# Quantifying and easing conflicting goals between interest groups in natural resource planning

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## ABSTRACT

Management of natural resources at a regional level is a compromise between a variety of objectives and interests. At the local level, the management of the forests depends upon the ownership structure, with forest owners using their forests as they see fit. A potential conflict occurs if the forest owners' management decisions are counter to the interests of society in general or the industry that relies on the forest resource as their raw material. We explore the intensity of this conflict at a regional level in several large boreal forest production landscapes. To explore the conflict, we investigate three main interest groups: (i) economically oriented forest owners, (ii) industry groups (focusing on maintaining an even timber supply) and (iii) a group representing general public interests (focusing on enhancing ecosystem services and biodiversity protection). The severity of conflicts differs between interest groups; we found a minor conflict between the economically oriented forest owners and industry, and a severe conflict among general public interests and the other groups. By quantifying the conflict, visualizing the impacts shared between interest groups, we anticipate that through shared discovery and understanding, forests can be managed to lessen the conflict between interest groups.

## INTRODUCTION

Managing forests to maintain a balance of the multiple and interrelated social, economic and environmental functions of forests is a crucial challenge for societies. Earlier work has shown that forest management aiming to maximize a single ecosystem services may cause losses in others (MEA 2005; Mönkkönen et al. 2018). For example, management with a main focus to maximize biomass harvests declined the ability of the forests to provide other provisioning (non-timber forest products), regulating and cultural services (Pohjanmies et al. 2017b) and may jeopardize biodiversity (Triviño et al. 2017). Previous research has mainly focused on mapping and exploring trade-offs among ecosystem services (e.g., Raudsepp-Hearne et al. 2010; Gamfeldt et al. 2013; Lutz et al. 2016) or investigated the coherence of guiding policies (e.g., Makkonen et al. 2015). Much of this earlier research on trade-offs between ecosystem services in forests has remained at a general level of identifying potential trade-offs among categories of goods and benefits with limited attempts to reconcile conflicting objectives.

Solving and easing conflicts between ecosystem services requires an identification and quantification of these conflicts but more challenging is to address the social context of the conflicts. In an environmental protection context, Redpath et al. (2015) define conflict as "situations that arise when two or more parties have strongly held views and one of those parties is attempting to assert its interests at the expense of the other". Different stakeholders have shown to have divergent preferences in the priorities of environment benefits from forests and in forest management practices (Nordén et al. 2017). Recently, Young et al. (2016) have proposed a systematic approach for government agencies to understand, address and manage conflict between stakeholder groups in biodiversity conflict. However, solving conflicts in ecosystem service context have not received much attention yet.

Reconciling conflicts between interest groups requires an evaluation of the severity of the conflicts among interest groups and methods for finding appropriate compromise solutions. Finding the feasible compromise solutions can be challenging as some commodities, such as timber, are considered private property benefiting primarily the landowner while others are considered public goods. Moreover, the benefits from these public goods are generated at different scales, for example, forest carbon sequestration provides a global benefit by reducing atmospheric $CO_2$ levels and mitigating climate change, while natural collectable products (e.g., berries and mushrooms) profit mostly the local community. Private landowners typically lack the incentive to manage land to provide ecosystem services and biodiversity conservation benefits in cases where the benefits produced on their land accrue to others (Mönkkönen et al. 2009). Quantifying such conflicts between producing private vs. public goods can help in the development of incentives to make decisions that reflect the value of ecosystem services and biodiversity conservation in general.

Regional planning processes have previously explored the interaction between interest groups, and the multi criteria decision-making process to find the most satisfactory alternative solution. Applications of participatory planning processes in a forestry context have examples from around the globe (i.e. Australia (Ananda and Herath 2009), Canada (Sheppard and Meitner 2005), Ireland (Bonsu et al. 2017), Sweden (Nordström et al. 2009) and Finland (Hiltunen et al. 2012)). These participatory processes often explore the decision problem through a very limited set of alternative solutions. The focus of the participatory planning process aims at determining which of these pre-defined solutions is the most acceptable. An alternative approach is to use a Pareto frontier approaches (Borges et al. 2014), which explores the entire range of possible solutions. This approach has only limited use in participatory planning, as it requires a large amount of data for the decision support system to guide the decision-maker to an as an acceptable solution, leading to the potential for other interactive solving methods (Ruiz et al. 2019). Previous studies have often focused either on the participatory process and preferential information or on the quantitative modelling of management decisions. Our study aims to bridge this gap using detailed quantitative modelling of management decisions and a range of potential solutions for various combinations of preference information. The approach we propose aims at exploring conflicts among decision-making groups, and the most heterogeneous group as it represents the general society aims to maximize the multifunctional value of the forest.

Several interest groups hold direct and indirect roles in the utilization and management of natural resources. For the specific case of boreal forests in Fennoscandia and the use of timber, we can differentiate between those actors on the supply side (forest owners), timber demand side (forest industry) and ecosystem service and biodiversity demand side (general public). On the supply side, private, small-scale forest owners at a local scale may lack clear preferences regarding the management of their forests and may be guided to conduct fellings according to the accustomed guidelines of timber procuring organizations (Gootee et al. 2010; Karppinen and Berghäll 2015). Though we recognize that private family forest owners are a versatile group with widely varying objectives and management styles, we have chosen to represent family forest owners as solely economically oriented for simplicity. On the demand side (saw and pulpwood), wood procurement professionals often have a very clear motivating objective, to meet timber quotas at the lowest cost. These quotas depend on the operations of the mill, and often remain rather steady from year to year. On a third side, there are elements of society that are not directly involved in forest management but still benefit from forest resources. This can be interpreted as the general public, benefiting from forest resources, such as collecting wild berries, hiking or bird watching (Bell et al. 2007).

Accurate identification of the needs and desires of the various interest groups can be difficult (Sandström et al. 2016). The simplifying assumption that each interest group will solely focus on the extreme solutions may not be desirable or sought after for any of the interest groups. For instance, while the general public may hold a vested interest in ensuring that sufficient resources are conserved to promote biodiversity and ecosystem service provision, some portion of this group may derive positive benefits from a strong forest industry. In a similar fashion, the general public may be impacted by the forest industry (directly or indirectly employed), and understand the need to balance the competing interests. To address these issues, research on multi-objective natural resource planning has focused on evaluating pre-defined potential compromise solutions that balance the conflict between the multiple interest groups, each with their own objectives (Nordström et al. 2009; Uhde et al. 2015). Using a small subset of compromise solutions is often justified due to the limited human capacity to compare between alternatives. However, using a limited number of alternatives reduces the stakeholder freedom of choice and limits the potential for efficient compromises between stakeholder groups.

Earlier studies dealing with conflicts among ecosystem services have paid very little attention on how to minimize the conflict amongst stakeholders with different priorities. Previous research focusing on participatory planning has focused on getting decision makers to communicate, describe their preferences and find the most acceptable plan from a pre-defined set (Kangas et al. 2005; Nordström et al. 2009). These analyses are of vital importance as if these conflicts are not resolved might result in inefficient planning and management of scarce natural resources. Here, our main aim is to explore, quantify and ease the potential conflicts between three key stakeholders in forest management planning: forest owners, industry requirements and general public. The novelty of this study is that we do not simply explore a single pre-defined set of outcomes as previous studies (e.g., Kangas et al. 2005; Nordström et al. 2009); rather we explore the interaction between the entire range of potential solutions (based on the interaction of the three interest group objectives). First, we start with the exploration of these conflicts through the multi-objective decision space, where each stakeholder group hold a clear extreme objective for what they expect from the forest. Then, we relax these extreme objectives to more reasonable objectives these stakeholders may hold after a thorough examination of policy documents. Specifically, we address the following questions: (i) to what extent conflicts among stakeholders can be managed with careful forest planning? (ii) what is the optimal combination of forest management to ease conflicts among stakeholders?

## MATERIALS AND METHODS

### Study area and forest growth simulations

To study the effects of forest management on the delivery of ecosystem services, we simulated the development of forest stands in our study region. Our study areas are located in southern and central Finland and encompass a set of 17 watersheds which we analysed simultaneously (Fig 1). These watersheds include forest stands which represent a wide range of both forest productivity and biodiversity assets. The entire region consisted of 32,276 stands, which corresponded to 48,770 ha, with all data provided by the Finnish Forest Center. The forest simulations were performed using the forest simulator SIMO (Rasinmäki et al. 2009) using the framework developed in our previous research (Eyvindson et al. 2018). A total of 19 management regimes were simulated for 100 years, composed of 20 five-year periods. Seventeen of these regimes reflect modified versions of the current clear felling style of forest management (labeled as *business as usual* (BAU)), one regime represents the management of uneven-aged forest through selective harvests (labeled as *continuous cover forestry* (CCF)), and the final management regime is to set aside the forest (i.e. do nothing). From the initial bare ground conditions, regeneration of trees is conducted artificially (seeding or planting) or naturally. As the seedlings grow, silvicultural treatments are conducted to promote growth. Depending on the specific BAU regime, thinning may be conducted to extract timber resources (up to three times), and a final felling is conducted at the end of the rotation. All final fellings include retention trees (a minimum of 10 $m^3$/ha), with some regimes increasing the amount of retention to 30 $m^3$/ha. Selective harvesting (CCF) was based on the periodic removal of large diameter trees based on basal area restrictions. For a comprehensive description of the management regimes, we refer readers to Appendix 1 from Eyvindson et al. (2018).

**The objectives and values of the interest groups**

For this study, we evaluate forest management using a multiple criteria approach to express the values of three regional level interest groups. These interest groups are the forest industry, private forest owners and the general public. To simplify the analysis, we have decided to first clearly define the key objectives of each interest group, we will then explore the decision space with more nuanced objectives. For the forest industry, the key objective is to maximize the steady flow of timber resources from the forest. For forest owners, the key objective is to maximize the economic value of the forest, represented by the net present value (NPV) of the timber extracted and standing timber in the forest. For the general public, the key objective is to maximize mutifunctionality of a selection of ecosystem service and biodiversity indicators.

The ecosystem services considered were carbon storage and bilberry yield while the biodiversity indicators were deadwood volume and a combined habitat suitability index representing six vertebrate species. To avoid double counting of timber production (an ecosystem service, of specific focus of the timber industry), we have excluded it from the multifunctionality measure. Carbon storage was evaluated as the sum of the carbon in the above- and below-ground biomass (evaluated as 50% of the dry biomass) and the carbon in the soil (using Yasso07 models for mineral soil (Liski et al. 2005; Tuomi et al. 2009, 2011) and carbon flux models proposed by Ojanen et al. (2014) for peat soils). The yield of bilberries was modeled using the approach from Miina et al. (2009), which require stand level characteristics as input variables. Deadwood volume was evaluated as the total volume of deadwood across decay and diameter classes multiplied by the inverse of the Simpson's diversity index based on the diversity of decay and diameter class (Triviño et al. 2017). This implies that stands with high deadwood volume evenly distributed among the classes will have the highest deadwood values. The combined habitat suitability index included preferred habitat types for six vertebrate species (capercaillie (*Tetrao urogallus*), flying squirrel (*Pteromys volans*), hazel grouse (*Bonasia bonasa*), long-tailed tit (*Aegithalos caudatus*), lesser-spotted woodpecker (*Dendrocopos minor*) and three-toed woodpecker (*Picoides tridactylus*); (see Mönkkönen et al. 2014 for further details)). The ecosystem services and biodiversity indicators were merged into a single index using the a concept of multifunctionality (Gamfeldt et al. 2013). For this case, we have defined landscape multifunctionality as the case where all ecosystem services and biodiversity features meet a specified minimum threshold value (defined in this case as the parameter $q$).

Identification of the nuanced interest group values was based on previous research into public opinions of forestry in Europe (EC 2015). The values from the general public were based on the EU level public consultation, were 1,011 respondents aged 15 years and older were interviewed in Finland (EC 2015) This information on public opinions on forestry strongly relates with previous research on the topic in Finland (Karppinen and Korhonen 2013; Lähtinen et al. 2016). Since the survey covers the whole country, the public perception may not correspond to the public perception of the studied region. For this study, the importance of each objective is identified in table 1.

**Evaluating solutions between interest groups**

To explore the efficient frontier between all three interest groups, we propose the following problem formulation:

$$\min\left(d_{IND} * w + d_{FOR} * (1 - w)\right) \quad [1]$$

Subject to:

$$\sum_{p \in P} \sum_{j \in J} \sum_{k=1}^{K_j} \frac{\left(x_{jk} z_{jkp}^{1}\right)}{(1+r)^{(2.5+(p-1)*5)}} = f_{FOR} \qquad [2]$$

$$argmin_{p \in P} \left( \sum_{j \in J} \sum_{k=1}^{K_j} x_{jk} z_{jkp}^{2} \right) = f_{IND} \qquad [3]$$

$$\sum_{p \in P} \sum_{j \in J} \sum_{k=1}^{K_j} x_{jk} z_{jkp}^{t} = f_{PUB_t}, \forall t = 3, \dots, T \qquad [4]$$

$$\frac{(f_{IND}^{*} - f_{IND})}{(f_{IND}^{*} - f_{IND*})} = d_{IND} \qquad [5]$$

$$\frac{(f_{FOR}^{*} - f_{FOR})}{(f_{FOR}^{*} - f_{FOR*})} = d_{FOR} \qquad [6]$$

$$argmin_{t \in T} \left( \frac{\left(f_{PUB_t}^{*} - f_{PUB_t}\right)}{\left(f_{PUB_t}^{*} - f_{PUB_{t*}}\right)} \right) = d_{PUB} \qquad [7]$$

$$d_{PUB} > q \qquad [8]$$

$$\sum_{k=1}^{K_j} x_{jk} = 1, \forall j = 1, \dots, J \qquad [9]$$

$$w, q \in (0,1), x_{jk} \in [0,1], \forall j \in J, k \in K \qquad [10]$$

where the subscript $FOR$, $IND$, $PUB_t$ represent the forest owners, industry and general public perspective, where the general public perspective consists of a set of criteria $T$, $d$ represents the deviations away from the maximum obtainable value, $w$ is a parameter to explore the frontier between the industry and forest owner perspective, $x_{jk}$ is the decision to harvest stand $j$ according to management regime $k$, $z_{jkp}^{t}$ is the value of criterion $t$ associated with conducting management regime $k$ on stand $j$ during period $p$, $r$ is a parameter for the discount rate, $f$, $f^*$ and $f_*$ represent the obtained, ideal (maximum) and anti-ideal (minimum) values for each criterion, $q$ is a parameter which sets the threshold values when calculating the multifunctionality (a value between 0 and 1). To evaluate the production possibility frontiers, the variables in the objective function [1] and equation [8] can be rotated (i.e. $d_{FOR}, d_{IND}, d_{PUB}$) and the entire problem can be solved through a slightly different perspective.

The objective function value (equation [1]) strives to minimize the normalized distances from the ideal value for both the FOR and IND criteria, weighted by the $w$ parameter. Equation [2] evaluates the NPV from the set of decisions, equation [3] evaluates the minimum periodic flow of timber throughout the planning horizon and equation [4] evaluates the set of biodiversity and ecosystem service criteria values. Equations [5], [6] and [7] evaluate the normalized distance from the ideal value for the forest owner, industry and public perspective. Equation [8] is a constraint that the normalized distance from the ideal general public perspective to be greater than or equal to a specific parameter ($q$), equation [9] is a constraint requiring that each stand has been completely assigned to some management regime $j$, and equation [10] provides bounds for the decision variable $x_{jk}$ and the parameters $w$ and $q$. We describe all variables and notations in table 3.

This problem formulation utilizes the theory of multiobjective optimization (see Miettinen 1999). To explore the Pareto front between the different interest group objectives, we rely on compromise programming, using a fixed distance metric of $L^1$ (Yu 1973). We focus only on Pareto efficient solutions (the set of efficient solutions) allowing for logical comparison between the solutions. The compromise programming approach relies on the examining the normalized distance to the maximal values to evaluate the trade-offs. For criteria which represent a single objective (such as NPV and even-flow of timber), the evaluation of the trade-off is relatively straight forward, as a minimum and maximum value can be found directly. For surrogate objectives (such as multifunctionality) the evaluation of the theoretical minimum and maximum value for the index is not straight forward, as the maximum or minimum value depends on the selection of criteria used to evaluate the index. To be of use for the decision maker, all contextual information must be provided. Thus, our multifunctionality proxy represents a predefined perspective on wide variety of benefits, with an aim to capture the multitude of benefits from the natural resources.

We mapped a frontier of the Pareto efficient solutions by evaluating the range between the theoretical maximums and minimums. This frontier allows for the visual evaluation of trade-offs between the selected criteria. As the multifunctionality (MF) was used as a constraint, the frontier can be seen as steps, where there are systematic lines representing specific thresholds for the multifunctionality. As the forest owner perspective is directly related to the NPV, a choice of an appropriate discount rate was required, for this study we used a discount rate of 3%. All optimizations were performed using the commercial optimization software (CPLEX version 12.8).

## RESULTS

Managing conflicts between interest groups will require a trade-off between the gains for one interest group and losses for another interest group. For this example, we have evaluated the conflict from two perspectives. The first is an extreme case when each interest group solely focuses on their own objective. For the second case, we aimed to map a realistic perspective to provide a frame for the conflict between the interest groups (Table 2) using data on public perception of main benefits of forests (Table 1). If we evaluate the conflict between the extreme solutions of each interest group, the conflicts are large (Table 2a). For this case, the results highlight that if either the forest owners or forest industry interests are maximized, the multifunctional value of the forest is minimized. This reflects a severe conflict between managing the forest for the general public benefits versus solely for industrial or economic benefits for forest owners. However, if each of the interest groups is not solely motivated by a single objective, this conflict is significantly reduced (Table 2b). However, the general trend remains, where conflict between public benefits and both forest industry and economically interested forest owners are the highest. For instance, if the forest is managed according solely to the forest industry interests, the general public will achieve 58% of their targeted desire for multifunctionality (a multifunctionality value of 0.29), while the net present value achieve 89% of the targeted NPV (representing a NPV of 7800 €) (Table 2b).

To explore the entire range of potential conflicts within the interest groups, we have created a Pareto efficient front of solutions as a 3-D surface (Figure 2). We represent this surface as a series of production possibility frontiers. This surface highlights the potential regional level conflict of the interest groups. If the interest groups hold an extreme position with regard to their objectives (the vertices of the 3-D surface in Figure 2), these points represent the maximum conflict possible (i.e. the points highlighted in Table 2a). Any relaxation from these extreme perspectives will result in a reduction in any conflict. The severity of conflict between three perspectives on forest management differs between studied interest groups. The interior grey triangle represents the range of conflicts between the targeted cases of the interest groups where each interest group is not solely motivated by a single objective but is willing to make compromise (i.e. the targets set in Table 2b). Compared with the extreme cases, the surveyed objectives highlight the mitigated need for compromise between all interest groups. In each of the graphs of Figure 2, we have identified which criteria are in harmony or conflict from the central compromise solution. From this point, an evaluation of the severity of conflict or promise of harmony is possible. In Figure 2b, the opportunity for conflict is very severe and the possibility for harmony is very limited. While, both Figures 2a and 2c highlight a much greater opportunity for both harmony and conflict.

The potential conflict differs between interest groups. The industry and public interests have a relatively even conflict, from either optimal perspective; both interest groups must give up a similar normalized value in the compromise solution (Figure 2a). The conflict between the general public and forest owner interests has rather similar properties to the conflict between industry and public interests (Figure 2b); however, there is much narrower range of possible solutions than between the industry and public interests. This equality in conflict is not demonstrated in Figure 2c, where the industry and individual forest owners have an unbalanced compromise. To meet the main objective of industry groups (much higher even-flows of timber), forest owners will see only minor impacts on the timber revenues (measured as net present value) of the forest. In Figure 2c, this can be seen through the relative changes in the performance of each objective, if the focus is on industry groups we obtain an even-flow of timber of around 1,300 $m^3$/ha per period and a net present value of 8,300 € per hectare. With a focus on forest owners, the net present value obtained increases by around 1,500 € per hectare (to 9,800 € per hectare) while the even flow of timber decreases by 830 $m^3$/ha for each period (to 460 $m^3$/ha for each period). This highlights the fluctuation in timber extraction if the forest owners solely rely on making harvesting decisions based on maximizing the net present value of their forests.

Forest management decisions offer options to mitigate the conflict between interest groups. For each solution used to generate the Pareto frontier, it is possible to examine the specific management regimes used. For the entire range of solutions, Figure 3 shows the case when the maximization of NPV (Figure 3a) and even-flow of timber resources (Figure 3b) is subject to a multifunctionality constraint. When we focus only on maximizing NPV, continuous cover forestry (CCF) dominates (41 %). Increasing the level of multifunctionality demand results in increases of the share of set asides, and in decreases of the share of BAU with short rotation. CCF remains an important management regime (between 29 and 44%) across the entire gradient of multifunctionality while green tree retention is important (12 - 22%) at the intermediate levels of multifunctionality. When we focus on maximizing the periodic even-flow of timber, rotation forestry (BAU) is a primarily used management type than when focusing on other objectives, and alternative BAU versions comprise 50% of management when multifunctionality does not constraint management. CCF, once again, remains important (between 29 and 41%) all throughout the entire gradient of the multifunctionality requirement. To obtain maximal multifunctionality for the general public, a modest level of harvesting activities is allowed and composed primarily of the management regimes CCF (27 - 30%) and delayed harvest BAU with green tree retention (5 - 7%). These management regimes are dominating due to their influence on some specific criteria; for example, the CCF management option produces large quantities of bilberry, while the specific BAU management option increases the quantity of deadwood for a period following harvest actions.

## Discussion

The focus of this study was to explore, quantify and ease the potential conflicts between three key stakeholders in forest management planning: forest owners, industry requirements and general public and suggest alternatives mitigate the conflict. We present a surface of relevant solutions to highlight a novel perspective that may assist interest groups in understanding the severity of conflict within the groups. This is done through an exploration of the three-dimensional range of possible outcomes. We provide guidance from an optimized landscape perspective, which is notoriously difficult to accomplish, due to inefficiencies caused by the ownership structure and priorities of individual forest owners (Eriksson and Hammer 2006; Angelstam et al. 2011).

To generate this range of possible outcomes several assumptions were taken to reflect various sources of preferential information. An assumption was taken on the key priorities of the different stakeholders, highlighting what could be evaluated as potential extreme views. We also assumed that differences between different objective values (for the different stakeholders) were of equal importance. These assumptions were taken to simply explore the frontier of decisions. To incorporate real preferential information into the decision process, alternative methods of incorporating preferential information may be needed, such as interactive decision making processes (Ruiz et al. 2019).

Our results highlight that the highest potential conflict is between the general public (focusing on non-economic benefits) and the economic interests of both the forest industry and economically orientated forest owners. The general orientation of economic interests (industry and forest owners) indicate a low source of conflict. This conflict can be further reduced as the forest industry and forest owners can negotiate a price that satisfies both. From a biomass supply perspective, Aguilar et al. (2014) highlighted how prices directly influence the willingness of forest owners to harvest their forest. Our findings about the conflict between resource extraction and both biodiversity conservation and ecosystem service provision are consistent with results from previous studies (e.g., Eriksson and Hammer 2006; Cheung and Sumaila 2008; McShane et al. 2011; Mönkkönen et al. 2014).

These results highlight the advantage of coordination between stakeholder groups. It is important to remember that each stakeholder group consists of human decision makers, each possessing internal conflicting views. While the different stakeholders hold different preferences towards the use of the forest, none of these stakeholders hold diametrically opposed positions. Industry stakeholders probably understand the value of appropriate maintenance of the forest ecosystem as the raw forest materials are obtained from the active maintenance of the natural resources (Lidskog and Löfmarck 2016). The general public benefits generally from income obtained through the sale of timber, and the products and jobs produced from industry (Turner et al. 2003). Forest owners enjoy the benefits provided by mature forests, while also enjoying the financial benefit from selling the timber to the industry (Ficko et al. 2017). Additionally, while there is real conflict between these groups, the portrayal of the severity of the conflict may be exaggerated as a political tool. For instance, to gain acceptance for projects causing environmental damage, their economic benefits may be exaggerated (O'Faircheallaigh 2010).

One of the main aims of environmental management research has been to search for 'win-win' situations (Tallis et al. 2008). The idea is that there are management options that are both economically sound and environmentally friendly. Unfortunately, intense resource extraction is more often in direct competition with ecological goals than it is in harmony (McShane et al. 2011). When considering between Pareto efficient management alternatives, the potential for any 'win-win' situations are explicitly unavailable. Fortunately, in our study, the surface of efficient solutions is concave, and a small change in one objective can result in a larger increase of another objective. This choice is still one that requires one interest group to be worse off in order to benefit another interest group. The planning process requires a compromise, selecting a solution that balances the outcomes for all interest groups (which may result in an equally unappealing outcome to all interest groups).

The severity of the 'realistic' conflict between groups shows the potential to meet at a not entirely undesirable solution for each interest group. To find a potential compromise solution that can be acceptable should be possible, if the interest groups are willing to negotiate or willing to be influenced by the other interest groups position. Participatory planning has shown promise in facilitating dialog amongst stakeholder groups, and can be an effective tool if the stakeholders can influence the final decision. By being able to influence the decision implies providing stakeholders power in the process, reflecting Citizen Power from Arnstein's ladder of participation (Arnstein 1969). In Finland, participatory planning processes have been used extensively in recent history; however the current trend in state owned forests is a lower participation from the general public in the planning process (Tikkanen 2018).

On privately held forests, participatory planning processes may have little value, as the forest owner serves as the sole decision maker. For these cases, alternative tools that provide incentives to forest owners to manage their forest in a specific way would be more beneficial (such as METSO in program Finland, https://www.syke.fi/metso/en). To improve the performance of these voluntary based conservation programs, a dialogue-approach for voluntary based conservation can provide stakeholders power in the process of conservation (Paloniemi et al. 2018).

To mediate these conflicts from a technical perspective, decision support systems have been used in facilitated participatory planning approaches (Nordström et al. 2009; Menzel et al. 2012; Sotirov et al. 2019). These systems strive to provide decision makers with as much information as they need to make the best decision possible. As with any black box, participants may be sceptical of the output (Menzel et al. 2012). Thus, in addition to developing trust between stakeholders, adding the use of decision support systems requires participants to develop trust in the generation of alternative solutions. One way to facilitate trust could be in the use of interactive decision processes. Operational research suggest the use of methods that allow for continual improvements in the solution, i.e. starting from the worst possible case from the perspective of all interest groups (see Miettinen and Ruiz 2016). This approach may more easily result in an acceptable compromise solution because improvements to a solution from all perspectives are more acceptable than cases requiring negotiations about the trade-offs between efficient solutions where one stakeholder needs to give up benefits to others (Aloysius et al. 2006).

In order to meet the needs and ease the conflicts among the different forest stakeholders the diversification of management regimes is essential. We found that in order to find a balance that meets the needs of all interest groups, the forest should be optimally managed primarily through set-asides, continuous cover forestry and green tree retentions. These findings are in line with previous studies that have shown that continuous cover forestry often outperforms clear-cut forestry in providing timber, non-timber ecosystem services and biodiversity (e.g., Lundmark et al. 2016; Tahvonen and Rämö 2016; Pukkala 2016; Peura et al. 2018). Moreover, continuous cover forestry is clearly dominating when maximizing the income of forest owners (Fig. 3a), and rotation forestry dominates when maximizing the periodic even-flow of timber (Fig. 3b). However, when the aim is the even-flow of timber then the proportion of the forest managed under continuous cover forestry is reduced because it is more difficult to ensure maximum timber flow over time with continuous cover forestry than with the business as usual clear-cut forestry.

The exact interpretation of the metrics used for the different stakeholder perspectives requires careful consideration. For the economically orientated forest owners we relied on the NPV, using a constant discount rate of 3% reflecting the rate commonly applied in European countries for evaluating social policies or projects (see Johansson, P.-O., and Kriström 2012 and references therein). The choice of the discount rate influences the timing of harvests. The implications for this study are that if the discount rate is changed, changes will occur between the conflict of forest owners and the industry perspective. For the general public, we rely on a measure of multifunctionality. The evaluation of multifunctionality depends on the criteria selected and the potential range of each criteria. Thus, this metric requires careful explanation to the stakeholders, as it is relative measure and needs unique interpretation for each decision process. For both of these metrics, the exact impact will depend on the structure of the forest, the extent of the planning horizon and management alternatives used in the analysis. If there is an even distribution of age classes, with little forest above regeneration age, then there will be very little conflict. For the case when there is an uneven age class distribution, or a large proportion of the stands with an age class above the regeneration age, then there will be significant conflict between these stakeholder groups.

This study has focused on the efficient allocation of management regimes to optimize between the three different objectives mimicking the preferences of different interest groups. Any adjustments to the use of the forest resources away from this frontier will result in inefficiencies, and will affect the provision of the various criteria under consideration. Introduction of inefficiencies will likely increase the conflict between these stakeholder groups. If the forest owners or industry groups are primarily of interest, the inclusion of inefficiencies will likely improve the benefits provided to the general public interest group. This is due to increased potential for increasing rotation periods, and simply not harvesting forested stands.

## Conclusion

With multiple demands placed on the use of natural resources, management of these resources requires prioritization based on the needs and desires of various interest groups. Acknowledging the potential for conflict between interest groups is important and can be useful in highlighting the imposition of compromises in the decision-making process. These conflicts amongst stakeholders may be eased through the appropriate use of problem framing. For instance, the worst case for each interest group could be used as the starting point in an interactive decision tool, so all interest groups can find a solution that improves upon this starting point. Through numerical computation, we can assess the potential (and reasonable) conflict between different interest groups. This quantification can assist in formulating strategies for offsetting the compromises required of the interest groups, and provides a means for incentivising land-use planning for biodiversity and ecosystem services.

Our results indicate that the strongest conflict, which is also the most difficult to solve, exists between forest owners and the general public. Thus, a socially sustainable forest policy would require some form of economic incentive to compensate forest owners willing to face severe economic losses from managing forests for the public good. Alternatively, this highlights the potential conservation value forest owners could bring if they desire to conserve their forests, and this could be done with a limited negative impact on the even flow of timber provided to the forest industry.

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Table 1. Targets for individual interest groups. Measured as percentage from theoretical maximum for each criterion. (MF – multifunctionality, NPV – Net present value, EVEN – Even flow of timber resources).

| % | MF | NPV | EVEN |
|---|---|---|---|
| Public | 72 | 44 | 42 |
| Forest owners | 30 | 84 | 50 |
| Industry groups | 42 | 69 | 71 |

Table 2. Conflict between the various interest groups (PUB – General public, FOR – Forest owners, IND – Industry groups). All values are normalized between 0 and 100, representing how close the achieved value is to the indicated preference. The extreme cases use the theoretical maximums for the criteria of interest for the various interest groups, while the targeted cases use the more realistic values provided in table 1 to evaluate the conflict. The values represent how close the selected management plans are to the competing interest groups.

| a) Extreme cases | | | | b) Targeted cases | | | |
|---|---|---|---|---|---|---|---|
| % | MF | NPV | EVEN | % | MF | NPV | EVEN |
| PUB | 100 | 0 | 0 | PUB | 100 | 42 | 58 |
| FOR | 0 | 100 | 78 | FOR | 66 | 100 | 89 |
| IND | 0 | 31 | 100 | IND | 65 | 74 | 100 |

| Symbol | Definition |
| --- | --- |
| **Sets:** | |
| $T$ | Set of criteria use in analysis |
| $P$ | Set of time periods under consideration |
| $J$ | Set of all forest stands |
| $K_j$ | Set of all management regimes for forest stand *j* |
| **Data:** | |
| $z_{jkp}^{t}$ | The value of criterion *t* when conducting management regime *k* on stand *j* for period *p* |
| $f_{FOR}^{*}, f_{IND}^{*}, f_{PUB}^{*}$ | The ideal value obtainable for each interest group |
| $f_{FOR*}, f_{IND*}, f_{PUB*}$ | The anti-ideal value obtainable for each interest group |
| **Variables:** | |
| $d_{FOR}, d_{IND}, d_{PUB}$ | The deviations away from the maximal value possible for each interest group |
| $f_{FOR}, f_{IND}, f_{PUB}$ | The value obtained for each interest group |
| **Decision Variables:** | |
| $x_{jk}$ | The decision to manage stand *j* according to management regime *k* |
| **Parameters:** | |
| $r$ | The discount rate |
| $q$ | Threshold value used when evaluating multifunctionality |
| $w$ | Value highlighting the relative importance between industry and forest owner interest groups. |

Table 3. List of notation used in the problem formulation

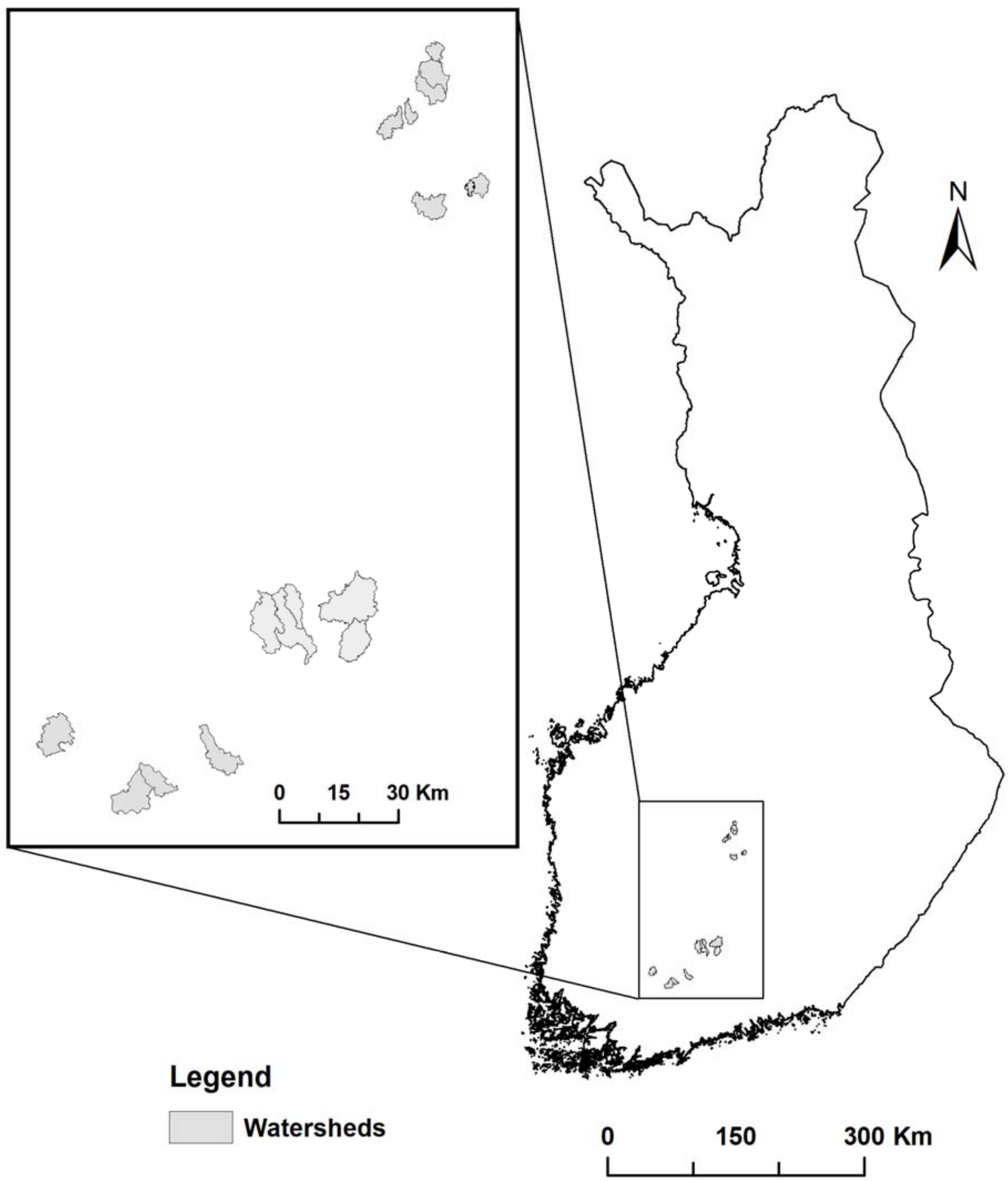


Fig 1. Location of 17 forested watersheds in Central and Southern Finland. The selection of watersheds represents a variation in both geographic and production capabilities.

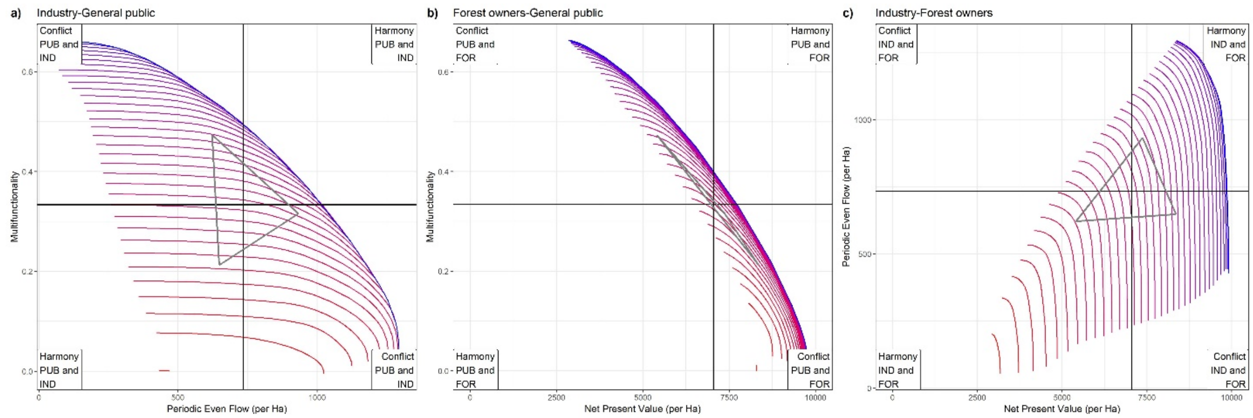


**Fig. 2** Pareto front of the theoretical maximum conflict between the objectives for the different interest groups. The interior grey triangle represents the range of conflicts between the surveyed objectives/ more realistic set of objectives of the interest groups  In each panel, the objective of the public (PUB) is to maximize the multifunctionality of the forest, the objective of forest industry (IND) is to maximize the even flow of timber, and the objective of the forest owners (FOR) is to maximize the net present value of timber. The production possibility frontiers (PPF) of a specific provision of the third criterion shown in each graph. The PPF lines increase in steps of +3%, with the extreme blue (red) color represents the minimum (maximum) value of the third criterion. Panel (a) illustrates "Industry - Public" conflict and the Forest owners perspective shown as NPV in colour scale ; Panel (b) shows "Forest owners - Public" conflict with the industry perspective shown as Even Flow in a colour scale; Panel (c) shows "Industry – Forest owners" conflict with the public perspective shown as multifunctionality in a colour scale. In each graph, we also identify the potential for harmony and conflict zones between the objectives on axes. Evaluation of harmony and conflict is carried out from the center of the targeted conflict triangle. The objectives can be considered being in harmony if an increase away from the center in one objective also improves the value of the other objective (upper right sector) or if decreases are associated (lower left). All other cases indicate conflicts.

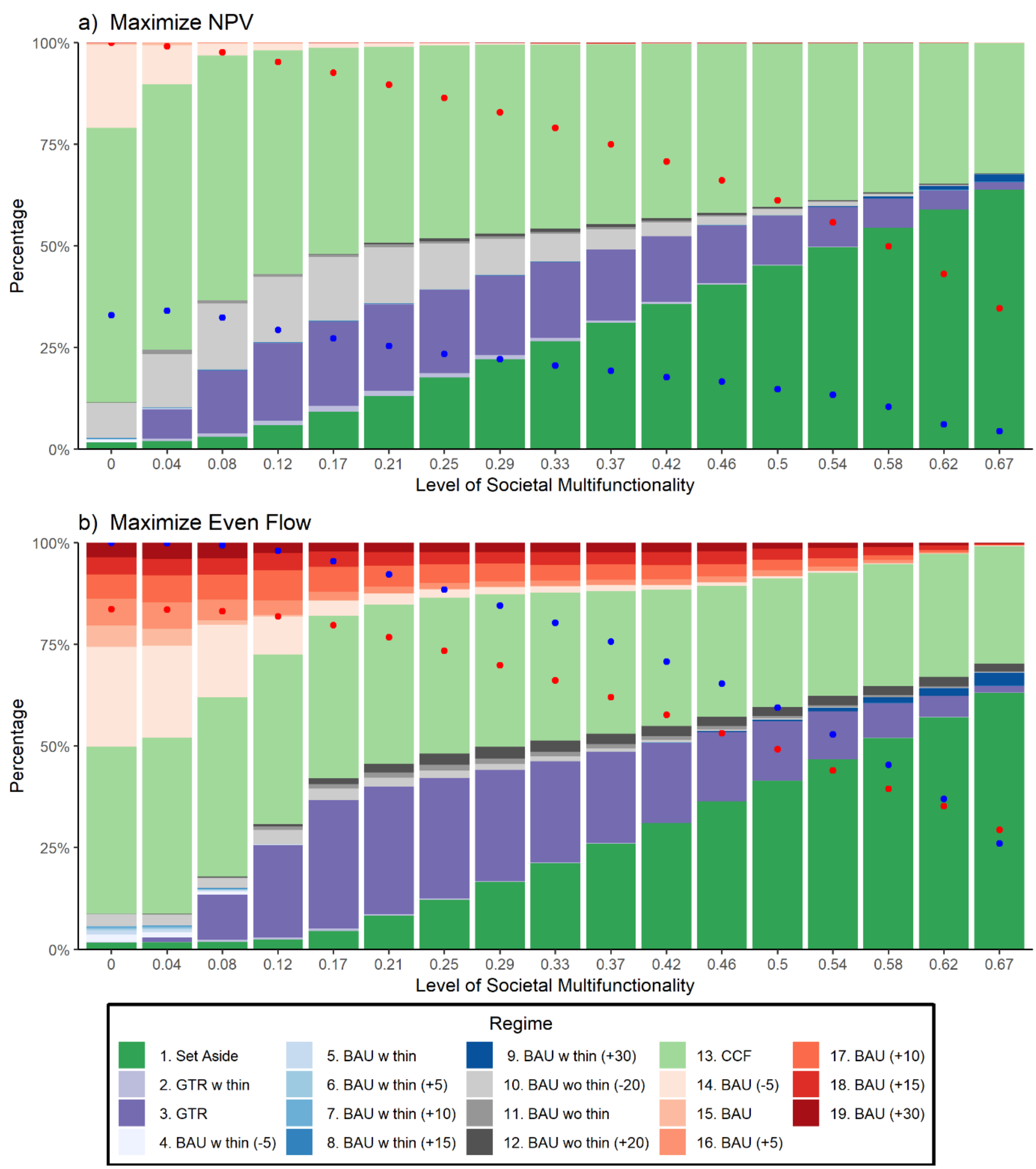


**Fig. 3** Range of management types when: a) maximizing net present value or b) maximizing the even-flow of timber while requiring a pre-defined level of multifunctionality. BAU refers to alternative clear-cut based management regimes with variable thinning intensities and rotation lengths (GTR = green tree retention, w thin = with thinnings before clear felling, wo thin = with no thinnings). CCF refers to continuous cover forestry with not final felling by clear-cut, and set aside denotes permanent protection (no management). The red and blue dots respectively represent the percentage of maximum NPV and Even flow obtained from each set of management alternatives. For description of management regimes readers are referred to Eyvindson et al. (2018).