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Corresponding Author: Mr. Brent D Matthies,

Corresponding Author's Institution: University of Helsinki

First Author: Brent D Matthies

Order of Authors: Brent D Matthies; Tuomo Kalliokoski; Kyle Eyvindson;
Nina Honkela; Janne I Hukkinen; Nea Kuusinen; Petri Räisänen; Lauri
Valsta

Abstract: Socially inefficient payment for ecosystem services (PES)
schemes result when adverse shifts in the provisioning of other ecosystem
services (ES) or overpayment to service providers occur. To address these
inefficiencies, a holistic evaluation of trade-offs between services
should be conducted in parallel with determining land owners' service
provisioning preferences. Recent evidence also suggests that nudging
stakeholders' preferences could be a useful policy design tool to address
global change challenges. Forest owners' landscape management preferences
were nudged to determine the impact to social efficiency of PES schemes
for biodiversity conservation and climate change mitigation in Finland.
ES indicators for biodiversity conservation, carbon storage, and albedo
impacts were included with traditional provisioning services (i.e.
timber) and bioenergy to assess the consequent intra-service trade-offs.
Synergies in provisioning of regulating services were identified, but
were found to be more efficient when the management objective is for
biodiversity conservation rather than climate change regulation. Nudging
led to marginal gains in service provisioning above the baseline
management and above neutral owner preferences, and increased aggregate
service provisioning. This demonstrates the importance of considering
intra-service trade-offs and that nudging could be an important tool for
designing efficient PES schemes.

Response to Reviewers: Reviewers' comments:

Editor: While this is an interesting paper, there are issues of clarity
of your arguments and English. Please make sure that these and the other
reviewer's comments are addressed in your revision.

General comments to the editor and reviewers:

We have taken the major comments that were given by both reviewers and
made the requested major changes to our paper. The primary feedback

centered on the lack of a cohesive argument to justify using trade-off analysis and nudging in the same paper. We agree that the argument was not clear in the original draft, and have made major changes to the introduction and the newly created discussion sections in an effort to clarify the methods purpose and the results (specifically those related to nudging). In doing so, it was necessary to make changes to the structure of the results section and have now added two new clearer tables to present the nudging outcomes. Due to restrictions of the journal regarding the number of figures/tables, it was necessary to move some of the original tables to the Supplementary materials. Additionally, based on feedback from the reviewers we have removed some of the analysis related to Eigen values from both documents. We have tried to provide reference to where the changes occurred, but due to some major edits it was not possible to be exact in all cases.

Reviewer #1: Overall, an interesting paper. I like the idea of applying a behavioral psychological approach to influence stakeholder decision-making in order to improve PES effectiveness by reducing programme inefficiencies, particularly policy costs, in conjunction with maximizing ecosystem service synergies by evaluating ES trade-offs. Nevertheless, I did find the article in several places difficult to work through and understand what was going on, a fact that I felt obscured the argument you're trying to make. In some cases I was also not convinced whether the 'nudging' effect was actually significant. Therefore I have spelled out below some areas where I think the article could be strengthened and improved to make your narrative and argument more robust and convincing.

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Specific Comments:

Due to the absence of page numbers and the non-continuous use of line numbers I have set the page on which the introduction starts as page 1.

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Introduction

Page 2 Line 6: It would be useful to define what you mean by bundling, as opposed to stacking for example, and its pros and cons. Also refer to some of the recent literature on bundling ES, for example: Turner et al., (2014) Landscape and Urban Planning 125, 89-104; Robertson et al., (2014) Frontiers in Ecology and the Environment 12, 186-193; Simonit and Perrings (2013) PNAS 110, 9326-9331; Deal et al., (2012) Forest Policy and Economics 17, 69-76; Cooley and Olander (2011) Nicholas Institute for Environmental Policy Solutions Working Paper NI WP 11-04.

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Done. See lines 41-43.

Page 2 Footnote 1: I presume you mean Engel et al., (2008) not (2010)?

We have deleted this and many of the other footnotes.

Page 3 Line 23: To my mind EU ETS is not a PES scheme, at least in the classical sense. I think at this point it is important to state what your underlying definition/criteria of a PES scheme is (i.e.is it Wunder's (2005) archetype or Pascual and Muradian's (2010) definition of a social transfer of resources?). Having then provided your criteria for what constitutes a PES design then state how the EU ETS and METSO II fit those criteria. At the moment it is not clear, and therefore it is not clear that you are comparing like for like.

You are correct. Our benchmark scheme was the New Zealand ETS scheme for carbon offsets for private forest owners, which is based on the international price for carbon set by the EU ETS scheme. We consider that to be a PES scheme. Therefore, we use the EU ETS as our basis. However, we did not make reference to this link previously and appreciate the comment. We have now indicated this link more clearly in the introduction, removed reference to EU ETS, and clarified the definition of PES that we use within the introduction. See lines 74-84.

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The map has been moved to the Supplementary materials (Section 1) due to journal restrictions on the number of figures/tables. We have improved the map based on the other reviewer's comments.

Page 6 Table 1: Make sure the table is correctly formatted for the journal style.

Based on a review of author guidelines and previous submissions, we believe that this style is appropriate for Elsevier.

Page 7 Lines 29-35: This sentence is somewhat convoluted, simplify to express the meaning more clearly.

We have rewritten this section to improve the clarity. See Section 2.5.

Page 7 Lines 39-48: This section as a whole is not clearly formulated, it is not straightforward to understand what you are trying to convey, and would benefit from being reworded.
        For example, with respect to lines 39-41, one interpretation could be that you're suggesting the degree of curvature for individual trade-off curves represents the extent of a trade-off or synergy between individual indicators and a comparator (e.g., the correlation of indicators A, B,C, D, and E against F)? However, this may not be the

case? Furthermore, in this section you also need to make clear what it is you mean by the term elasticities - remember your readership is going to be broad and so jargon may require explanation.

Secondly, for lines 42-46 would the following interpretation be correct: Management scenarios were applied to each site type and within each site type to each age class and covered a minimum of 10 hectares? Again, clarity in writing so what you're saying is not open to multiple interpretations.

Thirdly, line 46 may be better written as "Optimality was equated with the degree of economic return".

Fourthly, what do you mean by "attainable decision space"?

We agree that the original version of the modeling section was very difficult to understand. We have worked to edit it in a manner that gives a better step-by-step representation of the modeling and the analysis of the results. Terms have now been better defined here or in the results section. Elasticities are defined within the text and we try to use less 'economic' related jargon. We have tried to clarify 'attainable decision space'. See Section 2.5.

Page 7 line 54/55: Again, for clarity, I would suggest you state what you mean by "normalization" does this equate to "standardization"?

No, this is a term used in Multi Criteria Decision Analysis to refer to the creation of a zero-one scale and not standardization. We have now referred to a specific chapter in a text that outlines this method and tried to clarify it in the text. See lines 253-258.

Page 7 line 56/57: Replace zero-one with binary

This change is not consistent with the idea of zero-one normalization, as we are scaling achievement of all criteria between zero and one (i.e. between the minimum possible and maximum possible), and not either zero or one. See lines 253-258.

Page 8 Table 2: Ensure your table is correctly formatted

The author guidelines say only that the tables should be in a word processing format.

Page 10 line 32/33: Is this figure correct? Why would the subsidies for energy wood producers be assumed to be 0?

I assume that you mean the value of 0 euros for the subsidy. We use this subsidy value on the basis that the current subsidies will no longer exist in the future and it has been an appropriate assumption, due to this uncertainty, made by other Finnish studies (i.e. Kallio et al. 2011). See lines 179-186.

Results and Discussion

Page 11 line 43/44: Identify Figure C.7 in reference to Supplementary Information

We have identified all of the relationships with the Supplementary Materials throughout the text.

Page 11 lines 44-51: Suggested rephrasing to make this sentence clearer:

"Thus provisioning (i.e., pulp wood, saw timber and bioenergy) and regulating (i.e., BIV, CS and RF) ES demonstrated similarly highly negative and elastic values at 100% economic returns. At 50% economic returns their respective elasticities were similarly negative but much smaller in magnitude."

This is now rephrased in Section 3.1.

Page 11 lines 51-52: Suggested rephrasing to make sentence clearer: "Except for saw timber and pulpwood ES indicators were strongly negatively correlated with economic returns."

This has been rewritten in Section 3.1.

Page 12 Table 3: Make sure your table is correctly formatted for the journal style.

See response to previous similar comment.

Page 12 Lines 37-42: Need to make it clear where these figures have been obtained from (i.e. Figure C.7 Supplementary Information)

See response to previous similar comment.

Page 12 line 52/53: Really? How did you arrive at this value? What particular values of the climate mitigation indicators are you correlating? If you compare one way of measuring an indicator with another way of measuring the same indicator isn't this just autocorrelation?

This comment is extremely helpful and, we agree, there is a risk of autocorrelation if the same indicators are measured in different ways. However, for avoided radiative forcing we only include forcing from the albedo effect. This was not clear in the original manuscript and has now been clarified throughout the paper. This could be slightly confusing given that the avoided forcing from albedo effect and the carbon storage in forest biomass were stacked within the same PES scheme for climate change mitigation. We have tried to make this difference clear in Sections 2.3 (description of the indicators) and Section 3.1 (description of the trade-off results).

Page 13 Table 4: Make sure table is correctly formatted for the journal style

Page 14 Lines 9-11: Suggested rephrasing to improve sentence clarity: "Both CS and avoided RF were modestly positively correlated with BIV."

This should have been "moderately".

Page 14 Lines 11-14: Need to reference Figure 2 in this sentence; otherwise it is unclear as to where your numbers are taken from.

The figure has now been referenced.

Page 14 line 14/15: In between "due" and "divergence" it should be "to a" rather than "a"

This was rewritten.

Page 14 line 15/16: After "management activities" insert: (i.e., early harvesting and thinnings)

Done.

Page 14 lines 16-23: Remove the section that starts "These activities were" and ends "between CS and BIV", it is not necessary.

This was rewritten.

Page 14 merge lines 23-24/25 with line 33/34 so it now reads: "Both CS and RF reached perfect inelasticity with BIV at 50% BIV"

This was rewritten.

Page 14 lines 37/38 - 46/47: Start section 3.1 with this paragraph - get your message out up front and centre - and then use the proceeding paragraphs to justify and expand on this statement.

The second reviewer has suggested separating the results and discussion. Thus, we do not know if this comment is still valid.

Page 15 line 10/11: remove "of" after "summarizes"

This was rewritten.

Page 15 Table 5: Ensure that the table is formatted in the correct style for the journal

See response to same comment above.

Page 16 lines 20-31: Move to the beginning of section 3.2 and then discuss how your results enable you to address these challenges.

The second reviewer has suggested separating the results and discussion. Thus, we do not know if this comment is still valid.

Surely the main point to emphasise is that in both cases PES payments increased the LEV, so the question is which would be the better management option in each of the PES scenarios to adopt if you did not want to follow a BAU. Your opinion on this issue is not clear.

You are correct. We have discussed this in the text on lines 475-489.

Page 16 line 52: I would recommend starting section 3.3 with your assertion that nudging does make a difference and then present your evidence to convince the reader that this is the case. Beginning by describing a figure does not make for a strong narrative, nor is it a good way to present an argument.

This has now been done.

Page 16 line 55/56: Please identify the specific figure in Supplementary Information to which you are referring, in this case, I take it to be Figure C.8.

This has been done for all references to the Supplementary Materials.

Page 16 line 59, Page 17 line 4: The difference between nudged and non-nudged in Figure 3 appears to be minimal save for the CS case where differences are a little more obvious. Is the effect that you're registering really significant in terms of behaviour alteration? I don't find the evidence presented in Figure 3 all that convincing. I think you need to really make the case that these minor differences actually are significant from a behavioural point of view.

It was not possible to test the significance in this paper, but related (published) research looking at the same research question with other stakeholder groups did find a significant result. We refer to that research in our current paper and discuss the relationship to this research. See lines 456-462. Also, we have changed from Fig. 3 to two tables (4 and 5) that better demonstrate the benefits of nudging. See section 3.3.

Page 17 line 15: Euclidian distance: This section is not very clear. Suddenly we are discussing Euclidian distances and the argument for why is not explicitly presented, nor indeed is what this is actually a measure of and what this is evidence for at the end of the day. I think at the very least it is necessary to define what a Euclidian distance measure is, and why a term used in geometry has any bearing in this context, and furthermore, how you arrived at the numbers you included in the text.

We have removed this from the paper.

Page 18 lines 14-32: I would advise moving this segment to the beginning of section 3.3.

Various sections were moved around to improve the flow of the paper.

Page 18 line 48/49: The table you refer to here, which you've placed in Supplementary Information (i.e., Table C.9), would benefit from being inserted into the main text. After all, you're trying to make the argument that nudging works by reducing the inefficiencies in PES schemes (i.e., lowers costs) - here at least is presented some monetary figures that might support your claim in a more substantiated manner - much better than figure 3 which is not convincing.

This comment has now been noted and we have exchanged the table and figure in Section 3.3.

Page 19 lines 6-9: This sentence needs references.

Done. See lines 450-453.

Supplementary Material

Table C.8 Please explain how you derived the summary information you present in this table, it is not altogether clear.

This is now Table B.7 and we have briefly clarified what these values represent. They are the minimum and maximum values used in the normalization described in the text.

Reviewer #2: Reviewer suggestion: Major revision.

General comments:

English syntax is very inaccurate and makes the article very difficult to follow and to understand. It needs to be reviewed in terms of grammar and in terms of enunciation to make it clearer and understandable. It makes also very difficult to follow the sequence of argumentation and the general comprehension of the manuscript.

In this regard, it is also confusing the fact that the discussion is part of results. It makes results more difficult to identify and confuses the general comprehension of the manuscript. The results need to be clear and concise and isolated from the discussion section that is currently inexistent. The section 3.4. on limitations is somehow too short and naïve, and discusses aspects that are too far from the focus of the paper that should be on the validity of the model in real life, e.g. the fact that nudging is solely done with 10 forest owners, the fact that biodiversity indicators are extrapolated from existing coarse biodiversity modelling, how results would apply to other parts of Finland and to other social groups etc.

Overall, the paper contains valuable data and treats an interesting subject, but it fails to justify the conclusions that are announced in the abstract. The effect of nudging of ES is not clearly understood by the reader and the organization of the manuscript, plus English syntax, makes the overall manuscript in need of major revisions before it can be reassessed for publication. I further indicate below the sentences that I found problematic for the validity of this research piece.

We have made major edits to the paper in an effort to clarify the results and discussion sections. Based on these changes some of the edits noted below may no longer be valid. See our general comments to reviewers and the editor.

-Abstract:
"Environmental pressures on land use have increased interest in the provision of ecosystem services regulating climate change and biodiversity." Although just an introductory sentence in the abstract, the authors should also consider the increased importance for human health.

The abstract has been rewritten.

-1. Introduction:
"The concept of nudging refers to the design of a choice architecture in a way that alters human behavior predictably without forbidding options or changing economic incentives (Thaler and Sunstein, 2008)." Unclear.

This has been changed. See lines 55-57.

"We adopt a trade-off approach…": What justifies the use of trade-offs in combination with nudging?

A trade-off analysis demonstrates the potential social inefficiencies in how ecosystems are managed and payment schemes are designed. The aim of nudging is to increase social efficiency of PES schemes, but nudges could produce adverse trade-offs between schemes or service offerings.

Therefore, we believe that it is necessary to assess trade-offs. We have more clearly justified this throughout the text, and given further references regarding the inclusion of trade-off analysis with other evaluations (i.e. analysis of trade-offs and bundling of multiple ES).

"The ES include: carbon storage, avoided radiative forcing, biodiversity conservation, and commodity production." Commodity production is not and ES.

We have now clarified this in the text. See section 2.3.

-2.1. Description of the case area:
"The grid dimensions were 20 x 20 m and only grid points containing forest growing on mineral soil were considered." Why and what other types of soils exhist?

We have now clarified this in the text. See lines 95-97.

Figure 1: The map, as it stands right now -using Google data-, is too basic and not useful.

Erase and replace by another one doing a zoom at the 20x20km zone, and showing distribution of different forests, land uses and location of stakeholders. If it is not possible to do such map, then it is better to have no map than the current one.

The map has been changed and moved to the Supplementary materials (Section 1) due to journal restrictions on the number of figures/tables.

-2.2. Forest Management Scenarios:
"Also, NIPF owners do not always follow the economically optimal rotation." Why and which ones? This sentence has a different font size as if it was included later in the writing process and not fully integrated in the text.

This sentence was part of the original writing process. However, there are many authors and it was a formatting error that was, unfortunately, not caught prior to submission. It has now been fixed. Also, the sentence has now been clarified and a citation to support it has been added.

-2.3. Forest Owner Consultation:
"They were designed on a purely verbal basis.": What does this sentence mean?

"The aim of nudging…": Nudging should be a but more developed and explained in the introduction.

"In the consultation…": Why was this area selected? Why were this forest owners selected? Why only ten? Is it a sufficient number?

These issues have now been clarified. See Section 2.4.

-2.4. Multi-criteria decision analysis:
"Each plan is a set of…": How are the five scenarios used to set a management plan? The combination of concepts is very confuse.

"Landscape management portfolios…": Why this choice?

"Optimality was based…": Unclear meaning.

"Nudged and non-nudged groups…": Unclear meaning.

"Normalization, using two…": Again, very obscure explanation.

"For the trade-offs…": Very difficult to understand. Rephrase in a more simple and comprehensive way.

This section was overall unclear, and we have tried to address the lack of clarity through extensive editing. We have defined the noted elements and expanded the explanation of the modeling/analysis processes. Now 'nudged and non-nudged' is referred to as nudged and neutral. Hopefully this is now clearer. See Section 2.5.

Table 2: 'Percent of total forest landscape' is a bad English formulation.

The wording of the table header has now been adjusted. See Table 1.

-2.5. Indicator variables:

Economic returns is a not a 'scientifically-based criteria'?

The aim had been to note that economic returns were calculated based on the marginal achievement of the various other indicators. However, the wording was not clear and it has now been adjusted. We have also tried to be more precise in noting the associations between the indicators chosen and the ecosystem service classifications. See our rephrasing in Section 2.3.

"All non-economic indicators…": Inaccurate English and understanding of additionality. Additionality is the change that takes place as a result of program implementation, and that would not have happened without the program.

This is also our understanding of additionality. Thus, this is a clarity issue and we have tried to address it by adjusting the sentence in lines 149-150.

"It was then transformed…": Is this an annex or Supplementary information? I think that this equation should be in the main text.

This is a very common equation in climate sciences for transforming radiative forcing to CO_2 equivalent units (similar to basic discount formulas or financial ratios). Therefore, we do not feel it is necessary to include it in this text. See Section 2 in the Supplementary Materials.

"The price for energy wood…": Why adding the EU ETS offset on coal-based energy? The price of energy wood depends on production costs and intersection between offer and demand.

Coal-based energy producers need to purchase EU ETS to be able to emit carbon in Finland. Therefore, EU ETS are a cost of coal energy processing. This is the justification for the inclusion in the formula and has been used previously used in other studies. See lines 179-186.

"A starting price of…": We need a more recent figure. In 2015, prices could have changed a lot.

This comment is not completely clear. By 'starting price' we mean that this is the lowest price that we use in our study. We use this lower 'starting' price on the basis of expectations about future prices within the carbon offset market. Other studies (i.e. Kallio et al., 2011) also suggest this is an appropriate lower price for EU ETS in the future. Based on the recent changes in the market structure at the governance level, we still feel that this is an appropriate lower price. Finally, this program is not based on a specific current price. It is based on the expected price over the next 50 years. Therefore, we do not feel that it is necessary to make this change to the input data. See lines 179-188.

"Additionality was not considered…": This is a short coming of the existing PES program. Is it justified to maintain it in the current simulation? The sentence appears unclear to me.

It is a shortcoming of that scheme. We included additionality in our calculations, but it is not possible to create new input data. We still feel that it is justified to use this input data on the basis of data availability and the efforts we have made to account for additionality in our calculations.

-3. Results and discussion:

"Regulating and provisioning ES…": How are ES measured here? €/ha? Units/ha? Unclear. Unclear also why they mention the exclusion of PES returns.

This sentence has now changed. However, the units are available in the methods section. The indicators were all normalized so that they could be compared across various indicators with different units of measurement. We felt that the inclusion of units might also be confusing given that normalization removes the need for units. See Sections 2.3 and 3.1.

"Given that the yield…": Global in terms of the Earth?

This has been rewritten in Section 3.1.

"Thus, provisioning and regulating…": Unclear sentence.

This has been rewritten in Section 3.1.

"Therefore a reduction in…": It is difficult to show or accept this partial conclusion when the reader does not clearly understand what type of biodiversity modelling allows asserting this.

The biodiversity modeling was based on a scorecard approach that is clarified in the Supplementary materials. This accounting method for biodiversity was verified as part of the TNV scheme, which forms part of the European Union's Natura2000 network. It is also scientifically acceptable and has been used in numerous peer-reviewed publications (i.e. Juutinen and Ollikainen, 2010; Juutinen et al., 2013; Primmer et al., 2013; Juutinen et al., 2014). The aggregate indicator from the scorecard calculations, referred to as BIV in this article, was assessed on the basis of the TNV scheme's scorecard for each of the scenarios in this study. This was done following the principle of additionality outlined in

the text. The resulting value was then normalized and the Pareto optimal solutions were modeled to determine the trade-off between the aggregate biodiversity conservation value and all the other indicators and economic returns.

"The elasticities indicated…": Inaccurate phrasing, makes very difficult to understand the scientific meaning of the sentence.

We have clarified the meaning in lines 298-300 and 321-325.

Table 5: These payments are only including CO2 prices. What about biodiversity?

Both have now been included in the presented results. Previously they were found in the Supplementary Materials.

"PES programs present an opportunity…": This para follows a discussion style. As previously suggested, it would be better to have an independent discussion section.

We have created a separate discussion section.

"In Fig. 3a-d…": What does "considerations..." exactly mean?

We have removed this figure and replaced it with two tables.

"NIPF owners in both…": Why? That maybe means that their actual returns are before the economic return that was modelled.

It might mean that. It could also mean that even without being nudged, the forest owners had not previously considered alternative management objectives until the consultation. Therefore, relative to the baseline management they were willing to accept a loss after the consultation. See lines 463-470.

Fig. 3: These figures do not clearly illustrate how nudging improves PES efficiency.

We have now created two tables instead.

"Nevertheless, there were…": Discussion style better fit in a discussion independent section.

There is now a separate discussion.

-3.4. Limitations:

The way nudging was applied and how it influenced trade-offs is not clearly understood once the reader ends the manuscript.

We have addressed this limitation in the discussion section. See lines 457-507.

Dear Sir/Madam,

We are re-submitting this article "Nudging service providers and assessing service trade-offs to reduce the social inefficiencies of Payments for Ecosystem Services schemes" for further review and publication in *Environmental Science and Policy* following major revisions made to the paper. Thank you for the opportunity to further edit this paper.

We have taken both reviewers' comments into account. The text should now be more cohesive and conclusions clearer. To address the reviewer's primary concerns, we have now clarified our methods, presented our results using clearer tables, and included a broader discussion on the implications of our findings. Further responses to specific questions can be found in the responses to reviewers.

Sincerely,

Brent D. Matthies, Corresponding Author

Reviewers' comments:

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General comments to the editor and reviewers:

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Page 7 Lines 29-35: This sentence is somewhat convoluted, simplify to express the meaning more clearly.

We have rewritten this section to improve the clarity. See Section 2.5.

Page 7 Lines 39-48: This section as a whole is not clearly formulated, it is not straightforward to understand what you are trying to convey, and would benefit from being reworded.

     For example, with respect to lines 39-41, one interpretation could be that you're suggesting the degree of curvature for individual trade-off curves represents the extent of a trade-off or synergy between individual indicators and a comparator (e.g., the correlation of indicators A, B,C, D, and E against F)? However, this may not be the case? Furthermore, in this section you also need to make clear what it is you mean by the term elasticities - remember your readership is going to be broad and so jargon may require explanation.

     Secondly, for lines 42-46 would the following interpretation be correct: Management scenarios were applied to each site type and within each site type to each age class and covered a minimum of 10 hectares? Again, clarity in writing so what you're saying is not open to multiple interpretations.

     Thirdly, line 46 may be better written as "Optimality was equated with the degree of economic return".

     Fourthly, what do you mean by "attainable decision space"?

We agree that the original version of the modeling section was very difficult to understand. We have worked to edit it in a manner that gives a better step-by-step representation of the modeling and the analysis of the results. Terms have now been better defined here or in the results section. Elasticities are defined within the text and we try to use less 'economic' related jargon. We have tried to clarify 'attainable decision space'. See Section 2.5.

Page 7 line 54/55: Again, for clarity, I would suggest you state what you mean by "normalization" does this equate to "standardization"?

No, this is a term used in Multi Criteria Decision Analysis to refer to the creation of a zero-one scale and not standardization. We have now referred to a specific chapter in a text that outlines this method and tried to clarify it in the text. See lines 253-258.

Page 7 line 56/57: Replace zero-one with binary

This change is not consistent with the idea of zero-one normalization, as we are scaling achievement of all criteria between zero and one (i.e. between the minimum possible and maximum possible), and not either zero or one. See lines 253-258.

Page 8 Table 2: Ensure your table is correctly formatted

The author guidelines say only that the tables should be in a word processing format.

Page 10 line 32/33: Is this figure correct? Why would the subsidies for energy wood producers be assumed to be 0?

I assume that you mean the value of 0 euros for the subsidy. We use this subsidy value on the basis that the current subsidies will no longer exist in the future and it has been an appropriate assumption, due to this uncertainty, made by other Finnish studies (i.e. Kallio et al. 2011). See lines 179-186.

Results and Discussion

Page 11 line 43/44: Identify Figure C.7 in reference to Supplementary Information

We have identified all of the relationships with the Supplementary Materials throughout the text.

Page 11 lines 44-51: Suggested rephrasing to make this sentence clearer:
"Thus provisioning (i.e., pulp wood, saw timber and bioenergy) and regulating (i.e., BIV, CS and RF) ES demonstrated similarly highly negative and elastic values at 100% economic returns. At 50% economic returns their respective elasticities were similarly negative but much smaller in magnitude."

This is now rephrased in Section 3.1.

Page 11 lines 51-52: Suggested rephrasing to make sentence clearer:
"Except for saw timber and pulpwood ES indicators were strongly negatively correlated with economic returns."

This has been rewritten in Section 3.1.

Page 12 Table 3: Make sure your table is correctly formatted for the journal style.

See response to previous similar comment.

Page 12 Lines 37-42: Need to make it clear where these figures have been obtained from (i.e. Figure C.7 Supplementary Information)

See response to previous similar comment.

Page 12 line 52/53: Really? How did you arrive at this value? What particular values of the climate mitigation indicators are you correlating? If you compare one way of measuring an indicator with another way of measuring the same indicator isn't this just autocorrelation?

This comment is extremely helpful and, we agree, there is a risk of autocorrelation if the same indicators are measured in different ways. However, for avoided radiative forcing we only include forcing from the albedo effect. This was not clear in the original manuscript and has now been clarified throughout the paper. This could be slightly confusing given that the avoided forcing from albedo effect and the carbon storage in forest biomass were stacked within the same PES scheme for climate change mitigation. We have tried to make this difference clear in Sections 2.3 (description of the indicators) and Section 3.1 (description of the trade-off results).

Page 13 Table 4: Make sure table is correctly formatted for the journal style

Page 14 Lines 9-11: Suggested rephrasing to improve sentence clarity:
"Both CS and avoided RF were modestly positively correlated with BIV."

This should have been "moderately".

Page 14 Lines 11-14: Need to reference Figure 2 in this sentence; otherwise it is unclear as to where your numbers are taken from.

The figure has now been referenced.

Page 14 line 14/15: In between "due" and "divergence" it should be "to a" rather than "a"

This was rewritten.

Page 14 line 15/16: After "management activities" insert: (i.e., early harvesting and thinnings)

Done.

Page 14 lines 16-23: Remove the section that starts "These activities were" and ends "between CS and BIV", it is not necessary.

This was rewritten.

Page 14 merge lines 23-24/25 with line 33/34 so it now reads:
"Both CS and RF reached perfect inelasticity with BIV at 50% BIV"

This was rewritten.

Page 14 lines 37/38 - 46/47: Start section 3.1 with this paragraph - get your message out up front and centre - and then use the proceeding paragraphs to justify and expand on this statement.

The second reviewer has suggested separating the results and discussion. Thus, we do not know if this comment is still valid.

Page 15 line 10/11: remove "of" after "summarizes"

This was rewritten.

Page 15 Table 5: Ensure that the table is formatted in the correct style for the journal

See response to same comment above.

Page 16 lines 20-31: Move to the beginning of section 3.2 and then discuss how your results enable you to address these challenges.

The second reviewer has suggested separating the results and discussion. Thus, we do not know if this comment is still valid.

Surely the main point to emphasise is that in both cases PES payments increased the LEV, so the question is which would be the better management option in each of the PES scenarios to adopt if you did not want to follow a BAU. Your opinion on this issue is not clear.

You are correct. We have discussed this in the text on lines 475-489.

Page 16 line 52: I would recommend starting section 3.3 with your assertion that nudging does make a difference and then present your evidence to convince the reader that this is the case. Beginning by describing a figure does not make for a strong narrative, nor is it a good way to present an argument.

This has now been done.

Page 16 line 55/56: Please identify the specific figure in Supplementary Information to which you are referring, in this case, I take it to be Figure C.8.

This has been done for all references to the Supplementary Materials.

Page 16 line 59, Page 17 line 4: The difference between nudged and non-nudged in Figure 3 appears to be minimal save for the CS case where differences are a little more obvious. Is the effect that you're registering really significant in terms of behaviour alteration? I don't find the evidence presented in Figure 3 all that convincing. I think you need to really make the case that these minor differences actually are significant from a behavioural point of view.

It was not possible to test the significance in this paper, but related (published) research looking at the same research question with other stakeholder groups did find a significant result. We refer to that research in our current paper and discuss the relationship to this research. See lines 456-462. Also, we have changed from Fig. 3 to two tables (4 and 5) that better demonstrate the benefits of nudging. See section 3.3.

Page 17 line 15: Euclidian distance: This section is not very clear. Suddenly we are discussing Euclidian distances and the argument for why is not explicitly presented, nor indeed is what this is actually a measure of and what this is evidence for at the end of the day. I think at the very least it is necessary to define what a Euclidian distance measure is, and why a term used in geometry has any bearing in this context, and furthermore, how you arrived at the numbers you included in the text.

We have removed this from the paper.

Page 18 lines 14-32: I would advise moving this segment to the beginning of section 3.3.

Various sections were moved around to improve the flow of the paper.

Page 18 line 48/49: The table you refer to here, which you've placed in Supplementary Information (i.e., Table C.9), would benefit from being inserted into the main text. After all, you're trying to make the argument that nudging works by reducing the inefficiencies in PES schemes (i.e., lowers costs) - here at least is presented some monetary figures that might support your claim in a more substantiated manner - much better than figure 3 which is not convincing.

This comment has now been noted and we have exchanged the table and figure in Section 3.3.

Page 19 lines 6-9: This sentence needs references.

Done. See lines 450-453.

Supplementary Material

Table C.8 Please explain how you derived the summary information you present in this table, it is not altogether clear.

This is now Table B.7 and we have briefly clarified what these values represent. They are the minimum and maximum values used in the normalization described in the text.

Reviewer #2: Reviewer suggestion: Major revision.

General comments:

English syntax is very inaccurate and makes the article very difficult to follow and to understand. It needs to be reviewed in terms of grammar and in terms of enunciation to make it clearer and understandable. It makes also very difficult to follow the sequence of argumentation and the general comprehension of the manuscript.

In this regard, it is also confusing the fact that the discussion is part of results. It makes results more difficult to identify and confuses the general comprehension of the manuscript. The results need to be clear and concise and isolated from the discussion section that is currently inexistent. The section 3.4. on limitations is somehow too short and naïve, and discusses aspects that are too far from the focus of the paper that should be on the validity of the model in real life, e.g. the fact that nudging is solely done with 10 forest owners, the fact that biodiversity indicators are extrapolated from existing coarse biodiversity modelling, how results would apply to other parts of Finland and to other social groups etc.

Overall, the paper contains valuable data and treats an interesting subject, but it fails to justify the conclusions that are announced in the abstract. The effect of nudging of ES is not clearly understood by the reader and the organization of the manuscript, plus English syntax, makes the overall manuscript in need of major revisions before it can be reassessed for publication. I further indicate below the sentences that I found problematic for the validity of this research piece.

We have made major edits to the paper in an effort to clarify the results and discussion sections. Based on these changes some of the edits noted below may no longer be valid. See our general comments to reviewers and the editor.

-Abstract:
"Environmental pressures on land use have increased interest in the provision of ecosystem services regulating climate change and biodiversity." Although just an introductory sentence in the abstract, the authors should also consider the increased importance for human health.

The abstract has been rewritten.

-1. Introduction:
"The concept of nudging refers to the design of a choice architecture in a way that alters human behavior predictably without forbidding options or changing economic incentives (Thaler and Sunstein, 2008)." Unclear.

This has been changed. See lines 55-57.

"We adopt a trade-off approach…": What justifies the use of trade-offs in combination with nudging?

A trade-off analysis demonstrates the potential social inefficiencies in how ecosystems are managed and payment schemes are designed. The aim of nudging is to increase social efficiency of PES schemes, but nudges could produce adverse trade-offs between schemes or service offerings. Therefore, we believe that it is necessary to assess trade-offs. We have more clearly justified this throughout the text, and given further references regarding the inclusion of trade-off analysis with other evaluations (i.e. analysis of trade-offs and bundling of multiple ES).

"The ES include: carbon storage, avoided radiative forcing, biodiversity conservation, and commodity production." Commodity production is not and ES.

We have now clarified this in the text. See section 2.3.

-2.1. Description of the case area:
"The grid dimensions were 20 x 20 m and only grid points containing forest growing on mineral soil were considered." Why and what other types of soils exhist?

We have now clarified this in the text. See lines 95-97.

Figure 1: The map, as it stands right now -using Google data-, is too basic and not useful.

Erase and replace by another one doing a zoom at the 20x20km zone, and showing distribution of different forests, land uses and location of stakeholders. If it is not possible to do such map, then it is better to have no map than the current one.

The map has been changed and moved to the Supplementary materials (Section 1) due to journal restrictions on the number of figures/tables.

-2.2. Forest Management Scenarios:
"Also, NIPF owners do not always follow the economically optimal rotation." Why and which ones? This sentence has a different font size as if it was included later in the writing process and not fully integrated in the text.

This sentence was part of the original writing process. However, there are many authors and it was a formatting error that was, unfortunately, not caught prior to submission. It has now been fixed. Also, the sentence has now been clarified and a citation to support it has been added.

-2.3. Forest Owner Consultation:
"They were designed on a purely verbal basis.": What does this sentence mean?

"The aim of nudging…": Nudging should be a but more developed and explained in the introduction.

"In the consultation…": Why was this area selected? Why were this forest owners selected? Why only ten? Is it a sufficient number?

These issues have now been clarified. See Section 2.4.

-2.4. Multi-criteria decision analysis:
"Each plan is a set of…": How are the five scenarios used to set a management plan? The combination of concepts is very confuse.

"Landscape management portfolios…": Why this choice?

"Optimality was based…": Unclear meaning.

"Nudged and non-nudged groups…": Unclear meaning.

"Normalization, using two…": Again, very obscure explanation.

"For the trade-offs…": Very difficult to understand. Rephrase in a more simple and comprehensive way.

This section was overall unclear, and we have tried to address the lack of clarity through extensive editing. We have defined the noted elements and expanded the explanation of the modeling/analysis processes. Now 'nudged and non-nudged' is referred to as nudged and neutral. Hopefully this is now clearer. See Section 2.5.

Table 2: 'Percent of total forest landscape' is a bad English formulation.

The wording of the table header has now been adjusted. See Table 1.

-2.5. Indicator variables:

Economic returns is a not a 'scientifically-based criteria'?

The aim had been to note that economic returns were calculated based on the marginal achievement of the various other indicators. However, the wording was not clear and it has now been adjusted. We have also tried to be more precise in noting the associations between the indicators chosen and the ecosystem service classifications. See our rephrasing in Section 2.3.

"All non-economic indicators…": Inaccurate English and understanding of additionality. Additionality is the change that takes place as a result of program implementation, and that would not have happened without the program.

This is also our understanding of additionality. Thus, this is a clarity issue and we have tried to address it by adjusting the sentence in lines 149-150.

"It was then transformed…": Is this an annex or Supplementary information? I think that this equation should be in the main text.

This is a very common equation in climate sciences for transforming radiative forcing to CO2 equivalent units (similar to basic discount formulas or financial ratios). Therefore, we do not feel it is necessary to include it in this text. See Section 2 in the Supplementary Materials.

"The price for energy wood…": Why adding the EU ETS offset on coal-based energy? The price of energy wood depends on production costs and intersection between offer and demand.

Coal-based energy producers need to purchase EU ETS to be able to emit carbon in Finland. Therefore, EU ETS are a cost of coal energy processing. This is the justification for the inclusion in the formula and has been used previously used in other studies. See lines 179-186.

"A starting price of…": We need a more recent figure. In 2015, prices could have changed a lot.

This comment is not completely clear. By 'starting price' we mean that this is the lowest price that we use in our study. We use this lower 'starting' price on the basis of expectations about future prices within the carbon offset market. Other studies (i.e. Kallio et al., 2011) also suggest this is an appropriate lower price for EU ETS in the future. Based on the recent changes in the market structure at the governance level, we still feel that this is an appropriate lower price. Finally, this program is not based on a specific current price. It is based on the expected price over the next 50 years. Therefore, we do not feel that it is necessary to make this change to the input data. See lines 179-188.

"Additionality was not considered…": This is a short coming of the existing PES program. Is it justified to maintain it in the current simulation? The sentence appears unclear to me.

It is a shortcoming of that scheme. We included additionality in our calculations, but it is not possible to create new input data. We still feel that it is justified to use this input data on the basis of data availability and the efforts we have made to account for additionality in our calculations.

-3. Results and discussion:

"Regulating and provisioning ES…": How are ES measured here? €/ha? Units/ha? Unclear. Unclear also why they mention the exclusion of PES returns.

This sentence has now changed. However, the units are available in the methods section. The indicators were all normalized so that they could be compared across various indicators with different units of measurement. We felt that the inclusion of units might also be confusing given that normalization removes the need for units. See Sections 2.3 and 3.1.

"Given that the yield…": Global in terms of the Earth?

This has been rewritten in Section 3.1.

"Thus, provisioning and regulating…": Unclear sentence.

This has been rewritten in Section 3.1.

"Therefore a reduction in…": It is difficult to show or accept this partial conclusion when the reader does not clearly understand what type of biodiversity modelling allows asserting this.

The biodiversity modeling was based on a scorecard approach that is clarified in the Supplementary materials. This accounting method for biodiversity was verified as part of the TNV scheme, which forms part of the European Union's Natura2000 network. It is also scientifically acceptable and has been used in numerous peer-reviewed publications (i.e. Juutinen and Ollikainen, 2010; Juutinen et al., 2013; Primmer et al., 2013; Juutinen et al., 2014). The aggregate indicator from the scorecard calculations, referred to as BIV in this article, was assessed on the basis of the TNV scheme's scorecard for each of the scenarios in this study. This was done following the principle of additionality outlined in the text. The resulting value was then normalized and the Pareto optimal solutions were modeled to determine the trade-off between the aggregate biodiversity conservation value and all the other indicators and economic returns.

"The elasticities indicated…": Inaccurate phrasing, makes very difficult to understand the scientific meaning of the sentence.

We have clarified the meaning in lines 298-300 and 321-325.

Table 5: These payments are only including CO2 prices. What about biodiversity?

Both have now been included in the presented results. Previously they were found in the Supplementary Materials.

"PES programs present an opportunity…": This para follows a discussion style. As previously suggested, it would be better to have an independent discussion section.

We have created a separate discussion section.

"In Fig. 3a-d…": What does "considerations..." exactly mean?

We have removed this figure and replaced it with two tables.

"NIPF owners in both…": Why? That maybe means that their actual returns are before the economic return that was modelled.

It might mean that. It could also mean that even without being nudged, the forest owners had not previously considered alternative management objectives until the consultation. Therefore,

relative to the baseline management they were willing to accept a loss after the consultation. See lines 463-470.

Fig. 3: These figures do not clearly illustrate how nudging improves PES efficiency.

We have now created two tables instead.

"Nevertheless, there were…": Discussion style better fit in a discussion independent section.

There is now a separate discussion.

-3.4. Limitations:

The way nudging was applied and how it influenced trade-offs is not clearly understood once the reader ends the manuscript.

We have tried to address this limitation in the discussion section. See lines 457-507.

Highlights

Two PES schemes were evaluated for social efficiency improvements.

Nudging ecosystem service providers' preferences led to social efficiency gains for both PES schemes.

Nudging resulted in additional service provision above the Business-as-usual forest management.

Trade-off analysis demonstrated the importance of management objectives in achieving equitable service provisioning.

1 "Nudging service providers and assessing service trade-offs to reduce the social inefficiencies of
2 Payments for Ecosystem Services schemes"

Abstract

Socially inefficient payment for ecosystem services (PES) schemes result when adverse shifts in the provisioning of other ecosystem services (ES) or overpayment to service providers occur. To address these inefficiencies, a holistic evaluation of trade-offs between services should be conducted in parallel with determining land owners' service provisioning preferences. Recent evidence also suggests that nudging stakeholders' preferences could be a useful policy design tool to address global change challenges. Forest owners' landscape management preferences were nudged to determine the impact to social efficiency of PES schemes for biodiversity conservation and climate change mitigation in Finland. ES indicators for biodiversity conservation, carbon storage, and albedo impacts were included with traditional provisioning services (i.e. timber) and bioenergy to assess the consequent intra-service trade-offs. Synergies in provisioning of regulating services were identified, but were found to be more efficient when the management objective is for biodiversity conservation rather than climate change regulation. Nudging led to marginal gains in service provisioning above the baseline management and above neutral owner preferences, and increased aggregate service provisioning. This demonstrates the importance of considering intra-service trade-offs and that nudging could be an important tool for designing efficient PES schemes.

Key Words

Payment for ecosystem services; Social efficiency; Trade-off; Nudging; Ecosystem service

1. Introduction

Changes in landscape utilization decisions, intended to increase the provisioning of regulating ecosystem services (ES), are shaped by numerous social, economic, and environmental pressures resulting from competing objectives and trade-offs (Millennium Ecosystem Assessment, 2005; Heller and Zavaleta, 2009; Salafsky, 2011; McShane et al., 2011; Howe et al., 2014). Policy makers should avoid allocating all of the realized opportunity costs from these shifts to private land owners in an effort to maximize social well-being. Payments for ecosystem services (PES) are one policy measure designed to address this misallocation by making socially desirable practices profitable for private land owners (Pagiola, 2005; Engel et al., 2008). Still, socially inefficient schemes emerge when service providers are paid more than the social value of the services or when socially-undesirable land uses are incentivized leading to adverse intra-service trade-offs (Engel et al., 2008). To avoid creating these socially efficient schemes careful policy design is required.

Recent research has demonstrated that there are a number of different approaches for dealing with socially inefficient PES scheme design. Chan et al. (2006), Howe et al. (2014) and others recommend that a holistic trade-off analysis be adopted to account for provisioning synergies between different ES, which can be used to address potential overpayment by a given PES scheme

(Pagiola, 2005; Carpenter et al., 2009; Obersteiner et al., 2010). This can lead to the 'stacking'[1] or 'bundling' of complementary ES, those with connectedness or interdependence in provisioning, within a singular PES scheme, which aims to reduce the risk adverse intra-service trade-offs by incentivizing co-provisioning of service offerings at socially efficient levels (Simonit and Perrings, 2013; Turner et al., 2014). Engel et al. (2008) and Hejnowicz et al. (2014) also note that selectively targeting service providers an important approach for reducing costs and social inefficiency, and ensuring additionality within a PES scheme.

Still, if forest owners' preferences change over the course of the PES scheme, the resulting 'ideal' targeted service providers could temporally and spatially shift. Additionally, when stakeholder preferences are considered, trade-offs between regulating and provisioning ES frequently favor the latter and often lead to human-centric normative judgments[2] (Rantala and Primmer, 2003; Rodriguez et al., 2006; Margolis and Naevdal, 2007; Rockström et al., 2009). Consequently private management preferences can result in socially sub-optimal levels of ES, but excluding stakeholders from the planning phase may also reduce the viability of the policy (Gregory and Keeney, 1994; Chan et al., 2007; Bennett et al., 2009; McShane et al., 2011).

Dickinson et al. (2013) have recently proposed framing stakeholder consultations to nudge their preferences as an alternative, and potentially important, tool for designing policies intended to generate greater action on climate change mitigation (Thaler and Sunstein, 2008; Moser and Dilling, 2007; Sussman, 2009; Huutoniemi and Hukkinen, 2014). The concept of nudging refers to a way of influencing people's choices (i.e. about forestry management) without forbidding choice options or changing the economic feasibility of the alternatives (Thaler and Sunstein, 2008). We propose that nudging stakeholder preferences should also be considered as an additional tool for improving the social efficiency of PES; particularly in cases where forest ownership is private and fragmented across a large number of owners, as in southern Finland. By considering stakeholder preferences, we assume that future forest management shifts are not certain and that the PES schemes' success relies on acceptance by key stakeholders.

We surveyed Finnish non-industrial private forest (forest) owners to determine their ES provisioning preferences for their regional forested landscape. Half of the forest owners in the

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[1] Stacking is defined here as the bundling or stacking of multiple connected or interdependent ecosystem service offerings within a singular PES scheme, and not *credit stacking* that refers to many ecosystem service offerings being sold in multiple PES schemes for the same site (Robertson et al., 2014).
[2] Ecosystem services are defined here as an aspect of a given ecosystem that is utilized, passively or actively, in the production of human well-being (Fisher et al., 2009).

survey were nudged to evaluate the potential of this policy tool for improving the social efficiency of PES schemes. Forest owners were presented with management scenarios for business-as-usual, bioenergy, climate change mitigation, and biodiversity conservation objectives, and the associated expected economic returns. The economic returns included compensation for management shifts away from the BAU for two different PES schemes. The PES schemes were evaluated using six ES indicators, following Mönkkönen et al.'s (2014) methods for forested landscape planning, to determine if: the ES trade-offs led to adverse impacts on the provisioning of non-targeted ES, the considered PES price levels resulted in overpayment for service provisioning, or the nudging of forest owners led to increased marginal service provisioning relative to the baseline.

Climate change mitigation and biodiversity conservation form two of the foremost environmental pressures involved in forested landscape management planning (i.e. Carpenter et al., 2009; Anderson et al., 2011). Therefore, the two PES schemes were targeted towards those non-traditional forest management objectives. We define PES as a voluntary transaction for a well-defined ES with at least one buyer and one service provider meeting the conditionality principle (service provider secures service provision) based on the definition provided by Wunder (2007). Using that definition, the climate PES scheme was based on the New Zealand Emissions Trading Scheme (ETS) (Jiang et al., 2009) that uses the international carbon offset price to determine forest owner compensation, and the biodiversity PES scheme was based on the existing Finnish governments' METSO II conservation scheme that uses private bids for service provisioning contracts (Juutinen et al., 2013).

2. Material and methods
2.1. Description of the Case Area

In Finland, 52% of forest land is under private ownership and supplies 80% of the harvested wood volume for industrial uses. As such, Finland provides a suitable example of challenges in aligning forest owner's management preferences with the preferences of society. In the study area, forest ownership accounted for 73% of active forest management (FSYF, 2011). Stand inventory data for a 20 x 20 km square area around the Hyytiälä Forestry Field Station in southern Finland was provided by the Natural Resources Institute Finland from the Multi-Source National Forest Inventory (MS-NFI). The data contained land and forest site types and biometric information (Tomppo et al., 2008). Grid points containing forest growing on mineral soil or on ditched peatlands of same fertility were considered. Other peat soil sites (bogs, swamps etc.) containing trees constituted only a small proportion of the total area (3.2%), and were excluded from the

analysis. Forests were classified based on Finnish forest site types including: fertile *Oxalis-maianthemum* and *Oxalis-myrtillus* (OMT), medium fertile *Myrtillus* (MT), and less fertile *Vaccinium* (VT) (Cajander, 1949). These three site types were divided according to six initial stand age classes: 0, 20, 45, 70, 90, and 120 years. All of the scenarios considered a mixture of native boreal species: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris L.*), and silver birch (*Betula pendula*). Full descriptive statistics of the initial structure and a map of the site location are provided in Section 1 of the Supplementary Material.

2.2. Forest Management Scenario Modelling

Five scenarios were developed for a period of 37 years from 2013 to 2050. By selecting this time period we assumed that climate change mitigation impacts are time-bound and require immediate action. Scenarios were modelled using the stand-level yield and growth simulation model MOTTI, which is an empirically derived forest stand model using Finnish data (i.e. Hynynen et al., 2005; Salminen et al. 2005). MOTTI has previously been used for both stand- and landscape-level forest management modeling (i.e. Ahtikoski et al., 2011). Hynynen et al. (2005) provide a detailed model description.

The five scenarios were: BAU, Bioenergy (ENR), Climate (CLI1), Climate (CLI2), and Biodiversity (BDI). The BAU followed the Finnish Forestry Development Center's (TAPIO) recommended forestry practices (Hyvän metsänhoidon suositukset, 2006). It is considered a reasonable baseline for current management that should be implemented in practice in Finland (Yrjölä, 2002). Matthies et al. (2015) have shown previously that, although this BAU scenario was not economically optimized, it provides a suitable economic baseline. The non-BAU forest management practices were defined by experts at the University of Helsinki and the Natural Resources Institute Finland (LUKE).

In the ENR scenario, the aim was to produce bioenergy through a short rotation and a low investment approach. Regeneration was assumed to be natural, sapling tending and forest thinning were disregarded, and final harvests occurred when annual biomass growth stabilized or declined depending on site type. All above-ground forest biomass was used for energy production at thermal power plants. In CLI1 scenario, higher carbon storage (CS) was achieved through longer rotations and delayed thinnings. For CLI2 scenario the objective was both higher CS and increased beneficial albedo-related impacts. This was achieved by changing tree species from Norway spruce to silver birch (*Betula pendula*) in stands on fertile and medium fertile site types. Rotation ages for those deciduous species are shorter and this positively affected the albedo impact of management.

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Additionally, the albedo of silver birch is higher than that of Norway spruce. Higher CS was reached via longer rotations and delayed thinnings for both species. The BDI scenario achieved higher species diversity by favoring deciduous trees in thinnings, increasing coarse woody debris (CWD) accumulation, and lengthening the rotation (=130 years). The management regimes for each of the scenarios are provided in Section 1 of the Supplementary Material.

2.3. Ecosystem Service Indicators and Economic Returns Calculations

Six indicators were used for evaluating the level of ES achievement in each of the five forest management scenarios. Following Matthies et al. (2015), each of the indicators is listed below with their associated Common International Classification of Ecosystem Services (CICES) classification and supporting academic literature (CICES, 2013):

1. Net radiative forcing from albedo (RFA) (Regulating service – Climate regulation) (Anderson et al., 2011)

2. Net additional carbon storage (CS) (Regulating service – Atmospheric composition and climate regulation) (Canadell and Raupach, 2008)

3. Biodiversity Index Value (BIV)[3] (Regulating service – Habitat and gene pool protection) (Cardinale et al., 2006)

4. Harvested saw log volumes (Provisioning services – Biomass)

5. Harvested pulpwood volumes (Provisioning services – Biomass)

6. Harvested biomass for bioenergy (Provisioning services – Biomass-based energy sources)

The additionality principle was adopted in accounting for the six indicators over the 37 year period (Cathcart and Delaney, 2006). Any shifts away from BAU towards alternative management on the landscape were considered a shift towards management that would not have otherwise occurred, and the net achievement (measured as a normalized achievement for each indicator) relative to BAU was accounted for. Net CS was comprised of three carbon pools: short and long-term storage in wood products, and above- and below-ground biomass. RFA was converted into CO_2 equivalent units following Sjølie et al. (2013), and together with net CS, it was used for calculating the compensation under the climate PES scheme (i.e. Betts, 2000; Bonan, 2008; Thompson et al., 2009). BIV was originally developed as a biodiversity proxy indicator scorecard

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[3]This proxy variable refers to the aggregated biodiversity conservation potential of a given forest stand. CICES does not list biodiversity as an ecosystem service. However, biodiversity represents, in this study, the various ecosystem functions and processes that are listed by CICES as ecosystem services. Some of these services include: storm protection, lifecycle maintenance, habitat, and gene pool protection (CICES, 2013).

value for evaluating biodiversity conservation achievement in the Finnish TNV scheme. Three primary indicator categories were used in calculating BIV: coarse-woody debris, naturalness, and spatial characteristics (Primmer et al., 2013). BIV was the basis for determining compensation levels under the biodiversity PES scheme. Juutinen et al. (2013) and Juutinen and Ollikainen (2010) provide a full explanation of the scorecard and the TNV bidding processes respectively. Further explanation of the calculations for the ES indicators is available in Section 2 of the Supplementary Material.

For calculating the discounted economic returns for a variety of different ES from forest management, we adopt the Ecosystem Service Expectation Value (ESEV) approach following Matthies et al. (2015) using eq. (A.1). Those authors have demonstrated how the ESEV can be used for evaluating the perpetual management for a broader set of monetized ES beyond only provisioning ES. A discount rate of 3% was used in all calculations and is a commonly applied rate in boreal forest projects (i.e. Backéus et al., 2006; Pohjola and Valsta, 2007). At the landscape level for all returns, the return per hectare was calculated using the weighted sum of site type and age class relative to their respective proportion of the total forested area.

Prices and costs of saw log and pulpwood stumpage and silviculture regimes were based on average real stumpage and costing data ($€ \text{ m}^{-3}$) for the Pirkanmaa region over the period of 2001-2011 (See Section 3 in Supplementary Material) (FSYF, 2011; Statistics Finland, 2012). Costs varied according to each scenario's treatments (Table B.1). Pulpwood prices were assumed to always exceed those of energy wood by 1€ at all points of increase in energy wood prices (Anon., 2007; Heikkilä et al., 2009; Petty and Kärhä, 2011).

In Finland, the biomass energy price received by forest owners was assumed to be equal to the spot price of coal plus the cost of the required EU ETS offsets for coal-based energy production following Kallio et al. (2011) (See Eq. (A.2)) (Statistics Finland, 2012). Therefore, at the starting price for climate PES used in this study, $23€ \text{ ton CO}_2^{-1}$, the subsidies would be $0€ \text{ MWh}^{-1}$ as a result of shifts in energy provisioning away from the utilization of coal in Finland (Kallio et al., 2011). Based on research regarding future development of energy subsidies by Petty and Kärhä (2011) and Kallio et al. (2011), the long-term future development of energy wood subsidies in Finland were considered unknown.

For the climate PES scheme payments, a range of climate change mitigation offset prices from 23, 43, and $63€ \text{ ton CO}_2^{-1}$ were used for comparison. For biodiversity PES scheme payments, data

from the TNV scheme available for 2003-04 from Juutinen et al. (2013) was used (Detailed pricing information can be found in Section 3 in the Supplementary Material).

Juutinen et al. (2013), in their evaluation of the same dataset, removed information rents from the real costs of conservation. Information rents, a portion of the PES payment, represent a socially inefficient overpayment due to asymmetric information that benefits the forest owner in the bidding process (i.e. willing to provide the services without payment). Juutinen et al. (2013), to evaluate social inefficiency in the TNV scheme[4], used two 'Hartman' rotation price levels to create an uncertainty range to better reflect forest owner's possible amenity values. Hartman rotations exceed the optimal economic rotation due to a forest owner's preferences for non-monetary management objectives. Therefore, Hartman 1 price level (low) in this study represents a lower amenity value among forest owners than Hartman 2 (medium). We also evaluated the original prices paid in the TNV scheme that included information rents to provide a third price level.

Additionality of biodiversity provisioning was not considered in the TNV scheme, but was considered within the biodiversity PES scheme in this paper. This study followed the original TNV scheme policy of 10 (or 20) year contract lengths and applied it to both the biodiversity and climate PES schemes for comparison[5] (Primer et al., 2013). Payments were made at the beginning of each eligible 10-year period.

2.4. Forest Owner Consultation and Nudging

A stakeholder workshop was conducted at the Hyytiälä Field Station on October 10, 2013. Forest owners were presented with four stories of how forest management practices, under global change pressures, might develop in the Hyytiälä region in the next 50 years. The four stories were based on the five management scenarios. The two climate change scenarios were presented to forest owners together. Workshop participants were selected on the basis of previously conducted interviews.

Scientifically valid language understandable to an informed layperson was used. Half of the forest owners were presented with scenario texts containing original expressions, and half received nudged versions. Two of the scenario texts, Business-as-usual and Biodiversity, were nudged. The

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[4] Amenity values are defined here as the tangible or intangible qualities or characteristics of a given set of management practices on a forest property that contribute towards human appreciation of cultural, recreational, aesthetic or other attributes.
[5] Juutinen et al. (2014) also found that in managed stands the optimal contract length was 10-20 years and transaction costs affected contracting by reducing it only 8%.

nudged texts were designed according to findings in cognitive linguistics regarding the effects of language and framing on target audiences (Fauconnier and Turner, 1998; Lakoff and Johnson, 1999). For example, the terms "up" and "down" are systematically associated with positive and negative reactions, respectively.

The aim of nudging was to move each sentence in the nudged scenarios toward cognitive appeal and cognitive optimality by adjusting the researchers' original expressions into expressions containing explicit primary metaphors. A primary metaphor is a fundamental unit of language and thought that connects sensorimotor experience with subjective experience (Lakoff and Johnson, 1999). Cognitive appeal is achieved when a text contains primary metaphors associated with positive subjective experiences, such as happiness, affection and goodness (Hukkinen, 2012; Lakoff and Johnson, 1999). Conversely, primary metaphors associated with negative subjective experiences decrease cognitive appeal. Cognitive optimality measures the ease with which the human mind can imagine and simulate the text (Fauconnier and Turner, 1998; Hukkinen, 2012). When a structure of meaning is cognitively optimal, the human mind can "run" it effortlessly in imaginative mental simulation (Fauconnier and Turner, 1998).

Each text was connected to a brief questionnaire containing six indicators to measure cognitive appeal and cognitive optimality. The indicators were measured on the Visual Analogue Scale: the respondents are presented with a continuous line with two qualitatively described endpoints and asked to indicate which point on the line best characterizes their evaluation of the scenario. The endpoints are bipolar adjective pairs. The adjectives used for cognitive appeal were (1) "worth striving for" – "not worth striving for", (2) "believable" – "unbelievable" and (3) "realistic" – "unrealistic"; and the indicators for cognitive optimality are (1) "clear" – "unclear", (2) "consistent" – "inconsistent" and (3) "feels real" – "feels unreal". The indicators were used to understand the two aspects of cognitive attraction (For further explanation and questionnaire results see Section 4 of the Supplementary Material).

2.5. Trade-off and Landscape Management Modelling

Multi-criteria Decision Analysis (MCDA) methods are frequently used to evaluate forest owners' preferences and non-monetary forest attributes in landscape planning problems (i.e. Gehlbach, 1975; Munda, 2000; Herath and Prato, 2006). In this study, the trade-offs between indicator and optimization of the landscape management were both modelled using the "portfolio of landscape management scenarios" MCDA approach proposed by Mönkkönen et al. (2014).

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Trade-offs were evaluated by modelling for the Pareto optimal solutions, portfolios of management regimes, for 100 points over the range from minimum to maximum achievement of total economic returns excluding PES revenues. The resulting trade-offs between ES indicators were then reported. An optimal portfolio could consist of any of the five management scenarios. The outcome was non-inferior portfolios with respect to the considered optimization objective function (total economic returns) and constraints (i.e. site type and age class area constraints, forest owner's management preferences). Indicators were scaled to using the zero-one normalization, thus all indicators will be within the range of zero to ones. This was done to facilitate efficient comparison of trade-offs between variables where minimum and maximum possible achievement in each variable can be measured against the others without units. A value of zero was the minimum possible achievement of a given indicator over all of the considered management scenarios and one as the maximum achievement (See Jones and Tamiz (2010) for details).

Once the indicators were normalized, synergies in achievement for different ES could then be evaluated by examining the relationship between trade-off curves (i.e. elasticities, correlations). The calculation of elasticities and correlations was done following the approach of Mönkkönen et al. (2014).

In MCDA constraints act as limitations on the attainable decision space. Pareto optimal solutions constitute the efficient frontier of this space. Attainable solutions lay within the decision space at and below the frontier. In the evaluation of forest management problems often the frontier is constrained by private management preferences, and prevents the achievement of socially optimal levels of ES provisioning. This distance between the frontier and the social optimum represents the inefficiency that various measures (i.e. targeting, bundling, nudging etc.) aim to minimize. Pareto optimal solutions were constructed by constraining each starting age class and site type proportional to the starting forest inventory data. Given that starting inventories were fixed, additional stands of a given starting age class or site type were not allowed to be part of the optimal solution.

The preferences of the nudged and neutral groups (where nudged and neutral/non-nudged language was used, respectively) were then incorporated as constraints on the Pareto optimal landscape management portfolio. They determined the maximum proportion that a given management scenario could have in the optimal portfolio. An average of the nudged and neutral forest owners' management preferences was calculated based on survey responses (Averages are presented in Table 1). Management preferences were used to evaluate the social efficiency of the two PES schemes. Efficiency was evaluated on the basis of ES indicator achievement per unit of

baseline economic return and baseline ES indicator achievement. Baseline was defined as BAU management over the entire landscape (current management without intervention). To evaluate the changes from the baseline management case to the nudged and neutral alternatives, a percentage normalization was used (for details see Jones and Tamiz 2010). Thus, any achievement above 1 indicated an increase in provisioning of that variable above the baseline over the landscape.

Table 1. Percentage of the forested landscape allocated to the alternative management regimes for both nudged and neutral (n = 10) forest owner groups.

Forest Owner Group	BAU	ENR	CLI	BDI
Neutral	41.2	11.8	29.4	17.6
Nudge	25.9	15.6	32.5	26.0

3. Results
3.1. ES Indicator Trade-off curves and elasticities

The resulting Pareto optimal management solutions for each level of economic return allowed for an evaluation of the associated trade-offs between ES indicators. In Table 2, regulating services, including also bioenergy, had a strong negative correlation with economic returns. The inverse outcome was found for provisioning ES, excluding bioenergy, and economic returns. A reduction in those two provisioning services, saw logs and pulpwood, resulted in an increase in regulating services, such as biodiversity conservation, and decrease in economic returns when PES were not considered. CS had the weakest negative correlation with economic returns.

Table 2. Elasticities and correlations of trade-off between economic returns and all ecosystem service (ES) indicators.

Ecosystem Service Indicator	Elasticity at different levels of achievement in economic returns (%)						Correlation with Economic Returns
	100% [a]	50% [b]		25% [c]			
	Point [d]	Point	Arc [e] (100-50)	Point	Arc (100-25)	Arc (50-25)	
Biodiversity (BIV)	-329.35	-1.34	-5.63	-1.05	-2.79	-0.84	-0.97
Carbon storage (CS)	-329.35	-0.98	-5.63	1.79	-2.79	0.15	-0.76
Albedo Effect (RFA)	-329.35	-1.07	-5.63	1.28	-2.79	-0.05	-0.84
Saw timber harvest	-329.35	-0.50	-5.63	-2.31	-2.79	-0.44	0.95
Pulpwood harvest	-329.93	-1.94	-5.63	-2.73	-2.79	-1.53	1.00
Bioenergy harvest	-329.35	-1.77	-5.63	0.44	-2.79	-0.59	-0.90

a. 100% indicates that elasticity was calculated for the first two Pareto optimal solutions along the trade-off curve at 100% of income without PES revenues.
b. 50% indicates that elasticity was calculated for the first two Pareto optimal solutions along the trade-off curve at 50% of income without PES revenues.
c. 25% indicates that elasticity was calculated for the first two Pareto optimal solutions along the trade-off curve at 25% of income without PES revenues.
d. Point refers to the point elasticity at a given point along the trade-off curve.
e. Arc refers to the arc elasticity at a given arc segment along the trade-off curve.

Elasticity gives the proportional change in one variable related to a change in another. Evaluating the elasticities of the trade-off curves provided a basis for determining if marginal shifts in economic returns led to adverse marginal changes for a given ES indicator. Moving from the first Pareto optimum to the second was the most expensive shift, largest reduction in economic returns

versus all ES indicators, relative to all other Pareto optimum shifts (Table 2). The first Pareto optimum in this study consisted of landscape-wide adoption of the BAU scenario (current management). Subsequent Pareto shifts were less expensive. Additional provisioning of sawn timber and pulpwood was always negative for all subsequent Pareto optima relative to the first solution (See Fig. B.3 in Supplementary Material).

Without the inclusion of compensation for shifts in management, the trade-off between economic returns and regulating ES indicators meant that the maximum possible achievement in the ES indicators did not occur without a large reduction in the economic returns. The optimal achievement (100%) in CS and RFA was located at a 41% and 36% achievement in economic returns (excluding PES). The two climate change mitigation indicators had a strong positive intra-curve correlation (0.99); indicating a strong complementarity in co-provisioning these ES. Maximum BIV was achieved at a 91% reduction in economic returns (excluding PES). Although maximum achievement in BIV is not realized at the same level of economic returns, there are still strong potential synergies between all three regulating ES (Fig. 1).

Fig 1. Trade-off curves for carbon storage (CS) and avoided radiative forcing from the albedo effect (RFA) against Biodiversity Index Value (BIV). Indicators were normalized using a zero-one normalization scheme to compare indicator achievement. Achievement was measured based on additionality relative to baseline management (BAU).
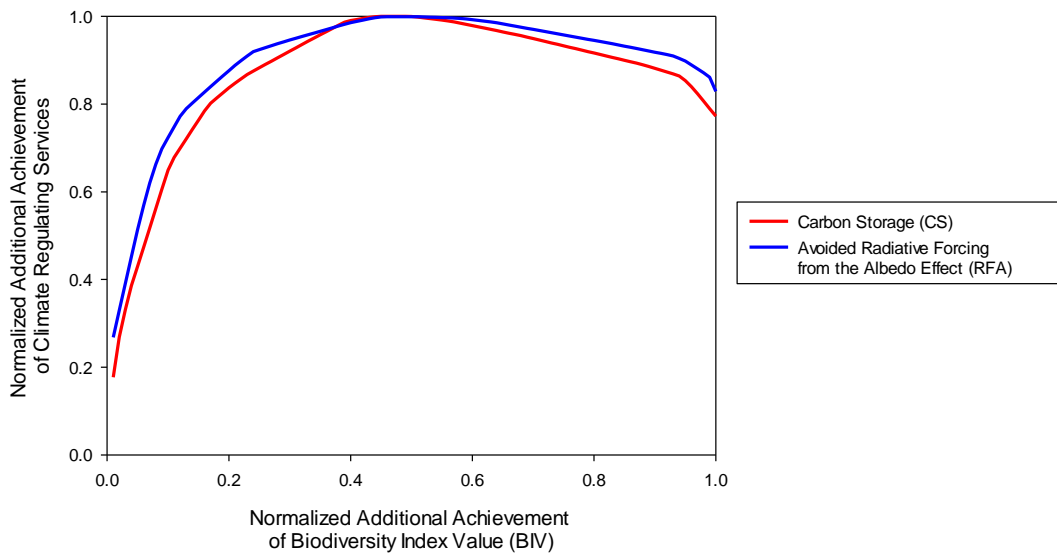
Intra-ES elasticities were also considered (Table 3). Elasticities between provisioning ES and regulating ES were always inelastic (negative). Negative elasticities indicate a win-lose trade-off between the two ES; a marginal increase in one ES results in a marginal decrease in another. Positive elasticities represent 'elastic' provisioning and a win-win trade-off; marginal increases in both ES. When RFA was evaluated relative to BIV, then the starting point elasticity, moving from

the first Pareto optimum to the second, was -4.28. This diminished to -1.74 moving from the second to third Pareto optimum, which was the same point elasticity as the elasticity of the first two Pareto optima between CS and BIV. Therefore, the first increments of increased climate change mitigation were expensive in terms of lost biodiversity conservation. At 100% of maximum achievement in BIV, CS achievement was 77% and RFA was 83%.

Perfect inelasticity, indicating that shifting management will not result in an increase or decrease in the provisioning of either ES, between RFA and BIV was reached at 100% of maximum RFA achievement and 50% of BIV achievement. The correlation between these two variables was moderately positive (0.53). The relationship between CS and BIV at the same levels of achievement; the two indicators were moderately positively correlated (0.51).

Table 3. Elasticities and correlations for trade-off curves of carbon storage (CS) and avoided radiative forcing from the albedo effect (RFA) against Biodiversity Index Value (BIV).

Comparative Ecosystem Service Indicator	Elasticity at different levels of BIV achievement (%)						Correlation with BIV
	100% [a]	50% [b]		25% [c]			
	Point [d]	Point	Arc [e] (100-50)	Point	Arc (100-25)	Arc (50-25)	
Carbon storage (CS)	-1.74	-0.05	-0.28	-0.22	0.04	0.10	0.51
Albedo Effect (RFA)	-4.28	0.00	-0.21	-0.12	0.02	0.07	0.53

a. 100% of BIV indicates that this is the elasticity of the first two Pareto optimal solutions along the curve.
b. 50% of BIV indicates that this is the elasticity of the two Pareto optimal solutions at the midpoint of the curve.
c. 25% of BIV indicates that this is the elasticity of the two Pareto optimal solutions at the point where 25% of biodiversity conservation is achieved.
d. Point refers to the point elasticity at a given point along the trade-off curve.
e. Arc refers to the arc elasticity at a given arc segment along the trade-off curve.

3.2. Payment for Ecosystem Services

When PES were excluded, the ESEV values were highest overall for the BAU scenario and the shift towards increased management for silver birch, to increase RFA, resulted in higher returns in scenario CLI2 over CLI1 (See Table B.8 in the Supplementary Materials). Including climate PES and provisioning service revenues led to incrementally increasing ESEV values over the range of climate PES prices for each of CLI1, CLI2, and BDI. At the highest climate PES price, BAU returns also increased due to the high prices' influence on pulpwood prices. Under the biodiversity-based PES scheme, ESEV values indicated the importance of calculating the amenity value of biodiversity-related management for forest owners. Including information rents led to much higher ESEV results for the CLI1, CLI2 and BDI scenarios. There is no change for BAU or ENR due to no additional service provisioning.

3.3. Nudging forest owners' landscape management preferences

Overall, owners for both nudged and neutral groups accepted a loss in provisioning service income and a gain in regulating ES relative to the current BAU. The difference in lost ESEV was more pronounced for the nudged group relative to the neutral group at low PES price levels and when PES were excluded. This difference decreased as prices increased from medium to high prices under the biodiversity PES scheme (-1.4 to -2.5% reduction below neutral owners and -7.4 to -3.5% of baseline ESEV) and climate PES scheme (-3.9 to -1.7% reduction below neutral owners and to +4.9 to +24.1% above the baseline ESEV) (Table 4).

Juutinen et al. (2013) noted that asymmetrical information due to information rent-seeking behavior by forest owners in the TNV bidding process resulted in an overpayment to forest owners. When the same BIV pricing data was applied to compensate for the opportunity costs of additional ES provisioning (above BAU management), then the achievement of economic returns under the biodiversity PES scheme relative to the baseline never exceeds 1 (Table 4).

Table 4. Normalized achievement of carbon storage (CS), avoided radiative forcing from the albedo effect (RFA), Biodiversity Index Value (BIV), and total economic returns relative to Business-as-Usual management baseline for nudged and neutral forest owners' preference constraints under biodiversity and climate-based PES schemes when economic returns were maximized. For economic returns, a value exceeding 1 represents an overpayment beyond the costs of conservation. For ES indicators, a value exceeding 1 represents increased achievement in provisioning additional to the BAU at the landscape level.

| Ecosystem Service Indicators | Forest Owner Group | | Economic Returns Scenarios | | | | |
| | | Excluding PES | Including Biodiversity PES ($€ \text{ BIV}^{-1}$) | | | Including Climate PES ($€ \text{ ton CO}_2^{-1}$) | |
			Hartman 1	Hartman 2	Info. Rent Included	23	43
Economic Returns	Neutral	0.796	0.799	0.940	0.988	0.920	1.088
	Nudge	0.642	0.700	0.926	0.963	0.864	1.049
	Nudge Difference	-0.154	-0.099	-0.014	-0.025	-0.056	-0.039
Biodiversity (BVI ha^{-1})	Neutral	1.095	1.097	1.178	1.166	1.150	1.148
	Nudge	1.115	1.141	1.222	1.177	1.150	1.133
	Nudge Difference	0.020	0.044	0.044	0.011	0.000	-0.015
Carbon storage (CS) (C kg ha^{-1})	Neutral	1.230	1.113	1.219	1.260	1.249	1.246
	Nudge	1.113	1.215	1.294	1.299	1.295	1.345
	Nudge Difference	-0.117	0.102	0.075	0.039	0.046	0.099
Albedo Effect (RFA) (W ha^{-1} 1E+10^{-1})	Neutral	1.012	1.007	1.010	1.012	1.012	1.012
	Nudge	1.007	1.012	1.013	1.015	1.014	1.017
	Nudge Difference	-0.005	0.005	0.003	0.003	0.002	0.005
Aggregated ES Indicators	Neutral	1.112	1.072	1.136	1.146	1.137	1.135
	Nudge	1.078	1.123	1.176	1.164	1.153	1.165
	Nudge Difference	-0.034	0.050	0.041	0.018	0.016	0.030

Table 4 shows that greater achievement in all regulating ES indicators for the nudged group, relative to the baseline management, was positive and above 1 (except for BIV at a climate PES

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price of 43€ ton $CO_2{}^{-1}$) when economic returns were maximized under increasing prices for both PES schemes. The same result was found when comparing between nudged and neutral groups. Nudged results were almost always higher and positive, but increasing PES scheme prices led to higher decreases in the marginal increased benefits from nudging. Aggregate regulating ES indicator achievement was higher in the climate PES scheme, but achievement in BIV was higher and more equitably realized compared to CS and RFA under the biodiversity PES scheme. The higher achievement under the climate PES scheme was the result of increases in CS and RFA that exceeded the loss in BIV achievement.

In Table 5, the landscape level ESEV, realized under optimization, relative to the baseline management ESEV divided by the aggregated regulating ES indicator achievement, reported in Table 4, relative to the baseline management ES achievement is calculated. The ratio demonstrates the environmental benefit per unit of income. Although aggregated ES provisioning decreases for the nudged group relative to the neutral group as price levels increase in Table 4, the environmental benefits remained higher and positive relative to the neutral group in Table 5.

Table 5. Social efficiency of environmental benefits for both nudged and neutral preference groups for both Payment for Ecosystem Service (PES) schemes and all associated price levels.

PES Scheme	Price Level	Forest Owner Group	Economic Returns (Normalized)	Aggregated ES Achievement	Ratio of ES per Economic Return
Excluding PES Schemes		Neutral	0.796	1.112	1.397
		Nudge	0.642	1.078	1.679
Biodiversity PES Scheme (€ BIV^{-1} ha^{-1})	Hartman 1	Neutral	0.799	1.072	1.342
		Nudge	0.700	1.123	1.604
	Hartman 2	Neutral	0.940	1.136	1.209
		Nudge	0.926	1.176	1.270
	Info. Rents Included	Neutral	0.988	1.146	1.160
		Nudge	0.963	1.164	1.209
Climate PES Scheme (€ ton $CO_2{}^{-1}$ha^{-1})	23	Neutral	0.920	1.137	1.236
		Nudge	0.864	1.153	1.334
	43	Neutral	1.088	1.135	1.043
		Nudge	1.049	1.165	1.111
	63	Neutral	1.258	1.147	0.912
		Nudge	1.241	1.174	0.946

4. Discussion

Our results indicate that a shift away from BAU management, when compensation is not provided, results in an economic loss for forest owners. Mönkkönen et al. (2014) noted in their similar study about the costs of biodiversity conservation in Finland, that there is a negative trade-off relationship between conservation and economic objectives. This trade-off also exists in this

study, and corresponds to the high initial cost of increased conservation due to the reduction in income from decreases in provisioning ES. The two PES schemes for biodiversity conservation and climate change mitigation were aimed to address the economic loss experienced by forest owners in a socially efficient manner.

By looking at the reported trade-offs and elasticities, it is possible to better estimate opportunity costs of management shifts and create more socially efficient compensation schemes. The complementary interactions between management for different regulating ES provide an opportunity for improving the efficiency of schemes targeted at specific ES. Synergies between management for RFA and BIV were higher than those between CS and BIV. This was due to the increased percentage of deciduous tree species in the stand structures of the CLI and BDI scenarios that were used to achieve increases in both indicators. However, there were also divergent management activities (i.e. harvesting, thinnings) that were adopted, which reduced the complementarity between RFA and BIV. These included: early harvesting, to support changes in avoided albedo-related impacts, and thinnings. The revenues from those management interventions resulted in CS and RFA being relatively less expensive, in terms of the associated opportunity costs (lost provisioning service revenues), when compared to biodiversity conservation.

As a result of these intra-service trade-off dynamics, biodiversity objectives were found to be more sensitive to shifts away from biodiversity-based management than climate change mitigation objectives were to shifts away from climate-based management. Thus, shifting preferences among forest owners away from biodiversity management by targeting management for other regulating ES through a PES scheme could increase the environmental cost of that scheme. In this study, incentivizing biodiversity conservation management, through a biodiversity-based PES scheme, resulted in more equitable achievement between regulating ES than under the climate PES scheme. Care should be taken in designing PES schemes targeting a specific ES or set of ES, so that management actions required to achieve the schemes objectives do not result in environmentally costly outcomes. The differing management practices that are necessary to achieve socially efficient levels of non-complimentary ES provisioning indicates the importance of evaluating intra-service trade-offs during PES scheme design. Thus, schemes should be designed to incentivize management actions that achieve the prescribed objectives without creating adverse trade-offs with other vital ES.

The bundling or stacking of multiple ES within a single PES scheme is one approach to address this challenge in a socially efficient manner (Turner et al., 2014). The goal of stacking ES is to

reduce the risk of adverse intra-service trade-offs, which is done by incentivizing the co-provisioning ES. Currently, PES schemes for climate change mitigation and biodiversity conservation in Finland are voluntary, and stacking ES is not common. However, stacking various ES in a singular scheme could act to decrease marginal service provisioning costs to society per unit of service provided. In our study, we have stacked CS and RFA into a climate-based PES scheme due to the high correlation noted in Section 3.1, and the co-provisioning complementarity between these two ES. Our results suggest that, in the case of boreal forests, further stacking of biodiversity conservation and climate change mitigation objectives is possible. This could be achieved if appropriate care is taken to determine those management interventions that are complimentary to achieving the correct balance between equitable and aggregate achievement of the desired outcomes.

As noted earlier, preferences of forest owners should also, along with intra-ES trade-offs, inform the policy-makers to reduce social inefficiencies and environmental costs. Offering payments that are insufficiently high to incentivize adoption of socially-optimal land uses, incentivizing adoption at a higher cost to society than the ES are worth, or paying for management practices that would have already been adopted all constitute inefficiencies in PES policy development (Pagiola, 2005; Pagiola and Platais, 2007; Engel et al., 2008).

Engel et al., (2008) suggest that targeting those service providers with lower policy costs, based on current preferences, is one means of reducing inefficiencies within a PES scheme. Still, if long term shifts in preferences for larger groups of forest owners could be attained, then further efficiency gains in PES schemes could be achieved. One tool that could be used to make these gains is nudging service providers by framing differently the way in which they are consulted. Additionally, there are various implementation challenges associated with PES schemes: free-ridership, coordination when bundling multiple ES, connectivity of land use management units over the landscape, and overall costs of management (Engel et al., 2008; Ferraro, 2011; Broch et al., 2013). Nudging service providers could address these challenges by reducing the need to seek out specific land owners. Increased size and connectivity of nudged service providers could reduce monitoring and transaction costs for scheme administration, and allow for targeting of specific geographical areas rather than specific individuals.

Nudging was explored in this study as a potential tool for improving how service providers are consulted and the related social efficiency gains for PES schemes. The sample size in this study was small, and is of course not representative. However, these results were, in 2014, cross-checked with

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two other samples (n=68 and n=46, respectively), testing the effect of the same set of scenarios. The results from a statistical analysis of all sets indicated that the trends observed in the Hyytiälä workshop data are robust enough to justify their use in the context of the current paper.

The environmental benefits noted, when owners were nudged under both PES schemes and all price levels, provide an important starting point for future research. The marginal environmental benefit per unit ESEV was always higher for the nudged group in comparison to the neutral group. Also, total ES achievement was higher for the nudged group for all PES schemes and price levels. Both of the consulted groups, nudged and neutral, gave higher than baseline levels of provisioning based on their forest management preference constraints. This indicates that even when forest owners were not nudged, consulting them about alternative management objectives led to stated preferences that were different from the baseline forest management (BAU).

Previous studies have noted that forest owner's preferences for ES provisioning can differ spatially, which can then act as a constraint on the connectivity of ES provisioning by different owners (Wilson et al., 2007; Broch et al., 2013). Wilson et al. (2007) note that, especially in the case of biodiversity conservation, connectivity in ES provisioning can be important for addressing ES 'hot spots'. Thus, targeting specific providers based on their value structures may not be an efficient means of addressing those provisioning challenges. Nudging forest owners could have important implications for the spatial design of the PES schemes, which aim to target ES provisioning from specific geographical areas.

The climate PES scheme had higher aggregate achievement in ES for both the nudged and neutral groups, but more equitable provisioning of all regulating ES was achieved under the biodiversity PES scheme. On this basis, the biodiversity PES scheme came closer to a socially efficient payment at the price levels that were paid in the TNV scheme, including information rents, and the climate scheme was closer under the lowest price level. Taking this result in conjunction with the intra-service trade-off analysis, the biodiversity PES scheme led to less adverse intra-service trade-offs and more holistic ES provisioning.

Despite the potential benefits of nudging, there some limitations, in the context of PES schemes, that need to be addressed by future research. We have incorporated the nudging effect as weighted averages of management preferences across the landscape. In the stakeholder workshop, however, it became clear that the forest owners were inclined to apply a mixture of management approaches. A

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more robust evaluation of the nudging effect would be obtained by testing the influence on owner preferences of different framings of specific combinations of stand level management scenarios.

It was not possible to include dynamic timber stumpage pricing, in response to increasing PES pricing within the model, within our model. This led to higher marginal environmental benefits and decreasing aggregated ES provisioning for the nudged group relative to the neutral group as PES price levels increased. Evaluation of the social efficiency of nudging requires that marginal environmental benefits per monetary unit of expenditure (PES payment) are reduced relative to the baseline (neutral group). However, within the structure of this study increasing PES prices and concurrently maximizing economic returns led to a seeming socially inefficient outcome, in terms of regulating ES provisioning per unit of return, between the nudged and neutral groups. Future research should include a more dynamic means of account for market effects on provisioning price levels.

Selinger and Powys Whyte (2010) and Burgess (2012) have also questioned the role and effectiveness of nudging as a policy tool to evaluate stakeholder's long-term preferences; especially outside of a laboratory environment. They note that Level 3 nudges, those nudges looking at complex global problems like climate change, have received limited recognition so far and produce emergent behavior that can be extremely difficult to predict (Allenby and Sarewitz, 2011; Selinger and Powys Whyte, 2012). These questions need to be explored further.

Finally, it is important to note that these results were calculated under the assumption of there would be no major shifts in the environmental conditions for forest management over the next 37 years. We also did not create a scenario where major shifts in long-term storage in wood products were considered. Both of these outcomes are possible, but it was necessary to create scenarios that were not overly complex for consulting with forest owners.

5. Conclusions

This study demonstrates the potential for reducing policy costs by nudging forest owners' preferences. Reducing the social and environmental costs of PES schemes by nudging land owners could have important implications for how PES schemes are designed and stakeholder engagement is structured. This can lead to greater preference for higher additional service provisioning. Nudging reduced the cost per unit of service provided and increased the total service provision by land owners. As a result, the marginal costs of ES provision could be decreased for society; increasing the efficiency of PES schemes. Many of these gains are a result of synergies in managing for

different regulating ES. Higher synergies were found under biodiversity-based management than climate mitigation-based management. Therefore, management incentives in PES schemes should be carefully constructed. Nudging service providers' preferences provides many possibilities for reducing social inefficiencies of PES schemes, but also raises new questions about the associated benefits, permanence and transaction costs. Future research is needed to determine the extent that this policy tool can be used in the development of more effective and efficient PES schemes.

Appendix A.

$$ESEV = \left[\sum_{t=0}^{T} h_t (1+r)^{-t} - w + \sum_{t=0}^{T} r_t (1+r)^{-t} - \sum_{t=0}^{T} c_t (1+r)^{-t}\right] \frac{1}{1-(1+r)^{-T}} \quad \text{(A.1)}$$

For discounting the perpetuity of a given stand management regime let w = regeneration costs occurred at the year 0, h_t = net harvest income at year t, r_t = all non-timber revenues occurring at time t, c_t = all non-timber costs occurring at time t, t = time when revenue or cost occurs, T = is the time period of perpetual future rotations after the initial standing timber is harvested, and r = real discount rate.

$$Biomass\ Price = 0.0722 \left((EU\ ETS * Coal_{Emission}) + Coal_{Spot}\right) \quad \text{(A.2)}$$

For calculating the biomass energy price based on the prices of carbon offsets and coal spot prices. Here the $EU\ ETS$ is the carbon emissions offset price, $Coal_{Emission}$ is the emissions factor of $ton\ of\ CO_2 MWh^{-1}$, $Coal_{Spot}$ is the long-term real spot price of coal assuming no real price growth and 0.722 is a constant representing the calorific value of one cubic meter of wood chips MWh^{-1} and is used to convert the price to € m^{-3} (Irish Energy Centre, 2000; Finnish Energy Industries, 2012).

Appendix B. Supplementary Material

Supplementary Material for this article can be found online.

References

Ahtikoski, A., Tuulentie, S., Hallikainen, V., Nivala, V., Vatanen, E., Tyrväinen, L., and Salminen, H. (2011) Potential Trade-Offs Between Nature-Based Tourism and Forestry, a Case Study in Northern Finland. Forests 2 (4), 894-912. DOI:10.3390/f2040894

Allenby, B., and Sarewitz, D. (2011) The Techno-Human Condition. MIT Press, Cambridge, USA.

Anderson, R. G., Canadell, J. G., Randerson, J. T., Jackson, R. B., Hungate, B. A., Baldocchi, D. D., Ban-Weiss, G. A., Bonan, G. B. Caldeira, K., Cao, L., Diffenbaugh, N. S., Gurney, K. R., Kueppers, L. M., Law, B. E., Luyssaert, S., and O'Halloran, T. L. (2011) Biophysical considerations in forestry for climate protection. Frontiers in Ecology and the Environment 9 (3), 174-182. DOI:10.1890/090179

Anon. (2007) Kestävän metsätalouden rahoituslaki (544). The Sustainable Silviculture Foundation Law (544): Suomen Säädöskokoelma (In Finnish).

Backéus, S., Wikström, P., and Lämås, T. (2006) Modeling carbon sequestration and timber production in a regional case study. Silva Fennica 40 (4), 615-629.

Bennett, E. M. Peterson, G. D., and Gordon, L. J. (2009) Understanding relationships among multiple ecosystem services. Ecology Letters 12, 1394-1404. DOI: 10.1111/j.1461-0248.2009.01387.x

Betts, R. A. (2000) Offset of the potential carbon sink from boreal afforestation by decreases in surface albedo. Nature 408, 187–90. DOI:10.1038/35041545

Bonan, G. B. (2008) Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science 320, 1444-1449. DOI:10.1126/science.1155121

Broch, S. W., Strange, N., Jacobsen, J. B., and Wilson, K. A. (2013) Farmers' willingness to provide ecosystem services and effects of their spatial distribution. Ecological Economics 92, 78-86. DOI:10.1016/j.ecolecon.2011.12.017

Burgess, A. (2012) 'Nudging' Healthy Lifestyles: The UK Experiments with the Behavioural Alternative to Regulation and the Market. European Journal of Risk Regulation 1, 3-16.

Cajander, A. K. (1949) Forest types and their significance. Acta Forestalia Fennica 56 (5), 1-71. http://hdl.handle.net/10138/17982

Canadell, J. G. and Raupach. M. R. (2008) Managing forests for climate change mitigation. Science 320 (5882), 1456-1457. DOI:10.1126/science.1155458

Cathcart, J., and Delaney, M. (2006) Carbon Accounting: Determining Carbon Offsets from Forest Projects, in Forests, Carbon and Climate Change: A Synthesis of Science Findings. Oregon Forest Resources Institute. Portland, USA. 182pp.

Cardinale, B. J., Srivastava, D. S., Duffy, J. E., Wright, J. P., Downing, A. L., Sankaran, M., and Jouseau, C. (2006) Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443, 989-992. DOI:10.1038/nature05202

Carpenter, S.R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., Dietz, T., Duraiappah, A. K., Oteng-Yeboah, A., Pereira, H. M., Perrings, C., Reid, W. V., Sarukhan, J., Scholes, R. J., and Whyte, A. (2009) Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. PNAS 106 (5), 1305-1312. DOI: 10.1073/pnas.0808772106

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., and Daily, G. C. (2006) Conservation planning for ecosystem services. PLoS Biology 4 (11), e379. DOI:10.1371/journal.pbio.0040379

Chan, K.M.A., Pringle, R. M., Ranganathan, J., Boggs, C. L., Chan, Y. L., Ehrlich, P. R., Haff, P. K., Heller, N. E., Al-Khafaji, K., and Macmynowski, D. P. (2007) When agendas collide: Human welfare and biological conservation. Conservation of Biology 21(1), 59–68.

CICES: Common International Classification of Ecosystem Services (2013) CICES Version 4.3. Last accessed on September 15th, 2015. Accessed via: http://cices.eu.

Diaz-Balteiro, L., and Romero, C. (2004) Sustainability of forest management plans: a discrete goal programming approach. Journal of Environmental Management 71, 351-359. DOI:10.1016/j.jenvman.2004.04.001

Dickinson, J. L., Crain, R., Yalowitz, S., and Cherry, T. M. (2013) How Framing Climate Change Influences Citizen Scientists' Intentions to Do Something About It. The Journal of Environmental Education 44 (3), 145-158. DOI:10.1080/00958964.2012.742032

Engel, S., Pagiola, S., and Wunder, S. (2008) Designing payments for environmental services in theory and practice: An overview of the issues. Ecological Economics 65, 663-674. DOI:10.1016/j.ecolecon.2008.03.011

Fauconnier, G., and Turner, M. (1998) Conceptual integration networks. Cognitive Science 22 (2), 133-187. DOI:10.1207/s15516709cog2202_1

Ferraro, P. J. (2011) The Future of Payments for Environmental Services. Conservation Biology 25 (6), 1134–1138. DOI:10.1111/j.1523-1739.2011.01791.x

Finnish Statistical Yearbook of Forestry (FSYF) (2011) Finnish Forest Research Institute, Helsinki, Finland.

Fisher, B., Turner, R. K., and Morling, P. (2009) Defining and classifying ecosystem services for decision making. Ecological Economics 68 (3), 643-653.DOI:10.1016/j.ecolecon.2008.09.014

Gehlbach, F. R. (1975) Investigation evaluation and priority ranking of natural areas. Biological Conservation 8, 79-88. DOI:10.1016/0006-3207(75)90033-6

Gregory, R. and Keeney, R.L. (1994) Creating policy alternatives using stakeholder values. Management Science 40, 1035-1048. DOI:10.1287/mnsc.40.8.1035

Heikkilä, J., Siren, M., Ahtikoski, A., Hynynen, J., Sauvula, T. and Lehtonen, M. (2009) Energy wood thinning as a part of the stand management of Scots pine and Norway spruce. Silva Fennica 43 (1), 129-146.

Hejnowicz, A. P., Raffaelli, D. G., Rudd, M. A., and White, P. C. L. (2014) Evaluating the outcomes of payments for ecosystem services programmes using a capital asset framework. Ecosystem Services 9, 83-97. DOI:10.1016/j.ecoser.2014.05.001

Heller, N. E., and Zavaleta, E. S. (2009) Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142, 14-32. DOI:10.1016/j.biocon.2008.10.006

Herath, G., and Prato, T. (eds.) (2006) Using Multi-Criteria Decision Analysis in Natural Resource Management. Ashgate Publishing Ltd., Hampshire, UK.

Howe, C., Suich, H., Vira, B., and Mace, G. M. (2014) Creating win-wins from trade-offs? Ecosystem serices for human well-being: A meta-analysis of ecosystem services trade-offs and synergies in the real world. Global Environmental Change 28, 263-275. DOI:10.1016/j.gloenvcha.2014.07.005

Hukkinen, J. I. (2012) Fit in the Body: Matching Embodied Cognition with Social-Ecological Systems. Ecology and Society 17(4), 30.

Hukkinen, J. I., and Huutoniemi, K. I. (2014) Heuristics as cognitive tools for pursuing sustainability, in K. Huutoniemi and P. Tapio (eds) Transdisciplinary Sustainability Studies: A Heuristic Approach, Routledge, London, UK, pp. 177-193.

Hynynen, J., Ahtikoski, A., Siitonen, J., Sievänen, R., and Liski, J. (2005) Applying the MOTTI simulator to analyse the effects of alternative management schedules on timber and non-timber production. Forest Ecology and Management 207, 5–18. DOI:10.1016/j.foreco.2004.10.015

Hyvän metsänhoidon suositukset (2006) Metsätalouden kehittämiskeskus Tapio. Metsäkustannus Oy., Helsinki, 100 p. ISSN 1239-6117, (In Finnish),

Jiang, N., Sharp, B., and Sheng, M. (2009) New Zealand's emissions trading scheme. New Zealand Economic Papers 43, 69-79. DOI:10.1080/00779950902803993

Jones, D., and Tamiz, M. (2010) Practical Goal Programming. Springer, New York, U.S.A.

Juutinen, A., and Ollikainen, M. (2010) Conservation Contracts for Forest Biodiversity: Theory and Experience from Finland. Forest Science 56 (2), 201-211.

Juutinen, A., Mäntymaa, E., and Ollikainen, M. (2013) Landowners' conservation motives and the size of information rents in environmental bidding systems. Journal of Forest Economics 19 (2), 128-148. DOI:10.1016/j.jfe.2012.12.001

Juutinen, A., Ollikainen, M., Mönkkönen, M., Reunanen, P., Tikkanen, O-P., and Kouki, J. (2014) Optimal contract length for biodiversity conservation under conservation budget constraint. Forest Policy and Economics (47), 14-24. DOI:10.1016/j.forpol.2013.11.00

Kallio, A. M. I., Anttila, P., McCormick, M., and Asikainen, A. (2011) Are the Finnish targets for the energy use of forest chips realistic: Assessment with a spatial market model. Journal of Forest Economics 17, 110-126. DOI:10.1016/j.jfe.2011.02.005

Lakoff, G., and Johnson, M. (1999) Philosophy in the flesh: The embodied mind and its challenge to western thought. Basic Books, New York, U.S.A.

Margolis, M. and Naevdal, E. (2008) Safe minimum standards in dynamic resource problems: conditions for living on the edge of risk. Environmental Resource Economics 40 (3), 401-423. DOI:10.1007/s10640-007-9162-z

Mason, R. O., and Mitroff, I. I. (1981) Challenging strategic planning assumptions: Theory, cases and techniques. Wiley, New York, USA.

Matthies, B. D., Kalliokoski, T., Ekholm, T., Hoen, H. F., and Valsta, L. T. (2015) Risk, reward, and payments for ecosystem services: A portfolio approach to ecosystem services and forestland investment. Ecosystem Services 16, 1-12. DOI:10.1016/j.ecoser.2015.08.006

McShane, T. O., Hirsch, P. D., Trung, T. C., Songorwa, A. N., Kinzig, A., Monteferri, B., Mutekanga, D., Van Thang, H., Luis Dammert, J., Pulgar-Vidal, M., Welch-Devine, M., Brosius, J. P., Coppolillo, P., and O'Connor, S. (2011) Hard choices: Making trade-offs between biodiversity conservation and human well-being. Biological Conservation 144 (3), 966–972. DOI:10.1016/j.biocon.2010.04.038

Millennium Ecosystem Assessment (2005) Washington, D. C., U.S.A., Island Press.

Moser, S., and Dilling, L. (2007) Creating a Climate for Climate Change: Communicating Climate Change and Facilitating Social Change. Cambridge University Press, Cambridge, UK.

Munda, G. (2000) Conceptualising and responding to complexity. Policy Research Brief No. 2. Environmental Valuation in Europe. In Spash, C. L., and Carter. C. (eds.), Cambridge Research for the Environment, Cambridge, UK.

Mönkkönen, M., Juutinen, A., Mazziotta, A., Miettinen, K., Podkopaev, D., Reunanen, P., Salminen, H., and Tikkanen, O-P. (2014) Spatially dynamic forest management to sustain biodiversity and economic returns. Journal of Environmental Management 134, 80-89. DOI:10.1016/j.jenvman.2013.12.021

Obersteiner, M., Böttcher, H., and Yamagata, Y. (2010) Terrestrial ecosystem management for climate change mitigation. Environmental Sustainability 2, 271-276. DOI:10.1016/j.cosust.2010.05.006

Pagiola, C. (2005) Assessing the Efficiency of Payments for Environmental Services Programs: a Framework for Analysis. World Bank, Washington, USA.

Pagiola, C., and Platais, G. (2007) Payments for Environmental Services: From Theory to Practice. World Bank, Washington, USA.

Petty, A. and Kärhä, K. (2011) Effects of subsidies on the profitability of energy wood production of wood chips from early thinnings in Finland. Forest Policy and Economics 13, 575-581. DOI:10.1016/j.forpol.2011.07.003

Pohjola, J., and Valsta, L. (2007) Carbon credits and management of Scots pine and Norway spruce stands in Finland. Forest Policy and Economics 9, 789-798. DOI:10.1016/j.forpol.2006.03.012

Powys Whyte, K., Selinger, E., Capan, A., and Sadowski, J. (2012) Nudge. Nudge or Shove. Shove-The Right Way for Nudges to Increase the Supply of Donated Cadavor Organs. American Journal of Bioethics 12, 32-39.

Primmer, E., Paloniemi, R., and Similä, J. (2013) Evolution of Finland's Forest Biodiversity Conservation Payments and the Institutional Constraints on Establishing New Policy. Society and Natural Resources 26, 1137-1154. DOI: 10.1080/08941920.2013.820814

Rantala, T., and Primmer, E. (2003) Value positions based on forest policy stakeholders' rhetoric in Finland. Environmental Science and Policy 6 (3), 205-216. DOI:10.1016/S1462-9011(03)00040-6

Robertson, M., BenDor, T. K., Lave, R., Riggsbee, A., Ruhl, J. B., and Doyle, M. (2014) Stacking ecosystem services. Fronteirs in Ecology and the Environment 12, 186–193. DOI:10.1890/110292

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J. (2009) A safe operating space for humanity. Nature 461, 472-475. DOI:10.1038/461472a

Rodriguez, J. P., Beard, Jr., T. D., Bennett, E. M., Cumming, G. S., Cork, S. J., Agard, J., Dobson, A. P., and Peterson, G. D. (2006) Trade-offs across Space, Time, and Ecosystem Services. Ecology and Society 11 (1), 28. http://hdl.handle.net/10535/2588

Salafsky, N. (2011) Integrating development with conservation: a means to a conservation end. or a mean end to conservation? Biological Conservation 144, 973-978. DOI:10.1016/j.biocon.2010.06.003

Salminen, H., Lehtonen, M., and Hynynen, J. (2005) Reusing legacy FORTRAN in the MOTTI growth and yield simulator. Computers and Electronics in Agriculture 49 (1), 103–113. DOI:10.1016/j.compag.2005.02.005

Selinger, E., and Powys Whyte, K. (2010) Competence and Trust in Choice Architecture. Knowledge, Technology, and Policy 23, 461-482. DOI: 10.1007/s12130-010-9127-3

Selinger, E., and Powys Whyte, K. (2012) Nudging Cannot Solve Complex Policy Problems. European Journal of Risk Regulation 26, 26-31.

Simonit, S., and Perrings, C. (2013) Bundling ecosystem services in the Panama Canal watershed. PNAS 110 (23), 9326–9331. DOI: 10.1073/pnas.1112242110

Sjølie, H. K., Latta, G. S., and Solberg, B. (2013) Potential impact of albedo incorporation in boreal forest sector climate change policy effectiveness. Climate Policy 13 (6), 665-679. DOI:10.1080/14693062.2013.786302

Statistics Finland (2012) Statistical Yearbook of Finland 2012. Statistics Finland, Helsinki, Finland.

Sussman, E. (2009) Climate Change Framing and Social Marketing: The Influences that Persuade. Pace Environmental Law Review 27, 313-324.

Thaler, R. H., and Sunstein, C. R. (2008) Nudge: Improving Decisions About Health, Wealth, and Happiness. Yale University Press, New Haven, USA.

Thompson, M., Adams, D., and Norman Johnson, K. (2009) The Albedo Effect and Forest Carbon Offset Design. Journal of Forestry 107 (8), 425-431.

Tomppo, E., Olsson, H., Ståhl, G., Nilsson, M., Hagner, O., and Katila, M. (2008) Combining national forest inventory field plots and remote sensing data for forest databases. Remote Sensing of Environment 112 (5), 1982-1999. DOI:10.1016/j.rse.2007.03.032

Turner, K. G., Vestergaard Odgaard, M., Bøcher, P. K., Dalgaard, T., and Svenning, J-C. (2014) Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. Landscape and Urban Planning 125, 89–104. DOI:10.1016/j.landurbplan.2014.02.007

Wilson, K. A., Underwood, E. C., Morrison, S. A., Klausmeyer, K. R., Murdoch, W. W., Reyers, B., Wardell-Johnson, G., Marquet, P. A., Rundel, P. W., McBride, M. F., Pressey, R. L., Bode, M., Hoekstra, J. M., Andelman, S., Looker, M., Rondinini, C., Kareiva, P., Shaw., M. R., and Possingham, H. P. (2007). Conserving biodiversity efficiently: what to do, where, and when. PLoS Biol 5 (9), e223. DOI:10.1371/journal.pbio.0050223

Wunder, S. (2007) The Efficiency of Payments for Environmental Services in Tropical Conservation. Conservation Biology 21 (1), 48–58. DOI:10.1111/j.1523-1739.2006.00559.x

Yrjölä, T. (2002) Forest management Guidelines and Practices in Finland. Sweden and Norway. In: European Forest Institute Internal Report 11. European Forest Institute, Joensuu, Finland.

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