results that he/she found out during CBA. As stated in the seventh step, project with the highest NPV should be recommended, but as there are uncertainties, the results of the sensitivity analysis should be taken in consideration as they might influence the decision-making process.

2.4 MICROECONOMIC BACKGROUND OF CBA

Compensating variation value is the maximum amount that a consumer of a good is willing to pay (thus commonly used term willingness to pay or WTP) to avoid the price increase. Equivalent variation, or willingness to accept (WTA), on the other hand is the amount of money that a consumer is willing to accept so that the price will increase. However, WTA and WTP describing a price change are not intuitive when looking changes in the quality of ecosystem service. Therefore, WTP and WTA can be adjusted so that WTP describes how much the consumer is willing to pay to preserve the ecosystem service at status quo level to avoid decreasing environmental quality. WTA on the other hand can be interpreted as the compensation level that the consumer would accept for the decay in the quality of the ecosystem service. This is further illustrated by following equations:

5. $CV(WTP) = e(q_{0,}u_0) - e(q_{1,}u_0) = y - e(q_{1,}u_0)$

6. $EV(WTA) = e(q_{0,}u_1) - e(q_{1,}u_1) = e(q_{0,}u_1) - y$

Equations 5 and 6 (Randall & Stoll, 1980)[3] are central pieces of the microeconomic theory behind CBA, when it comes to assessing policies and projects that are effecting the environment, and as mentioned before, these equations are slightly modified from the initial description. Instead of changes in price $p_0 \overset{\Delta}{\rightarrow} p_1$, we are focusing on to the quality change of non-market good $q_0 \overset{\Delta}{\rightarrow} q_1$. This is because price changes cannot be used to describe the quality changes in CBA's that are evaluating projects and policies linked to non-market goods - such as this thesis.

From the perspective of this study, WTA & WTP are used indirectly. The aim is to find out current utility level that visitors are getting from the research area at the moment. This is obtained from previous valuation studies that were conducted by Finnish Natural Resource Center (Luonnonvarakeskus, LUKE). (Pouta & Tienhaara, 2018; Tienhaara et al., 2018) The aim is to find out the costs for the selected NBS, which are sufficient enough to keep the water quality at least at status quo level, or in the best case improve it. As the utility level objective is the same as the current one, we are trying to find out the WTP of ecosystem service users of this lake i.e. how much they are willing to pay to preserve each water quality level.

Second important microeconomic theory that is closely related to CBA is the Pareto efficiency. It is a concept that is used to describe efficiency in economics. Definition of Pareto optimal allocation according to Mas-Colell (1995, p. 312) starts from defining following economy in equation[4] 7.

$$7. \quad \sum_{i=1}^{I} x_{li} \leq \omega_l + \sum_{j=1}^{J} y_{lj} \quad for\ l = 1, \dots, L.$$

[3] Where e is money metric utility function and initially consumer has income y and quantity q_0 of non-market good corresponding to utility level u_0 (Randall & Stoll, 1980)

[4] Consisting: I Consumers (indexed by $i = 1, \dots, I$), J firms (indexed by $j = 1, \dots, J$) and L goods (indexed by $l = 1, \dots, L$). Consumer i's preferences over consumption bundles $x_i = (x_{1i}, \dots, x_{Li})$ in his consumption set $X_i \subset \mathbb{R}^L$are represented by utility function $u_i(\cdot)$. Total amount of each good ($l = 1, \dots, L$) initially available in economy (endowment of good l), is denoted by $\omega_l \geq 0, for\ l = 1, \dots, L$ Each firm j has available to it the production possibilities according production set $Y_j \subset \mathbb{R}^L$. Y_j is a production vector $y_j = (y_{1j}, \dots, y_{Lj}) \in \mathbb{R}^L$. Total amount of good l available for economy is $\omega_l + \sum_{j=1}^{J} y_{lj}$ (Mas-Colell et al., 1995)

Where economic allocation$(x_1, \ldots, x_I, y_1, \ldots, y_J)$ is a specification of a consumption vector ($x_i \in X_i$) for each consumer ($i = 1, \ldots, I$) and a production vector ($y_j \in Y_j$) for each firm ($j = 1, \ldots, J$). The allocation $(x_1, \ldots, x_I, y_1, \ldots, y_J)$ is feasible if equation 3 holds.

From this stand point Mas-Colell (1995) derives the definition of Pareto optimal allocation as following: A feasible allocation $(x_1, \ldots, x_I, y_1, \ldots, y_J)$ is Pareto optimal if there is no other feasible allocation $(x_1', \ldots, x_I', y_1', \ldots, y_J')$ such that $u_i(x_i') \geq u_i(x_1)$ for all $i = 1, \ldots, I$ and $u_i(x_i') > u_i(x_1)$ for some i. This definition given above can be interpreted by Pareto efficiency of definition of Boardman (2014, p. 27) " *An allocation of goods is Pareto efficient if no alternative allocation can make at least one person better off without making anyone else worse off."* So economy is in a point, where improvements are impossible. (Nyborg, 2012)

Pareto criteria for decision making has raised from this definition of efficiency. The base idea is that decision maker should only implement projects/policies, if it makes someone better off, without making someone else worse off. (Nyborg, 2012). This is however a bit unrealistic demand, or at least rather tricky in the real world. If we consider a project with high positive impact on large population and insignificant amount of negative impact on one person, Pareto criteria would rule this project out.

There are however ways to overcome this problem by defining a less strict rule in the case of Hicks-Kaldor criterion and by modifying the original rule to potential Pareto efficiency rule. Hicks-Kaldor criterion (1939; 1939) suggests that project/policy under consideration should be implemented, if the aggregated net present value of project/policy is positive. (Nyborg, 2012). This foundation provided by Hicks-Kaldor and their criteria is the basis of potential Pareto efficiency rule where "... *project should be implemented, if redistributive measures could hypothetically have made it a Pareto improvement."* (Nyborg, 2012, p. 23) This basically means that a policy maker can adopt policies and projects which have positive net present value and possibility to compensate the "losers" in case of project implementation/policy change and thus policy/project can be Pareto improving. (Boardman, 2014)

2.5 CBA AND UNCERTAINTY

CBA is, and should be, criticized as it is not a flawless technique to assess if a project should be implemented or not. Two aspects that can be pointed out are how it handles uncertainty, and how it handles distributional issues.

There usually are a lot of uncertainties when one formulates a CBA case: Projected investment costs, benefits, effects and changes in demand/supply of the affected good may vary and usually there is no a clearly observable way to measure these whilst ex ante CBA is conducted as every project is unique. Measuring project's impacts to a non-market good such as recreation value of environment, such as this thesis, makes dealing with the uncertainty even more of a challenging task.

Despite all the efforts made to find benefits, costs, demand/supply, impacts and benefits that corresponds to the real world as good as they can, uncertainties still exist. To be able to assess them and their significance, there are ways to take in consideration these contingent events that may, or may not occur, and how they alter the outcome of the CBA and whether the project should or should not be implemented. The basic principle is to calculate the cost of risk and subtract this from the net benefits that project yields. (Nurmi, 2019) Requirements for calculating the cost of risk that are needed are: Attitude toward risk separately for each individual, income of each individual and the changes in income for each individual following the project. (Boadway, 2006) However, in some cases it is impossible to determine the probabilities of different outcomes. In this case one can assess the risks indirectly by looking at robust investment strategies or performing best-worst-case analysis. (Boadway, 2006)

It is worth to mention the eighth step of the Boardman's (2014) CBA process here as well: Perform sensitivity analysis. The aim of this step is to assess how change in parameter values that were used in the CBA calculations effects to the output value of CBA and NPV it yields. This can be done for example by making a sensitivity analysis or with Monte-Carlo simulations. (Nurmi, 2019) Which alternative is better is largely dependent on the complexity of the particular case being assessed. In this thesis, the uncertainty is analyzed with Monte-Carlo simulation, which is explained in section 7.2.

2.6 DISTRIBUTIONAL PROBLEMS WITH CBA

A second large problem in CBA is, as already mentioned, how to deal with WTP/WTA of people with different incomes. If we reflect this issue back to the nine steps presented in section 1.2, we can rephrase the step 2 to "whose benefits and costs count, and how much".

According to Nurmi & Ahtiainen (2018): *"Without adjusting or "weighting" monetary welfare changes to take into account the social marginal utility of money, CBA is systematically favorable to those who value money the least relative to alternative numeraires (Boadway, 2006; Brekke, 1997; Dreze, 1998)"*

Boardman (2014, p. 493) has explained necessity for distributional weighting with three arguments. Income has diminishing marginal utility, the income distribution should be more equal and the "one person, one vote should apply. First of the argument is center piece of basic microeconomics. The law of diminishing marginal utility means that person gets less utility from consumed unit than previous one. In the case of income, this law can be interpreted so that each euro that consumer is getting is providing less utility than the euro received before. The second and the third argument by Boardman (2014) are based on ethical arguments. Income distribution should be more equal. Social welfare would be higher because unequal income distribution could lead to civil disorder in the most extreme situations. (Boardman, 2014). "One person, one vote argument" is largely based on the principals of democracy. Generally, in demography's it is viewed that each person should have the possibility to have influence over decision making, in contrast to a case where the influence power of decision making is proportional to the income and the wealth of the person.

According to previous study (Nurmi & Ahtiainen, 2018), distributional weighting is in many cases backed up by economic theory, but in the case of where income transfers and taxes are viable options to a Pareto dominant solution compared to the project that would be chosen based on the distributional weighted CBA, Pareto dominant should be chosen. One of the indicators that can be used to trace out how the benefit are allocated between income groups is the income elasticity of WTP/WTA. (Nurmi & Ahtiainen, 2018). If the elasticity gets values smaller than one, benefits are distributed regressively and in the opposite case, where elasticity is higher than one, benefits are distributed progressively. (Ebert, 2003)

There are various different ways to incorporate distributional weights to the CBA formula and there exists literature, how to do it in practice (Adler, 2016; Boardman, 2014; Dennig, Budolfson, Fleurbaey, Siebert, & Socolow, 2015; Fleurbaey, Luchini, Muller, & Schokkaert, 2013). The theory behind of these different methods is not went through in this thesis, as it is not the main focus of work.

3. ENVIRONMENTAL VALUATION

This section focuses on explaining environmental valuation and methods that are commonly used in the field of environmental economics to valuate ecosystem services in monetary terms. The main purpose of this section is to provide an overview, how non-market ecosystem services can be valued and to provide theoretical background for the empirical part of this thesis. Focus in this overview is on the travel cost method, contingent valuation method and the combination of these two methods. There are two reasons for this: These were the methods used by Finnish Natural Resource Institute in their valuation research regarding recreation in Lake Puruvesi, from which the results are used in this CBA in the benefit estimation part. From a theoretical point-of-view, these two represents well the two main branches of valuation methods: Travel cost method represents revealed preferences and contingent behavior represents stated preferences.

Monetary value of an ecosystem service provided by the environment is rather difficult to assess. This is because many of the ecosystem services are non-market goods which means that it is impossible to review market prices of these services, as the market does not exist for these goods or services. However, it is critical for decision makers to be able to estimate the value in some way, so they can make decisions which affect ecosystems and their users in a way that it is based on more than a mere “educated guess”.

The main issue in environmental valuation is that demand curve for public goods is not observable. It is impossible to fully reveal the behavior, how public goods (ecosystem services in the boundaries of this thesis) are consumed. (Herriges & Kling, 1999, p. 2) This statement can be elaborated further by looking Figure 1 below.

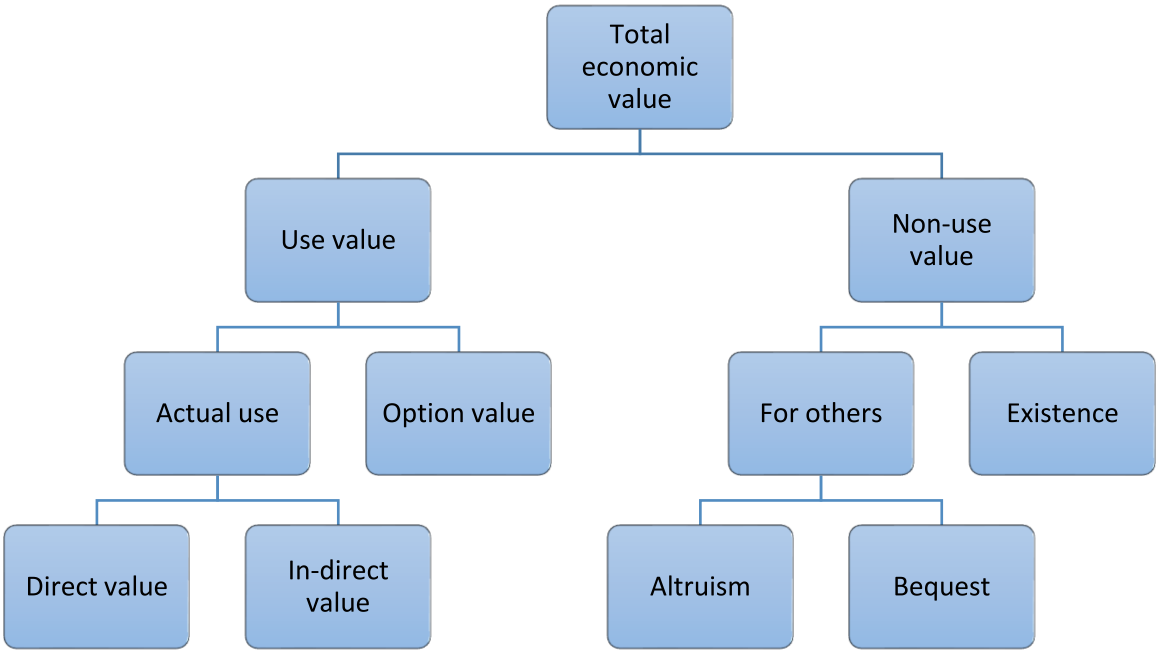


Figure 3.1.1 Total economic value. (Turner, Bateman, & Pearce, 1994, p.29)

Figure 3.1.1 above shows a common typology to divide the total economic value (TEV) to its different value components. This also illustrates one of the main issues in environmental valuation described before. Total use values are based on the actual use or planned use of the good. (Bateman, Ian J., 2002, p. 28) This can be e.g. recreational fishing in a lake. However, it is important to note, that only values under the direct value category can have a direct market price. This could be the monetary value of timber growing in a forest for example. In-direct value is a similar concept, but in this value category there is no price for the action.

Actual physical use of the ecosystem service is rather easy concept to grasp. However, rest of the values are based on less tangible use and are therefore trickier. Option value means that individual is willing to pay for the ecosystem service to have the option to use it in the future. (Bateman, Ian J., 2002, p. 28) Option value could be viewed as an investment for the future, as individual is prepared to lose some consumption at present for the expected value and utility increase in the future, e.g. willingness to keep the water quality at a good level if individual wants to receive actual use value in the future from recreation.

Non-use values refers to a case where the users of ecosystem services are willing to pay for the existence of the ecosystem service even though there is no actual, planned or possible use. (Bateman, Ian J., 2002, p. 28).As depicted in figure 1, these values can be categorized to altruism, bequest and existence values.

Existence value means that individual is willing to pay to preserve the quality of a non-market good, even though there is no usable value for anyone. Individual receives utility by just knowing that something exists. Example from this kind would be biodiversity and healthy population of species. (Bateman, Ian J., 2002, p. 28) Border between these values can be opaque e.g. biodiversity and healthy populations of fishes will also impact to use value as professional and recreational fishing utilizes actual values of the fish population. Altruistic and bequest values are based on the individuals WTP from ecosystem service so that other people can use this ecosystem service. The difference between these value categories is that bequest value rises from needs to provide future generations possibilities for consumption and altruistic on the other hand from the current generations possibilities.[5] (Bateman, Ian J., 2002)

3.1 VALUATION METHODS

This section drives deeper into the concept of the total economic value and to different methods that allows researchers to assess and find the utility in monetary terms that individuals obtain from ecosystem service consumption, which furthermore helps researchers to find out demand for these services.

Following figure below (Figure 3.1.2) illustrates the categorization of different valuation techniques by Bateman (2002, p.30). The two main branches are revealed and stated preferences methods. Use values of a good can be assessed with revealed preference methods, because use of good is a concrete action which can be observed. Bateman describes this phenomenon as a “behavioral trail”, which is not present in the non-use value category. Because concrete actions are done, values extracted through revealed preference methods reflect quite well the real value of good. However, as valuation is done by evaluating past actions, it is inaccurate to use this method to evaluate effects of

[5] Reasoning why non-value WTP exists is interesting question, as it seems that it is not fitting well to microeconomic assumption of utility maximization, especially in the case of bequest value and it is quite philosophical subject.

possible hypothetical actions in the future as new projects and policies might be out of the range of the past actions. (Whitehead, Pattanayak, Houtven, & Gelso, 2005, p. 875)

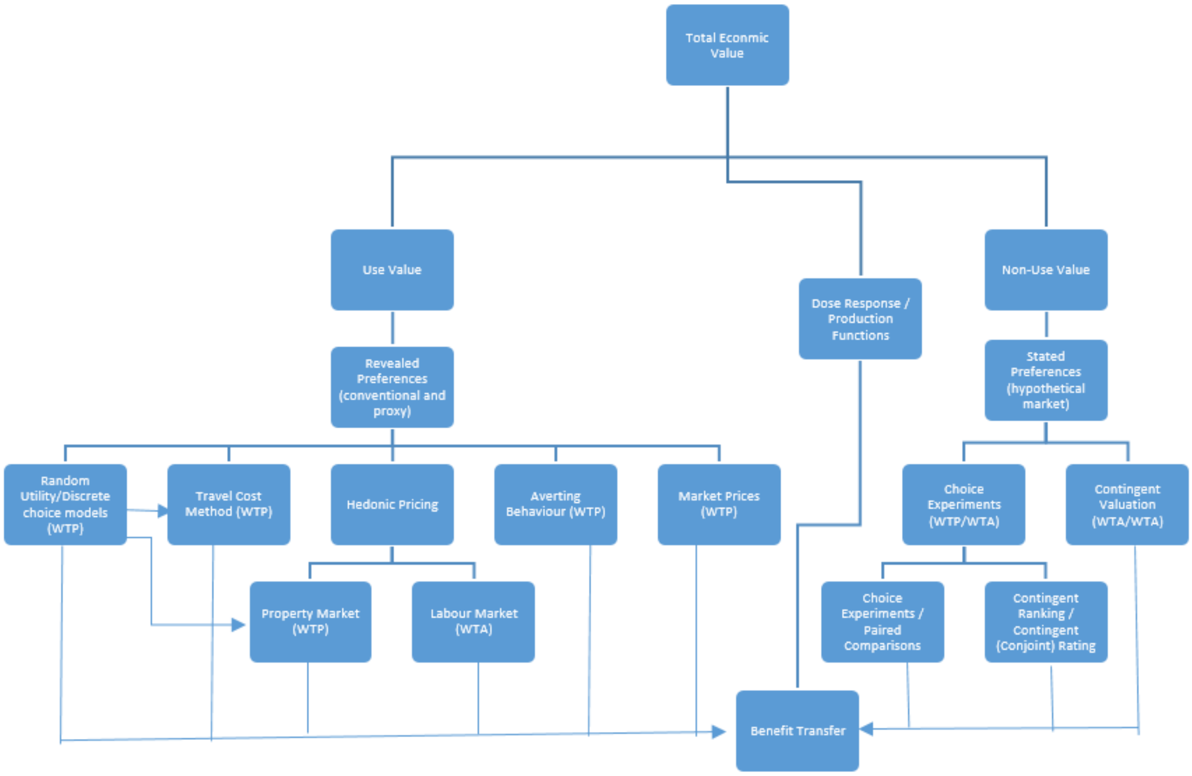


Figure 3.1.2 Economic valuation techniques. (Bateman, Ian J., 2002, p. 30)

As the name suggests, stated preferences are extracted through statements from individuals who are getting utility from an ecosystem service. This is typically done by using surveys by telephone, mail, online etc. Researcher creates a hypothetical market by using question sets and estimates the value based on the received answers. Stated preference methods are flexible and allows researcher construct policy / project models and estimate their effects. However, hypothetical nature of questions places respondents in to demanding position as hypothetical scenarios might be hard to grasp in situations where complete information is not available. Despite this, it is at the moment the only way to estimate non-use value in monetary terms. (Whitehead et al., 2005, p. 875)

3.2 REVEALED PREFERENCES

In this section, we are focusing on travel cost method (TC) as a revealed preferences valuation method. This overview focuses on TC as it is one main method used to derive benefit estimates from the study site. Other revealed preference methods exist (Figure 1.)

as well but are left out of the theoretical framework deliberately while TC-method is presented as an example of this type of method in this study.

The principle behind TC is that because individuals who are visiting the recreation site with varying travel distances, the variation in distances and the frequency of trips can be used to find the demand curve. (Whitehead et al., 2005, p. 874) General form to this demand can be expressed as following equation where $r = number\ of\ trips,\ tc_r = trip\ cost\ to\ the\ site, tc_s = trip\ costs\ to\ other\ sites, y = income\ and\ z = demographic\ variables.$ (Ovaskainen & Rekola, 2015):

$$8. \quad r = f(tc_r, tc_s, y, z)$$

This allows the investigator to find the demand of an ecosystem service that is based on the actual observed behavior. However, the effectiveness of this method is quite limited when the aim is to assess the monetary value of a quality change of an ecosystem service. This is because TC lacks ability to assess hypothetical situations as the demand curve gained from TC modelling is based on historical data. However, TC method is a suitable method for the estimation of the current value of the ecosystem services, which can be valuable information by itself and adequate information in some studies that focus obtaining the current value of recreation for example. In some cases, such as in this work, it is necessary to study what kind of impacts the quality changes in ecosystem service has to the demand curve. In situations like this, TC model needs to be supplemented with stated preferences environmental valuation methods, which are briefly explained in the next section.

3.3 STATED PREFERENCES

Data obtained from contingent valuation surveys can be a useful supplement with TC data mentioned in the previous section. A general understanding regarding stated preferences is that it is not as accurate as the revealed preference method. (Englin & Cameron, 1996) One of the main reasons is that a demand function is generated through hypothetical situations introduced in surveys in contrast to actual observed behavior as in stated preferences (SP) methods. However, data from stated preference methods is the most accurate available, when assessing hypothetical situations, like changes in the quality of an ecosystem service. This section focuses on contingent valuation method as an example of SP methods.

Contingent valuation method (CV) should be applied when the total value of a particular ecosystem service is assessed. Other methods such as choice models are more suitable for situations where the value of ecosystem service can be divided into different attributes of the service, and the value of a change of some attribute is valued. (Bateman, Ian J., 2002) There are basically three main methods to gather data for CV model which are electronic surveys, telephone interviews and face-to-face interviews. (Bateman, Ian J., 2002). Objective of a CV survey is to directly ask from the ecosystem services consumer what is his/her WTP/WTA for the current state and for the state in the hypothetical scenarios. Example could be a three-scenario survey, where the ecosystem service users are asked to estimate how much they would be willing accept compensation if the quality degrades, what is their current WTP for the status quo situation, and how much they would be willing to pay for the increase in the environmental quality. This is directly linked to the microeconomic background explained in section 2.4 and equivalent variance and compensating variation as the goal of CV is to measure these two. (FAO, 2000)

According to Bateman (2002) one of the greatest threats to the integrity of this CV method is its hypothetical nature which might lead to a bias. There are at least two ways that the bias can emerge. First one is that the respondent does not understand the question: Hypothetical nature of the questions can make the questions rather intangible for the respondents and it might be quite hard for them to perceive how they would act on various hypothetical situations.

The second reason for the possible bias is that as the respondents are questioned, they can perceive that they have a chance to act according to their own agenda. This means that instead of answering according to their own true WTP for the ecosystem service scenario, they can “play game” and over/underestimate their WTP depending on their desired outcome. For example, resident living nearby recreational waterfront could overestimate his/her WTP of this site, if he/she guesses that there are infrastructure development plans for this site, which could harm his/her interests in the area.

3.4 COMBINING REVEALED AND STATED PREFERENCES

Travel cost method alone is not enough to provide monetary value for hypothetical situations i.e. changes in the status of ecosystem service. Therefore, it is necessary to describe and discuss how to combine revealed and stated preference valuation methods.

In some cases, TC and CV methods are also supplemented by hedonic pricing method, which allows assessing the value of recreation use from property prices. (Artell, 2013; Parsons, 2014)

However, in this research the recreation value is derived from combined TC and contingent behavior (CB) method model. Main property of the CB is that instead of directly asking WTP for different scenarios, like in CV-method, the respondent is asked to tell how many visits he/she would take under different levels of environmental quality. (Tienhaara et al., 2018) This could be seen as a “hypothetical travel cost model” where instead of observing real life visits frequency and travel costs, they are estimated these in different environmental quality scenarios based on the responses, and instead of trying to solve how the WTP would change in a different scenario, this method tries to find out how a scenario change will affect to the frequency of visits for each individual.

Formula 2.4.1 (Englin & Cameron, 1996) below shows the basic mathematical background combining the TC and CB models together where TRIPS = quantity demanded, costs are travel costs to the site, C is a vector of individual respondent characteristics, A is a vector of site specific attributes and D is a dummy variable for indicating whether trip and cost information is observed (D=1) or contingent behavior data (D=0). (Englin & Cameron, 1996, p. 136).

9. $TRIPS = F(costs, X, A, D)$

This demand function can then be used to find out the underlining value of ecosystem service based on actual behavior (D=1) or if the demand is based on survey answers (D=0). In a sense this can be viewed as an extension to the basic TC formula 8. which was given in previous section.

Combined TC and contingent behavior model were used to retrieve the benefit side of the CBA for this research. (Pouta & Tienhaara, 2018; Pouta, Lankia, & Tienhaara, 2019; Tienhaara et al., 2018) However, these results, their interpretation and analyzing is covered in section 5.2.

4. FOREST ECONOMICS

The purpose of this section is to give an overview about methodologies and background of forest economics. This is necessary, because the cost part of the CBA requires the use of a profit maximization model for the forest owners in the study area and hence background and existing literature needs to be covered. The forest economic model and inputs used in this CBA are more thoroughly covered in the empirical part of this work in section 6. This section provides brief hierarchical overview for four different economic approaches which are used to evaluate the management of natural resources. The aim is to firstly explain the general landowner's management problem and then extend the review to forest optimization models which are: Faustmann model, optimal thinning-clear-cut model and lastly size structured optimization model of forest which is also used in the empirical part of this research.

One part of this work is to evaluate, what is the economic loss if the forest owner changes immediately to CCF management, before this it is however necessary to define, what CCF is and how it differs from Rotation Forest Management (RF), which is the current dominant management style in forest industry. Pukkala (2012) characterizes RF with three distinctive phases: Establishment, thinning and clear-cutting. Forest growing in RF is usually homogenic with respect to tree species, size and age classes. Because of this, RF's could be seen as tree plantations. As the stand is typically homogenous, rotation analysis focuses on finding the optimal harvesting time for single tree species. (Amacher, Koskela, & Ollikainen, 2009)

RF phases, Establishment, thinning and clear-cutting, can be seen as mutually exclusive. According to Pukkala (2012), CCF these phases can overlap with each other. Hence, a forest managed with CCF can be more heterogenous with respect to its tree species, size classes and age classes. Therefore, analyzing CCF requires more detailed models and the aim of the analysis is to *"...seeks to determine how a given land area should be allocated to growing forest stands of different ages and, for each homogenous stand, the optimal rotation age."* (Amacher et al., 2009, p.28) Alternative, a more detailed characterization (Davies, Haufe, & Pommerening, 2008) states that such forest should retain continuous cover by avoiding large clear-cuttings, promote stability and minimize disturbances and use native/site-adapted species to support naturalness.

4.1 LANDOWNER'S MANAGEMENT PROBLEM

The aim of this section is to provide theoretical background behind the aforementioned analysis. This done by introducing different economic models in a hierarchical way with respect to their complexity from generic simple models to quite detailed empirical models, which are then later utilized in the empirical part of this work.

Although the mixed species forests with different age classes is the natural development of forests, the forestry has been developed to grow monocultural forests to provide a steady stream of high-quality timber. (Gerlach, Gilmore., Puettmann, & Zasada, 2002) The main reason for this industrial plantation type regime is that it is relatively simple to manage, the costs are low, and the timber production can be maximized easily. (Pukkala & Gadow, 2012)

The landowner's management problem can be viewed as the basic foundation for economic analysis of optimal use of natural resources and can be expressed with following formula (Pukkala & Gadow, 2012)

$$10.\ NPV = \sum_{t=0}^{\infty} e^{-rt} \left[\sum_{i=1}^{m} p_{it} q_{it} \sum_{j=1}^{n} C_{jt}\right]$$

Where landowner is trying to maximize his/her NPV. Interest rate is r, m represents all services and products that land area offers, q_{it} corresponds quantity of each service or product and p_{it} their price. These can be products such as timber or less tangible services such as hunting licenses. Costs (C_{jt}) from all activities (n) are deducted from revenues which is then multiplied by discount factor to yield net present value. Landowner's management problem can be also expressed with general dynamic models, either in a continuous or in a discrete time formulation (Clark & Munro, 1975; Clark, 1976; Plourde, 1970)

4.2 FAUSTMANT'S MODEL

Maybe the most basic model to evaluate profitability of forest is to apply Faustmann (1849) formula.

11. $J(t) = -w + e^{-rt}pF(t) + e^{-rt}[-w + e^{-rt}pF(t)] + e^{-r2t}[-w + e^{-rt}pF(t)] + e^{-r3t} \ldots \infty$
12. $J(t) = \sum_{i=0}^{\infty} e^{-rit} [-w + e^{-rt}pF(t)]$
13. $\sum_{i=0}^{\infty} e^{-rit} = \frac{1}{1-e^{-rt}}$ When t > 0 and r >0.
14. $\Rightarrow J(t) = \frac{-w+e^{-rt}pF(t)}{1-e^{-rt}}$

Where r equals interest rate, e^{-rt} is continuous time discount factor, w is planting cost per hectare, p is stumpage price, $F(t)$ is stand volume as a function of stand age and J is value of bare land. The key problem that Faustmann formula is trying to solve is: How long has the forest owner wait to clear-cut his/her forest to maximize profits from it, i.e. the optimal harvest age. (Alavalapati & Kant, 2014) The optimality condition of this model is (Amacher et al., 2009, p.20) *"...optimal rotation is chosen so that the value of current annual increment, pf '(t), captured by delaying the harvest for one period of time…equals the opportunity cost of delaying harvest...)* or in other words *"It is optimal to clearcut when the stand value growth rate falls short of interest earnings on the value of bare land and revenues from the next clearcut."* (Tahvonen, 2019)

As one can see, the Faustmann formula resembles the landowner's management formula given in previous section and it could be seen as an application of this general form. This model is also a rather crude model and it is restricted to consider only single tree species in an even-aged forest (Tahvonen, 2015), which means the model does not characterize real life that well and certainly not the characteristics of the study site of this work. Hence, the model used in this thesis is a much more complex size-structured optimizing model. However, Faustmann formula gives a basic theoretical standpoint about bare land value approximation.

4.3 OPTIMAL THINNING-CLEARCUT MODEL: THE CLARK VERSION OF THE KILKKI AND VÄISÄNEN MODEL

The Clark version of Kilkki & Väisänen model (Clark, 1976; Kilkki & Väisänen, 1969) can be seen as an dynamic extension to the Faustmann model for economic optimization of forest and it can be expressed as following:

$$15.\ max_{\{h(t),t\in[0,T],x(T),T\in[0,\infty]} J = \frac{-w+\int_0^T ph(t)e^{-\delta t}dt+e^{-\delta T}px(T)}{1-e^{-\delta T}},$$

subject to

$$\dot{x}(t) = g(t)f[x(t)] - h(t), x(0) = x_0,$$

$$0 \leq h(t) \leq h_{max}$$

$$x(T) \geq 0$$

Where w is regeneration cost, p is wood stumpage price, h(t) is thinning m^3/year, δ is interest rate, x(t) and g(t) are stand function and ageing function of the forest, f(x(t) is density dependent growth and ẋ is the time derivative of x(t).

One of the key features of this model is that it includes thinning of the forest which is not included to Faustmann. Even though the model is more detailed it still can be solved analytically, which is not possible in the case of more complex models like in the case of size structured optimization model explained in the next section. Beside of this, the model is still unrealistic as the forest is assumed to be a homogenous biomass. (Tahvonen, 2019)

4.4 SIZE STRUCTURED OPTIMAZION OF FOREST

This work uses size structured optimization model of forest to obtain estimates of the current value of forests in the study site and compares these values to situation where clear-cutting is restricted in the model. Theoretical base of the size-structured optimization model was presented by Olli Tahvonen (2015; 2016) and has since applied and solved numerically (Parkatti et al., 2019; Rämö & Tahvonen, 2016). Detailed overview and parametric results of the model is explained in article titled *Economics of boreal conifer species in continuous cover and rotation forestry* (Parkatti et al., 2019) which is briefly summarized here and the optimization problem is given as following:

$$16.\ max_{\{h_{st}, \delta_t, t=t_0,\ldots,T,T\},} J(\boldsymbol{x}_{t0}, T) = -w + \sum_{t=t_0}^{T-1}[R(\boldsymbol{h}_t) - C_{th}(\boldsymbol{h}_t) - \delta_t C_f]b^{\Delta(t+1)} + \frac{[R(\boldsymbol{X_t}) - C_{CC}(\boldsymbol{X_t}) - \delta_T C_f]b^{\Delta(T+1)})}{1-b^{\Delta(T+1)}},$$

subject to

$$(1.), \ x_{1,t+1} = \emptyset(\boldsymbol{X}_t) + [1 - \alpha_1\big(\boldsymbol{X}_{t)} - \mu_1(\boldsymbol{X}_t)\big]x_{1t} - h_t, \qquad t = t_0, \ldots, T$$

$$(2.), x_{s+1,t+1} = \alpha_s(\boldsymbol{X}_{t)}x_{st} + [1 - \alpha_{s+1}(\boldsymbol{X}_t) - \pi_{s+1}(\boldsymbol{X}_t)]x_{s+1,t} - h_{s+1,t}, \ s = 1, \ldots, n-1, t = t_0, \ldots, T$$

$$(3.), h_{st} = \delta_t h_{st}, s = 1, t = t_0, \ldots, T, \delta_t: Z \in \{0,1\}$$

$$(4.), \boldsymbol{X}_{t0}, given$$

The number of trees in size class s at beginning of period t can be expressed as x_{st} and stand state can be expressed at any moment as $\mathbf{x}_t = x_{1t}, x_{2t}, \ldots x_{nt}$. $0 \leq \mu s(\mathbf{x}t) \leq 1$, s=1,…, n represents the fraction of mortality of the trees and thus the fraction of the trees remaining in the same class during period t is $1-\alpha_s(\mathbf{x}_t)-\mu_s(\mathbf{x}_t)\geq 0$. Ingrowth function ϕ represents the natural regeneration of the forest. Harvest of size class s at the end of each period t is denoted by h_{st} and thus $\mathbf{h}_t=h_{1t}, h_{2t}, \ldots, h_{nt}$.

Revenues from harvesting and thinning are given by $R(\mathbf{h}_t)$ and $R(\mathbf{X}_T)$ and the costs from harvesting and thinning are given by $C_{th}(\mathbf{h}_t)$ and $C_{cc}(\mathbf{X}_T)$. Net present value of artificial regeneration after clear cut, but before t_0 are given by w. Discrete time discount factor is $b^{\Delta} = /(1+r)^{\Delta}$ in the equation where r is interest rate and Δ is the length of the period. Fixed harvest costs are $\delta_t C_f$ Binary values in δ_t:Z ∈ {0,1},t = t_0, t_0+1…, and the Boolean operator $h_s t = \delta_t h_{st}$ allows the harvest intensity ($\mathbf{h}_{st}$) to be optimized freely.

This model allows rotation period to be either fixed or infinitely long which implicates that the optimal solution for forest management is CCF and vice versa, finite rotation period implicates that the optimal solution is rotation forestry.

Numerical values that are used in this work are further explained in the empirical part in section 6.3. However, as one can see, the economic models describing forest optimization here are largely build on top of each other. However, as the models gets more detailed, the computational requirements to solve such model gets tougher.

5. BENEFITS

This section focuses on explaining the results of valuation research conducted in Puruvesi region and how these results are used in this research. Objectives of this section is then to explain further CBA formulation for this study, what kind of benefits visitors are obtaining from the study site, what are the characteristics of the water quality of the site, and what assumptions were made, and last, explaining the finalized consumer surplus results. It is rather important to note that the NBS impact quantification is at the moment limited, because there are not nutrient flow models yet, which could be utilized in this thesis to further improve the accuracy of the project impacts of the NBSs.

5.1 FORMULATING CBA FOR CASE THE STUDY SITE

Following solutions were already proposed during previous research for the improved water quality in the research area (Suomen Metsäkeskus et al., 2013): Buffer zones, lighter logging equipment, logging waste recovery, ditch cleaning, settling lagoons, pipe dams, wetlands and overland flow fields.

However, buffer zones and continuous cover forestry were the chosen NBS for this project and thus they are investigated in this CBA. One could argue for this selection for several reasons. Some of the methods that were mentioned above, such as wetlands and management fishing are already being done in different project such as FRESHABIT. (Pro Puruvesi ry, 2019) Another reason is that CCF in particular is “hot topic” in public discussion and therefore important solution to study.

According to Nieminen (2018) *“Drained peatland forests have proven to be a significantly greater source of nutrients, total and dissolved organic carbon (TOC and DOC) as well as suspended sediments (SS) to receiving water courses than undrained peatlands or upland forests. (Finer et al., 2010; Nieminen, Mika et al., 2015)”* This is the base assumption behind the CCF NBS in this research: CCF forest management can mitigate nutrient load from catchment area to waterbodies better than RF as climate change and more frequent extreme weather events will increase the nutrient loading. (Kaukonen et al., 2018) When forest is managed by CCF system, continuous tree stand exists. This mitigates the need for the ditch network maintenance as the tree stand can use water by interception and transpiration. (Gadow & Pukkala, 2012; Nieminen, M. et al., 2018; Sarkkola et al., 2010; Sarkkola et al., 2013) In RF method this is not possible as forest is even aged and harvested on the same time, and thus continuous interception and transpiration does not exist. When continuous interception and transpiration are absent, water will accumulate to soil and requires ditch network creation from forest owner.

According to Nieminen et al. (2018) ditch maintenance is needed between 20-40 years in RF. This means that the amount of suspended sediments released from forest is constantly higher than in CCF and increases SS export 50% compared to natural run-off, which causes 2/3 out of all forestry nutrient loading. (Nieminen, M. et al., 2018; Nieminen, Mika et al., 2018) Clearcutting after RF period and necessary artificial regeneration phase also causes major increase in N, P and DOC load. In the case of CCF these do not occur in same scale, because regeneration phase is natural i.e. absent or minimal ditch digging and maintenance.

Third reason that could argue for this selection is that CCF and buffer zones enables stakeholder engagement in a more fundamental level to this area if compared to these “point solutions” which only affect on small areas rather than whole forest areas. This is important, because stakeholder engagement is one of the goals of OPERANDUM project. (OPERANDUM, 2019a; OPERANDUM, 2019d). In addition to these, one might argue whether the solutions that the Finnish Forest Center (Suomen Metsäkeskus) has brought up in fact meet with the critera of NBS as some of them are infact quite invasive like pipe dams for example.

The objective of the benefit section is to find out the utility that ecosystem service consumers (i.e. tourists, local residents and other visitors) are obtaining from this area by finding their demand function as explained in section 3, as the objective of this project is to find ways to keep water quality on the status quo level. However, as will be soon explained in section 5.3, the water quality in the study site of sub-catchment area of Kuonanjoki is already on the lowest scenario. Hence, we are trying to find out what is the value of recreation benefits that visitors would get in each water quality scenarios (table 4.3.1) and then compare, what is the difference, if the water quality in study site increases from the lowest rank to the next one.

5.2 BENEFITS FROM RECREATION

It has been studied that water quality correlates with the frequency that people use water for swimming and fishing recreation. Fishing especially has been found to be sensitive towards water quality and fishers were eager to switch their recreation site depending on water quality. (Vesterinen, Pouta, Huhtala, & Neuvonen, 2010) Therefore it is sensible to argue that status quo level of the water quality or better will bring higher NPV for the recreation in the study site.

In deliverable (Tienhaara et al., 2018) researchers have already approximated the benefits of recreation and water conservation on Lake Puruvesi **before the management actions.** The benefits that are used in calculations are derived from the results of these two surveys and resulting deliverables. Thus, the analysis is *ex ante* CBA, which means it is conducted while project or policy, implementation of NBS in the case of Puruvesi, is under consideration before it is started or implemented. However, these studies were conducted to whole Puruvesi region, which consist the quite remarkable tourist site of Punkaharju. Recreation benefits of this study are based on the findings of these studies, but it is important to note that no valuation research was conducted to this sub-area of original study, but because the study site of this research is sub-area of the original study, we are directly using these benefit estimates.

5.3 WATER QUALITY SCENARIOS IN STUDY SITE

In this research, the benefits are derived from deliverables from recreation value research conducted by LUKE (Pouta & Tienhaara, 2018; Pouta et al., 2019; Tienhaara et al., 2018). All of the applied models are based on different water quality scenarios as seen in table below. (Pouta et al., 2019) As the water quality in the study site is in a poor condition, the water quality currently corresponds the water quality scenario D and the benefits are calculated based on this scenario. There is a knowledge cap, how demand for recreation changes if the water quality level drops below level D. Therefore, it is impossible to assess, what kind of benefit loss visitors would obtain if the water quality would decrease even further. Hence it is not possible to assess this side of benefits with the current knowledge.

Table 5.3.1 Different water quality scenarios in Puruvesi (Pouta et al., 2019)

	Scenario A	Scenario B	Scenario C	Scenario D
Water clarity	Over 8 meters	6 meters	4 meters	2 meters
Blue-green algal blooms	None	1–4 days	5–10 days	More than 10 days
Sliming	None	Slight	Some	Abundant
Quantity of reeds on the beach	None	Individual stems	Patchy	Abundant
Muddiness of the beach	No mud	Under 2 cm	3-10 cm	Over 10 cm

The average water quality level in Lake Puruvesi is currently between scenarios A and B and is considered to be excellent, especially in the deeper parts of lake. (Pouta et al., 2019) The contrast between the characteristics of the study site and Lake Puruvesi are therefore quite staggering, as the current water quality of the study site corresponds scenario D as the current visibility level in the Kuonanjärvi is roughly 1 meter and the blue-green algal blooms are abundant[6]. Therefore, the study site is considered to have water quality corresponding scenario D. (Tossavainen, 2019)

Waters from the sub-catchment area of Kuonanjärvi flows to Savonlahti-inlet which has visibility of 1 meter as well. Nearby waters of this inlet however have visibility of 2.61-3.35 meters. (Rautio, 2017) With this evidence, it also can be argued that the NBS to reduce eutrophication can have positive impact to other areas, Lake Puruvesi in this case, because the study site is a sub-catchment area of Puruvesi, and eventually the water will flow there.

These water quality scenarios presented in table 5.3.1 were used in the contingent behavior part of the TC-CB model study to find out the welfare effects of water quality changes in Puruvesi, which are presented in table 5.3.2. This is because TC-model alone is not sufficient to model the value of ecosystem service in hypothetical situations as explained in section 3.

The demand for visits and CS per trip is divided between three classes in the model shown in following table.

[6] In contrast to this, the water visibility was over 2 meters in the same area when it was first measured in 1960's (Tossavainen, 2019)

Table 5.3.2 Consumer surpluses per class based on LC-model. (Pouta et al., 2019, p. 19)

	Class 1			Class 2			Class 3				
								Cycling/ walking		Other	
	Visits per year	CS, €	Annual CS, €	Visits per year	CS, €	Annual CS, €	Visits, per year	CS, €	Annual CS, €	CS, €	Annual CS, €
Level A	43	110	4725	4	370	1481	217	5,2	1128	116	25231
Level B	39	110	4286	3	370	1111	209	5,2	1087	116	24300
Level C	28	110	3077	2	370	741	192	5,2	998	116	22323
Level D	18	110	1978	2	370	741	128	5,1	652	78	10000

Classes 1 and 3 represents people who are living nearby the study site, or they are owners of vacation house in the area: CS and demand in class 1 corresponds to the behavior of weekend visitor / vacation house owner and class 3 to the local resident. Class 2 is classified as the tourists that visits the study site. (Pouta et al., 2019, p. 18)

Table 5.3.2 illustrates how water quality level changes interacts with the demand for visits, and how much each trip yields consumer surplus for the visitor. Visit frequency is the main interaction that the water quality change has in this model. Water quality increase increases trip frequency and consumer surplus is static in almost all of the cases: CS changes only when the water quality level changes from D to C in Class 3.

Visit estimates for class 2 (tourists) should be evaluated critically. This is because the smaller study site of Kuonanjoki drainage basin does not contain similar remarkable recreation sites for wider tourist audience as the Puruvesi and its area of Punkaharju for example. However, this is the best information available to assess the number of tourist visits to the study site. A More detailed version would require separate visitor survey in this smaller area of Kuonanjärvi sub-catchment area. In visitor estimation the author used proportions of each class types from the original study to estimate the total amount of visitors for all user classes. It is important to note however, that this number is most likely an overestimate in the case of class 2 for the reasons mentioned before.

5.4 DEMOGRAPHICS OF STUDY SITE

As the results of previous study are applied to the smaller study site, demographic information about visitors is needed. This means the numbers of vacation homeowners and local residents and estimates how often they are using recreation services. Previous study (Lankia, Kopperoinen, Pouta, & Neuvonen, 2015) shows that 96% of people in Finland participates in outdoor recreation at least once during year. This percentage is used to estimate the share from the total population of residents which are using ecosystem services of study the site.

Population and vocational homeowner estimates are derived from Paavo - Open data by postal code area data of Statistics Finland. (Tilastokeskus, 2019) In Kerimäki region there was 3243 residents and 1079 vacation houses in 2017 according to this data. However, it is important to note that these are rough estimates and this data is not as precise as it could be as it lacks certain spatial aspects as it is only based on postal code criteria. Better estimates from userbase of area could be made with the geospatial data of Statistics Finland, but unfortunately this data is not open to use freely. With this data the correct information from the vacation houses and residents in the immediate area of study site could be extracted with geoinformation systems such as QGIS or ARC GIS.

The median size households of vacation homeowners were 2.3 in 2007. (Tilastokeskus, 2007) Size distribution between the classes in the used valuation report was following: Class 1 = 51%, class 2 = 34% and class 3 = 16%. By using this information, total annual visits estimate is 8477 and by using class 2 share of 16% it was estimated that there are 2882 tourists (class 2) visitors annually. Because of the inaccuracies of postal code classification, further spatial analysis was concluded. Postal code area, where initial visitor data was extracted was clipped by using address data (Population Register Center, 2018), drainage basin data (Suomen ympäristökeskus & ELY-keskukset., 2019) and postal code data (Tilastokeskus, 2019). By with these, three different scenarios for visitors were created presented in table 5.5.1 below. Doing this allows more precise analysis taking the inaccuracy and insufficient data explained above in consideration.

5.5 RESULTS FROM BENEFIT ESTIMATION

With the information presented previously, the following calculations for annual consumer surplus of recreation benefits were done. Table 5.5.1 presents different visitor scenarios that are used for the final benefit calculations for each water quality scenarios. In this table each class represents different visitor type from table 4.3.2, where class 1 visitors are the vacation homeowners, class 2 are the tourists and class 3 are the local residents.

Scenarios on the rows represent different visitor estimates based on the spatial analysis of the study site. Scenario 3 is the coarsest and it is based on the postal code data and based on the findings explained in section 5.4. In scenario 1 the author restricted the area by using address data and area of Kuonanjoki sub-catchment area to find out, how many residential buildings are in the sub-catchment area. Sizes of each class-types were then estimated by using proportions of scenario 3 values. Similar approach was used in scenario 2 as well, but in this case the area that was used to restrict address data was sub-catchment area of Kuonanjoki and Puruvesi, that are inside of postal code area. By this we can rule out residents from 58200 area that are living in different sub-catchment area than in Kuonanjoki or Puruvesi and hence improve accuracy.

This classification is explained by the map in the figure 5.5.1, where the red line marks the sub catchment area of Kuonanjoki (scenario 1), the orange line marks the area of Puruvesi catchment area, the green line marks postal code area of Kerimäki (scenario 3) and the white line marks postal code area that is restricted by the catchment areas (scenario 2).

Figure 5.5.1 Visitor estimate scenarios in study area. (Population Register Center, 2018; Suomen ympäristökeskus & ELY-keskukset., 2019; Tilastokeskus, 2019)

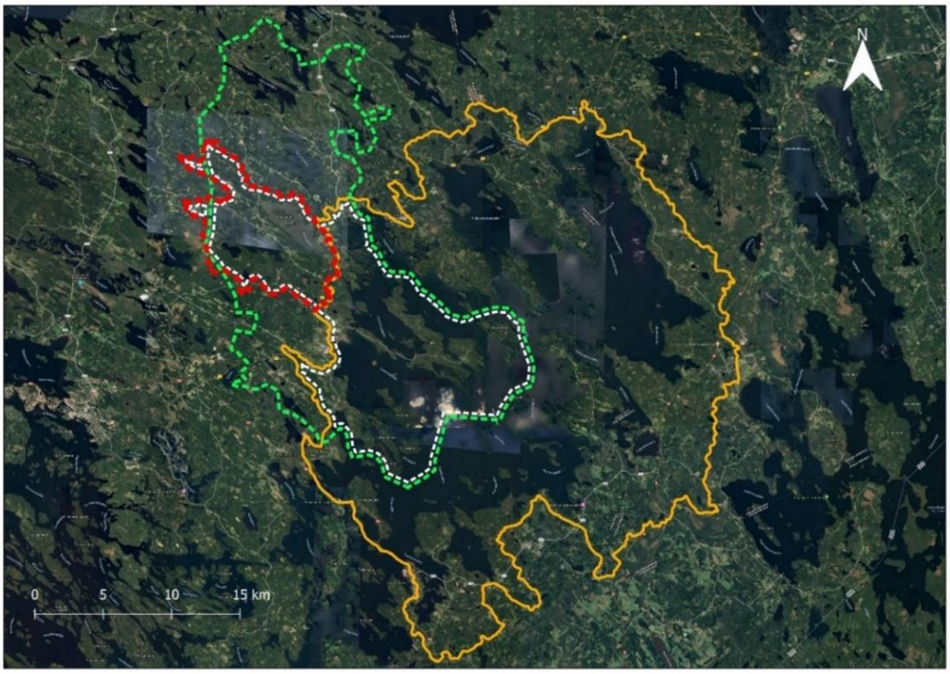


Table 5.5.1 Annual predicted visitors to study site.

	PREDICTED ANNUAL VISITS		
	SCENARIO 1	SCENARIO 2	SCENARIO 3
CLASS 1	239	1618	2482
CLASS 2	278	1879	2882
CLASS 3	300	2029	3113
TOTAL	817	5525	8477

Results from the visitor estimation are presented in table 5.5.2 above. One can easily see a rather large difference in estimates between scenarios 1 and 2. This is largely because of municipality of Kerimäki, which is the largest population center in the area and located just outside Kuonanjoki sub-catchment area (red line), and thus highly effects scenario 2 and 3 estimates.

When these visitor estimates are combined with the results of travel cost-contingent behavior models results presented in section 5.3 (table 5.3.2), we get the following consumer surplus estimates for each water quality and visitor estimate scenarios presented in table 5.5.2 below.

Table 5.5.2 Recreation benefits from different visitor scenarios.

SCENARIO 1, BENEFITS FROM SUB-CATCHMENT AREA OF KUONANJOKI (€)

Water quality	Class 1 CS	class 2 CS	Class 3 CS	Total annual CS (mil. €)
A	1130470	411440	269687	1.812
B	1025310	308580	259745	1.594
C	736120	205720	238617	1.180
D	473220	205720	156019	0.835

SCENARIO 2, BENEFITS FROM CONSOLIDATED SUB-CATCHMENT AREA AND POSTAL CODE AREA (€)

Water quality	Class 1 CS	class 2 CS	Class 3 CS	Total annual CS (mil. €)
A	7653140	2780920	1825751	12.26
B	6941220	2085690	1758442	10.79
C	4983440	1390460	1615411	7.989
D	3203640	1390460	1056230	5.650

SCENARIO 3, BENEFITS FROM POSTAL CODE AREA (58200) (€)

Water quality	Class 1 CS	class 2 CS	Class 3 CS	Total annual CS (mil. €)
A	11739860	4265360	2800688	18.81
B	10647780	3199020	2697437	16.54
C	7644560	2132680	2478028	12.26
D	4914360	2132680	1620249	8.667

The resulting annual CS is highly sensitive to the scope and accuracy of the visit estimates, as visitor scenario 1 with water quality D currently yields 0.835 million euros of CS annually, whilst the postal code restriction yields CS of 8.667 million annually with the same water quality. However, this is the best accuracy that available data can produce as mentioned earlier. Problems with accuracy are further tackled in section 6 where the results of sensitivity analysis are explained. From these results we can see that most of the CS is coming from the vacation homeowners (class 1) as its share is the largest from the total CS with the current water quality level (scenario D) is ~53%. Class 2 (tourists) CS is static with lower water quality levels D and C but increases when water quality rises to level A and B. Change in CS from increased water quality from D to A is the least in the class 3 (~72.8%).

6. COSTS

The objective of this section is similar to the previous one, but instead of focusing on benefits, this section explains how the cost items of the CBA were calculated, which methods were used and what assumptions were made during and before the calculations. In this study, we assume that large scale CCF forest management and buffer zones will have a positive impact on the water quality. In the scenario one, we assume that the water quality is improved in the direct sub-catchment area; in the scenario two we assume that the water quality is also improved in the connecting bay area of Savonlahti; and in the scenario three, we assume that the water quality is improved in the connecting bay are of Savonlahti and results into more users into affecting area (Figure 5.5.1). During OPERANDUM project we will gather information about the actual impacts on the water quality and precision of the scenarios will improve.

6.1 COSTS OF NATURE-BASED SOLUTIONS IMPLEMENTATION

The NBS's that have been chosen to be assessed for this project are riparian buffer zones and CCF forest management. These solutions were chosen as they are predicted to be the most effective methods to mitigate nutrient load from covering forest areas to the nearby water bodies. One of the main reasons for this is that the sub-catchment area of Kuonanjoki-Savonlahti 94% of area is covered by forest. (Ollikainen, 2019a) Only roughly 6% of area is covered by agriculture which means that assumption can be made that the most significant impact to nutrient loading will be made by altering the way, how forests are managed.

Costs from implementing these methods are derived by first estimating the net present value of current forest of sub catchment area by finding the economic optimal choice for harvesting. In the case of continuous cover forestry this value is compared to "second best choice" where clearcutting of stands is ruled out in optimization. The difference between these two values is the economic loss for the forest owners. In the case of buffer zones, the optimized value is the final cost for the forest owners as it is assumed that this area is left out from any forestry activities.

The estimates of forest types and the characteristics for sample forest simulation are retrieved by using geo-information system, mainly QGIS program. Parametric values that are needed for the net present value calculations with size structured optimization model presented in section 4.4, are discount rate, age of trees, growth location, heat sum, tree species, stem distribution and cutting regulations that are specified for this case.

6.2 ROTATION FORESTRY AND CONTINUOUS COVER FORESTRY

The area of peatland in Finland is approximately 10 million hectares, which represents one third of the land area. From this area approximately six million hectares have been ditched between years 1930-1990. (Nieminen, Mika et al., 2010) These figures can elaborate why the research question of NBS implementation is crucial and why continuous cover forestry (CCF) has been chosen to be evaluated in this study. Characteristics of the study site explained in section one supports the similarity between the study site and the data from whole country, as the study site is mostly covered by forest and from which ≈ 30% is covered by peatland as following table 6.2.1 shows. Hence, it could be argued that findings of this research could be scaled upwards in similar cases.

Table 6.2.1 Kuonanjoki-Savonlahti-area. (Ollikainen, 2019a)

Sub-catchment area of Kuonajoki-Savonlahti		
Total area	7300	Hectares
Water	1750	Hectares
Fields	350	Hectares
Forest	5230	Hectares
Total forest area	5230	Hectares
Peatland forest	1500	Hectares
Trenched peatland forest	1200	Hectares

Previous research has shown that CCF is an economically feasible option for Rotation Forestry (RF). (Parkatti et al., 2019) Latest research has been able to mitigate the defects of static models by utilizing dynamic optimization models where rotation period of forest is optimized. (Rämö & Tahvonen, 2015; Tahvonen, 2015; Tahvonen, 2016) Results of recent research regarding CCF and rising interest to prepare for climate change and concern how to mitigate its effects has caused change in the forest management instructions towards to CCF from earlier RF paradigm in certain situations such as in the case of peatland forests. (Metsätalouden kehittämiskeskus Tapio, 2019a; Metsätalouden kehittämiskeskus Tapio, 2019b)

6.3 FOREST OWNERS PROFIT MAXIMIZATION PROBLEM

In this CBA we are trying to solve the maximized profit from forest to forest owner and then compare this to solution where clearcutting is restricted. Instead of Faustmann, because of the limitations mentioned in section 5, this research is using size-structured optimization model. The objective of this model according Tahvonen (2015) is: *"…maximize the present value of net timber revenues by optimizing regeneration, timing, number, and type of thinning, as well as the rotation period."*

From the economic point of view, finding the optimized maximum profit in different scenarios is the only way to make any comparisons between two different management methods and therefore a right way to derive and compare the costs that NBS implementation will have.

Result of infinitely long rotation period in this model implies that CCF is the optimal solution for forestry and vice versa, finite period implies that RF is the most suitable forestry type. (Parkatti et al., 2019) Optimized rotation period gives the maximized bare land value of studied area for the forest owners. However, in this thesis we are not interested which method is economically most optimal, although this result is still obtained as a by-product of the optimization process and is a valuable finding for the discussion whether forest owners should switch from rotation forests to CCF forest management. Instead the aim is to assess what is the optimized net present value of forest in the research area and compare the NPV of this solution to the NPV of the optimized CCF solution, where forest owners are "forced" to implement CCF forestry and clearcutting is restricted.

Parametric values that are required for the calculations are: Discount rate, current age of trees in the area, habitat, heat summation, tree species, stem distribution, regeneration and logging costs and logging restrictions. Main source for required parameters was open source data of Finnish forests gathered and maintained by Finnish Forest Center. (2017) 16x16m grid data was processed in QGIS and required parameters were extracted from this.

Stem distribution was simulated based on this data by Sakari Sarkkola from Finnish Natural Resources Institute (LUKE) according model created by Siipilehto, Sarkkola, & Mehtätalo (2007). Logging and regeneration costs were estimated to be 1401€/ha.

Logging restrictions are derived from Finnish government owned forest management advisory and consultancy company Tapio's guidebooks for forestry (Äijälä, Koistinen, Sved, Vanhatalo, & Väisänen, 2019; Vanhatalo et al., 2015) Heat summation of study site used was 1332, which is official average from Finnish meteorological institute. Finally, the discount rate used in calculation chosen was 3% which is the recommended discount rate by European Union for CBAs in developed states in EU. (Sartori et al., 2014)

Focus on the optimization is to find out the NPV of clear-cutting ready spruce forests which are growing on peatland. There are several reasons for this selection. Selecting grids that contain clearcutting ready trees is justified because growth of forest is a slow process, but actions required to cope with eutrophication needs to be taken in a shorter time frame and therefore the most immediate actions for nutrient load reduction can be made in areas that are ready for clearcutting. Grids with main tree species of Norway spruce (*Picea abies)* were selected because CCF is favorable to this specie as it regenerates naturally quite easily. (Äijälä et al., 2019) Peatlands on the other hand were selected, because they are suitable for the CCF method (Äijälä et al., 2019; Metsätalouden kehittämiskeskus Tapio, 2019c) and because as already mentioned, peatlands, especially ditched, are a great source of nutrients to the water bodies.

Underlining idea for the cost approximation is that forest owners are "forced" to switch to CCF immediately, which means they are unable to gain their maximized profit from current forest management regime. Optimal CCF (infinite rotation), where clearcutting is not allowed, is calculated and the maximized results are compared to the optimized result of same calculation, but without restrictions. From this standpoint, optimization gives two results for forest owners: What kind of forest management they should use, and what kind of costs they would face, if they would change instantly to CCF.

6.4 BUFFER ZONES

Buffer zones, that are concerned to be one NBS to be implemented, are waterfront areas that are left out from any forestry activities i.e. harvesting or thinning in this case. The base idea behind buffer zones is that they act as barriers or *buffers* for the nutrient and small-particle-load that is caused by forestry and to reduce erosion. In addition to this, these buffer zones have additional role as they act as preserver of biodiversity and landscape. (Suomen Metsäkeskus et al., 2013, p. 99)

Buffer zone costs are derived by calculating the length of the shorelines of water bodies in the research area. After this, buffer zone needs to be defined: What is the distance that needs to be left out from forestry to its natural state from the shoreline. When this distance has been defined, bare land value of the buffer zones can be calculated and will be used as a cost estimate in this analysis as forest owners will lost this income, if buffer zones would be implemented. The recommended buffer zone length according to Forest Center of Finland is 15 meters from water which will be used in this research. (Suomen Metsäkeskus et al., 2013, p. 99) With this information total area of buffer zone can be calculated in QGIS, which equals area of 95,17 hectares.

Figure 6.4.1 Waterfronts in Kuonanjoki-Savonlahti sub-catchment area. (Ollikainen, 2019b)

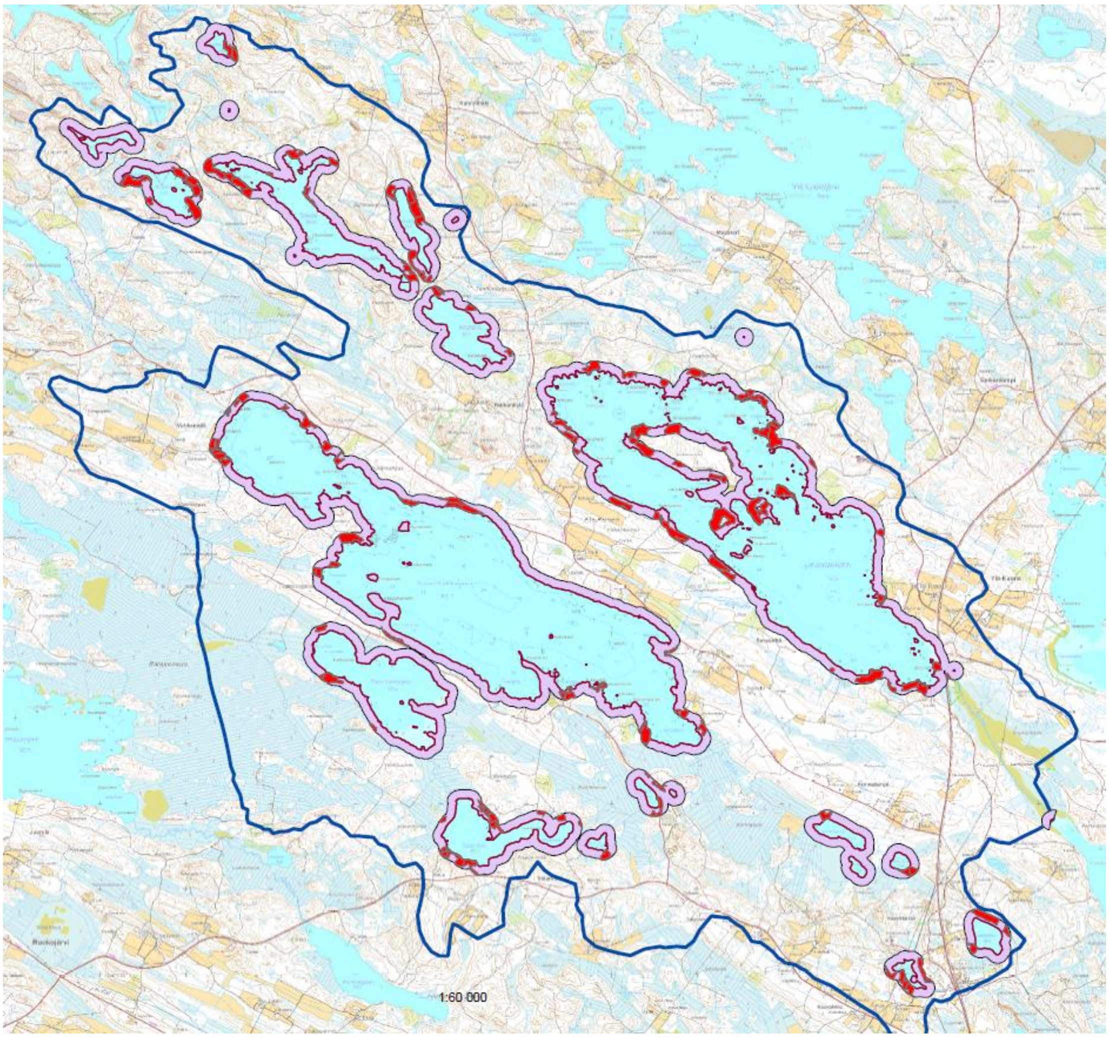
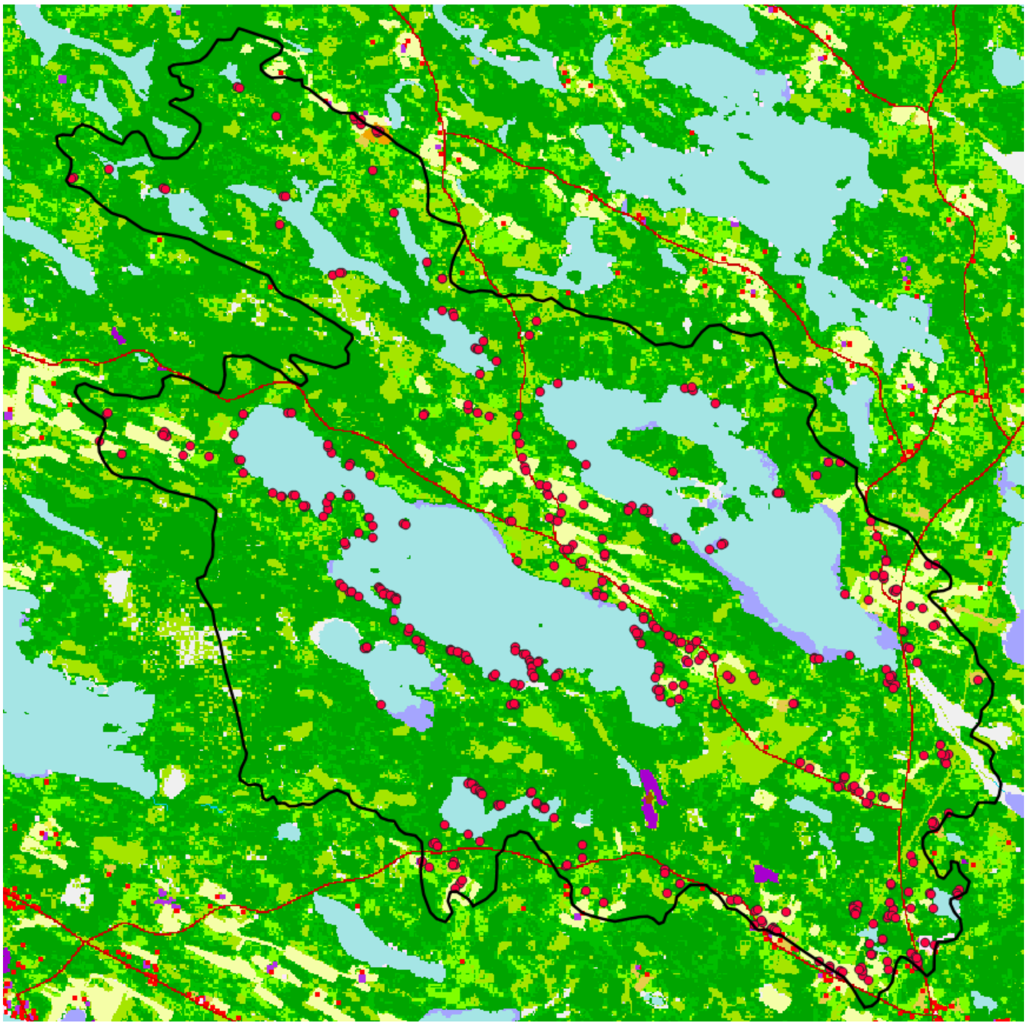


Figure 6.4.1 above shows the waterfronts in red, where these buffer zones are projected to be implemented. Blue line shows the boundary of the sub catchment area of the research area.

Costs from implementing the buffer zones are calculated in a similar fashion, as costs from CCF. The study utilizes the size structured optimization model described earlier in section 4.4. Requirements for parameters and data are similar and are obtained from the same sources. In this case however there are no selection criteria for a particular soil type, main tree species or development classes. This makes the forest data more heterogenous compared to the CCF calculations. Also, the optimization is a simpler task as the objective is to find, what is the current value of the bare land and standing forest in this area. This is the economic loss that buffer zone implementation will impose to the forest owners as they would not be able to get income from that area anymore.

However, there is one inherently big flaw in this method that causes inaccuracies. It is not clear what proportion of the buffer zone area is viable for forestry. This is because some of the calculated zones will be on islands and there are many vocational and full-time residents near the water bodies as seen in following map in figure 6.4.2 where residential and vocational houses are marked with red dots. In other words, it is quite opaque which of the forest areas in the buffer zone area could be calculated as forest that could be realistically be considered as commercial forest and thus would be reasonable to harvest. There are several islands also included in the waterfront area and it is unclear, if it is practical to harvest wood from these areas, as harvesting costs could be too high. With these inaccuracies in mind, it can be said that the aggregated optimization result will give the maximum and the most conservative total cost from the area. Inaccuracies rising from these facts will be taken in consideration in the Monte-Carlo simulation.

Figure 6.4.2 Permanent residents and vacation housing in study site.



6.5 RESULTS FROM COST ESTIMATION

As mentioned before, the initial state of the forest and its stem-distribution in both NBS methods was simulated based on work of Siipilehto, Sarkkola, & Mehtätalo. (2007) This simulation yielded following stem distributions (tables 6.5.1 & 6.5.2) that were used in optimization as the sample forests that characterizes respectively areas for CCF and buffer zones. From these simulated results we can see how many individual trees in each size class are in the simulated hectare of forest, which is then used in the optimization. Simulation calculations of stem distributions itself were made by Sakari Sarkkola from LUKE.

In the forest area that is chosen to be transformed into CCF forest in table 6.5.1, there are lots of larger size spruces with quite many small birches. This is mainly because of the restriction rules for the data from which the simulation was constructed presented in section 6.3. The main point in CCF data restrictions is to rule CCF to cover spruce forests on peatlands, that are ready for harvest as the forest actions for these forests have the most immediate consequences to nutrient flow in the study area. The reason why pine distribution has been left out is because of this as well. Its stem distribution in this sample was relatively small and would have caused optimization computations to take longer time without significantly affecting outcome.

Table 6.5.1 CCF sample forest size class distribution.

INITIAL SIZE-DISTRIBUTION IN CCF		
Size-class	**Spruce**	**Birch**
2.5	113.4	85.8
7.5	13.4	15.1
12.5	20.3	13.6
17.5	38.9	15.2
22.5	75.5	16.1
27.5	115.7	14.9
32.5	119.7	9.7
37.5	34.2	2.4
42.5	1.9	0.4
47.5	0.0	0.0

If we compare previous table to table 565.2, we can see that the forest in the buffer zone sample is quite different. There are now three tree species instead of two, and there are lots of small trees. The reason for this is that unlike CCF case, there is not any selection criteria or restrictions for the sample forest. Buffer zones defined for this study in section 6.4 requires that forests under 15 meters from water bodies are restricted from any forestry actions and therefore the data used in simulations is much more heterogenous as is the resulting sample forest as well.

Table 6.5.2 Buffer zone sample forest size class distribution.

INITIAL SIZE-DISTRIBUTION IN BUFFER ZONE			
Size-class	Pine	Spruce	Birch
2.5	8.3	47.3	448.5
7.5	10.3	54.5	240.0
12.5	10.2	47.8	198.6
17.5	12.0	44.4	144.2
22.5	14.0	38.6	76.5
27.5	12.3	24.5	28.0
32.5	6.3	8.7	8.4
37.5	2.4	0.9	1.3
42.5	0.6	0.1	0.2
47.5	0.0	0.0	0.0

Optimization calculations results yielded following results: Optimal forest management for the area where CCF is projected to be the NBS (peatland spruce forests which are ready for harvest) is in fact CCF, but the switch to CCF is made after a clear-cut. Optimal forest management for the buffer zone according to data and parameters presented in this thesis is CCF as well. These calculations were made using model presented in section 4.4 by Vesa-Pekka Parkatti from University of Helsinki.

The first objective to find out the cost of implementing NBS for the forest owners was to find out optimal forest management regime and harvest periods for the sample forest. In this case result was that forest owner should clear-cut and then start use CCF method. This answer was compared to NBS optimal solution, where clear-cuts are not allowed. When these two were compared, the economics loss for forest owner is 731.46€/ha.

The idea in buffer zone cost calculations is similar. Objective was to find out the optimal harvest period to the sample forest, what is the NPV of standing trees and bare land value. Resulting net present value of buffer zone sample forest was 9098€/ha. This means that, if the forest owners are forced to implement buffer zones as NBS, they face an economic loss of 9098€ for each hectare they own forest that are meeting buffer zone criteria in the study site. When these presented results are aggregated with the area of corresponding forest in study site, following table can be formulated to illustrate the estimated total maximum costs from selected NBS's.

Table 6.5.3 Aggregated costs from NBS's

CCF (total area 58.95 hectares)		
	RF CCF NPV	CCF NPV
Total cost (€)	867074€	823950€
Economic loss (CCF-RF)		-43124€
Buffer zone (total area 95,17 hectares)		
	NPV Rotation forestry + Bare land value	CCF NPV
Total cost (€)	819029	865834
difference (CCF-RF)	46804€	

From table 6.5.3 above we can find out the final aggregated results of optimization. In both cases it is worth wile to note that CCF is the optimal forest management method for forestry. This is alone a significant finding from this research. If we compare the economic choices, we can see that the total cost for CCF implementation without option of clear-cutting causes economic loss of ~43.000€ to forest owners. In the case of buffer zones this loss is much higher, ~865.000€. This is because buffer zones are left totally out of any forestry activity, which naturally leads to higher economic loss for forest owners.

7. ANALYSIS AND DEALING WITH UNCERTANTIY

7.1 RESULTS

This section focuses on describing the results from benefit and cost calculations and how uncertainty is dealt in this CBA. Table 7.1.1 below consists finalized results. The table collects each of the cost and benefit item calculated for this work. Total annual consumer surplus is multiplied with perpetuity factor with 3% interest rate to obtain NPV of recreation benefits. Costs from the sample forests are deducted from benefit NPV's, which yields the net present values of social benefits on the last column.

As one can see, the cost side is fixed as it is assumed that NBS's are implemented to the whole area that meets the NBS criteria in both cases and thus is the most conservative cost estimate. Also, in a CBA, one can either fix the benefit side or the cost side and perform sensitivity analysis to either of the two. This is because one can fix either the benefits or costs, and then speculate about the resulting benefits (or costs) that correspond this level of costs (or benefits). (Boardman, 2014)

It is of course impossible to force forest owners to make the required action and therefore these costs are hypothetical. Despite this flaw, the presented results of NPV of NBS's may be useful information to stakeholders, especially local forest owners to support their decision making and hence support implementation of voluntary NBS methods to this area.

We can see from the results that NSB is positive in every scenario. This is an important finding, as one of the basic principles of a CBA is to recommend project, if the NSB is positive. (Boardman, 2014) The second thing to note from this table is that the benefits are highly sensitive to the visitor estimation. Annual estimate for CS ranges from €0.8 million to €8.69 million in water quality class D and on the other hand, costs are fixed. Natural reason behind this is that forest management activities can only be made inside the sub-catchment area, and in this work, it is assumed that the NBS implementation will be done in a full extend and the costs represents the most conservative estimate i.e. the maximum costs from NBS's. Thus, the hydrological borders, i.e. sub-catchment area of Kuonanjärvi, of the study site constricts, where NBS's can be implemented. On the other hand, there is not similar natural border for visitors which constraints benefit estimation similarly.

Table 7.1.1 Estimated NSB results.

NPV				
Visitor scenario 1: Benefits from sub-catchment area of Kuonanjoki (€)			Costs	
Scenario	Total annual CS (mil. €)	Perpetuity (mil. €)	Total costs (mil. €)	NSB NPV (Million €)
A	1.8115976	60.38658667	0.90895884	59.47762783
B	1.5936352	53.12117333	0.90895884	52.21221449
C	1.1804576	39.34858667	0.90895884	38.43962783
D	0.8349592	27.93394667	0.90895884	27.02498783
Visitor scenario 2: Benefits from consolidated sub-catchment area and postal code area (€)				
Scenario				
A	12.2598112	408.6603733	0.90895884	407.7514145
B	10.7853524	359.5117467	0.90895884	358.6027879
C	7.9893112	266.3103733	0.90895884	265.4014145
D	5.6710408	189.0346933	0.90895884	188.1257345
Visitor scenario 3: Benefits from postal code area (€)				
Scenario				
A	18.8059088	626.8636267	0.90895884	625.9546679
B	16.5442376	551.4745867	0.90895884	550.5656279
C	12.2552688	408.50896	0.90895884	407.6000012
D	8.6990592	289.96864	0.90895884	289.0596812

If we further look into the results presented in sections 5.5 and in table 7.1.1, we can conclude that these results support recent findings of economic viability of CCF (Metsätalouden kehittämiskeskus Tapio, 2019b; Metsätalouden kehittämiskeskus Tapio, 2019c; Parkatti et al., 2019; Rämö & Tahvonen, 2016) and we can conclude that in similar forests that was simulated in this study, CCF is the optimal forest regime. However, the optimal economic choice is to clear-cut everything and then switch to CCF. As the computations could be done only one time for this thesis, it is impossible to assess how parameter changes would affect to the optimal solution. The computation limits that complex optimization calculations have are severe restriction for this size-structured forest optimization method. Therefore, in a sensitivity analysis changes in parameter values like in a discount rate cannot be assessed.

However, we can assess uncertainty by looking at the regeneration costs and the area of the shoreline that is used in forestry. This is because regeneration cost is applied only once, because the optimal solution with simulated forests parameter values is CCF after cutting the existing stand and thus implying that regeneration costs will occur only once and can be deducted from NPV of the forest. However, change in regeneration price does not change the optimal solution until regeneration costs drops below 909.21€/ha, which is an unlikely scenario and thus regeneration costs are treated as fixed.

The area of buffer zones that is currently used by forestry is debatable. Figure 6.4.2 shows that there are currently many residents laying on the buffer zone area, and it is unlikely that harsh forestry actions will be imposed to the near proximity of these residents. This however depends largely on the ownership of the forests. So, in this sense, it can be said that the economic loss of buffer zones (865834€) given in section 6.5 is the maximum economic loss that can occur based on calculations presented in this thesis.

7.2 MONTE CARLO SIMULATION

As previously mentioned, CBA should cope with its inherent uncertainty somehow. In this study this is done firstly by presenting the results in table 7.1.1 as a crude scenario based worst-best case analysis. However, as the modelling of the quantified impacts is currently still in progress, it is quite impossible to put any probabilities to the benefit scenarios that would withstand critical assessment. Therefore, the author has chosen to use Monte-Carlo-simulation (MC) as a method to observe uncertainty in this study. This method is suitable statistical tool in cases where *"… the investigation of statistical estimators whose properties cannot be adequately determined through mathematical techniques alone."* (Boardman, 2014, p.184) The basic idea in this simulation is to define inputs that may have effect on the final output of NPV, then the NPV calculation is made multiple times where the defined inputs are randomly sampled based on their distribution.

In this study following variables were chosen to be sampled: Benefits from recreation when water quality increases current level of scenario D to scenario C (table 5.3.1) and the buffer zone area that is used in forestry, as it is highly unlikely that whole shore line is used in forestry due large amount of residents in area and some of the forests are in islands, which are hard to get in with machinery (figure 6.4.2).

It is important to note that the inputs for CCF and buffer zone net present value could not be included to this simulation for computation limits explained before. Therefore, running the Monte-Carlo simulation with these inputs is not practical in any sense as it would take impractical amount of time to finish as one optimization takes several days of computing time, and Monte-Carlo simulation accuracy depends on number of iterations. That is why the author used optimization results of costs as exogeneous variables in the simulation. This is also the reason, why the discount rate is fixed as this value is inside the optimization calculations as well.

In the analysis it was assumed that both these simulated values are normally distributed. Change of CS in each scenario was summed together to get the mean (2.0723 million €.) Lower bound CS change was deducted from mean and this was multiplied with 3, to get standard deviation (sd) for distribution. Similar approach was used to obtain mean and sd for the proportion of the area that is in forestry use in buffer zones. It was assumed that the real area that is used is somewhere between 50%-90% of the area. Hence the mean was 66.62ha and sd 6.344ha[7]. When this simulation was sampled 100000000 times following results were obtained.

[7] The whole R code that was used in MC-simulation attached to appendices.

Figure 7.2.1 MC-simulated annual NPV

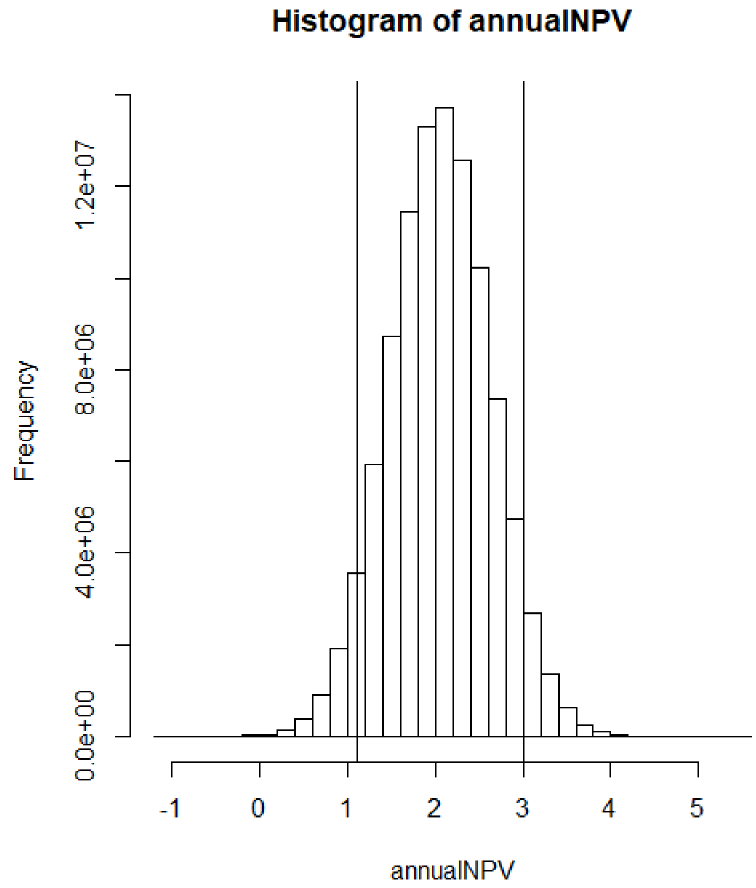


Figure 7.2.1 shows the annual NPV that comes, if water quality changes from water quality scenario D to C. Simulation yielded mean of 2.052867 million euros for annual NPV with quantiles of 5% = 1.104241; 95% = 3.001261. If perpetuity factor with discount rate of 3% is used, the total NPV from this project is estimated to be 68.42892 million euros, if the water quality increases from D to C level.

With these findings we can conclude that implementing CCF and buffer zones with these models and assumptions, would yield positive net present value and positive net social benefits from this project and thus should be recommended to decision makers.

8. CONCLUSIONS

This last section concludes the findings of CBA, and critically reviews what could be improved and what kind of future research possibilities this thesis yields.

Before reviewing results and analysis it is good to recall the research question from introduction: Is it economically feasible to implement continuous cover forestry and buffer zones as nature-based solutions to mitigate nutrient loading in research area so that the water quality will stay at least at the current level in the future? Short answer to this question, in the light of the findings and analysis, is yes, if we are strictly looking results and the fact that net social benefits are positive. Thus, the main conclusions that can be find from the results of this CBA is that with these parameters used, NSB of the project is estimated to be positive. Hence, the author recommends, according to the formula 1 in section 2, implementing these methods, however with certain precautions. However, the real answer is not that simple, and the resulting recommendation requires cautious interpretation.

Despite the encouraging findings, there are at the moment opaque areas relating the quantified impacts of CCF and buffer zones as NBS. The real quantified impact of nutrient flow model is still under progress in OPERANDUM and FRESHABIT projects, and for this reason it is impossible to take the nutrient model within the scope of this thesis. This model can have significant impact for the results of this thesis in the future, as currently impacts of NBS's are backed up by the findings of previous research explained in section 5, but the actual spatial, hydrological, geological and ecological interactions of the study site are still unclear. Therefore, the reader should interpret the resulting NPV and recommendation with this precaution in mind.

The study found out that CCF is the economically optimal choice for forest management in both simulated sample forests. This is the second most important finding from the results of this research. Even though the empiric impact chain modeling for NBS's is still under construction, the author can give recommendation with supporting evidence backed by the results of this study, to forest owners that own forest in the study site to encourage them to adapt CCF as the forest management choice in the forests that match with the sample forests. This is a mutually beneficial finding because as explained before in section 6, CCF has many benefits to mitigate nutrient flow and eutrophication and forest owners have now alternative way to increase their revenues whilst contributing nutrient and eutrophication mitigation. The economic loss for forest owners is relatively small in the second-best solution, if the forest owners would voluntarily choose to switch immediately to thinning’s and CCF instead of clearcutting and then choosing CCF, which is the economically optimal choice with model and parameter values used in this thesis.

In OPERANDUM project, the findings of this thesis can be scaled up to provide estimates how NBS’s can be applied to the whole region of Puruvesi, not just to the sub-catchment area and then review, if these area economically feasible NBSs. This optimal CCF result is also a significant finding in a larger scale, not just inside the framework of the OPERANDUM. There might be similar lakes in other regions of Finland or in foreign countries which can utilize the result of the CCF optimization in their decision making.

Intuitive interpretation of the author is that the economic loss for instantly switching to CCF would be even more easier and economically feasible in similar spruce forests in peatlands that are not yet ready for clearcutting, as the value of the standing trees is not yet that great and the switch would not be that harsh as it is now when the whole sample forest is ready for clearcutting. This would be an interesting area to continue research. This interpretation also suggests that the cost estimates are really conservative in this work, as the focus is on mature stands and the optimal forest management for less developed stand in similar environment could be more smooth compared to the optimal solution for the sample forest of this work.

If we look other aspects of this research critically, there is much room for further and more precise investigation in the benefit side as well. This study was somewhat limited to use pre-existing research made by LUKE. Even though the study site of Kuonanjoki sub-catchment area is similar and near Puruvesi, they are rather different because the study site does not have such tourist attractions that Puruvesi has such as national park, remarkable landscapes and museums. Therefore, the visit estimates for tourists is most likely not as accurate it could have been especially in the case of tourist class. However, to get this kind of information, a new valuation study should be conducted for the study site which was not possible in the scope of this research. Overall, the data that was used to retrieve the visitor scenarios was limited as well as mentioned before. Statistics Finland has higher resolution data available for the population density and the recreational housing which could be used to increase the accuracy of visitor estimation, but it was not used due its high price.

Another future possibility to increase the scope of this study would be to assess, what happens if the NBS's are not implemented and how this would impact the recreational benefit values. This would require further development of the water quality scenarios as currently the lowest scenario corresponds already the water quality in the study site. With wider range of different water quality scenarios worse than class D, one could estimate what kind of economic loss decreasing water quality would impose to the recreational visitors and further study the benefits that are obtained from ability to keep the status quo water quality and what would be the avoided costs.

Despite all these limitations, this CBA, models created and applied, and its results are as accurate and detailed as possible, in this timeline and with these skills and knowledge of the author. The academic background of the author, and hence this works as well, is in environmental economics. This means that the focus is mostly on the socio-economic aspects in this work. A More comprehensive model would require interdisciplinary cooperation: The more accurate and sophisticated CBA would and should take the ecological, and hydro-physiological models under construction in the CBA framework and produce more accurate estimation from the economic outcome of the project.

There are lots of opportunities to continue this research when the nutrient model is finished. For example, it would be interesting to see, what kind of quantified effect the location of forests and the NBS implementation has to the nutrient flow in study site and finally to the water quality. Now we assume, that all suitable areas are used for NBS that are meeting pre-defined criteria. However, spatial aspects of NBS's impacts are currently unknown and it might be that CCF in some place is more impactful than in other location. Then the task would be to determine which forest areas can impact the most to the nutrient flow reduction. This kind of study could also answer what is the minimum level of NBS implementation that ensures positive impact for nutrient mitigation.

Another possible future research for this subject is to take all the possible nutrient flow reduction methods in consideration and assess which combination would be the most cost-effective to reduce nutrient loading from forests. This could be very beneficially in larger scale as well, when similar eutrophication risks caused by climate change threats other waters in Finland.

Interactions and dynamics of such complex phenomena as climate change are very tough tasks to predict. For this reason, it is also important to prepare to adapt to climate change, instead focusing on the mitigation only, so that resilience of such sites as Puruvesi will retain their quality which then helps citizens to adapt to effects of climate change. Therefore, the future focus on similar studies should be on the adaptation side as well, where focus is more on how people can cope with the already happened effects of climate change.

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APPENDICES

MONTE-CARLO SIMULATION CODE IN R.

```
n=10000000


benefit<-rnorm(n,2.0723064*1000000,0.5766224*1000000)
bufferarea<-rnorm(n,66.62026,6.344786667)
buffercost<-9097.59
ccf<-43124.54093
NPV<-benefit/0.03-(bufferarea*buffercost+ccf)
annualNPV<-NPV*0.03/1000000

hist(annualNPV)
abline(v=quantile(annualNPV,c(0.05,0.95)))
quantile(annualNPV,c(0.05,0.95))

mean(NPV)
mean(NPV)*0.03
hist(NPV)
hist(benefit)
```