ADDRESSING FOREST AND NATURAL RESOURCES MANAGEMENT PLANNING WITH MULTICRITERIA APPROACHES AND GROUP DECISION-MAKING TECHNIQUES

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THESIS PRESENTED TO OBTAIN THE DOCTOR DEGREE (PhD) IN FORESTRY ENGINEERING AND NATURAL RESOURCES

2022

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Instituições Financiadoras e âmbito:

Programa de doutoramento FCT (Sustainable Forests and Products, SUSFOR) - PD/BD/128257/2016

2022

Nothing is more difficult, and therefore more precious, than to be able to decide.

Napoléon Bonaparte (1769-1821)

ACKNOWLEDGEMENTS

The Ph.D. research was a long way that resulted from countless interactions, discussions, discoveries, experiences and above all learning, shared either with colleagues who worked with me or contributed with their knowledge or with family and friends. I am grateful to the people who crossed my way and made me think, question, understand, and laugh during these last five years. All contributed to this work in some way. Thank you!

A huge thanks to Prof. José Guilherme Borges, my supervisor, who encouraged me to embrace this challenge, for his friendship and valuable advice, continuous support, and the availability revealed throughout these years of work. Thanks for the helpful supervision and encouragement, for the criticisms, corrections, and suggestions made during the relevant guidance, for helping to relativize the reviewer's analysis, and for providing me with all the necessary facilities to develop this research. It was a privilege to learn and work with you.

Very grateful to Keith Reynolds, my supervisor, for his friendship and outstanding support, for welcoming me at the Corvallis Forestry Sciences Laboratory, providing the necessary facilities to develop the research, for sharing his knowledge, the stimulating discussions about the methodology and results, as well as for all the advice. Thanks for the information about Corvallis that let me a straightforward adaptation and for revealing the fantastic natural places of Oregon. It was a great life experience! I learned a lot and enjoyed working with you.

I thank all my Forchangian colleagues in general for their support. I am particularly grateful to Susete Marques for clarifying my questions, testing questionnaires, explaining how to work with the multicriteria Pareto frontier method, and for the great support and companionship. To Brigite Botequim for her availability to help with workshops, explain the ecosystem services indicators, and for the care and friendship. To Marco Marto for his assistance with the multicriteria questionnaire and Pareto frontier database. To Patrícia Pécurto and Catarina Tavares for their help during the workshop and focus group session. To Prof. Margarida Tomé, Paula Soares, Susana Barreiro, João Rua, Ágata Lam and Ana Raquel Rodrigues for their fellowship and care. This adventure would be more challenging without them!

Grateful to all my co-authors. To Nataly Juerges, who introduced me to the actor analysis. To Manuela Oliveira for helping with statistical analysis and for her friendship. To Milena Lakicevic for assisting the multicriteria questionnaire and preferences aggregation but, above all, for her friendship and shared experience in Corvallis. To Philip Murphy for the CDP clarifications and pertinent analysis of the results. To Steve Paplanus for helping with EMDS.

Thankful to Carlos Caldas for our longstanding friendship, his criticisms and direct analysis, and our valuable and interesting discussions.

My sincere thanks to all actors who participated and contributed to this research. Their commitment and knowledge were determinants to the success of the participatory process.

Thanks to Sandra Pinto, from Associação Florestal do Vale do Sousa, for helping identify and contact forest owners and for the information about the forest management of Vale do Sousa.

Thanks to Maria João Canadas and Ana Novais for the valuable feedback on the interview guideline of the actor analysis.

Grateful to the Corvallis Forest Science Laboratory, Pacific Northwest Research Station - Forest Service, for being welcome by all and for providing facilities to carry out my research. I am particularly thankful to Tony Youngblood and Mario Isaias-Vera for their support. I loved the Thirsty Thursdays. Thank you for the excellent mood!

Thankful to the Portuguese Foundation for Science and Technology (FCT) under the Doctoral Program SUSFOR - Sustainable Forests and Products PD.00157.2012 for granted my Ph.D. research through the scholarship PD/BD/128257/2016, the Forest Research Center and Laboratory Terra and the projects ALTERFOR, SuFoRun, BioEcosys, MODfIRE and NOBEL for their financial support.

I thank the journal’s reviewers of my published articles for their valuable criticisms, helpful suggestions, and comments, improving the text's readability.

Thankful to all my friends who supported and always encouraged me on this journey.

Grateful to Glória Neves for taking care of my vegetable garden so I could focus on the Ph.D.

A heartfelt thanks to my beloved family for their love, unconditional trust, and never-ending support.

Finally, I am grateful to my husband Pedro for always being by my side, for his incredible support and confidence in this long journey. Thank you for always believing and encouraging me in each challenge. It has been an amazing lifetime trip and I am loving it!

ABSTRACT

Sustainable forest management planning is challenged by the expectation for natural resources to provide a broad range of ecosystem services (ES). This can become more complex in joint management areas because the decision can involve several to many actors with different interests and objectives.

The goal of this research is to facilitate forest management planning that best reflects the diversity of actors' interests and that is better suited to face the challenges of the 21st century by (1) identifying the relevant actors and factors that impact forest management decisions (actor analysis); (2) assessing actors' preferences for forest management models (FMMs) and ES (two-stage questionnaires); (3) developing a combined multicriteria decision analysis and group decision-making approach to quantify the criteria weights and rank seven FMMs (cognitive map, multicriteria questionnaire, and Delphi survey); (4) applying a Group Multicriteria Spatial Decision Support System approach to negotiate consensual solutions for seven ES, according to the objectives of four interest groups, and spatially prioritize the allocation of ES to forest management units.

We report results from an application in Vale do Sousa, in northwestern Portugal. There was a consensus among the actors for a forest resilient to wildfires and a multifunctional forest that offers a diversity of ES but can be profitable. In two-stage questionnaires, actors ranked the FMM of pure eucalypt higher. However, in the multicriteria questionnaire, the FMM with the highest performance was the pedunculate oak and eucalypt was the least preferable. We found significant differences in priority scores between civil society and the other three groups, highlighting civil society and market agents as the most discordant groups.

These findings contribute to a better understanding of forest management decisions. They can support joint management areas managers and other decision-makers in enhancing landscape-level, collaborative, and sustainable forest management planning, thus facilitating its implementation.

Keywords: ecosystem services; forest management models; participatory planning; multicriteria decision analysis; joint management areas

RESUMO

O planeamento da gestão florestal sustentável é desafiado pela expectativa dos recursos naturais fornecerem uma ampla diversidade de serviços de ecossistema (SE). Em áreas de gestão agrupada poderá tornar-se mais complexo, pois a decisão envolve muitos atores com diferentes interesses e objetivos.

Pretende-se facilitar o planeamento da gestão florestal que melhor reflita os interesses dos atores e possa enfrentar os atuais desafios ao (1) identificar os principais atores e fatores impactantes nas decisões de gestão florestal (análise de atores); (2) avaliar as suas preferências por modelos de gestão florestal (MGF) e SE (questionários em duas fases); (3) desenvolver uma abordagem combinada de análise de decisão multicritério e decisão em grupo para quantificar os pesos dos critérios e classificar sete MGF (mapa cognitivo, questionário multicritério e pesquisa Delphi); (4) aplicar uma abordagem de Sistema de Apoio à Decisão Espacial Multicritério de Grupo para negociar soluções consensuais para sete SE, de acordo com os objetivos de quatro grupos de interesse, e priorizar espacialmente a alocação dos SE aos talhões de gestão.

Reportamos os resultados de aplicação no Vale do Sousa, no noroeste de Portugal. Verificou-se um consenso por uma floresta resiliente aos incêndios rurais e multifuncional, com diversificação de SE, mas rentável. No questionário simples, o MGF preferido foi o puro de eucalipto. No entanto, no questionário multicritério o MGF com melhor desempenho foi o carvalho-alvarinho e o eucalipto o menos preferido. Apuraram-se diferenças significativas nas prioridades entre a sociedade civil e os outros três grupos, destacando-se a sociedade civil e os agentes de mercado como os grupos mais discordantes.

Estes resultados contribuem para um melhor entendimento das decisões de gestão florestal. Podem apoiar os gestores de áreas de gestão agrupada e outros decisores na melhoria do planeamento colaborativo da gestão florestal sustentável à escala da paisagem, facilitando a sua implementação.

Palavras-chave: serviços de ecossistema; modelos de gestão florestal; planeamento participativo; análise de decisão multicritério; áreas de gestão agrupada

RESUMO ALARGADO

O planeamento da gestão florestal sustentável é atualmente desafiado quer pela expectativa dos recursos naturais fornecerem uma ampla diversidade de serviços de ecossistema (SE), quer pelas ameaças das alterações climáticas, da complexa dinâmica dos mercados globais e da pressão da sociedade. Além disso, no planeamento deverão ser considerados diversos critérios no processo de tomada de decisão subjacente. Estes desafios tornam-se ainda mais complexos em áreas de gestão agrupada (ex.: ZIF - Zonas de Intervenção Florestal, AIGP - Áreas Integradas de Gestão da Paisagem), pois a decisão poderá envolver muitos atores com diferentes interesses e objetivos. As abordagens participativas podem apoiar a integrar as preferências e as prioridades dos atores no planeamento da gestão florestal à escala da paisagem e, assim, enfrentar estes desafios.

Em Portugal, na maioria das ZIF prevalecem as práticas tradicionais de gestão florestal com foco apenas em alguns SE (ex.: fornecimento de madeira). Sendo o principal objetivo da ZIF a gestão florestal conjunta à escala da paisagem, o envolvimento dos proprietários florestais e de outros atores nas decisões de gestão florestal torna-se ainda mais exigente e fundamental. A participação dos atores nas decisões de planeamento da gestão florestal compromete-os a implementar ou apoiar a gestão florestal planeada e promove o sentimento de pertença à gestão conjunta. Tanto quanto é do nosso conhecimento, em Portugal são poucas as referências da aplicação de técnicas participativas em áreas de gestão agrupada, como as ZIF, para apoiar o planeamento da gestão florestal.

Estas lacunas motivaram a presente tese, nomeadamente a falta de aplicação de abordagens participativas nas áreas de gestão agrupada, visando antecipar problemas e conflitos, envolvendo os atores na tomada de decisão em grupo para identificar os seus interesses e prioridades, selecionar e categorizar modelos de gestão florestal (MGF), e priorizar a atribuição de SE aos talhões florestais (unidades homogéneas de gestão). É uma oportunidade para contribuir para o desenvolvimento de metodologias participativas adequadas a áreas de gestão agrupada que podem motivar os proprietários florestais a implementarem as decisões florestais nas quais podem participar, facilitando, assim, a gestão florestal conjunta que melhor reflita os seus interesses e prioridades, assim como, fazer face aos atuais desafios.

Neste âmbito desenvolvemos um processo participativo que visou quatro objetivos específicos: (1) identificar os atores mais relevantes para a gestão florestal e caracterizar em

detalhe o contexto de gestão florestal de uma área de estudo; (2) avaliar as principais preferências dos atores por SE e MGF e o impacto da informação e das discussões participativas sobre as suas opiniões e a aprendizagem social; (3) desenvolver uma abordagem combinada de análise de decisão multicritério e de tomada de decisão em grupo para identificar e quantificar os critérios/subcritérios mais relevantes nas decisões de gestão florestal e avaliar o desempenho dos MGF; (4) aplicar um Sistema de Apoio à Decisão Multicritério Espacial de Grupo para priorizar a alocação de SE aos talhões.

A área de estudo selecionada para desenvolver este trabalho foi o Vale do Sousa, localizado no Noroeste de Portugal Continental. Com uma área total de 14.840 ha, está organizado em duas áreas de gestão conjunta: ZIF de Entre-Douro-e-Sousa e ZIF do Paiva. A área é maioritariamente florestal e as espécies florestais predominantes são o eucalipto (*Eucalyptus globulus* Labill) e o pinheiro-bravo (*Pinus pinaster* Aiton) em povoamentos puros e mistos. Os incêndios rurais têm sido muito frequentes na área de estudo, com uma significativa extensão de área ardida na última década. Todas estas características do Vale do Sousa podem ser consideradas representativas da gestão florestal desta região.

A metodologia aplicada inova e integra a oferta de SE, a aplicação de abordagens multicritério e de decisão em grupo para responder aos quatro objetivos específicos da tese, estando estruturada em quatro artigos publicados em jornais científicos com revisão de pares (Capítulos II a V). O processo participativo apoiou o desenvolvimento desta investigação no Vale do Sousa, integrando dois workshops e um processo baseado em várias técnicas participativas, tendo decorrido de forma sequencial e interativa entre todas as fases:

(1) Aplicada a análise de atores, com base em 40 entrevistas presenciais, para identificação dos atores mais relevantes para a gestão florestal do Vale do Sousa, com análise dos seus interesses por SE e categorização dos problemas, conflitos, influência e recursos de poder relacionados com as decisões de gestão florestal (Capítulo II).

(2) Com base na informação do Capítulo II, foram convidados os principais atores florestais para um workshop e aplicada a técnica de questionários em duas fases (pré- e pós-questionário) para (a) quantificar as preferências dos atores por MGF, opções de gestão pós-fogo, funções florestais e SE; (b) discutir e selecionar MGF atuais e alternativos (misto de pinheiro-bravo e eucalipto, misto de eucalipto e pinheiro-bravo, puro de eucalipto, puro de castanheiro, puro de pinheiro-bravo, puro de carvalho-alvarinho, puro de sobreiro); (c) avaliar o impacto da informação e das discussões participativas nas opiniões dos atores e o efeito da interação social na sua aprendizagem e conhecimento (Capítulo III).

(3) Abordagem combinada de análise de decisão multicritério e tomada de decisão em grupo através da (a) elaboração com os atores de um mapa cognitivo para identificar e discutir os critérios e subcritérios mais relevantes nas decisões de gestão florestal; (b) com base na informação dos Capítulos II e III e no mapa cognitivo, estruturação da árvore de decisão e do questionário multicritério para elicitação da importância dos critérios e subcritérios através dum processo de comparação de pares (técnica de AHP - Analytic Hierarchy Process) e de avaliação do desempenho dos sete MGF (técnica SMART - Simple Multi-Attribute Rating Technique (SMART); (c) aplicação da técnica de Delphi, em duas rondas, para recolher as preferências dos atores (Capítulo IV).

(4) Alocação espacial de sete SE (biodiversidade, sequestro de carbono, cortiça, serviços culturais, erosão do solo, resistência aos incêndios rurais, madeira) aos talhões, de acordo com os objetivos de quatro grupos de interesse - agentes de mercado, administração pública, proprietários florestais e sociedade civil. Aplicada uma abordagem de Sistema de Apoio à Decisão Espacial Multicritério de Grupo combinando (a) os pesos da análise multicritério agregados por grupo de interesse (Capítulo IV); (b) discutidas soluções consensuais dos sete SE, em grupos focais, utilizando o método multicritério da fronteira de Pareto; (c) utilizado o Sistema de Apoio à Decisão de Gestão de Ecossistemas (EMDS - Ecosystem Management Decision Support), com sistema de informação geográfica (SIG), para priorizar a alocação dos SE aos talhões, à escala da paisagem (Capítulo V).

A análise de atores permitiu um diagnóstico aprofundado do atual contexto da gestão florestal no Vale do Sousa. De uma forma geral, verificou-se um grande interesse dos atores pelo fornecimento de madeira e regulamentação dos incêndios rurais. No entanto, quase metade dos atores identificou a floresta multifuncional como sendo a gestão florestal ideal para o Vale do Sousa. Na análise multicritério os atores atribuíram maior importância aos critérios do rendimento económico e aos riscos, e menor importância aos serviços culturais.

Na análise da preferência pelos MGF, os resultados foram distintos de acordo com a abordagem utilizada. No questionário simples os MGF preferidos foram os puros de pinheiro-bravo e de eucalipto e os MGF menos preferidos os puros de castanheiro e de carvalho-alvarinho. No entanto, nos resultados do questionário multicritério as preferências foram contrastantes, com os MGF puros de carvalho-alvarinho e de castanheiro a obterem os melhores desempenhos e o MGF puro de eucalipto o menor desempenho. De salientar que quando os atores responderam ao questionário multicritério tinha sido publicada legislação que restringe a expansão do eucalipto, pelo que os atores poderão ter procurado MGF alternativos ao do eucalipto.

O grupo dos proprietários florestais selecionou a produção de madeira como a primeira prioridade de alocação de SE, com prioridades mais baixas para os restantes SE. Em oposição, o grupo da sociedade civil atribuiu maiores prioridades à biodiversidade, cortiça e sequestro de carbono, tendo atribuído a menor prioridade à produção de madeira. Verificaram-se diferenças significativas nas pontuações de prioridades entre o grupo da sociedade civil e os outros três grupos, destacando-se os grupos da sociedade civil e dos agentes de mercado como os grupos mais discordantes. Os grupos mais concordantes foram os proprietários florestais e a administração pública.

A metodologia e os resultados obtidos podem contribuir para apoiar o planeamento da gestão florestal, antecipando problemas e conflitos e utilizando processos participativos com os atores para os resolver. As abordagens participativas demonstraram ser uma ferramenta com potencial para a negociação de soluções consensuais à escala da paisagem, as quais podem integrar os diferentes interesses dos atores e fornecer uma ampla diversidade de SE. Também sugerem que os workshops e as discussões participativas contribuem para o conhecimento social e a aprendizagem dos atores. São também uma oportunidade para melhorar o planeamento da gestão florestal promovendo planos de gestão colaborativos à escala da paisagem que podem contribuir para a diversificação dos MGF e de SE, melhorando a sua utilidade para os atores e facilitando a sua implementação.

PREAMBLE

This thesis is comprised of a set of four articles published in scientific peer-reviewed journals. It encompasses a detailed description of a participatory process, explaining the procedures of an actor analysis, multicriteria approaches, and group decision-making techniques, aiming at collaborative forest management planning. The contextualization and motivation of the work developed for the thesis are described in the general introduction (Chapter I). The scientific papers are included in the following chapters:

Chapter	Title
II	**Marques, M.**, Juerges, N., Borges, J.G. 2020. Appraisal framework for actor interest and power analysis in forest management - Insights from Northern Portugal. Forest Policy and Economics. 111, 14. https://doi.org/10.1016/j.forpol.2019.102049
III	**Marques, M.**, Oliveira, M., Borges, J.G. 2020. An approach to assess actors' preferences and social learning to enhance participatory forest management planning. Trees, Forests and People. 2, 16. https://doi.org/10.1016/j.tfp.2020.100026
IV	**Marques, M.**, Reynolds, K.M., Marto, M., Lakicevic, M., Caldas, C., Murphy, P. J., Borges, J. G. 2021. Multicriteria Decision Analysis and Group Decision-Making to Select Stand-Level Forest Management Models and Support Landscape-Level Collaborative Planning. Forests.12, 399. https://doi.org/10.3390/f12040399
V	**Marques, M.**, Reynolds, K.M., Marques, S., Marto, M., Paplanus, S., Borges, J.G. 2021. A Participatory and Spatial Multicriteria Decision Approach to Prioritize the Allocation of Ecosystem Services to Management Units. Land, 10, 747. https://doi:10.3390/land10070747

As the first author of these scientific papers, Marlene Marques was responsible for all the research and analysis in all studies and was the main writer. The co-authors assisted in the research design, analyzed the data, discussed the results, and edited the manuscripts. During the Ph.D. research, Marlene Marques made two international visits on the Corvallis Forestry Sciences Laboratory, Pacific Northwest Research Station - Forest Service, United States Department of Agriculture, in the USA. These two visits supported the development of Chapter IV (visit of 2018) and Chapter V (visit of 2019).

This research is part of the PhD funded and supported by the Portuguese Foundation for Science and Technology (FCT) under the Doctoral Program SUSFOR - Sustainable Forests and Products PD.00157.2012 and through the Doctoral Research Scholarship PD/BD/128257/2016. The work done for this thesis was also developed under the scope of the following research projects:

Period	Project Name	Type of Financing
2017 - 2020	ALTERFOR: Alternative models and robust decision-making for future forest management (grant agreement no. 676754).	European Union's Horizon 2020 Research and Innovation Programme
2017-2020	Forest Research Center (CEF) and Laboratory Terra, School of Agriculture (ISA), University of Lisbon (grant agreements UID/AGR/00239/2013 and UIDB/00239/2020)	Portuguese Foundation for Science and Technology (FCT)
2018 - 2019	SuFoRun: Models and decision support tools for integrated forest policy development under global change and associated risk and uncertainty (grant agreement no. 691149; H2020-MSCA-RISE-2015)	Marie Skodowska-Curie Research and Innovation Staff Exchange (RISE) within the H2020 Work Programme
2019 - 2020	BioEcosys: Forest ecosystem management decision-making methods - an integrated bio-economic approach to sustainability (grant agreement LISBOA - 01-0145 - FEDER - 030391 - PTDC/ASP - SIL/ 30391/ 2017)	Portuguese Foundation for Science and Technology (FCT) and Compete 2020
2019 - 2020	MODfIRE: A multiple criteria approach to integrate wildfire behavior in forest management planning. (grant agreement PCIF/MOS/0217/2017).	Portuguese Foundation for Science and Technology (FCT)
2019 - 2020	NOBEL: Novel business models to sustainably supply forest ecosystem services (grant agreement no. 773324) which is part of the ERA-NET Cofund ForestValue	European Union's Horizon 2020 Research and Innovation Programme

During the Ph.D., Marlene Marques collaborated with other research topics resulting in the following publications as co-author or author:

Type	Title
Article	Juerges, N., Arts, B., Masiero, M., Hoogstra-Klein, M., Borges, J. G., Brodrechtova, Y., Brukas, V., Canadas, M. J., Carvalho, P. O., Corradini, G., Corrigan, E., Felton, A., Karahalil, U., Karakoc, U., Krott, M., van Laar, J., Lodin, I., Lundholm, A., Makrickienė, E., **Marques, M.**, Mendes, A., Mozgeris, G., Novais, A., Pettenella, D., Pivoriūnas, N., Sari, B. 2021. Power analysis as a tool to analyse trade-offs between ecosystem services in forest management: A case study from nine European countries. Ecosyst. Serv. 49. https://doi.org/10.1016/j.ecoser.2021.101290
Article	Mesquita, M., Marques, S., **Marques, M.**, Marto, M., Constantino, M., Borges, J. G. 2021. An optimization approach to design forest road networks and plan timber transportation. Operational Research. https://doi.org/10.1007/s12351-021-00640-7
Article	Juerges, N., Arts, B., Masiero, M., Başkent, E. Z., Borges, J. G., Brodrechtova, Y., Brukas, V., Canadas, M. J., Carvalho, P. O., Corradini, G., Corrigan, E., Felton, A., Hoogstra-Klein, M., Krott, M., van Laar, J., Lodin, I., Lundholm, A., Makrickienė, E., **Marques, M.**, Mendes, A., Mozgeris, G., Novais, A., Pettenella, D., Pivoriūnas, N. 2020. Integrating ecosystem services in power analysis in forest governance: A comparison across nine European countries. Forest Policy and Economics, 121. https://doi.org/10.1016/j.forpol.2020.102317
Article	Marto, M., Reynolds, K. M., Borges, J. G., Bushenkov, V. A., Marques, S., **Marques, M.**, Barreiro, S., Botequim, B., Tomé, M. 2019. Web-based forest resources management decision support system. Forests, 10(12), 1079. https://doi.org/10.3390/f10121079
National Journal Article	Borges, J. G., **Marques, M.** 2019. Investigação europeia em gestão florestal faz testes no Vale do Sousa. ECO (jornal online) https://eco.sapo.pt/2019/10/10/investigacao-europeia-em-gestao-florestal-faz-testes-no-vale-do-sousa/
Report	**Marques, M.,** Lopes, L., Correia, F., Silva, C., Caldas, C., Borges, J.G. 2018. Gestão florestal das áreas comunitárias de Vale de Rio Mau e da Serra da Boneca. Resultados do processo participativo. 35 pp. Centro de Estudos Florestais, Instituto Superior de Agronomia, Junta de Freguesia de Rio Mau e Junta de Freguesia de Sebolido.
Report	Juerges, N., Krott, M., Lundholm, A., Corrigan, E., Masiero, M., Pettenella, D., Makrickienė, E., Mozgeris, G., Pivoriūnas, N., Lynikas, M., Brukas, V., Arts, B., Hoogstra-Klein, M., Laar, J. van, Borges, J.G., **Marques, M.**, Carvalho, P.O., Canadas, M.J., Novais, A., Mendes, A., Sottomayor, M., Pinto, S., Brodrechtova, I., Smreček, R., Bahýľ, J., Bošela, M., Sedmák, R., Tuček, J., Lodin, I., Başkent, E.Z., Karahalil, U., Karakoç, U., Sari, B. 2017. Internal Report on actors driving forest management in selected European countries. 388 pp. ALTERFOR project. Reference to reports and Research Papers available in https://alterfor-project.eu/

The research developed during the Ph.D. was presented at national and international conferences:

Oral communications as the first author

Marques, M. 2021. Online focus group planning. ALNUS Project Mid-Term Meeting, January 20. Online meeting via Zoom platform.

Marques, M. 2019. Análise Multicritério. Decisão em grupo. Gestão florestal. Café com Ciência. Centro de Estudos Florestais, Instituto Superior de Agronomia. 5 de dezembro de 2019. Lisboa.

Marques, M., Reynolds, K., Borges, J. G. 2019. Addressing forest and natural resources management planning with participatory processes. SuFoRun International Conference “Models and decision Support tools for integrated Forest policy development under global change and associated Risk and Uncertainty. – the SuFoRun experience”, September 24-27, Ubatupa, Brazil.

Marques, M., Reynolds, K., Borges, J. G. 2019. Addressing forest and natural resources management planning with multicriteria approaches and group decision-making techniques. SuFoRun participants meeting. July 16, Corvallis, USA.

Marques, M., Caldas, C., Borges, J.G. 2018. Work Package 4 - Reflection on Travellab. ALTERFOR 3rd cross-project meeting. June 12-14, Porto, Portugal

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CHAPTER I

General Introduction and Research Outline

I.1. Background

The European Union Forest Strategy (2014-2020) aims at sustainable forest management to protect and achieve the balanced development of multiple forest functions and at effective use of resources, including the provision of a diversity of ecosystem services (ES) such as the provision of wood and non-wood forest products, carbon sequestration, biodiversity, soil erosion protection, water quality, and recreational activities (E.U., 2021). The broad range of ES provided by forests contributes to the commitments of the European Union Biodiversity Strategy for 2030, the 2015 Paris Agreement on Climate Change, the 2018 Bioeconomy Strategy, and the 2030 Agenda for Sustainable Development, to support the European Green Deal, and to meet critical societal objectives (E.U., 2019; U.N., 2015a, 2015b).

However, under the increasing pressures of climate change impacts, markets, and social demand, forest management faces new challenges. Thus, forest management must improve sustainability and enhance the current goals focused on a few ES by also considering diversification, promoting a bio-economy, and involving different actors to achieve a more consensual sustainable forest management. It can be challenging for forest owners and managers to adapt their current forest management practices to this new demanding situation, considering other ES besides those that provide them with income.

Traditional forest management has mainly focused on economic wood production (McGrath et al., 2015; Puettmann et al., 2015). In the last decades, a large amount of scientific knowledge has addressed various stand-related techniques to improve production and quality (e.g., Cameron, 2002; Li et al., 2020; Yoshimoto et al., 2016), as well as forest management models (FMMs) that consider optimal rotations, harvesting, and sustainable yield (von Teuffel et al., 2006). This pool of knowledge provides a solid scientific base for traditional forest management practices, but management is often carried out, disregarding the emerging scientific evidence or lacking new evidence (Koning et al., 2014).

For Puettmann et al. (2015), the difference between traditional and alternative forest management approaches is based on the balance of selected values and objectives. The authors stated that traditional forest management emphasizes commodity production and only considers other objectives as constraints (e.g., accounting for natural processes, maintaining species diversity). In contrast, alternative forest management approaches emphasize explicit consideration of all values to achieve a sustainable provision of a set of ES. Likewise, there is a gap between the legislated or theoretical ideal forest management and current forest management practices (Başkent et al., 2005).

Even so, in the last decades, the demand for multiple ES has gradually increased due to societal demand (e.g., landscape and outdoor recreation) and concern for biodiversity, wildfires regulation, and climate change impacts (Wei et al., 2017; Zhai et al., 2020). Similarly, there is an increasing number of ES assessments (Bagstad et al., 2013; Häyhä and Franzese, 2014), some associated with different forest management alternatives (e.g., Biber et al., 2015; Duncker et al., 2012; Gamfeldt et al., 2013). However, ES assessments face substantial challenges and pitfalls, for example, the weakness or absence of trade-off analysis, the omission of fair compensation for non-market services, and often the mismanagement of economic valuation (Lele et al., 2013). Whereas stand-level decisions regarding FMMs implementation are essential, decisions about landscape-scale combinations of different FMMs that dictate ES outcomes related to, for example, biodiversity impacts or wildfire resilience are often not well formulated (Azevedo et al., 2014).

The cumulative scientific knowledge does not necessarily lead to forest management that best responds to the concerns, goals, or preferences of forest owners or forest managers, or even to the local population or to societal needs and interests, beyond forest product markets (e.g., timber). Most scientific research is usually conducted purporting relatively modest modifications of FMMs without considering more radical alternatives in the context of significant changes in sustainable management, that is, in the socio-bio-economic domains (Puettmann et al., 2015).

Forest management planning can be complex mainly due to the multiplicity of diverse criteria involved in the underlying decision-making process (Diaz-Balteiro and Romero, 2008; Ortiz-Urbina et al., 2019; Segura et al., 2014). The complexity of planning increases when sustainability is the objective because this requires a multi-faceted vision regarding actors' interests and priorities (Fabra-Crespo et al., 2012; Nordström et al., 2010). So, every decision made affects diverse criteria concerning economic (e.g., timber, hunting), environmental (e.g., biodiversity conservation, soil erosion), and social issues (e.g., recreational activities) (Diaz-Balteiro and Romero, 2008).

A participatory approach actively involves actors in the decision-making process, in which they affect, or are affected by, the issues to be addressed and contribute different interests and multiple objectives to forest management decisions and strategies (Martins and Borges, 2007; Paletto et al., 2016; Slocum, 2003). In recent decades, the application of participatory approaches has increased in policymaking, decision-making, and other issues that impact the public or specific actors (Bruges and Smith, 2008).

Article 7 of the 2015 Paris Agreement recognizes the importance of participatory approaches for integrating different actors and incorporating relevant socioeconomic and environmental policies and actions into climate change adaptation (U.N., 2015b). Article 12 is also dedicated to public cooperation and participation in enhancing actions under the Paris Agreement. Several authors have reinforced the importance of involving actors in the participatory decision-making process of environmental management (Acosta and Corral, 2017; De Meo et al., 2011; Kangas et al., 2014, 2010; Mendoza and Prabhu, 2006; Nordström et al., 2010; Saarikoski et al., 2010; Sheppard and Meitner, 2005; Vainikainen et al., 2008).

Actors with different interests and goals can generate conflicts in forest management decisions. Group decision-making is usually applied when distinct goals and potential conflicts of interest are involved (Mendoza and Martins, 2006). This method involves actors in forest management discussions and is considered to improve the quality of decisions by sharing their concerns and goals, potentially minimizing conflicts of interest, increasing the awareness of group responsibility within the forest owners and managers, and substantively improving the quality of decisions in terms of total social benefit (Buchy and Hoverman, 2000; Slocum, 2003). Moreover, the actors' involvement enhances communication, understanding and collaboration, builds trust, promotes shared solutions, gathers knowledge, and thus facilitates the implementation of forest management decisions (Bruña-García and Marey-Pérez, 2014; Juerges et al., 2018; Reed et al., 2010, 2009; Voinov et al., 2016).

Group decision-making is becoming increasingly relevant in natural resource management because multiple values are treated simultaneously in time and space, and numerous actors must be included in the decision process (Schmoldt and Peterson, 2000). Likewise, group decision-making is critical in joint management areas with many actors who have different interests, priorities, and points of view about how the forest should be managed (Martins and Borges, 2007).

There are different group interaction techniques in participatory decision analysis and group decision-making (e.g., workshops, cognitive mapping, questionnaires, Delphi surveys, focus groups, decision conferences) that help structure group goals, criteria, and preferences. However, participatory methods can only be selected when the objectives of the process have been specified, the level of actors' engagement has been identified, and relevant actors have been selected to be invited to participate (Reed, 2008).

The participatory decision-making process typically starts by surveying the actors involved and analyzing the decision context for valuable actors' involvement. Decision-makers need to understand who is involved, what interests they have, who is affected, and who influences or has the power resources to impact the forestry decisions (Reed et al., 2009; Voinov et al., 2016). The actor analysis technique can support this process by identifying the actors with interests, influence, and power in forest management decisions, the actors to involve, and providing a broad perspective on social involvement in decision-making (Grilli et al., 2015; Reed et al., 2009). The actor analysis technique has been widely applied in natural resources management (Bryson, 2004; Prell et al., 2009; Reed et al., 2009).

The complexity of decision-making is essentially due to the multiplicity of perspectives, constraints, and variables that should be considered in the decision, requiring the comparison of alternatives to achieve competing goals (Cinelli et al., 2020; Esmail and Geneletti, 2018). Raiffa (1968, p. 271) stated that "the spirit of decision analysis is divide and conquer: decompose a complex problem into simpler problems, get one's thinking straight on these simpler problems, paste this analysis together with logical glue, and come out with a program of action for the complex problem". Later Phillips (1990, p. 150) remarked that "decision analysis helps to provide a structure to thinking, a language for expressing concerns of the group and a way of combining different perspectives."

The decision analysis must be understandable by all actors, so the models should ideally be simple but not simplistic, because they need to adjust to the specific decision problem, be transparent, and allow the actors to identify with the process (Phillips, 2002). Moreover, understanding the fundamental decision objective (or objectives) is crucial for formulating the decision problem and specifying alternatives because trade-offs must be made in almost any decision problem.

Decision-making processes should be designed to apply participatory approaches, encouraging actors to be actively involved in forestry decisions, increasing social sustainability and social acceptability of the forest management decisions, and contributing to the success of the forest management policies or planning (Bruña-García and Marey-Pérez, 2014; De Meo et al., 2011; Juerges et al., 2018; Kangas et al., 2006; Martins and Borges, 2007).

Multicriteria decision analysis (MCDA), also referred to as Multicriteria Decision Aid or Multicriteria Decision-Making (MCDM), is a method that has been used for several decades to support decision-making by structuring decision problems and assessing a set of alternatives that reflects their suitability to the decision-maker by identifying and comparing multiple criteria, and by eliciting preferences in a straightforward representation, resulting in a ranking, or performance scores, of the alternatives (Belton and Stewart, 2002; Cinelli et al., 2020; Esmail and Geneletti, 2018; Marttunen et al., 2021). Belton and Stewart (2002) detail the theoretical foundations of MCDA approaches, present a comparative analysis of strengths and weaknesses and describe the key phases of the process.

MCDA is a suitable method to support forest management decision-making because its focus is supporting a wide range of decision criteria and actors with different goals and opinions, integrating their conflicting interests, and identifying alternatives (Ananda and Herath, 2009; Belton and Stewart, 2002; Castro and Urios, 2016; Keeney and Raiffa, 1993; Munda, 2005). Although MCDA typically deals with conflicting preferences, it can be considered a transparent method and a structured framework to improve discussion (Castro and Urios, 2016). Thus, MCDA can support forest management planning decisions by improving actors' relationships, selecting, prioritizing, or ranking the alternatives that best reflect their interests.

Subjectivity is inherent in decision-making. MCDA seeks to make the need for subjective judgments explicit and integrate them transparently, which is very important when multiple actors are involved (Belton and Stewart, 2002). One of MCDA's strengths is its ability to support group decision-making by integrating subjective values and priorities into the evaluation (Marttunen et al., 2021). Thus, MCDA methods are appropriate to deal with sustainable forest management planning (Ananda and Herath, 2009).

There is a growing application of MCDA methods to assess complex decision-making situations of natural resources with multiple criteria and objectives (Belton and Stewart, 2002), and there is an increasing interest in using multicriteria approaches and group decision-making techniques applied to forestry decisions (Diaz-Balteiro and Romero, 2008). MCDA has been applied to numerous natural resource management decisions for almost a century (Ananda and Herath, 2009; Diaz-Balteiro and Romero, 2008; Hujala et al., 2013; Kangas and Kangas, 2005; Maroto et al., 2013; Mendoza and Martins, 2006; Uhde et al., 2015). MCDA and group decision-making are powerful techniques for dealing with strategic decision problems (Borges et al., 2017; Maroto, 2015).

MCDA and group decision-making promote a shared understanding of the decision problem, but not necessarily consensus. Actors learn about others' opinions and priorities and defend their own, improving actors' relationships and increasing trust. MCDA and group decision-making can be more socially acceptable than the summary of individual opinions because it helps actors develop a sense of common purpose while discussing individual differences of opinion (Uhde et al., 2015). However, the consensus is a goal that takes time to achieve. It is necessary to involve actors throughout the process, and rarely do all actors have the same opinion. They will be more open to finding a group solution that meets the broader interests rather than focusing on individual interests (Sandker et al., 2010). When actors are familiar with group decision-making, they can learn from past decisions and share their knowledge with other actors to improve the group decisions. Group decision-making techniques incentivize actors to express their opinion and confidence in their preferences and make choices using MCDA approaches.

To select a decision-making approach, several issues need to be considered. The decision objectives, the time and budget available, the information required and available, the capability of actors to discuss and decide, the potential conflicts of interests, the actors' degree of involvement (Luyet et al., 2012; Voinov et al., 2016). Uhde et al. (2015) recommended hybrid methods for decision-making processes in comparison to the sole use of MCDA. Hybrid MCDA methods can integrate optimization, Geographic Information System (GIS) mapping, and Decision Support Systems (Ortiz-Urbina et al., 2019; Uhde et al., 2015).

Analysis of the future development of a forested landscape according to the group decision-making is facilitated using sophisticated Decision Support Systems (DSS). The FORSYS COST Action documented about 100 systems worldwide (Borges et al., 2014b). However, most DSS have been developed to support management decisions concerning timber production, and several systems are struggling with representing changes in wood demand structures (Hurmekoski and Hetemäki, 2013; Segura et al., 2014). Other challenges are using, and adapting them to, project different ES outcomes (Menzel et al., 2012) and support trade-off analysis and group decision-making (Borges et al., 2014a).

MCDA techniques integrated into DSS can facilitate group decision-making (Acosta and Corral, 2017; Reynolds et al., 2014; Shao and Reynolds, 2006). DSS are currently being used to combine local site-specific information such as inputs from groups' decisions to identify and rank priority integrated landscape proposals within the forest management planning framework and visualize the results in a spatial context supported by GIS.

Despite the importance of sustainable forest management with the diversification of ES and the involvement of actors in forest management decisions, the literature on MCDA applications in forest management decision problems involving group decision-making show a lack of applied research to Mediterranean forests and particularly to joint management areas involving several to many actors (Ananda and Herath, 2009; Diaz-Balteiro and Romero, 2008; Maroto, 2015; Mendoza and Martins, 2006).

I.2. Knowledge gaps and motivation

Although several policies aim to promote forest management in Portugal, these policies have been poorly implemented so far (Valente et al., 2015a). This situation is mainly due to the scarcity of participatory management initiatives involving actors in the forest management decision-making process (Valente et al., 2015b). Moreover, in joint management areas, e.g., ZIF (the acronym for *Zona de Intervenção Florestal* in Portuguese) and AIGP (the acronym for *Áreas Integradas de Gestão da Paisagem* in Portuguese), forest management challenges are even more prominent because they typically involve many small-scale forest owners.

In addition, traditional forest management practices in ZIF have only focused on a few ES (mainly wood provisioning). When the primary goal of ZIF is joint forest management, the involvement of forest owners and other actors in forest management decisions becomes even more demanding. The participation of the actors in the forest management planning decisions commits them to implement or support the planned forest management and promotes the feeling of belonging to the joint management.

To our knowledge, in Portugal, there are few references to the application of participatory techniques and group decision-making in ZIF to identify the interests and concerns of the actors, select and rank FMMs and prioritize the allocation of ES to management units (MUs). As one notable exception, Valente (2013) developed a stakeholder participatory approach (based on workshops and questionnaires) for discussing and negotiating local strategies for sustainable forest management in a ZIF in central Portugal.

In addition, Borges et al. (2017) applied a combined methodology of participatory workshops and multicriteria decision methods to support the development and negotiation of targets for the supply of ES in ZIF Chouto Parreira (Chamusca) and ZIF Paiva and Entre-Douro e Sousa (Vale do Sousa). Xavier et al. (2015) developed a methodology based on the multicriteria approach to support decisions for mitigating wildfire risk in a ZIF in the Algarve region in southern Portugal. However, these examples focused on specific subjects and not the broader context of forest management planning.

These gaps motivated this thesis; namely, the limited application of participatory approaches to joint management areas, anticipating problems and conflicts, involving actors in group decision-making, selecting the FMMs and the supply of ES, and prioritizing the allocation of ES. A successful approach to participatory forest management planning ideally starts by understanding the context encompassing forest management and then develops an exploratory and participatory process that best suits the actors' interests and goals. It is an opportunity to develop participatory methodologies suited to joint management areas that can motivate forest owners to implement the forest decisions in which they participate.

I.3. Objectives

This research tackled the knowledge gaps that constrain the participatory forest management planning in ZIF, addressing the following broad question: **"How can we facilitate the forest and natural resource management planning of joint management areas that best reflect actors' interests and priorities and the challenges of the 21st century?"** This question was addressed by researching a set of issues considered important to improve joint collaborative forest management planning by developing a participatory process that aggregates the preferences and objectives of actors. For this purpose, we outline four specific objectives of this thesis:

1. Identify the relevant forest management actors and characterize the forest management context thoroughly for a case study area.

2. Assess actors' key preferences for ES and FMMs and evaluate the impact of information and participatory discussions on their opinion and social learning.

3. Develop a combined MCDA and group decision-making process to identify and quantify the most relevant forest management decision criteria/sub-criteria and the performance of the FMMs.

4. Apply a Group Multicriteria Spatial Decision Support System approach to prioritize the allocation of ES to MUs.

I.4. Research outline and thesis structure

The research work evolved a methodology that innovates and integrates the supply of ES, multicriteria approaches and group decision-making to achieve the four specific objectives of this thesis. A participatory process supported the development of this research within a case study area in the form of two workshops and an iterative process based on several participatory techniques: face-to-face interviews and actor analysis (Reed et al., 2009), combined MCDA and group decision-making (Belton and Stewart, 2002), cognitive mapping (Eden and Ackermann, 2004), Analytic Hierarchy Process (AHP) pairwise comparisons (Saaty, 2008, 1980), Simple Multi-Attribute Rating Technique (SMART) (Goodwin and Wright, 2004), Delphi survey (Linstone and Turoff, 2002), multicriteria Pareto frontier method (Lotov et al., 2004), focus group (Krueger and Casey, 2015) and Ecosystem Management Decision Support (EMDS) (Reynolds et al., 2014).

The case study area selected to develop the research was Vale do Sousa, located in northwestern Portugal (Figure I.1). Covering 14,840 ha, the study area is organized in two joint management areas: ZIF of Entre-Douro-e-Sousa (North of Douro River) and ZIF of Paiva (South of Douro River). The two ZIF have a total of 360 forest owners (industrial and non-industrial). The forest ownership is mostly private and scattered among mostly small forest holdings. It is a forested landscape where the predominant species are eucalypt (*Eucalyptus globulus* Labill) and maritime pine (*Pinus pinaster* Aiton) in pure and mixed stands. Wildfires have been widespread in the case study area. Over the last decade (2009 to 2019), the total area burned extended to 11,719 ha in Vale do Sousa (ICNF, 2021). The years with the largest burnt area were: 2010 (1920 ha, 12.9% of the total area), 2016 (1763 ha, 11.9% of the total area), and 2017 (4006 ha, 27.0% of the total area). All these attributes of Vale do Sousa can be considered representative of the ZIF forest management of northwestern Portugal.

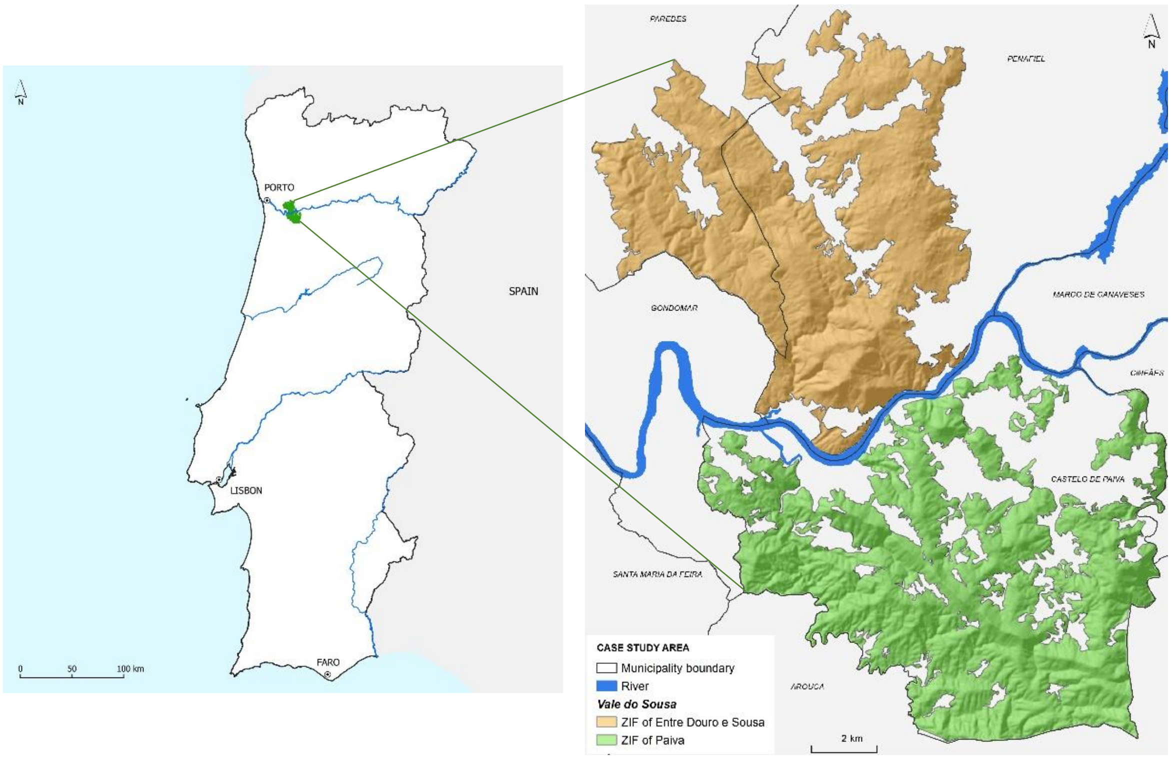

Figure I.1. Vale do Sousa case study area.

The thesis includes six chapters organized to achieve the four objectives (Figure I.2). Chapter I provides the objectives of the thesis and background for a better understanding of the research context developed throughout the thesis. The research is structured in four articles published in scientific peer-reviewed journals (Chapters II to V). The research process was sequential and interactive between all phases:

a) Chapter II develops an actor analysis, based on face-to-face interviews to identify the relevant forest management actors and other forestry-related actors for Vale do Sousa, analyzing their interests in ES, allowing forestry-related problems, conflicts, influence, and power to be categorized. Characterized how power resources, problems, and conflicts affect and influence forest management decisions. The actor analysis entailed the definition of clear roles for different relevant actors. The outputs from this chapter (actor analysis) provided the information needed to develop Chapters III and IV.

b) Given the information provided by Chapter II, relevant forest actors were invited to a workshop and responded to two-stage questionnaires to identify the key preferences of actors for ES and FMMs, to discuss and select current and alternative FMMs, and to evaluate how information and participatory discussions influence actors' preferences and social learning (Chapter III). The outputs of this chapter (ES and FMM preferences, FMMs alternatives) provided the information required to develop Chapter IV.

c) Chapter IV describes a combined MCDA and group decision-making approach. During a workshop, actors identified and discussed the most relevant criteria for deciding forest management (cognitive mapping technique). Taking further input from Chapters II and III and the cognitive map, we developed a multicriteria questionnaire (AHP, SMART, and Delphi survey) approach to quantify the criteria/sub-criteria weights and the performance of seven FMMs that best reflect actors' joint preferences. The outputs of this chapter (criteria and sub-criteria weights) provided data needed to develop Chapter V.

d) Chapter V applies a Group Multicriteria Spatial Decision Support System approach by combining the aggregated decision models weights from Chapter IV and the consensual solutions of multicriteria Pareto frontier method for seven ES, discussed in focus groups, into the Ecosystem Management Decision Support (EMDS) system with GIS to prioritize the allocation of ES to MUs at the landscape-level and spatially evaluated potential for conflicts of ES allocation priorities among interest groups.

Finally, Chapter VI presents general conclusions of the thesis, summarizing the contribution of the research work and identifying potential future research to improve the work developed.

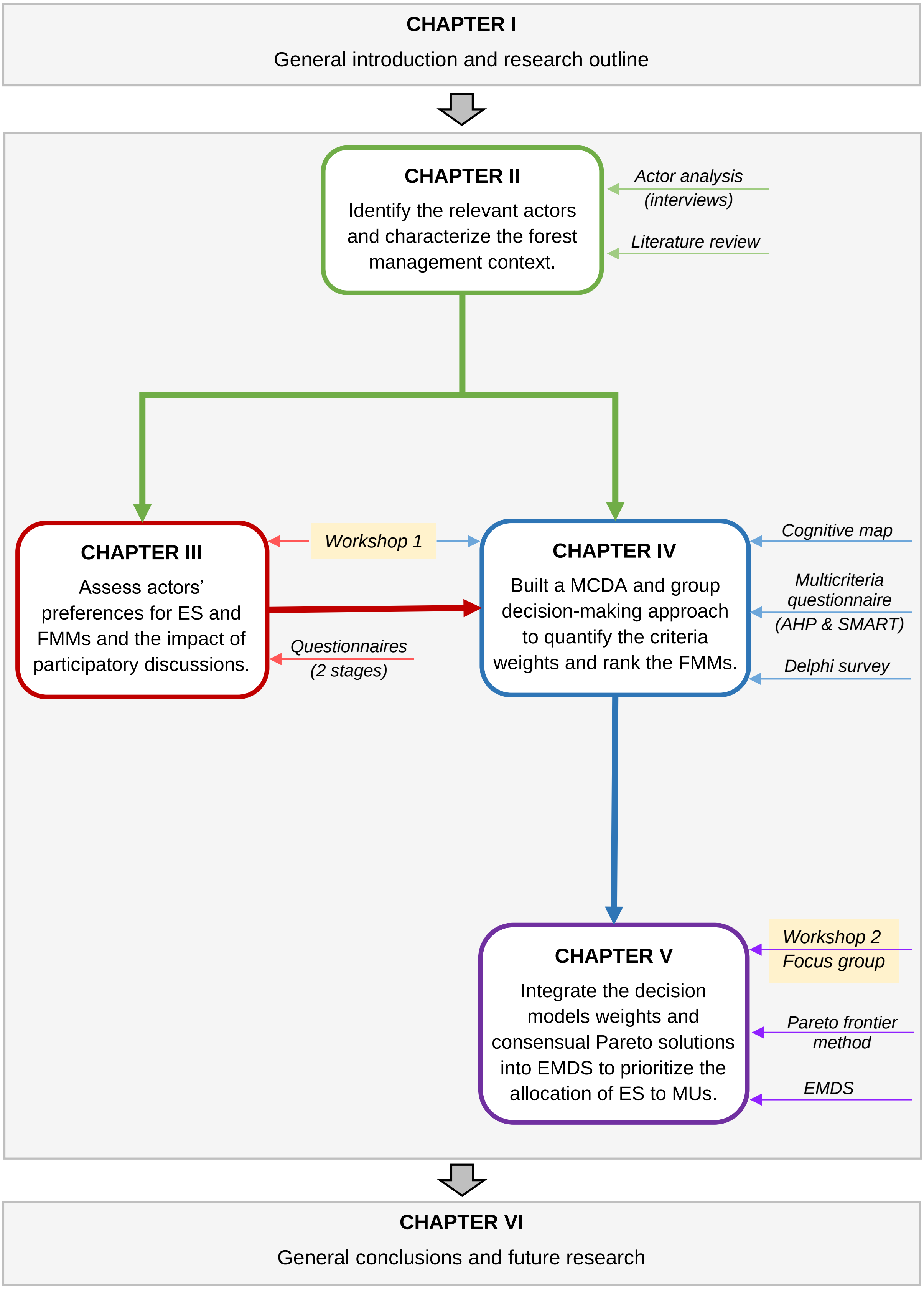

Figure I.2. Research outline and thesis structure.

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CHAPTER II

Appraisal framework for actor interest and power analysis in forest management - Insights from Northern Portugal

Paper published in *Forest Policy and Economics*

Marques, M., Juerges, N., Borges, J.G. 2020. Appraisal framework for actor interest and power analysis in forest management - Insights from Northern Portugal. Forest Policy and Economics. 111, 14. https://doi.org/10.1016/j.forpol.2019.102049

Forest Policy and Economics 111 (2020) 102049

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Appraisal framework for actor interest and power analysis in forest management - Insights from Northern Portugal

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ARTICLE INFO

Keywords:
Ecosystem services
Interests
Influence
Conflicts
Power resources
Forest management planning

ABSTRACT

Forest management is currently challenged by the need to address an increasing demand for a wide range of ecosystem services. Addressing this challenge requires landscape-level supply approaches that may bring together multiple interests and goals of forest actors. Characterizing these interests and the corresponding forest management context is thus a prerequisite for an effective landscape-level approach. In this manuscript we develop actor analysis to characterize a forest management context. We implement and test the analysis in Vale do Sousa, in North-Western Portugal. The analysis encompassed the identification of key actors and 40 interviews. Results show that the analysis provides a thorough diagnosis of the current forest management context in Vale do Sousa. The findings give a snapshot of the actors and factors – interests, influential actors, conflicts, problems and power resources – that frame forest decisions. Specifically, results show the keen interest of all groups on wood provisioning and on regulating wildfires. However, actors have also revealed a strong interest in water quality, soil erosion prevention, biodiversity, landscape aesthetics and environmental education. Thus, there is a significant interest in the diversification of the provision of ecosystem services. Almost half of the actors have identified the multifunctional forest as being the ideal forest management framework for Vale do Sousa. Findings thus evince the potential of a participatory approach to negotiate a consensual landscape-level solution that may integrate the different actors' interests and provide a wide range of ecosystem services. This may be facilitated by another finding from actor analysis. A regional Forest Owners Association was recognized as the most influential actor and may support the development and negotiation of multiple objective landscape-level forest ecosystem management plans. In summary, these results may contribute to a better understanding of the forest management context in Vale do Sousa and to supporting the effectiveness of forest management planning. They may contribute further to anticipate problems and conflicts and to develop with actors from Vale do Sousa participatory processes to address them.

1. Introduction

Pressures on forest ecosystems are very likely to increase as a consequence of socioeconomic and demographic trends. A growing population will demand more products (e.g., wood) to be extracted from forest ecosystems. At the same time, forest managers must cope with the impacts of these harvesting activities on the sustainability of the supply of a wider range of ecosystems services (e.g., wildfire protection, water, and biodiversity). Addressing this challenge requires a joint landscape-level approach to forest management planning. It requires further cooperation across ownerships with various interests and goals.

A key success factor to joint collaborative landscape-level forest management is the forest actors' involvement in the decision-making process (Martins and Borges 2007). Such involvement increases the social acceptance of measures and actions of forest management (Bruña-García and Marey-Pérez 2014). A participatory approach is an important tool to address different actor interests in ecosystem services and thus help develop effective forest management strategies (Borges et al. 2017; Martins and Borges 2007; Paletto et al. 2016). Actor analysis is a qualitative approach, which can be used to improve the understanding of issues related to forest management and thus contribute to the effectiveness of forest management planning at landscape-level and policy-making (Martins and Borges 2007). Actor analysis is the first step in a participatory process, as it includes the initial contact with the actors, and it sets up the process for organizing the actors' network for the following participatory stages.

Specifically, actor analysis provides insight into the main actors' concerns related to the forest management, from local to national level;

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https://doi.org/10.1016/j.forpol.2019.102049
Received 30 March 2019; Received in revised form 28 October 2019
1389-9341/

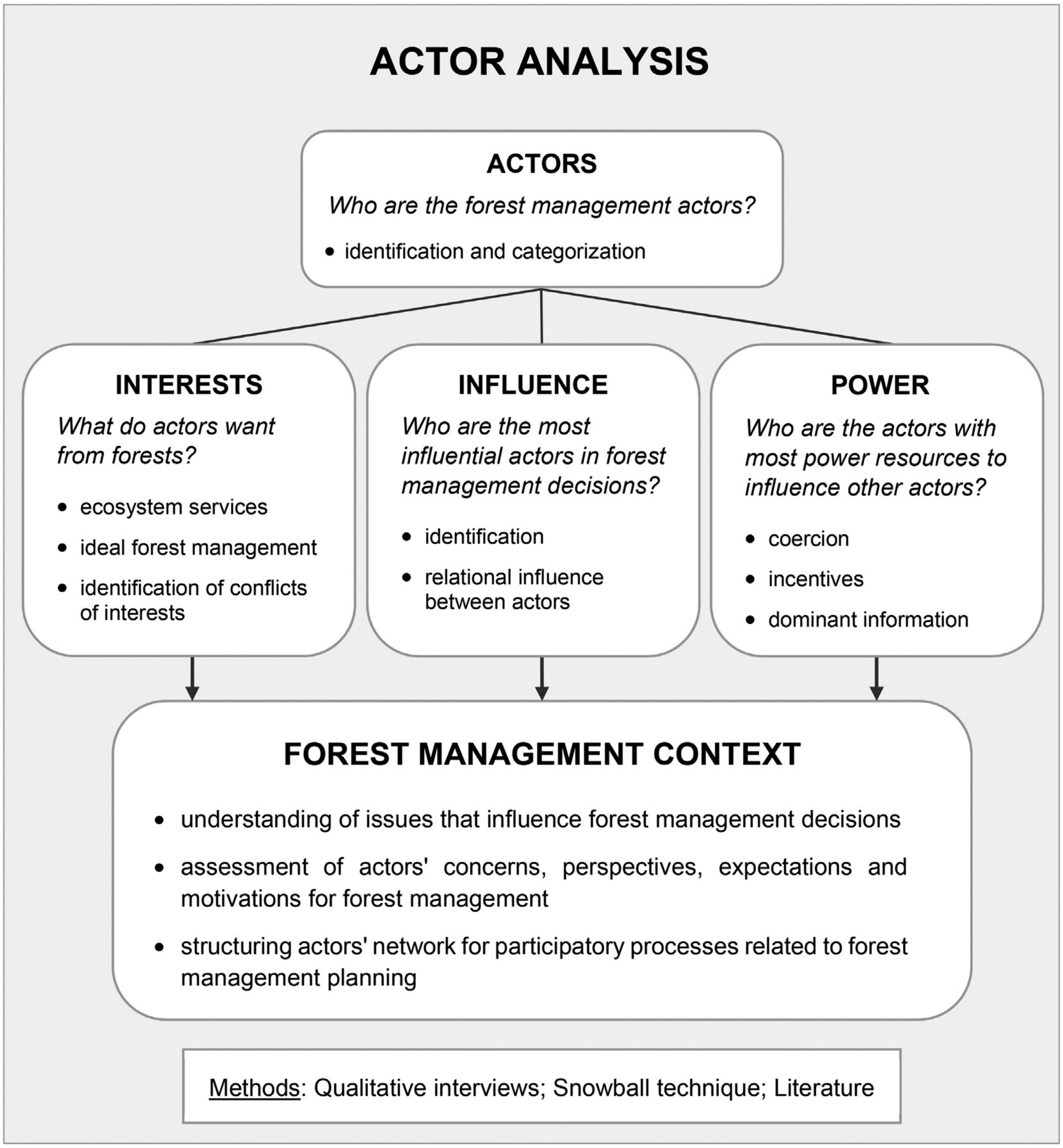

Fig. 1. Actor analysis framework for forest management context assessment.

assesses the influence and the power resources that different actors can have on forest management decisions; and identifies actors' relational influence. This kind of analysis contributes to the understanding of actors' perspectives and helps identify their motivations for forest management decisions (e.g., what forest owners want or need to diversify the provision of ecosystem services from their forest land). The actor analysis findings also provide forest managers, decision-makers or policy-makers with recommendations for the development of future actions, such as strategies for forest management, new policies or policy instruments (Raum 2018).

There are some examples of actor analysis associated with forest management in Portugal, e.g., Valente et al. (2015b) studied the main issues affecting forests and forest management in a municipality located in central Portugal, and Marta-Costa et al. (2016) analyzed stakeholder perceptions of forests and forest management in a conservation area in Northern Portugal. However, the research of actors' concepts of forest management is scarce (Feliciano et al. 2017), and no thorough analysis of actors' influence and power resources in forest management decisions has been developed in Northern Portugal. Generally, forest policy studies assume that all actors have the same interests or goals for forest management (Purnomo et al. 2012). Furthermore, in Portugal, there is a poor implementation of forest policies and management practices, and this is mostly due to the insufficiency of the participation of relevant actors in the decision-making process (Valente et al. 2015a). This context suggests the need for a thorough characterization of the forest management in order to increase the effectiveness of planning processes.

The main objective of this research was thus to develop and implement actor analysis to characterize thoroughly a forest management context. For that purpose, actor analysis entailed the identification of the forest management actors, the characterization of their influence and power resources, the highlight of their interests in ecosystem services, of main conflicts, and of problems that may impact forest management decisions. We start by presenting a short summary of actor analysis. We use a case study – Vale do Sousa – in North-Western Portugal to illustrate the development and application of actor analysis. It is a forested landscape extending over 14,840 ha, with a forest ownership structure characterized by small forest holdings, mostly privately owned. Vale do Sousa might be considered representative of actors' interests, forest management practices and forest ownership structure (Juerges et al. 2017). Nevertheless, its forest management context has not been characterized yet. This research addresses this knowledge gap. Specifically, it develops the analysis of the actors and factors (interests, conflicts, problems, and power resources) that influence forest management decisions in Vale do Sousa. In summary, the motivation for this research and its added value is to provide decision-makers with information and recommendations for enhancing policy instruments as well as forest management planning in joint management areas. By helping anticipate problems and conflicts this research may contribute to the effectiveness of participatory processes to develop joint collaborative management plans in Vale do Sousa. This research approach may also contribute to address joint forest management planning in other areas.

2. Theoretical background

2.1. Actor analysis

An actor is defined as "a social entity, a person or an organization, able to act on or exert influence on a decision. In other words: actors are those parties that have a certain interest in the system and/or that have some ability to influence that system, either directly or indirectly" (Enserink et al. 2010, p. 80). On the other hand, the term stakeholder refers to individuals, groups or organizations that have an interest or a stake in decision-making processes and can affect or are affected by an evaluation process or its findings (Bryson and Patton 2015; Enserink et al. 2010). In practice, both terms are often used as synonyms (Enserink et al. 2010). However, in our research, we use the term actor.

The actor analysis is rooted in the method more commonly known as stakeholder analysis (Enserink et al. 2010). An actor (or stakeholder) analysis can be described as "a holistic approach or procedure for gaining an understanding of a system, and assessing the impact of changes to that system, by means of identifying the key actors or stakeholders and assessing their respective interests in the system" (Grimble and Wellard 1997, p. 175). In addition, actor analysis produces knowledge that can be brought to the decision-making processes about the relevant actors involved in forest management (Fig. 1), i.e. their interests, influence, conflicts, problems, values, power resources, etc. (Brugha and Varvasovszky 2000), providing an overview of who is relevant in forest management and who is affected by a decision (Marttunen et al. 2017). This kind of findings and knowledge helps link forest actors to policy-making processes and forest management planning (Hermans and Thissen 2009).

The actor (or stakeholder) analysis has become increasingly popular in natural resources' management (Bryson 2004; Prell et al. 2009; Reed et al. 2009), reflecting a growing recognition of the importance of actors involved in environmental decision-making (Prell et al. 2009). However, a general evaluation of the scientific publications' frequency in the last three decades, included in the Expanded Web of Science database (2019), reveals that only 13 publications focus on actor (or stakeholder) analysis and forest management while 45 publications address actor analysis in a broader forestry context. There is a wide variety of tools and approaches for actor analysis in different contexts and disciplines (Bryson 2004; Hermans and Thissen 2009; Reed 2008; Reed et al. 2009). Methodologically, the actors' opinions, values and perceptions can be collected using different techniques from: a) primary sources, such as face-to-face interviews (using checklists or semi-structured interviews), structured questionnaires, focus groups (Enserink et al. 2010; Reed et al. 2009; Varvasovszky and Brugha 2000); and b) secondary sources, like published and unpublished documents, reports, policy statements, websites (Varvasovszky and Brugha 2000).

The actor analysis findings provide valuable information that can be used to propose or develop future policy-making actions such as new policies or strategies, policy instruments and recommendations (Raum 2018). They may be used further for the preparation of participatory processes (Hermans 2008; Nordström et al. 2010) or for forest planning, involving different forest owners in joint collaborative management areas (ZIF). In recent scientific publications, there are examples of actor (or stakeholder) analysis associated with forests and forest management (e.g., Kane et al., 2018; Pastorella et al. 2016; Sténs et al. 2016).

In the case of Portugal, we emphasize two studies associated with forest management. Valente et al. (2015b) analyzed the main issues affecting forests and forest management in a municipality located in central Portugal. According to the findings, the most important forest function for stakeholders was timber production. The main problems affecting forest management were forest fires, aging, depopulation and the abandonment of rural activities. Further, Marta-Costa et al. (2016) investigated the stakeholder perceptions about forests and forest management in a conservation area in the North of the country. According to the stakeholders' opinions, forest management is very affected by forest fires and agrarian abandonment, along with degradation of forest areas due to depopulation, old age, and absenteeism.

The findings from these two studies have revealed that the issues that have more influence on forest management in Portugal are forest fires, aging and abandonment of forest and related activities. Wildfires have been widespread in continental Portugal, burning extensive forest areas. In the years of 2003, 2005 and 2017 wildfires burned more than 200,000 ha of forest and shrubs area (ICNF 2018). In general, over the period 2001–2017 the total burnt area in continental Portugal amounted to more than 2 million hectares, which represents 36.5% of forest and shrubland (ICNF 2013, 2018). According to the last National Forest Inventory (ICNF 2013), the forest area decreased about 4.6%, from 1995 to 2010, which corresponds to a net loss rate of −0.3%/year (−10,000 ha/year). The decrease of forest areas is related to the occurrence of frequent and intense wildfires and pest and diseases, particularly in maritime pine stands (*Pinus pinaster*). Forest statistics (ICNF 2013, 2018) also report other trends such as the abandonment of agriculture (−12% of area) and the increase of shrubland (+4.7% of area).

2.2. Interests

Interests are understood as being "based on action orientation, adhered to by individuals or groups, and they designate the benefits the individual or group can receive from a certain object, such as a forest" (Krott 2005, p. 8). Actors' interests are associated with their goals, cultural values, and financial incentives. Asking an actor directly about their interests is a way of determining them. However, the actors may hide their real interests (Schusser 2013). Therefore, responses may not be enough, and interests should also be assessed through observations of actor behavior (Schusser et al. 2015). Thus, interviews are a useful technique for assessing actors' behavior and their responses regarding forest interests. A realistic estimation of actors' interests for ecosystem services or forest management can be incorporated into political decision-making or forest planning and help promote the development of win-win-strategies between forest actors and policy-makers or forest managers (Böcher and Krott 2016).

2.3. Influence

Actor influence is understood as the ability to alter other actors' behavior or perception of a situation, through information and communication, from what would have occurred without that information (Betsill and Corell 2001; Paletto et al. 2016). Usually, actors apply their influence according to their interests (Frooman 1999). Besides the identification of the most influential actors, it is also essential to understand the relational influence between actors, pinpointing with whom are they linked, how are the connections and its strength. Social network analysis (SNA) can help in the identification of relational influence, mapping the relations through a social network diagram, where the nodes are actors, and the ties are the connections between them (Kosorukoff 2011). The reader is referred to Aurenhammer et al. (2018) for details about an analysis of core values and beliefs of influential forest management actors, in five European countries (Germany, Slovenia, Spain, Portugal, and Latvia).

2.4. Power resources

Many authors (Arts and Van Tatenhove 2004; Betsill and Corell 2001; Krott et al. 2014; Sova et al. 2013) debate the complexity of the concepts "power" and "influence". For instance, Sova et al. (2013, p.12) refers that "power is often used interchangeably with the concept of influence (i.e., power produces influence and influence produces power)", and Krott et al. (2014, p. 35) argue that "forest policy authors use the terms 'influence' and 'capacity' to address processes similar to power". In contrast to influence, which derives from the relationship between actors, power can be based on resources or relations (Betsill and Corell 2001; Krott et al. 2014). In this study, power is defined as "the capability of an actor to influence other actors" (Krott et al. 2014, p. 35).

The power comes from the control of relevant resources, the asymmetrical distribution of resources or/and the ability of actors to mobilize resources to obtain the desired outcome (Arts and Van Tatenhove 2004; Brass 1984). Resources enable actors to influence the environment around them, including other actors, relationships, and rules in a network, increasing their capability to control or influence other actors with few alternative sources for acquiring the resource (Brass 1984; Enserink et al. 2010). The analysis of actors' power resources is useful to support decision-making of forest policy and forest management situations, where actors have different interests, the resources are limited and controlled by some of them (Mayers 2005).

3. Materials and methods

3.1. Case study area

The case study area of Vale do Sousa is located approximately 50 km East of Porto city, in North-Western Portugal region (Fig. 2). Vale do Sousa extends over an area of 14,840 ha and corresponds to two ZIF areas (joint collaborative management area), separated by Douro River: Entre-Douro-e-Sousa (North of the Douro River) and Paiva (South of the Douro River). In Vale do Sousa forests are the primary land use. The predominant species are eucalypt (*Eucalyptus globulus* Labill), for pulpwood, and maritime pine (*Pinus pinaster* Aiton), for sawlogs, in both pure and mixed stands. The forest holdings are privately owned, small scale and fragmented in multiple blocks (e.g., a forest owner with 36.4 ha of forest land held 50 blocks).

3.2. Actor analysis

The process of actor analysis encompassed three main stages: 1) the identification of actors, their characterization and classification into groups of interests; 2) qualitative interviews, conducted in a face-to-face meeting and call conference; 3) data analysis, coding the qualitative data, for frequency statistics, for mapping the actor's relations into a social network analysis (SNA), and for conducting a power resources analysis. For this study, we used qualitative interviews as the primary source of information and complemented it with information in the literature, e.g., previous studies and reports in Vale do Sousa (e.g., Integral Future-Oriented Integrated Management of European Forest Landscapes, 2015) and Portuguese forestry legislation.

3.2.1. Identification of actors

We started the research by the identification and characterization of the relevant actors who: a) had interest in forest management and ecosystem services; b) influence, directly or indirectly, forest management; c) were related to forestry and forest management; and d) were able and willing to talk about their viewpoints and expectations about forest management issues. The actors were identified by an interactive process (Reed et al. 2009) that involved three sources of information: a) list of stakeholders from a previous research project (Integral Future-Oriented Integrated Management of European Forest Landscapes, 2015) in Vale do Sousa (16 actors); b) research team contacts and regional Forest Owners' Association (AFVS) recommendations (17 actors); and c) results from the use of a snowballing technique, the interviewees were asked to identify other relevant actors who have influence or interests in forest management and could be involved in the actor analysis (seven actors). Not only individual persons (e.g., forest owners) were considered as actors but also organizations, institutions, and other relevant entities. Through this procedure, at the end of actor analysis, we identified, interviewed and characterized a total of 40 suitable actors (Table 1).

This approach allows flexibility in actors' identification and selection. Nevertheless, in order to avoid introducing bias in the analysis we included a) heterogeneous actors with a variety of interests; b) actors with potential influence and power over forest management decisions; c) actors with potential conflicts of interest with other actors; and d) forest owners with different forest size properties. The time frame and the financial resources constraints determined the number limit of actors interviewed. The actors were categorized into four groups according to their interests in forest management, based on interviews and literature: civil society, forest owners, market agents and public administration (Table 1). Interest groups can be defined as "organized groups with the aim to influence public policy without seeking to attain political office themselves" (Juerges and Newig 2015b).

3.2.2. Qualitative interviews

The first task of this stage was to develop the interview guide. It was first created in English and then translated and adapted to Portuguese (Juerges et al. 2017). Before the interviews, three researchers evaluated the guide for suggestions and improvements. Then two researchers pretested the interview guide. Also, the interviewer had training on how to conduct the interviews following the interview guide. To elicit actors' opinions with a qualitative-quantitative approach the interview guide encompassed both open-ended and closed-ended questions. It consisted of 27 questions divided into four thematic parts. In this manuscript we only present results from the Parts I and II. Part I focused on interviewed personal information, current position, role and years of work in the organization, forest-related work in Vale do Sousa within the last ten years, issues and concerns about silvicultural topics.

Next, Part II targeted the identification of the main actors' interests for ecosystem services, the current situation of forest management (decisions influence relations, conflicts and problems), and the ideal target forest according to the interviewee point of view. It elicited further a recommendation of other relevant actors to be interviewed (snowball technique). To evaluate the importance and interest for ecosystem services we provided a list of ecosystem services available in Vale do Sousa, according to the TEEB classification (TEEB 2010) and asked the interviewees the questions: "From your point of view, what are the most important forest ecosystem services in Vale do Sousa? And which is the level of importance for each forest ecosystem services, considering three levels: 0 = neutral; 1 = low importance; 2 = medium importance; 3 = strong importance?" The actors assigned high importance to the ecosystem services that they have more interest in or can get benefits from.

In order to perceive the influence on forest management decisions we asked the interviewees the following open-ended question: "Which actors or organizations are most influential when it comes to forest management decisions in Vale do Sousa?". To complement this information and analyze the relational influence of actors on forest management decisions, using the SNA technique, we asked the interviewees the following open-ended question: "With which individuals or organizations do you exchange information about silvicultural topics?". With the purpose of analyzing potential actors' coalitions, we also asked the interviewees: "Which individuals or groups do support your positions and interests?" and "Which do oppose your positions and interests?". To assess the main local conflicts and problems that may influence forest management, we asked the interviewees two open-ended

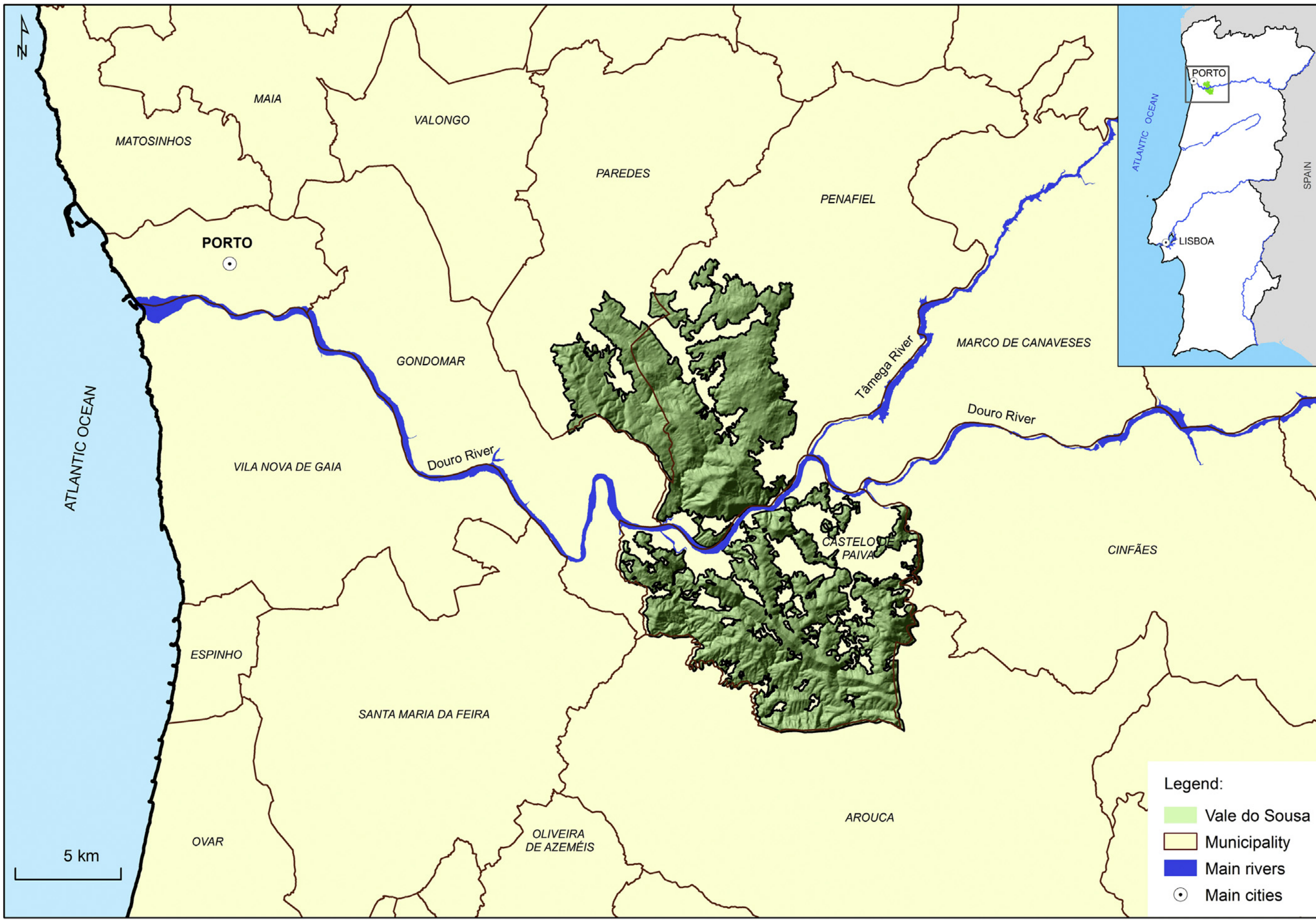

Fig. 2. Location of Vale do Sousa case study area in North-Western Portugal.

Table 1
Identification of actors, their categorization in interest groups, number of interviews and actors interviewed.

Interest group	Type of actor	Total of interviews	Actors interviewed
Civil society	Environmental NGO	3	3
	Forest certification	2	2
Forest owners	Forest owners' association	3	3
	Forest owner (non-industrial)	8	9
	Parish council with community properties	2	2
Market agents	Biomass industry	1	1
	Forest services provider	2	2
	Forest services provider and wood buyer	4	4
	Forest investment fund	1	2
	Wood industry	3	4
	Wood industry association	3	3
Public administration	Forest authority	5	6
	Municipality	3	3
	Total	40	44

questions: “What are the most important conflicts and problems in the forests of the Vale do Sousa that can influence forest management?” and “Which individuals or groups are involved in those conflicts or problems?”

The second task was interviews scheduling. An introductory email was sent to the actors explaining the importance of the study and asking if they were available for an interview. This contact was followed by phone calls to schedule the interviews. Some actors asked for the list of questions before accepting to be interviewed. The following task was the actors' interviews. The goal was to collect different opinions, perceptions and information about values, interests, influence and power resources related to forest management decisions. The interviews were semi-structured; it means that they were relatively open but followed a common interview guide (Juerges and Newig 2015a). The semi-structured interviews allow the collection of specific data in a structured way, with significant depth or “richness”, while keeping the focus sufficiently broad to accommodate other subjects and topics not considered initially (Reed et al. 2009; Varvasovszky and Brugha 2000). In the study, we carried out 36 individual interviews and four interviews with two interviewees from the same organization, totaling 40 interviews and 44 actors interviewed (Table 1). The interviews were conducted in a face-to-face meeting (35 interviews) or call conference (five interviews), between October and November 2016. We held face-to-face interviews at the actors' office, at home or another convenient location for them.

At the beginning of the interviews, the interviewer explained: a) the goal and the methodology of the actor analysis; and b) the location and land use of Vale do Sousa with the help of thematic maps. The interviewer ensured to the interviewees that their responses would remain anonymous to allow an open dialogue (Juerges and Newig 2015a). We recorded the interviews with the verbal consent of the interviewees. Only one actor did not allow recording, so the interview was written during the meeting. We structured the interviews for one hour but lasted from 32 min to one hour and 55 min, resulting in a total of 42 h, with an average of one hour and three minutes. The same interviewer conducted all the interviews working with the support of a supervisor. Collecting qualitative data by single analysts can ensure a uniform approach and higher reliability of data (Varvasovszky and Brugha 2000). The interviewer clarified with the interviewees some issues related to their answers and asked additional questions for more details when they approached new subjects or topics. The interviewer tried proactively no to bias the interviewees' responses, letting them speak freely and not encourage them to answer in a certain way (Bhattacherjee 2012).

3.2.3. Data analysis

We used a grounded theory approach (Charmaz 2006; Glaser and Strauss 1967; Reed 2008) to analyze the data. All material from the interviews, audio and written document, was transcribed and coded using MAXQDA Analytics Pro 2018, release 18.1.1 (Verbi GmbH, Berlin, Germany) software. For statistical analysis, we used the software IBM SPSS Statistics (Armonk, NY: IBM Corp.). The data analysis encompassed the following tasks:

a) First results and draft of the code's structure: during the interviews, the interviewer wrote down notes of the key issues, observations, comments, and behaviors, which may help interpret the interviewees' answers. With these notes, we organized in an excel file the first draft of codes structure, according to the main topics and keywords identified by the interviewees. This information encompassed the results of this primary data analysis.
b) Audio processing: we structured, in MAXQDA, the codes using the excel file from the previous task. All audio interviews were transcribed and coded in MAXQDA. We decided not to transcribe the audio *ipsis verbis* due to time consumption, but a summary with the most relevant issues and topics identified by the interviewees. During the audio coding, we refined the structure of the codes due to the identification of further codes. We grouped the codes into the thematic questions totalizing 27 groups of codes and 366 sub-codes. Coding the interviews aimed at creating quantitative data for statistical analysis and qualitative information for a report, a social network analysis (SNA) and power resources analysis.
c) Data processing: codes frequency statistics analysis, counting how often the interviewees mentioned each code (influential actors, supporters and opponents, conflicts and problems); median scores of the importance level of ecosystem services; interpretation of specific topics using the transcriptions (text analysis) and presentation of the results; development of SNA for assessing the actors relational influence.

The SNA is influential for quantifying, analyzing and visualizing the role and position of actors in the network and the relational influence among them (Paletto et al. 2016). We developed the SNA using the open source GEPHI 0.9.2 software (Bastian et al. 2009). For relational influence we applied a network centrality measure – the degree centrality. This measure refers to the number of nodes (individual actors) to whom an actor was directly tied or connected to (relationship) and represents the level of communication activity - the ability to communicate directly with others (Korhonen et al. 2018; Kosorukoff 2011; Freeman 1978; Mizruchi and Potts 1998). The actors mentioned more often have a high degree centrality. These actors have more relation and communication connections with other actors, and so they have a greater influence. The node position was determined firstly by using the "Force Atlas" algorithm layout, where the linked nodes are attracted to each other and the non-linked nodes are pushed apart, and secondly by clustering by interest group.

For analyzing actors power resources we assessed their power based on the actor-centered power approach (Krott et al. 2014), considering three criteria: a) coercion, altering behavior by force, including the threat of force and even bluffing about force that does not really exist; b) incentives, altering behavior by material and immaterial (dis-) advantage; and c) dominant information, altering behavior by unverified information trusted by the subordinate, ideology or expert knowledge. We evaluated the power resources of actors related to forest management in Vale do Sousa, on three levels: strong impact (+ + +), medium impact (+ +) or low impact (+). For this analysis, we used qualitative information from: a) actors' interviews; b) literature; and c) forestry legislation. Having strong power resources means that the actor can have a strong impact on forest management, often against the interests of others. In contrast, having low power resources indicates that the actor can apply the power strategy to some extent, but is not able to achieve his own interests against the will of others. Having medium power resources means that the actor can hold interests against the interests of some actors with few power resources but is not able to impact forest management substantially against the interests of actors who have stronger power resources. Furthermore, the categorization of actors according to their interests (Table 1) is also important to a clear identification of the powerful actors (Maryudi and Sahide 2017).

4. Results

From the 44 interviewed actors, 32 were male and 12 were female. Fifteen interviewed actors managed 2890 ha of forestland in Vale do Sousa, which represents 19.5% of the total area. Of the interviewees, the wood industry managed most of the area (15.2%), followed by parish council with community properties (2.2%) and non-industrial forest owners (2.1%). Of the nine non-industrial forest owners, six have inherited their properties and three purchase and have managed their properties for more than 20 years. The remaining actors have, on average, 15 years of experience in the forestry sector.

For 53% of the interviewed actors, the most critical issue related to their forest work is the wildfire, followed by forest management (50% of the actors) and forest certification (30% of the actors). About 65% of actors are very concerned with wildfires in Vale do Sousa and pointed out the size of the burned area, the improper use of fire and the high number of wildfires occurrences. They are also worried with the lack of forest management as a consequence of: a) abandonment or disinterest of forest owners (35% of actors); b) low investment in forest management (28% of actors); c) loss of forest value (28% of actors); and d) the complexity of the planning processes, namely the access to financial forest funds and the need for compliance with forest policy and laws (20% of the actors).

Over the last ten years the activities prominent in Vale do Sousa were fuel treatments for wildfire prevention (48% of actors), reforestation (40% of actors), thinning and eucalypt shoot selection (35% of actors), forest certification (30% of actors), environmental education and information (25% of actors) and harvesting (25% of actors). About 48% of actors considered multifunctional forestry to provide a wide range of ecosystem services, as the ideal forest management paradigm. Besides, the interviewees also indicated the need to promote joint forest management at the landscape scale (40%) as well as the forest profitability (25%).

4.1. Interests in ecosystem services

The results show some consensual ecosystem services interests by

Table 2
Interests of actors in ecosystem services according to the level of importance, by interest group.

Ecosystem service	Interest group				Total (n = 40)
	Civil society (n = 5)	Forest owners (n = 13)	Market agents (n = 14)	Public administration (n = 8)	
	Median				
Provisioning	1.0	1.0	2.0	1.0	1.0
Wood provision	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**
Game provision	1.0	1.0	1.0	1.5	1.0
Fish provision	0.0	1.0	1.0	1.0	1.0
Mushrooms	2.0	1.0	2.0	0.5	1.0
Medicinal plants	1.0	1.0	1.5	0.0	1.0
Honey	2.0	2.0	2.0	2.0	2.0
Supporting	**3.0**	2.5	**3.0**	2.0	**3.0**
Biodiversity	**3.0**	**3.0**	**3.0**	2.0	**3.0**
Habitats	**3.0**	2.0	**3.0**	2.0	2.0
Regulating	3.0	3.0	3.0	2.0	3.0
Wildfires reduction	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**
Pest and diseases control	1.0	**3.0**	**3.0**	2.5	**3.0**
Carbon sequestration	**3.0**	**3.0**	2.5	1.5	**3.0**
Climate regulation	**3.0**	**3.0**	**3.0**	1.0	2.0
Water quality	**3.0**	**3.0**	**3.0**	2.5	**3.0**
Soil erosion prevention	**3.0**	**3.0**	**3.0**	2.0	**3.0**
Cultural	**3.0**	**3.0**	**3.0**	2.0	**3.0**
Outdoor recreation	**3.0**	2.0	2.0	2.0	2.0
Landscape aesthetics	**3.0**	**3.0**	**3.0**	2.0	2.0
Tourism	1.0	2.0	2.5	2.0	2.0
Environmental education	**3.0**	**3.0**	**3.0**	2.0	**3.0**
Research & Development	2.0	**3.0**	**3.0**	2.0	**3.0**

n = number of interviews; 0.0 to 0.4 = neutral; 0.5 to 1.4 = low importance; 1.5 to 2.4 = medium importance; 2.5 to 3.0 = strong importance.

the different groups, e.g., provisioning of wood and regulation of wildfires. Actors have also a strong interest in water quality, soil erosion prevention, biodiversity, landscape aesthetics and environmental education. Nevertheless, they evince different opinions for other ecosystem services (Table 2). All groups have a keen interest in wood supply (timber, fuelwood and other biomass for energy). However, actors such as “forest owners” and “market agents” (e.g., wood industries) depend economically, directly or indirectly, on the forest. Thus, their forest management interests are for high harvesting intensities, because they are concerned with profitability, and for low amounts of shrubs in the forest because of wildfire risk. Most forest owners and forest managers support the selection of forest species and ecosystem services to address the market demand (from wood industries). Actors from “civil society” and “public administration” groups mentioned their interest in low harvesting intensities, long-term species, and different ecosystem services. The interests of nature conservation actors, from the “civil society” group, are related to the protection of forest resources. Their central ecosystem service interests are on nature conservation, with native broadleaves forests (e.g., chestnut) and a more biodiverse forest.

All groups are interested in high resistance to wildfires and pests and diseases, soil erosion prevention and water quality. The wildfires reduction has a keen interest for all actors within Vale do Sousa because of the substantial number of fires and the resulting burned area. Wildfires are a negative incentive to forest investment and management, affecting the multifunctionality of forests. The interest of cultural services actors' is for ecosystem services and forests that produce landscape enhancement and recreational opportunities.

4.2. Influence on forest management decisions

The majority of the forest actors interviewed (27 interviewees; 68%) have indicated the Forest Owners Association as the one with more influence in forest decisions (Fig. 3). The regional Forest Owners Association (AFVS – Forest Owners Association of Vale do Sousa) has been effective in influencing forest owners and their management practices when they ask for its technical advice. However, in general, forest owners apply traditional forest management practices without the benefit of a forest management plan or technical advice. Typically, the forest owners decide according to the example provided by neighbors (“forest management by imitation”). They also point out the Wood industry (20 interviews; 50%), due to the profitable forest management they practice and the market demand. Furthermore, they mentioned the National Forest Authority (14 interviews; 35%) and the Municipalities (13 interviews; 33%) because they define regulatory framework for forest management practices and they also provide technical advice when this is requested.

During the interviews, the actors frequently argued that proper forest management example is one of the most important tools to influence decision-making, because *“forest owners want to see good examples of forest management, only in this way they can be influenced, doing through the “imitation“ of what is profitable”* (PA5 - Regional forest authority). Moreover, “*focus on forest management demonstrating with examples that producing wood in a well-done manner, observing the good forestry practices and forest certification systems, with the least impact of forest operations is profitable. It is needed to scale the forest, and the ZIF can be a solution. It will be important to know how to integrate the different actors in forest management”* (MA3 - Pulpwood industry). However, *“forest owners would like to do forest management following good examples, but they did not even have money to manage forest fuels”* (FO11 – Parish council with community properties).

The SNA diagram of relational influence according to the degree of centrality (Fig. 4), shows that there are three distinct clusters of actors:

a) The actors who related with a large number of actors and can be considered as those who can influence or be influenced more significantly: regional forest owners association (FO1; FO2); national forest owners association (FO13); national forest authority (PA1); forest services providers association (MA14); municipalities (PA4, PA3; PA2); regional forest services providers and wood buyer (MA8; MA7, MA11; MA6); pulpwood industries (MA3; MA2).
b) The actors who related with a medium number of actors: non-industrial forest owners (FO4; FO3; FO6; FO5; FO7; FO8; FO9; FO10); regional forest authority (PA6; PA5); forest certification (CS5); wood industry associations (MA12; MA5).
c) The actors who have few relations and therefore can be considered as the ones with the weakest influence: regional forest services provider and wood buyer (MA9); wood industry association (MA10); environmental NGO (CS4, CS1, CS3); parish council with community properties (FO11; FO12); regional forest authority (PA8; PA7); forest certification (CS2); pine wood industry (MA4); biomass industry (MA13); forest investment fund (MA1).

We evaluated the coalitions between actors analyzing the supporters and opponents of the interviewees. Most interviewees (25 interviews; 63%) identified the regional Forest Owners Association (AFVS) as their main supporter, followed by forest owners (8 interviews; 20%) and associates of the interviewee entity (7 interviews; 18%). About 60% of the actors did not identify opponents, which does not necessarily mean that there aren't opponents. From these results and actors' interests,

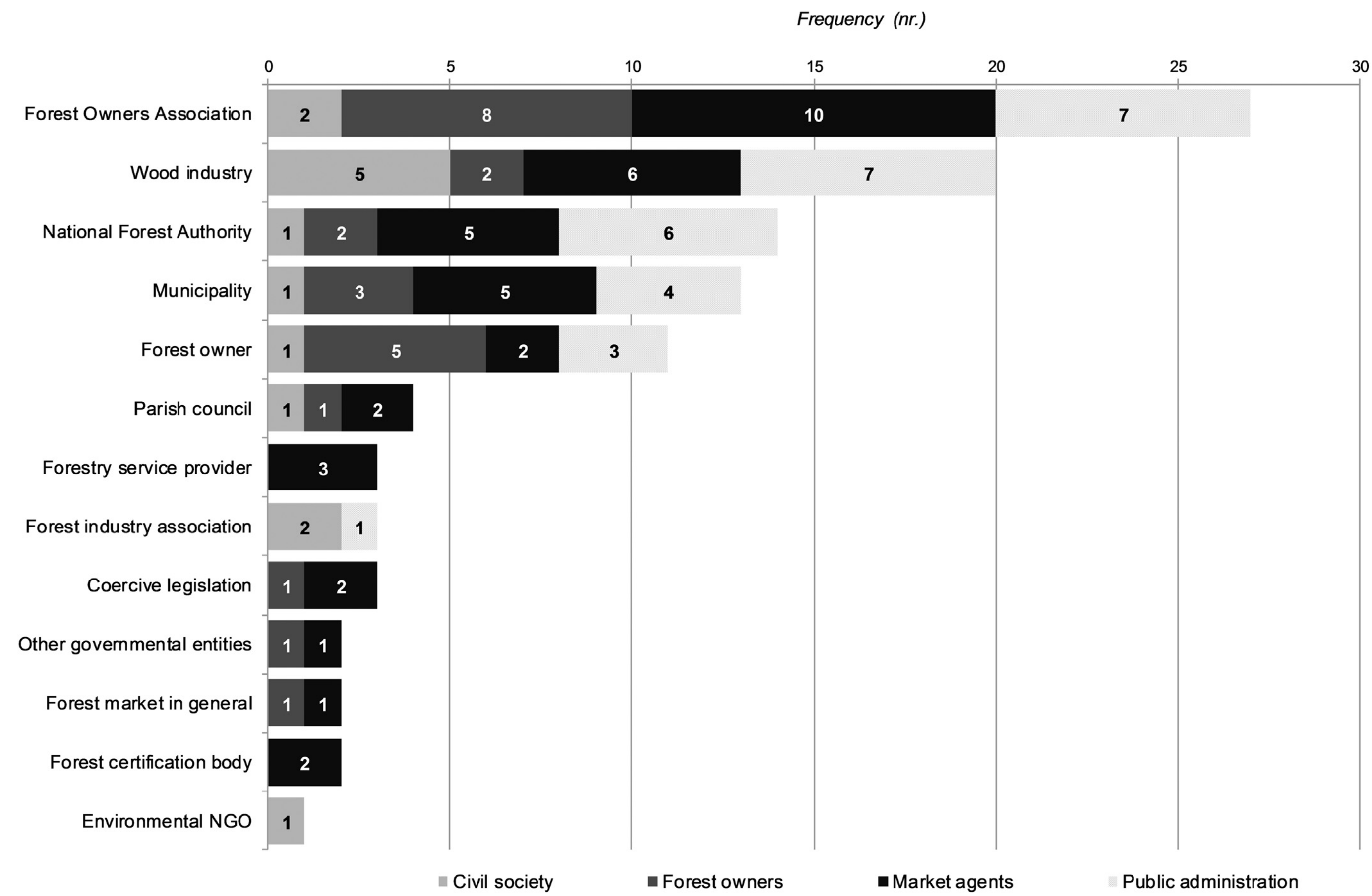

Fig. 3. Actors with influence when it comes to forest management decisions in Vale do Sousa, by interest group.

influence and actions targeting forest management it was possible to identify three main coalitions:

- Economic coalition, consisting of market agents (wood industry, wood buyers), forest owners (industrial and non-industrial) and forest managers. These actors have a strong interest in the economic profitability of the forest. The dominant model associated to forest management is focused primarily on wood provision. For example, this coalition opposes policy constraints to the use of eucalyptus plantations.
- Nature protection coalition, encompassing the national forest authority, municipalities, environmental NGO, forest certification bodies, forest owners with no economic interest in the forest (e.g. parish councils with communal properties). Their forest management focus is on the protection of forest resources, e.g. soil erosion and water quality, as well as the promotion of biodiversity and forest species diversification. This coalition is mostly interested in supporting and regulating forest ecosystem services.
- Social and recreational coalition, encompassing recreational and leisure organizations, motorized enthusiasts, population in general that develop recreational activities in the forest. Their interests have little reflection in national forest policies. However, in Vale do Sousa their interests and actions have an impact on forests and can be influential at the local level since they have free access to the forest even if it is private. Their forest management model stresses the recreational point of view.

4.3. Conflicts and problems that influence forest management decisions

Conflicts and problems influence forest management decisions. The interviewees point out distinct conflicts of interest in Vale do Sousa. Nevertheless, many agreed in listing two major conflicts. First, half of the interviewees stated that the outdoor motorized recreation activities, particularly the unorganized activities that take place in the forest without the authorization of forest owners, is the major forest management conflict in Vale do Sousa. These activities cause three types of impacts: a) on the forest, by the opening of rails in the forest stands, causing the destruction of the vegetation cover (forest and riparian galleries) and consequent soil erosion; b) financial, the forest owner has to pay for the recovery of the forest and the infrastructures (e.g., forest roads); and c) social, because of the stress to the forest owners (forest properties invaded and destroyed) as to the local population due to the noise it causes. This conflict is between the economic and nature proctection coalitions and the social and recreational coalition. The interviewees mentioned that this type of activities in forests should be regulated and controlled because of its negative impact on forests and the pressure on forest owners and the local population. *"There is an added advantage of organized activities as serve as surveillance regarding wildfires. However, the conflicts that occur are related to the unorganized motorized activities in the forest, i.e., the ones that happen without authorization request to cross private properties"* (MA2 – Pulpwood industry).

The second conflict, identified by 40% of the interviewees, was between the monoculture of eucalypt for wood supply and biodiversity. This conflict is between forest owners and managers (economic coalition) and the National Forest Authority and environmental NGO (nature protection coalition). *"The lack of forestry planning, on the landscape scale, leads to the difficulty of the owner to understand that on his property he cannot plant eucalyptus in ecological corridor area without being compensated for this (trade-off of not having a productive forest to provide a non-market ecosystem service). Is important to find payment mechanisms for non-market ecosystem services so low productive areas can be a conservation*

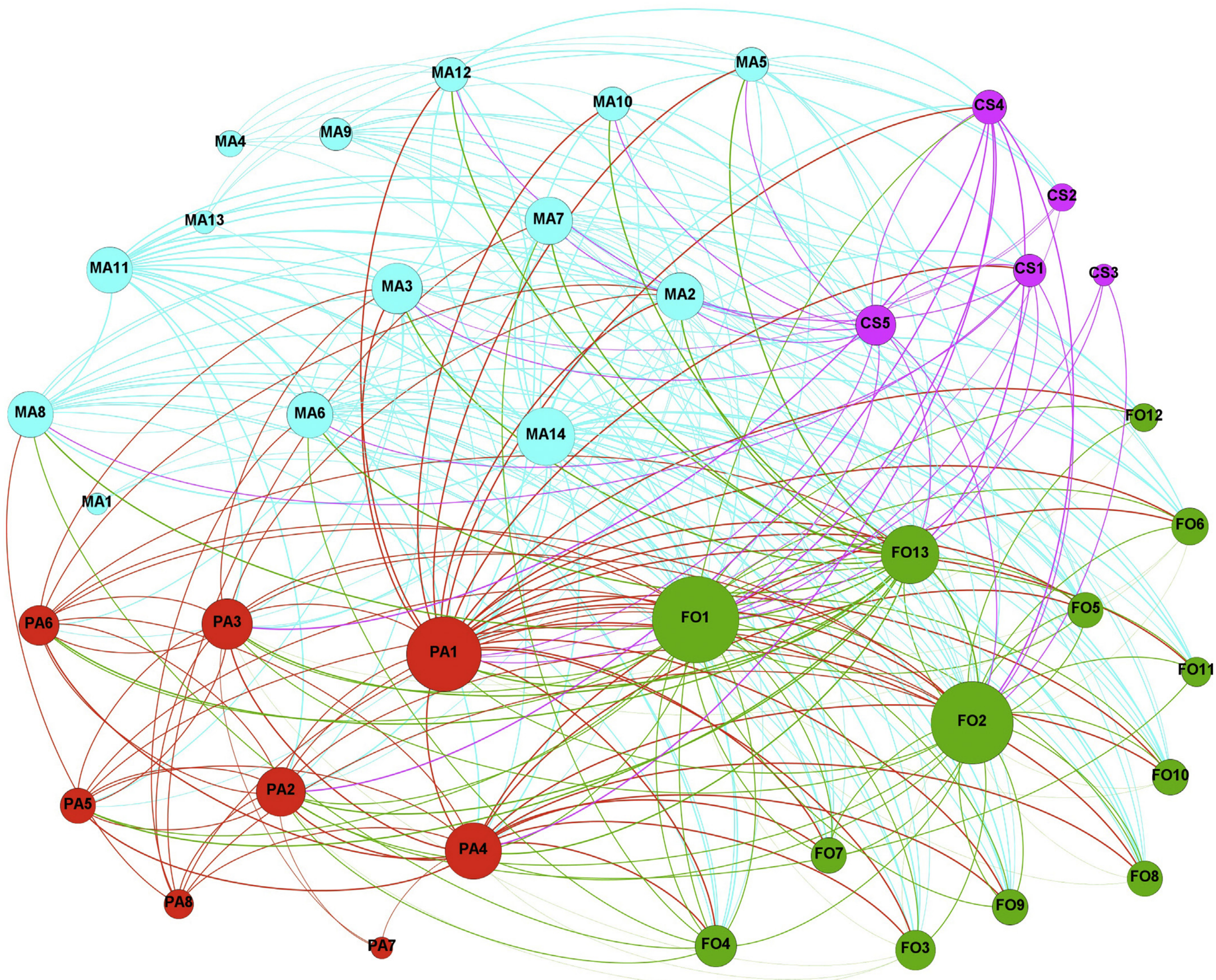

Fig. 4. Social relational influence network (n = 40). Nodes are sized according to the degree of centrality, the larger the node, the more information is exchanged by the actor with other actors (CS = civil society; FO = forest owners; MA = market agents; PA = public administration).

area. These conflicts should be managed through dialogue between forest owners and public administration" (CS1 – National environmental NGO).

The interviewees identified a range of problems in Vale do Sousa that influence the decisions (Fig. 5). For most of them (37 interviewees, 93%) the problem that can influence most forest management decisions is wildfire risk. Over the period, 2001–2017, a total of 16,756 ha were burnt in Vale do Sousa. In 2005 about 5383 ha (36.3% of total area) and in 2017 circa 4006 ha (27.0% of total area) were burned, respectively. These events greatly influence forest management decisions of forest owners and forest managers. They prefer short rotation eucalypt stands (10 to 12 years coppice) because, overall, the income loss is smaller in the case of a wildfire occurrence (big fires cycle is about ten years). Therefore, forest species with longer rotations, such as maritime pine or chestnut *(Castanea sativa* Mill), are less preferred by forest owners.

"In Vale do Sousa there is a serious problem of wildfires, with a high number of fires occurrences. It will be important to solve the problem of wildfires as well as the value of the forest. The application of good forestry practices will address many of the problems of wildfires, and its consequences, like soil erosion" (MA3 – Pulpwood industry) and *"wildfires are so problematic that it leads forest owners to give up the forest management"* (FO7 – Forest owner). Furthermore, *"climatic conditions favor the rapid development of shrubs, increasing the fuel load and making the task of fuel management more difficult and costlier for forest owners. They only invest in forest management if the forest has value or is mandatory by law. Is also important to change the use of fire in the forest; it can be achieved through information, forest awareness, and forest management"* (PA5 – Regional forest authority).

The invasive alien species are also a problem (31 interviewees, 78%) because of the difficulty in its control, which is scattered throughout Vale do Sousa. In the managed forest areas, it is not a problem because invasive alien species are controlled. However, the interviewees stated that *"the wildfires promote the appearance of invasive alien species"* (CS4 – National environmental NGO) and *"if there is no forest management will be complicated to control invasive alien species. Where there is acacia, the other forest species have serious difficulties to survive. Moreover, the wood industry does not want acacia wood"* (MA6 - Regional forest services provider and wood buyer).

Pest and diseases have affected the forest and are nowadays a severe problem in Vale do Sousa (30 interviewees, 75%). Earlier, the pine nematode (*Bursaphelenchus xylophilus*), and more recently the *Gonipterus platensis* in the eucalyptus stands. According to the interviewees, this problem is also related to the wildfires because "*pest and diseases are one of the collateral damages of the wildfires caused by the imbalance in the forest ecosystem*" (MA14 - Forest services providers

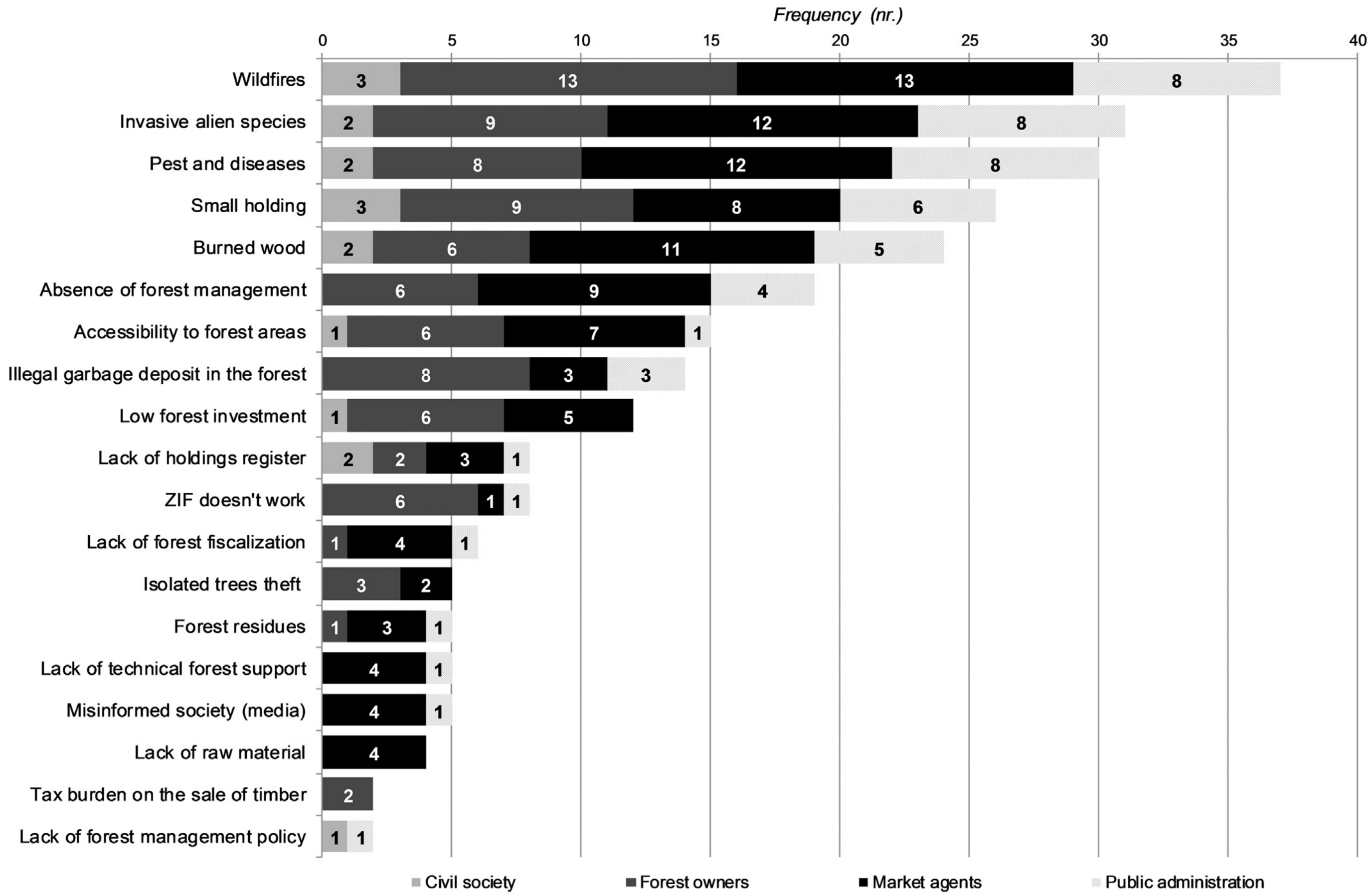

Fig. 5. Problems that can influence forest management decisions in Vale do Sousa, by interest group

association) and *"extensive areas with the same species provide the spread of pests and diseases"* (CS4 - National environmental NGO).

4.4. Power resources to influence the forest actors' decisions

The results indicate that "market agents" and "public administration" groups have the strongest power resources to impact forest management in Vale do Sousa, while "forest owners" and "civil society" groups have a medium power (Table 3).

The "market agents" group controls the wood market prices and therefore employ indirect coercion in the choice of species by the forest owner. The direct coercion is related to the demand and control of wood or biomass which the industry wants to receive. The demand for wood and the prices offered are incentives for forest owners to follow the preferences of the timber industries in the choice of forest species as well as of the intensity of cutting. Further, some actors within the

Table 3
Overview of power resources of different interest group in Vale do Sousa.

Interest group	Means of coercion	Incentives	Dominant information	Overall power resources
Civil society	+ +	+ +	+ +	Medium
Environmental NGO	+	+	+ +	Low
Forest certification	+ +	+ +	+ +	Medium
Forest owners	+ + +	+ +	+ +	Medium
Forest owners' association	+ +	+ + +	+ + +	Strong
Forest owner (non-industrial)	+ + +	+	+	Medium
Parish council with community properties	+ + +	+	+	Medium
Market agents	+ + +	+ + +	+ + +	Strong
Biomass industry	+ + +	+ +	+ + +	Strong
Forest services provider	+ + +	+ + +	+ + +	Strong
Forest services provider and wood buyer	+ + +	+ + +	+ + +	Strong
Forest investment fund	+ +	+ +	+ + +	Medium
Wood industry	+ + +	+ + +	+ + +	Strong
Wood industry association	+ +	+ +	+ + +	Medium
Public administration	+ + +	+ +	+ + +	Strong
Forest authority	+ + +	+ + +	+ + +	Strong
Municipality	+ + +	+	+ +	Medium

+ + + = strong impact; + + = medium impact; + = low impact.

“market agents” group do training actions for forest owners and other actors, advising them about the species to select and how to manage the forest. Unverified information on forest management is disseminated in direct contact with forest owners, providing advise. Some industries play a role in the enhancing of forest management practices by developing research, owning nurseries and publishing technical forestry information.

The “public administration” group has a coercive authority through forestry policy, legislation, and authorizations related to forest management. The power resources are mainly *“through legislation and regulations that determine how forest management should be done. Besides, the approval of the forest management plans by the public administration constraint the individual options for the forest property”* (PA1 - National forest authority). The group establishes material incentives through the financing of forest management measures and immaterial incentives over the national forest management strategy, legislation and other obligatory regulations. *“The financial incentives are a way of motivating forest management”* (PA5 - Regional forest authority). The group has its own information (forest inventory and several technical studies). They hold technical sessions and training actions and develop research in partnership with Research Centers. They publish technical forestry information.

The coercion of “forest owners” group is based on the direct access to forests and decision-making power over properties based on their private property rights. In Vale do Sousa forests are mainly privately owned. Therefore, private forest owners have the ultimate forest management decisions (e.g., species, harvesting). The Forest Owners Association incentives morally forest owners to manage their forest and not to abandon it. They also provide to its members and other forest owners' technical advice and information about public policy instruments related to forests.

The Forest Certification body, from “civil society” group, exerts coercion through the grant or withdraw of the forest management certification. This actor establishes immaterial incentives by appealing to moral standards, giving a label for more sustainable forest management and providing, indirectly, market incentives due to increased prices for certified timber. The environmental NGO defends biodiverse forests and develops diverse projects to persuade the plantation of an autochthonous forest. This actor has a limited impact in Vale do Sousa but establishes immaterial incentives by appealing to moral and norms as environment and nature advocates. The group has several studies and publications related to forest management. The groups “civil society”, “market agents” and “public administration” disseminate unverified information on forest management in lobbying, public relations, contribution to research projects, reports, technical documents and general participation in public discourse (workshops, seminars, meetings, working groups, media).

Results show that the strongest actors, i.e. the actors with the same overall power resources classification (strong in the three levels of power analysis) are: “Forest services provider”, “Forest services provider and wood buyer”, “Wood industry” and “Forest authority”. The three actors from the “market agents” group are directly involved in forest management either by working with forest owners or else by managing their own forest areas. The “Forest authority” is indirectly involved in forest management by both a) coercion, e.g., authorizing (or not) specific management options (e.g. species use), and b) providing subsidies. Forest management is strongly influenced by these four actors because they have relevant power resources to influence the others actors' actions and decisions.

5. Discussion

The purpose of this study was the development of actor analysis to characterize the forest management context in Vale do Sousa. This entailed the identification of the main actors and of issues that influence the forest management decisions (interests, influential actors, conflicts, problems, and power resources). This knowledge is needed to increase the effectiveness of forest management planning. These results may help ZIF managers develop a collaborative landscape-level management planning process to target the provision of a wide range of ecosystem services. The development of this process will benefit from the actor analysis results as it calls for the coordination of decisions made by the actors involved. The actor analysis highlighted a strong interest for wood provision and wildfires reduction, and also revealed a keen interest in water quality, soil erosion prevention, biodiversity, landscape aesthetics and environmental education. This may help managers set priorities to engage ownerships and actors in a multiple objective forest management planning process.

Moreover, the identification of the main conflicts and problems that impact and influence forest management is also very useful to ZIF managers. The findings highlight the need to balance the interests between the economic and nature protection coalitions and the social and recreational coalition. The unorganized outdoor motorized recreation activities are one of the conflicts of interest that can most negatively influence forest management in Vale do Sousa. Actors considered this conflict as a disincentive to forest management. The proximity of Vale do Sousa to the second largest city in Portugal leads to an intensive use of the forest for a range of cultural activities. This pressure and the resulting conflict reinforce the importance of integrating cultural services into forest management planning by ZIF managers. Furthermore, these findings highlight the need of regulation and supervision of outdoor motorized recreation activities, safeguarding the interests of forest owners. The effectiveness of this regulation may build from the promotion of awareness among sports enthusiasts and the population in general about the impacts of these activities. ZIF managers may promote further the dialogue between forest owners and sports enthusiasts to develop a negotiated balance between interests in provisioning and cultural services.

ZIF managers also need to balance conflicting interests between wood production and biodiversity. Actors concerned with the profitable use of forests (economic coalition) are not opposed to nature conservation and increased biodiversity as long as they receive payments for the ecosystem services they provide. Thus, this conflict might be addressed by adequate policy instruments to internalize forest externalities. Nevertheless, the Forest Owners Association as one of the most influential actors in forest management may support the development and negotiation of multiple objective landscape-level forest ecosystem management plans and the estimation of opportunity costs associated with conservation strategies. This may be influential to the design of adequate policy tools to promote the supply of biodiversity.

The results also underline the importance of forest management to address the main problems in Vale do Sousa acknowledged by the interviewees - wildfires, invasive alien species, and pest and diseases. According to the interviewees' experience, forest management plans may be designed to prevent and control invasive alien species as well as to consider a wider range of ecosystem services. The impacts of wildfires can be reduced with landscape-level planning targeting wildfire resistance levels. ZIF managers may use this information to help forest owners understand the spatial and temporal interactions of forest management decisions and their impact on the provision of regulatory ecosystem services. According to the interviewees the abandonment, the disinvestment, the disinterest in forest management and the decrease in forest value result from the lack of strategies for addressing the conflicts and the problems to forest management. This research has provided information that may be useful to develop these strategies by ZIF managers, namely, to motivate forest owners to develop landscape-level forest management to contribute to a forest more resilient to wildfires and to pest and diseases.

This research showed further that almost half of the interviewees target a multifunctional and profitable forest providing a wide range of ecosystem services. However, it highlighted further that different interests for ecosystem services can lead to different ideas regarding the ideal forest management for Vale do Sousa. This diversity of interests suggests the use by ZIF managers of participatory techniques to help actors discuss and negotiate their interests. This research also showed that payments for non-market ecosystem services would be influential to develop a multifunctional approach to forest management that can be economically sustainable for forest owners.

Powerful actors, from "market agents" and "public administration" groups, can have a relevant role in promoting a landscape-level multifunctional forest manaagememt approach, mostly through material incentives and information. Namely, it will be important to develop business models to attract payments for non-market ecosystem services. The "public administration" group manage financial incentives programs and may promote this kind of mechanisms. The "market agents" group can support the non-market payment mechanisms as a social responsibility for the use of natural resources. These actors have dominant information and can work together to disseminate forest management alternatives that integrate different ecosystem services. This information should be clearly explained, with reference and demonstration of current examples: a) the basket of ecosystem services available in Vale do Sousa (what); b) the forest management practices (how to do); and c) all the costs and expenses, i.e., the net present value (how much).

The results of this actor analysis can be compared with other studies reported in scientific publications. Our findings reinforce that wildfires are the most influential problem in forest management decisions in Portugal (Marta-Costa et al. 2016; Valente et al. 2015b). They also confirm the actors' interests for cultural and regulating services (Clemente et al. 2015). The findings can be different according to the region and socioeconomic context. For example, in the Aurenhammer et al. (2018) research, market and state were considered the most influential actors. Conversely, in this study, the Forest Owners' Association was acknowledged as the actor with more influence. The present research analyzed the actors involved in forest management and presents information not yet documented in scientific studies, namely the relational influence and power resources in a Portuguese region. This research is influential to promote adequate forest management strategies.

Actors' opinions and perceptions can be collected using different techniques such as interviews, focus groups, questionnaires (Brescancin et al. 2018; Varvasovszky and Brugha 2000). Interviews are the most personalized form of data gathering (Bhattacherjee 2012). The main advantages are: a) building trust and relationships with actors (Reed et al. 2009); b) collecting qualitative and quantitate information asking the actors for more details about their opinions; c) understanding their behavior and emotions; d) explaining the questions and avoid misunderstandings; and e) all actors have the same opportunity to express themselves on the same issues.

Nevertheless, interviews are time and financial consuming technique and need personal involvement and interviewer training. The interviewees identified 19 more actors they considered relevant for the study. However, due to the time and budget limitation, it was not possible to interview them. Although, they were invited to take part in other participatory events in the frame of the study (workshops, questionnaires). Interviews and processing were time intensive; the actors' interviews were long (over one hour), resulting in 42 h of recording to process and analyze. Nevertheless, we got a rich understanding of the different points of view related to actors' forest management decisions. Another limitation of the study is related to the period of the interviews, since the responses of the actors may be associated with recent events that are more present in their minds. In this study, we conducted the interviews in the autumn, at the end of the fire season. Although the fires were recurrent in Vale do Sousa, two months before the interviews one fire burned 1763 ha (11.9% of Vale do Sousa). All actors mentioned the wildfires of that year and the problems associated with it, and half of them talked about that specific fire in Vale do Sousa.

Only a complete understanding of the different actors' opinions of forest management can support decision-makers in the development of strategies for improving synergies (Brescancin et al. 2018) between forest management and market and social demands. The actor analysis, as a consultation and collaboration tool, helps increase trust in decision-makers and the transparency of the decision-making process (Brescancin et al. 2018). The results from this research are useful to support policy-making as well as ZIF forest management planning.

6. Conclusions

The findings of this study emphasize the importance of the actor analysis as an analytic tool to provide an understanding of actors' perspectives, expectations and concerns. This analysis provides a snapshot of the forest management context for Vale do Sousa. It highlights the need to integrate different interests in forest management and to address conflicts and problems. These results have several implications for forest owners, forest managers, ZIF managers and decision-makers. It provides information useful to develop more effective forest management planning processes and forest policy programs. This is influential to promote a joint landscape-level forest management.

First, it gives a big picture about the ecosystem services that are of strong importance for actors and need thus to be addressed by forest management. Wood provision and wildfires reduction ranked very high and are consensual for all interest groups. Also, with high importance are the biodiversity, water quality, soil erosion prevention, landscape aesthetics and environmental education. This leads us to conclude that the multifunctional forest management approach is the one that best reflects the diversity of interests and ideals of actors in Vale do Sousa. Second, this study identifies the conflicts of interests that can be a disincentive for forest management, particularly between the provisioning services (economic and nature protection coalitions) and cultural services (social and recreational coalition), as well as between biodiversity (nature protection coalition) and provisioning services (economic coalition). This research highlights that these conflicts may be addressed through participatory forest management and the negotiation of a consensual forest management plan that can integrate different interests and objectives.

Third, the findings show that the major problems are, in addition to wildfires, the invasive alien species and pests and diseases. According to the experience of the interviewees, these problems can be minimized by landscape-level forest management. Fourth, the results reveal that the most influential actors are the Forest Owners Association, Wood Industry, National Forest Authority and municipalities. However, according to actors, good examples of forest management have also a great influence in forest managers decisions, since often they practice a "forest management by imitation". Thus, it will be relevant to develop forest management examples in Vale do Sousa by the influential actors to forest owners, forest managers and decision-makers that may be sued to demonstrate the type of forest management to follow. The groups with strongest power resources to impact forest management in Vale do Sousa, the "market agents" and the "public administration", can have also an important role to accomplish this task.

The actors involved in this research revealed a great interest in communicating their preferences and objectives as well as participating in the search of forest management solutions to Vale do Sousa. Future research will build from these findings to focus on the development of participatory multi-criteria decision analysis to integrate further the actors' priorities and expectations in the Vale do Sousa joint landscape-level management planning process. The diversity of interests in ecosystem services enhances the use of this technique that can enable actors to combine alternative forest management programs according to the diversity of ecosystem services in a trade-off analysis.

Disclaimer

Responsibility for the information and views set out in this article/

publication lies entirely with the authors.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Acknowledgments

This work has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 676754 with the title 'Alternative models for future forest management' (ALTERFOR), as well as from the project LISBOA-01-0145-FEDER-030391 with the title 'Forest ecosystem management decision-making methods — an integrated bio-economic approach to sustainability' (BIOECOSYS). We thank the Fundação para a Ciência e a Tecnologia (Portugal) for funding the Ph.D. grant of Marlene Marques (PD/BD/128257/2016) and for support from the Forest Research Center Project UID/AGR/00239/2013. We warmly thank all the actors who have participated in the interviews. We want to thank Maria João Canadas and Ana Novais for valuable feedback on the interview guideline, and Sandra Pinto for helping identify and contact forest owners from Vale do Sousa for the interviews.

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CHAPTER III

An approach to assess actors' preferences and social learning to enhance participatory forest management planning

Paper published in *Trees, Forests and People*

Marques, M., Oliveira, M., Borges, J.G. 2020. An approach to assess actors' preferences and social learning to enhance participatory forest management planning. Trees, Forests and People. 2, 16. https://doi.org/10.1016/j.tfp.2020.100026

Trees, Forests and People 2 (2020) 100026

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.elsevier.com/locate/tfp

An approach to assess actors' preferences and social learning to enhance participatory forest management planning

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ARTICLE INFO

Keywords:
Participatory approach
Forest management models
Ecosystem services
Preferences ranking
Opinion change
Social learning

ABSTRACT

Forest management planning is often challenged by the need to address contrasting preferences from several actors. Participatory approaches may help integrate actors' preferences and demands and thus address this challenge. Workshops that encompass a participatory approach may further influence actors' opinions and knowledge through social interaction and facilitate the development of collaborative landscape-level planning. Nevertheless, there is little experience of formal assessment of impacts of workshops with participatory approaches. This research addresses this gap. The emphasis is on the development of an approach (a) to quantify actors' preferences for forest management models, post-fire management options, forest functions, and ecosystem services; (b) to assess the impact of participatory discussions on actors' opinions; and (c) to evaluate the effect of social interaction on the actors' learning and knowledge. The methodology involves a workshop with participatory approach, matched pre- and post-questionnaires, a non-parametric test, the Wilcoxon Signed-rank test for paired samples, and a self-evaluation questionnaire.

We report results from an application to a joint forest management area in Vale do Sousa, in North-Western Portugal. Findings suggest that workshop and participatory discussions do contribute to social knowledge and learning about forest management models. Actors debated alternatives that can address their financial and wildfire risk-resistance concerns. Also, during the participatory discussions, actors expressed their interest in multifunctional forestry. These findings also suggest an opportunity to enhance forest management planning by promoting landscape-level collaborative forest management plans that may contribute to the diversification of forest management models and to the provision of a wider range of ecosystem services. However, more research is needed to strengthen the pre- and post-questionnaire approach, giving more time to actors to reflect on their preferences, to improve methods for quantifying social learning and to develop actors' engagement strategies.

1. Introduction

Forest management entails a range of actors with different interests, preferences, and opinions. Consequently, there are distinct ideas about how the forest should be planned and managed (Cowling et al., 2014). The participatory involvement of these actors at an early stage of planning and in all its steps is becoming increasingly important for forest management (Cowling et al., 2014; Martins and Borges, 2007; Reed, 2008). Participatory processes provide information that can help forest managers and decision-makers understand actors' preferences and expectations and thus develop tailored plans and policies, increasing their social acceptance and sustainability (Balest et al., 2016; Carmona et al., 2013; Kangas et al., 2006; Sarvašová et al., 2014). Several studies report the importance of the assessment and integration of actors' interests and concerns in forest management processes (e.g., Borges et al., 2017; Bruña-García and Marey-Pérez, 2018; Maroto et al., 2013; Nordström et al., 2010).

Moreover, the literature reports the application of participatory techniques to assess actors' preferences for forest management and ecosystem services. For example, Sarkissian et al. (2018) explored the stakeholders' preferences to select native tree species according to conservation priority and ecological suitability for reforestation in Lebanon, while Focacci et al. (2017) evaluated stakeholders' preferences for firewood, timber, non-wood forest products, tourism and recreation, hydrogeological protection, landscape contemplation and nature, and air quality conservation, in a case study in Southern Italy. Rossi et al. (2011) evaluated the preferences of forestland owners for selected forest management treatment practices offered under the pro-

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https://doi.org/10.1016/j.tfp.2020.100026
Received 10 June 2020; Received in revised form 9 August 2020; Accepted 13 August 2020
Available online 17 August 2020

Table 1
Levels of actors' involvement in participatory approaches.

Level of involvement	Description	Participatory techniques (examples)	Pros	Cons
Information	Information provided to actors aiming to assist them in understanding the problem, the alternatives, the opportunities and/ or solutions	• Newsletter and press releases • Reports • Presentations, public hearings • Internet webpage	• Low cost • Limited resources and logistics • Fast to inform large audience	• Lack of new information • Absence of actors' interaction • Controlled disclosure of information
Consultation	Two-way flow of information to gain feedback on analysis, alternatives and/ or decisions and respond feedback	• Interviews • Questionnaires and surveys • Workshop • Cognitive map	• Qualitative and/ or quantitative primary information collected in a short time • Easy to compare data during the analysis	• Only ask for opinions and not involve actors in decision-making • Bias may appear in data if not effectively supported and conducted
Collaboration	Joint activities with actors engaged in problem solving and the development of proposals	• Workshop with participatory discussions • Focus group • Multicriteria analysis • Scenario analysis • Consensus conference	• Interaction among actors • Depth discussions • Broader perspectives • Boost actors' engagement • Increased consensus and understanding of other actors' points of view	• Limited number of actors • Actors time demand • Need an experienced facilitator with expertise • It can be expensive • Lack of willing to talk openly
Co-decision	Collaboration where there is shared control of decision making			
Empowerment	Transfer of control of level of decision making	• Workshop • Focus group • Consensus conference	• Give actors the sense of ownership	• Actors not interested in implementing the decision

Adapted from Brescancin et al. (2018); Cowling et al. (2014); Luyet et al. (2012)

gram "Southern pine beetle prevention cost-share" to improve stand health in six states of USA. Kant and Lee (2004) analyzed four forest stakeholder groups preferences for ten aggregated forest values in Northwestern Ontario, Canada.

Engaging actors with different preferences, opinions, and expectations in participatory approaches can enrich forest management planning. Additionally, this collaboration improves the relationships among actors and decision-makers, promoting informed decisions, understanding, trust, and social learning (Blackstock et al., 2007; Reed et al., 2010; Voinov and Bousquet, 2010). Furthermore, actors' collaboration is different according to their level of involvement in participatory approaches. It is a continuum of actor involvement, from passive dissemination of information to active engagement and empowerment (Arnstein's, 1969; Reed, 2008) with pros and cons (Table 1). According to the literature (Howard, 1980; Lafon et al., 2004), participatory approaches that involve active participation (e.g., workshops and focus groups where participants express themselves and participate in discussions) appear to influence actors' opinion, learning and knowledge more than passive participation with indirect involvement (e.g., reading, hearing a lecture, attending meetings without speaking up).

In the list different participatory techniques for actor involvement (Table 1), like questionnaires and surveys, can support forest management planning by gathering qualitative and/or quantitative information about actors' preferences. This technique has several interesting features. Firstly, it is an affordable and expeditious method of collecting data; secondly, it allows actors to remain anonymous, maximizing their comfort and encouraging more sincere responses; thirdly, it is not too time-consuming; and fourthly, its data processing is faster when compared with interviews or multicriteria decision analysis. Thus, a survey questionnaire is an easy application tool that can assist decision-makers to get fast primary data.

Furthermore, the pre- and post-survey technique can help assess the impact of participatory approaches on actors' opinions and knowledge. This technique consists of two stages. An identical survey tool (e.g., questionnaire) is used before (pre-survey) and after (post-survey) a participatory assessment (e.g., meeting, workshop, field demonstration). Afterward, participants' answers to both surveys are statistically compared to quantify the differences and check whether opinion changes took place. According to Smith (1994), actors' opinions and interests do not change rapidly or unpredictably, and yet they may indeed change. Thus, time is needed between the pre- and the post-questionnaire so that participants can think and reflect about the information provided. However, according to some applications in the framework of natural resources management, the period to reflect before post-survey can vary from one day to more than one year.

For example, Upton et al. (2019) applied pre- and post-surveys to confirm the successful impact of a thinning demonstration in imparting knowledge to forest owners. They responded the post-survey 18 months after the demonstration. Lafon et al. (2004) applied this methodology to evaluate the influence of active participation on stakeholders' knowledge and opinions regarding wildlife management. The time interval between the pre- and the post-questionnaire was about one year. Mayer et al. (2017) conducted three participatory workshops, over a four-month period. The authors applied the pre-questionnaire on the first day of the first workshop and the post-questionnaire was administered at the last workshop (after four months). Likewise, they verified that the participatory workshops impacted participants' abilities on modeling and their beliefs on utility and accuracy of water resources systems models. During a five-day workshop, Fatorić and Seekamp (2017) confirmed that policy presentations and value-based deliberations about climate change adaptation of cultural resources not only influenced participants' opinions and understanding but also enhanced their social learning. The authors applied the pre-questionnaire prior the first workshop session (first day) and the post-questionnaire after the last workshop session (fifth day). Canfield et al. (2015) found that a one-day deliberative forum (or workshop) was useful in shifting participants' perceptions about the importance of climate change but did not significantly influence objective knowledge or energy policies to mitigate and adapt to climate change. Participants answered the pre-questionnaire when they arrived at the forum and completed the post-questionnaire at the end of the event. Ashworth et al., 2013; Ooi and Tan, 2015 and Robles-Morua et al., 2014 also report the use of pre- and post-questionnaires in a one-day workshop. Based on former contacts and interactions with the actors (Marques et al. 2020) we deemed that a one-day workshop would be suitable for this research.

Nevertheless, to our knowledge, the pre- and post-survey methodology has not yet been used in a forest management planning framework to analyze the actors' preferences as well as opinion change and social learning. This research aims at addressing this gap. It is motivated by the fact that the quantification of the actors' preferences can provide a first overview of the actors' perceptions and opinions related to forest management and the provision of ecosystem services. Moreover, assessing the influence of a participatory approach on actors' opinions and social learning can indicate whether in-depth discussions or the application of further participatory techniques are needed to address misunderstandings or the lack of information to support forest management decisions. Furthermore, it can be an opportunity for forest managers and policymakers to assess how actors perceive alternatives to current forest management practices.

This research encompasses thus three objectives. Firstly, it aims at collecting primary data about (a) actors forest management planning preferences for forest management models, post-fire management options, forest functions, and ecosystem services, by a quantitative survey approach (individual quantitative information); and (b) actors opinions and points of view by participatory discussions (group qualitative information). Secondly, it aims at evaluating the impact of the presentations and participatory discussions on the actors' forest management preferences and opinions. Thirdly, it aims at assessing the effect of social interaction during the workshop on the actors' learning and knowledge. The methodology to address these objectives involves a workshop with participatory approach, matched pre- and post-questionnaires and a non-parametric test, the Wilcoxon Signed-rank test for paired samples, and a self-evaluation questionnaire.

2. Material and methods

2.1. Case study area

We applied our approach to a joint forest management area (ZIF) in Vale do Sousa, in North-Western Portugal (Fig. 1). It is a forested landscape extending over 14,840 ha, where eucalypt (*Eucalyptus globulus* Labill), and maritime pine (*Pinus pinaster* Aiton), in both pure and mixed stands, are the predominant species. The forest ownership is mostly private and fragmented into small forest holdings. There are some community areas managed by the local parish councils. The ZIF has 360 forest owners as members. Wildfires have been frequent and severe in Vale do Sousa. Over the period from 2005 to 2017, the area burned extended up to of 14,798 ha in Vale do Sousa (ICNF, 2019). The years with the largest burnt area were: 2005 (5383 ha, 36.3% of the total area) and 2017 (4006 ha, 27.0% of the total area).

Vale do Sousa is characterized by multiple actors' interests and high relevance of economic forest resources. Previous research (Borges et al., 2017; Juerges et al., 2017; Marques et al., 2020) revealed actors' keen interests in wood provisioning, particularly eucalypt pulpwood, as well as in wildfire risk reduction. The multiplicity of decision-makers, as well as the multitude of ecosystem services, make Vale do Sousa an interesting test case for our approach.

2.2. Research design

We implemented pre- and post-questionnaires, i.e., we used identical questionnaires in two steps to assess and analyze the actors' preferences and opinion changes over a full-day workshop. The evaluation of the presence and direction of opinion change enables us to analyze if and how information and discussions during the workshop can influence actors' opinions (Fatorić and Seekamp, 2017; Lafon et al., 2004) as well as social knowledge and learning (Reed et al., 2010).

2.2.1. Questionnaires structure

The questionnaire to implement the pre- and post-survey was were designed based upon a review of previous studies on the characterization of the forest management context in Vale do Sousa (Borges et al., 2017; Juerges et al., 2017; Marques et al., 2020). The pre- and post-questionnaires were divided into three thematic parts, and encompassed a total of nine questions, for an estimated 10-minutes response. It aimed to collect quantitative information targeting the elicitation of preferences. It did not ask for a justification of actor's preferences (qualitative information). However, all lists of Parts II and III allowed actors to add other unlisted features.

Part I collected actors' personal information, such as forest work experience. We also asked actors to indicate, from a list, the type of forest management actor to which they belonged. Next, Part II focused on forest management. It included questions aiming at the elicitation of actors' preferences. Specifically, they were asked (a) to rank six forest management models (FMMs) according to their preferences; (b) to propose a forest area distribution of Vale do Sousa by the FMMs (percentage); (c) to rank ten forest management post-fire options according to their preferences; and (d) to select two preferred forest functions from a list of seven. Part III targeted the elicitation of preferences for ecosystem services, ranking a list of eight by order of importance. In the ranking questions, we asked actors to rank in from "most preferred" to "least preferred".

In addition, we structured a self-evaluation questionnaire using a 5-point Likert scale ("very weak" to "very strong") for an estimated 5-minutes response. This questionnaire directly asks the actors a) to evaluate the level of importance of their participation and other actors in the discussions during the workshop; and b) to appraise whether presentations and discussions influenced their opinion and knowledge.

All the questionnaires were implemented in Portuguese. To prevent questionnaire bias and misinterpretation (Choi and Pak, 2005), we designed and structured all the questions using simple wording, e.g., avoiding ambiguous and complex questions, technical jargon, and uncommon words. Moreover, the questionnaires were pre-tested by three researchers.

2.2.2. Actors

To facilitate the discussion by the actors, the workshop was not announced to the public but restricted to invited actors. Furthermore, we built from past research (Integral Future-Oriented Integrated Management of European Forest Landscapes, 2015) as well as more recent studies (Juerges et al., 2017; Marques et al., 2020) to identify and invite 46 actors representing different interests in forest management (Table 2).

Of the 46 invited actors, a total of 33 actors attended the workshop and completed the pre-questionnaire (71.7%). However, only 24 actors out of these 33 completed the post-questionnaire (Table 2). Nine of 33 actors were not available to participate in the workshop all day. At the end of the day, 21 actors answered the self-evaluation questionnaire. The invited actors comprised a broadly representative sample of interests (Rowe and Frewer, 2000) for forest management in Vale do Sousa (Table 2). Thus, we categorized the actors into four groups according to their interests in forest management (Juerges and Newig, 2015; Marques et al., 2020).

2.2.3. Workshop

Two months before the workshop date, we sent an invitation email to actors, explaining the event objectives and asking to "save the date". One month before the workshop, we contacted actors by phone, reinforcing the invitation, explaining the agenda, and asking for confirmation of attendance. The final agenda was sent three weeks before the workshop. A week before, we called again actors who had not confirmed their participation yet. The workshop was held in November 2017, and it extended

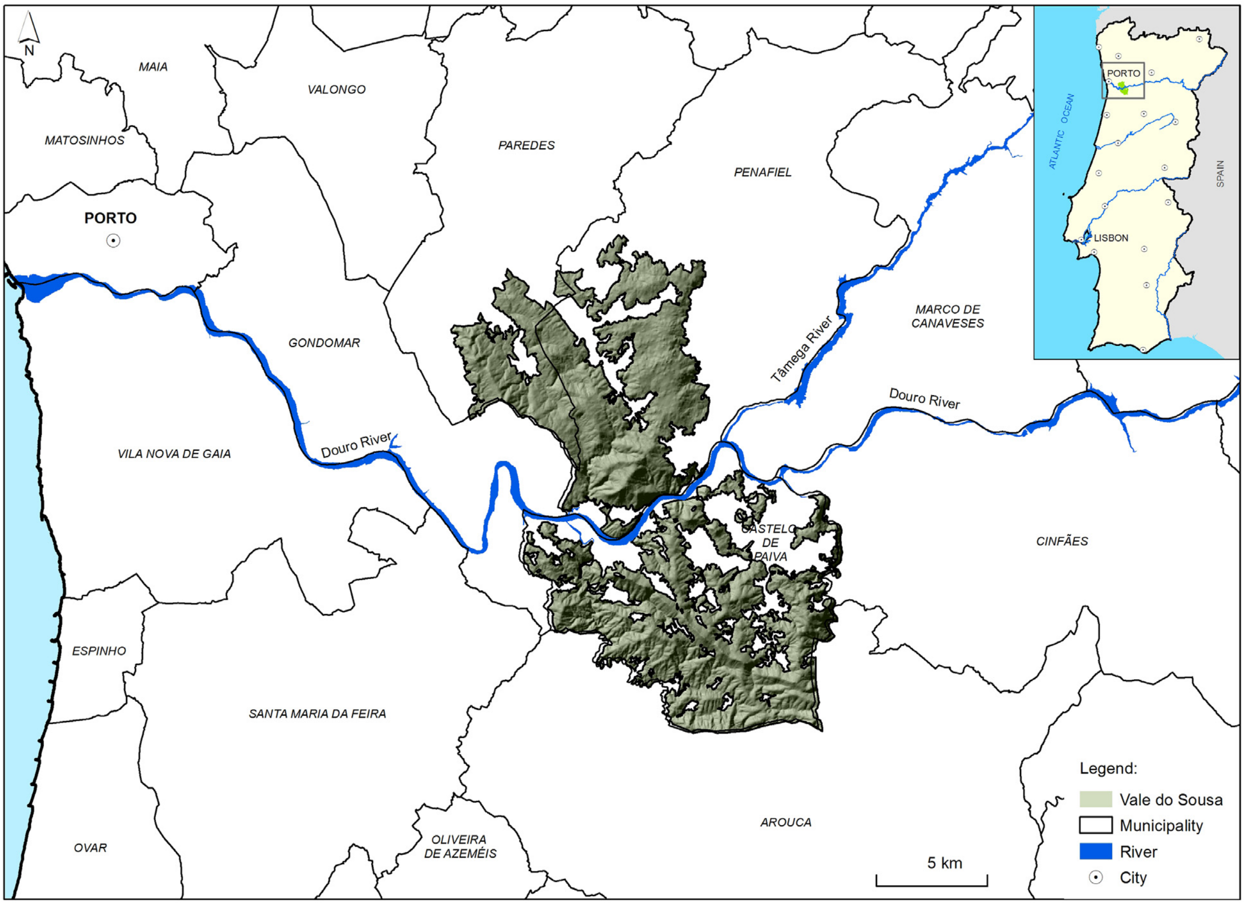

Fig. 1. Location of Vale do Sousa case study area.

Table 2
Identification of the actors invited to the workshop and who answered the questionnaires, categorized by interest group.

Interest group and type of actor	Invited to the workshop	Questionnaire		
		pre-	post-	evaluation
Civil society	***7***	***6***	***4***	***3***
Environmental NGO	4	3	1	2
Forest certification	3	3	3	1
Forest owners	***17***	***12***	***6***	***6***
Forest owners' association	3	3	1	1
Forest owners (non-industrial)	11	7	5	5
Parish council with community areas	3	2	0	0
Market agents	***16***	***10***	***10***	***8***
Biomass industry	1	0	0	0
Forest investment fund	2	1	1	1
Forest services provider	2	1	1	1
Forest services provider and wood buyer	3	3	3	3
Wood industry	4	3	3	3
Wood industry association	4	2	2	0
Public administration	***6***	***5***	***4***	***4***
Forest authority	3	3	2	2
Municipality	3	2	2	2
Total	**46**	**33**	**24**	**21**

over one day in the city of Porto. We chose this location because it is close to Vale do Sousa, about 30 min' drive, and is where most actors live or work.

In order to facilitate the discussion by the actors during the workshop, we set up the tables to create a large U-shape allowing all actors to be able to see at all times (a) each other; (b) the speakers (researchers); and (c) the discussion facilitators. During the workshop, we conducted a pre- and post-questionnaire. We distributed the pre-questionnaire after a welcome message and a brief introduction to the workshop goals and agenda. We stressed that questions focused on forest management in the Vale do Sousa case study area – the pre-questionnaire included a map of it on its last page.

After the actors completed the pre-questionnaire, two presentations were made. The way information is presented can influence decisions and social knowledge. So, speakers (researchers) tried to use simple discourse and presentations. The first presentation focused on actor analysis of the forest management context in Vale do Sousa (Juerges et al., 2017; Marques et al., 2020). It included a characterization of (a) actors interests for forest management and ecosystem services; (b) influential actors in forest management decisions; (c) main conflicts of interests and problems; (d) power resources to influence the forest actors' decisions (Marques et al. 2020). The second presentation characterized the contribution of stand-level FMMs to the provision of ecosystem services available in Vale do Sousa. For that purpose, it included (a) a short description – e.g., regeneration, fuel treatment and thinning options, rotation ages – of current FMMs (mixed maritime pine and eucalypt, mixed eucalypt and maritime pine, pure chestnut and pure eucalypt) and of two proposals of alternative FMMs (pure maritime pine and pure pedunculate oak); and (b) a graphical comparison of the provision of ecosystem services (e.g., biodiversity, carbon sequestration, cultural services, resin, water quality, wildfires resistance, wood) by each FMM.

Then, two facilitators encouraged a participative discussion of the information provided. The participatory discussions aimed to collect actors' opinions and points of view, i.e. qualitative information, that can complement and support the quantitative information from the pre- and post-questionnaires. The facilitators had previous mediation experience in participatory discussions, and they were knowledgeable about Vale do Sousa forest management issues and actors profiles and interests. They tried to conduct the discussion in an independent, impartial, and unbiased way (Rowe and Frewer, 2000). The facilitators asked actors to speak openly and freely in order to (a) identify different perspectives on forest management in the case study area; (b) check points of view and opinions on the FMMs presented; and (c) discuss the integration of more FMMs that can meet actors' expectations to improve forest management planning. The facilitators aimed a shared understanding of the forest management planning options and opinions and not necessarily a consensus.

The actors answered the post-questionnaire after lunch at the beginning of the afternoon session. At the end of the day, we asked actors to respond to the self-evaluation questionnaire targeting the assessment of their participation as well as of others. We assigned each actor an alphanumeric code to link the actors' pre- and post-questionnaire responses and so that answers were anonymous.

2.3. Data analysis

We conducted a statistical analysis using the software IBM SPSS Statistics, version 25 (Armonk, NY: IBM Corp.), to understand and compare preferences and choices. We estimated statistics only for the 24 matched pre- and post-questionnaires. First, we used descriptive statistics to summarize the actors' characteristics and profiles. Next, we developed a statistical analysis of the frequencies to multiple-choice questions.

Then, we considered ranks as ordinal data and applied statistical tests to identify shifts in rankings as well as to explore whether the differences observed in the sample were statistically significant. We used a 5% value as a reference value for hypothesis testing, meaning we established the inference with an error probability of less than 5%. Since sample size was comparably low and we worked with categorical figures, and as the T-test is used for larger samples with normal distribution, we resorted to the non-parametric Wilcoxon test to assess differences between two repeated measurements (pre- and post-questionnaire). The Wilcoxon Signed-rank test for paired samples states the hypotheses:

H_0: The distribution of the variable values at both times (pre- and post-questionnaire) is equal.

H_1: The distribution of variable values at both times (pre- and post-questionnaire) is different.

When the proof value is higher than 5%, the null hypothesis is not rejected, i.e., there are no statistically significant differences between the two pairs of measures. Otherwise, when the proof value is less than 5% ($\alpha < 0.05$), the null hypothesis is rejected, and the alternative hypothesis is accepted; that is, there are statistically significant differences between two pairs of measures. We ranked the results according to the post-questionnaire. In the case of a tie between the means, we used the standard deviation to rank it (i.e., the mean with lower standard deviation was ranked higher). As the sample size by interest group was very small (four to 10 actors per group) we only applied the Wilcoxon Signed-rank test to the set of 24 matched pre- and post-questionnaires.

3. Results

3.1. Actors' profile

About 54.2% of the actors had professional experience in forestry or had held forest properties for over 20 years (Table 3). Only 8.4% of the actors had less than nine years of experience - they belonged to the group of Market agents. Wood industry actors from the Market agents' group (20.8% of total actors) managed an area larger than 100 ha. Nevertheless, most forest owners manage an area ranging from 2 to 50 ha.

The fragmentation and dispersion of forest blocks are typical in Vale do Sousa. About 50% of forest owners manage less than five blocks. Still, 33.3% manage between 10 and 100 blocks. In the case of Market agents, 30.0% manage more than 150 blocks. Actors manage pure eucalypt (26.7%) and mixed eucalypt and maritime pine (10.2%) FMMs. Most of the actors who manage forest areas stated they willingness to convert the area of maritime pine and eucalyptus stands to other species (e.g., chestnut), in case there is financial compensation.

3.2. Forest management models

In the pre-questionnaire (Table 4), on average, preferences were higher for *Pure maritime pine* (M = 4.88, SD = 1.57) and *Mixed eucalypt and maritime pine* (M = 4.79, SD = 1.91). The lower preference was for *Other forest management model* (M = 2.17, SD = 2.10), with actors identifying as alternative models: "Native mixed forests and Riparian galleries", "Mixed broadleaves stands with cork oak and birch", "Pure poplar", "Mixed stands with red oak", "Broadleaves stands" and "Pure stone pine", each for one actor.

On average, in the post-questionnaire (Table 4), the actors maintain their preference for *Pure maritime pine* (M = 4.88, SD = 1.62), followed by *Pure eucalypt* (M = 4.63, SD = 2.30). The lower preference remained for *Other forest management model* (M = 2.79, SD = 2.55). Four actors listed "Cork oak (pure or mixed with other oaks)", while two actors proposed "Mixed broadleaves", one actor suggested "Native mixed forests and Riparian galleries", and one actor indicated "Pure poplar".

The *p*-value is less than 5% for the differences between the pre- and post-questionnaire for *Other forest management model* (Table 4). Therefore, the null hypothesis is rejected and accepted the alternative hypothesis. The preference for *Other forest management model* increased significantly from the pre- to the post-questionnaire, with statistically significant differences observed (Z = -2.200, p = 0.028). While in the pre-questionnaire six FMMs were proposed by six actors, in the post-questionnaire the proposals were more consensual, since four FMMs were proposed by eight actors. The cork oak FMM was proposed by one actor on the pre-questionnaire while it was proposed by four in the post-questionnaire. However, the direction of actors' preferences did not change significantly in the case of the remaining FMMs, since the *p*-value is higher than 5% for the differences between the pre- and post-questionnaire, indicating strong evidence for the null hypothesis.

Regarding the distribution of the area by FMM, in the post-questionnaire, actors associated a higher percentage to *Pure eucalypt* (M = 34.63%, SD = 31.66%) and *Pure maritime pine* (M = 15.46%, SD = 15.68%) (Table 4).

For the *Other forest management model,* in the pre-questionnaire (M = 4.96%, SD = 12.26%), the actors suggested "Native mixed forests, and Riparian galleries", "Pure poplar" and "Mixed broadleaves stand", each by one actor. While in the post-questionnaire (M = 13.92%, SD = 19.47%), four actors proposed "Cork oak", three actors specified "Mixed broadleaves", one actor stated "Native mixed forests and Riparian galleries" and one actor listed "Pure poplar.

From pre- to post-questionnaire, the percentage of forest area associated with the models *Pure eucalypt* (Z = -2.190, p = 0.029) and *Other forest management model* (Z = -2.737, p = 0.006) increased significantly. By contrast, the percentage of forest area decreased significantly from pre- to post-questionnaire for the models *Mixed eucalypt and maritime pine* (Z = -2.045, p = 0.041) and *Pure chestnut* models (Z = -2.333, p = 0.020). Actors maintain their preferences about the forest area associated with the remaining three FMMs, since it did not change significantly (p > 0.05).

Table 3
Profile of respondent actors by interest group.

Characteristics	All actors (*n*=24)	Interest group			
		Civil society (*n*=4)	Forest owners (*n*=6)	Market agents (*n*=10)	Public administration (*n*=4)
(% of n)					
Experience (years)					
<= 4	4.2	0.0	0.0	10.0	0.0
5 – 9	4.2	0.0	0.0	10.0	0.0
10 – 14	16.7	25.0	16.7	0.0	50.0
15 – 19	20.8	25.0	16.7	30.0	0.0
>= 20	54.2	50.0	66.7	50.0	50.0
Forestland managed (ha)					
< 2	4.2	25.0	0.0	0.0	0.0
[2 - 5[	8.3	0.0	16.7	0.0	25.0
[5 - 20[	16.7	0.0	50.0	10.0	0.0
[20 - 50[	8.3	0.0	16.7	10.0	0.0
[50 - 100[	0.0	0.0	0.0	0.0	0.0
>= 100	20.8	0.0	0.0	50.0	0.0
Not applicable*	41.7	75.0	16.7**	30.0	75.0
Number of blocks					
< 5	20.8	25.0	50.0	0.0	25.0
[5 - 10[	4.2	0.0	0.0	10.0	0.0
[10 - 50[	8.3	0.0	16.7	10.0	0.0
[50 - 100[	12.5	0.0	16.7	20.0	0.0
[100 - 150[	0.0	0.0	0.0	0.0	0.0
>= 150	12.5	0.0	0.0	30.0	0.0
Not applicable*	41.7	75.0	16.7	30.0	75.0
Forest management model (% of the total area managed)					
Pure maritime pine	6.3	0.0	3.3	13.0	0.0
Pure eucalypt	26.7	0.0	35.0	43.0	0.0
Pure chestnut	0.2	0.0	0.0	0.5	0.0
Pure oak stand	1.5	0.0	3.3	1.5	0.0
Mixed of maritime pine and eucalypt	3.1	3.8	2.5	4.5	0.0
Mixed of eucalyptand maritime pine	10.2	12.5	18.3	0.5	25.0
Other forest management model***	7.0	8.8	20.8	0.9	0.0
Shrubs	3.4	5.0	0.0	6.1	0.0
Not applicable*	41.7	75.0	16.7	30.0	75.0

* Actors who do not manage forestland
** Forest Owners' Association
*** Strawberry tree, cork oak, plane trees, walnut tree, red oak, Douglas fir, and cedars.

During the participatory discussions, one actor from the Public Administration group proposed cork oak as an alternative FMM. Several actors expressed their agreement, generating a very participative discussion about the advantages of the cork oak, namely, to provide a regular income, and as a solution for dry areas. In Portugal, the cork oak is used to produce cork. Although, some actors mentioned that it could also be implemented as a coppice system to produce biomass. This option was also discussed for the pedunculate oak, as the rotation age is very long. Actors referred that it is very difficult to convince forest owners plant species with extended rotations, so the coppice system may be attractive as it contributes to anticipate income.

Throughout the discussion, there was a consensus among the actors that the FMMs with extended rotations would be hard to implement in Vale do Sousa due to the occurrence of wildfires (the fire recurrence period is about ten years). Actors agreed about the importance of riparian broadleaves as an alternative FMM for the water lines. Actors emphasized that a riparian FMM can promote discontinuity in the landscape and make it more resistant to wildfires and, at same time, foster the biodiversity in ecological corridors.

Discussions had a strong focus on economic importance of FMMs and how its profitability is paramount to forest owners and managers (e.g. eucalypt and maritime pine FMMs). Forest managers stressed that models should be adjusted for shorten rotations to address the wildfire recurrence period. Actors from the Market Agents group mentioned further that the pine industry prefers wood aged 30-35. In addition, some forest owners reported a high mortality of chestnut stands in Vale do Sousa. So, this FMM does not rank high in their preferences.

3.3. Forest management post-fire options

In the pre- and post-questionnaire (Table 5), the actors' preferences for forest management post-fire options were higher, on average, for *Increasing the diversity of forest species* (pre-questionnaire: M = 8.88, SD = 2.59; post-questionnaire: M = 9.00, SD = 2.36) and *Waiting for natural regeneration* (pre-questionnaire: M = 7.50, SD = 3.04; post-questionnaire: M = 7.21, SD = 3.08).

In the pre-questionnaire for the question *Converting the existing forest management model* (M = 4.29, SD = 3.81), actors suggested eleven conversion options. Two actors proposed "Planting other broadleaves" while the options "Forest stands with shrub mosaics (e.g., strawberry tree)", "FMM for nature conservation", "Modeling at landscape scale with areas for production, conservation, and ecological corridors", "Agroforestry mosaics with mixed broadleaves stands", "Grazing, mixed profitable and multi-purpose forest stands", "Forestland consolidation (parceling)", "Coercing landowners to join in reforestation", "Model that includes professional management", "Recreational and cultural services" and "Coppice stands" were proposed each by one actor. As to the question *Other post-fire option* (M = 2.71, SD = 3.17) actors proposed seven options: "(Re)establishing native mixed forests", "Restoring and planting cork oak", "Poplar stand in riparian areas", "Decreasing the area of monoculture forests", "Following the requirements of the forest certification process", "Creating road and divisional network appropriate to the scale and size of the property" and "Other uses (ex.: agriculture)" each by one actor.

The same number of conversion options were proposed in the post-questionnaire for the question *Converting the existing forest management*

Table 4
Pre- and post-questionnaire results and differences of preferences for forest management models and its area distribution (n=24). Rank according to the post-questionnaire.

	Pre-questionnaire		Post-questionnaire		Pre- and post-questionnaire differences				Z	*p*-value
					Variation		95% Confidence interval			
	Mean (SD)	Rank	Mean (SD)	Rank	Mean (SD)	Rank	Lower	Upper		
Forest management model (7 to 1)										
Pure maritime pine	4.88 (1.569)	1	4.88 (1.624)	1	→ 0.00 (0.978)	→ 0	-0.413	0.413	-0.144	0.886
Pure eucalypt	4.38 (2.481)	6	4.63 (2.300)	2	↑ 0.25 (1.622)	↑ 4	-0.935	0.435	-0.926	0.354
Mixed maritime pine and eucalypt	4.71 (1.517)	3	4.50 (1.745)	3	↓ -0.21 (1.615)	→ 0	-0.473	0.890	-0.216	0.829
Mixed eucalypt and maritime pine	4.79 (1.911)	2	4.42 (1.998)	4	↓ -0.38 (1.408)	↓ -2	-0.220	0.970	-1.144	0.253
Pure chestnut	4.54 (1.719)	4	4.33 (1.633)	5	↓ -0.21 (1.474)	↓ -1	-0.414	0.831	-0.715	0.474
Pure pedunculate oak	4.46 (2.021)	5	4.33 (1.993)	5	↓ -0.13 (1.329)	→ 0	-0.436	0.686	-0.203	0.839
Other FMM	2.17 (2.099)	7	2.79 (2.553)	7	↑ 0.63 (1.439)	→ 0	-1.233	-0.017	-2.200	**0.028***
Area distribution by forest management model (% of the area)										
Pure eucalypt	27.04 (31.706)	1	34.63 (31.662)	1	↑ 7.58 (18.094)	→ 0	-15.224	0.057	-2.190	**0.029***
Pure maritime pine	13.33 (14.257)	4	15.46 (15.682)	2	↑ 2.13 (11.543)	↑ 2	-6.999	2.749	-1.220	0.222
Other FMM	4.96 (12.256)	7	13.92 (19.473)	3	↑ 8.96 (17.102)	↑ 4	-16.180	-1.737	-2.737	**0.006****
Pure pedunculate oak	12.58 (13.237)	6	11.33 (13.014)	4	↓ -1.25 (6.180)	↑ 2	-1.360	3.860	-1.076	0.282
Mixed maritime pine and eucalypt	12.92 (13.413)	5	8.71 (11.745)	5	↓ -4.21 (13.022)	→ 0	-1.290	9.707	-1.417	0.157
Mixed eucalypt and maritime pine	14.75 (16.971)	2	8.50 (12.090)	6	↓ -6.25 (14.161)	↓ -4	0.270	12.230	-2.045	**0.041***
Pure chestnut	14.42 (15.197)	3	8.25 (9.013)	7	↓ -6.17 (13.477)	↓ -4	0.476	11.857	-2.333	**0.020***

* significant at $p < 0.05$; ** significant at $p < 0.01$; SD – standard deviation; ↑ increase; ↓ decrease; → no variation

Table 5
Pre- and post-questionnaire results and differences of preferences for forest management post-fire options (n=24). Rank according to the post-questionnaire.

	Pre-questionnaire		Post-questionnaire		Pre- and post-questionnaire differences				Z	*p*-value
					Variation		95% Confidence interval			
	Mean (SD)	Rank	Mean (SD)	Rank	Mean (SD)	Rank	Lower	Upper		
Forest management post-fire option (11 to 1)										
Increasing the diversity of forest species	8.88 (2.593)	1	9.00 (2.359)	1	↑ 0.12 (2.133)	⇨ 0	-1.026	0.776	-0.040	0.968
Waiting for natural regeneration	7.50 (3.036)	2	7.21 (3.078)	2	↓ -0.29 (1.706)	⇨ 0	-0.429	1.012	-0.611	0.541
Planting pure chestnut	6.75 (2.524)	5	7.04 (2.255)	3	↑ 0.29 (1.756)	↑ 2	-1.033	0.450	-0.885	0.376
Planting pure pedunculate oak	7.38 (2.810)	3	7.00 (2.621)	4	↓ -0.38 (1.813)	↓ -1	-0.391	1.141	-0.963	0.335
Planting pure maritime pine	7.13 (2.007)	4	6.83 (2.648)	5	↓ -0.29 (2.440)	↓ -1	-0.739	1.322	-0.753	0.452
Planting mixed maritime pine and eucalypt	6.38 (2.337)	8	6.58 (2.412)	6	↑ 0.21 (2.570)	↑ 2	-1.294	0.877	-0.453	0.651
Planting mixed eucalypt and maritime pine	6.54 (3.050)	6	6.58 (2.977)	6	↑ 0.04 (2.386)	⇨ 0	-1.049	0.966	-0.029	0.977
Maintain existing forest occupation	5.04 (3.316)	9	5.54 (3.203)	9	↑ 0.50 (3.776)	⇨ 0	-2.095	1.095	-0.390	0.697
Planting pure eucalypt	6.50 (2.919)	7	6.25 (3.287)	8	↓ -0.25 (2.400)	↓ -1	-0.764	1.264	-0.690	0.490
Converting the existing FMM	4.29 (3.805)	10	5.08 (3.966)	10	↑ 0.79 (3.489)	⇨ 0	-2.265	0.682	-1.204	0.228
Other post-fire option	2.71 (3.169)	11	1.58 (1.840)	11	↓ -1.13 (2.833)	⇨ 0	-0.071	2.321	-2.032	**0.042***

* significant at $p < 0.05$; SD – standard deviation; ↑ increase; ↓ decrease; ⇨ no variation

model (M = 5.08, SD = 3.97) namely: “Other broadleaves”, “Mixed broadleaves”, “Cork oak”, “Native mixed species (or in combination with interesting exotic species)”, “Native and riparian forest”, “Mixed maritime pine to pure maritime pine”, “Maritime pine revolutions of 25 to 30 years old at most”, “Model for nature conservation”, “Profitable and sustainable forest species”, “Forestland consolidation (parceling)”, “FMM that includes professional management”, each for one actors. However, for the question *Other post-fire option* (M = 1.58, SD = 1.84), actors proposed three options: “Pastures, agriculture and others”, “Poplar stand in riparian areas”, and “Any sustainable FMM”, each by one actor.

The preference for *Other post-fire option* decreased significantly from the pre-questionnaire to the post-questionnaire, with statistically significant differences observed (Z = -2.032, $p = 0.042$). However, there was no significantly shift in the direction of the actors' preferences for the remaining forest management post-fire options, from pre- to post-questionnaire ($p > 0.05$).

According to actor analysis of the forest management context in Vale do Sousa (Juerges et al., 2017; Marques et al., 2020), wildfire risk was considered as the problem that can influence most forest management decisions. During the participatory discussion session, forest managers reinforced the importance of this problem in their decisions. Some forest owners have reported that this situation has discouraged them from investing in forest management. They also argued that, due to the high recurrence of wildfires, their forest management post-fire options are related to low-cost options (e.g. waiting for natural regeneration). However, forest managers were consensual in the preference for species diversification and for a multifunctional forest that may allow them to (a) reduce wildfire risk; and (b) promote diversify of its forestry revenues.

3.4. Forest functions and ecosystem services

Actors selected *Wood production* (M = 91.67%, SD =28.23%) as the most important forest function in the pre-questionnaire (Table 6), followed by *Cultural services promotion* (29.17%, SD = 46.43%). Regarding the question *Other forest function* (M = 8.33%, SD = 28.23%) one actor identified “Forest jobs creation and maintenance”.

In the post-questionnaire (Table 6), *Wood production* (M = 75.00%, SD = 44.23%) ranked also first, followed by *Water quality protection* (M = 33.33%, SD = 48.15%). As to the question *Other forest function* (M = 12.50%, SD = 33.78%), the answers included “Water cycle regulation” and “Fire prevention”, each by an actor. However, the preference for the function *Wood production* decreased significantly from the pre- to the post-questionnaire (Z = -2,000, $p = 0.046$). For the remaining forest functions the observed differences were not statistically significant ($p > 0.05$) since actors' preferences did not shift significantly from pre- to post-questionnaire.

On average, in the pre-questionnaire (Table 6), the preferred ecosystem services was *Wood* (M= 5.63, SD = 2.86), followed by *Water Quality* (M = 5.33, SD = 2.12). The most preferred ecosystem service is the same in the post-questionnaire (M = 6.42, SD = 2.47), while *Biodiversity* (M = 5.38, SD = 1.72) ranks second. Even so, the observed differences from pre- to post-questionnaire were not statistically significant ($p > 0.05$) for all the ecosystem services. Actors did not significantly change the direction of their opinion and maintained their preferences for ecosystem services.

The graphical comparison of ecosystem service indicators by FMM raised several questions about the possibility of ecosystem services, in addition to wood, being profitable. Some actors were unaware of this possibility (e.g. carbon market). Furthermore, actors from Public Administration and Civil Society interest groups stressed the importance of diversifying the forest functions and ecosystem services to contribute for a sustainable forest management. However, the provision of non-market services in the case study area depend on the possibility of attracting payments for them.

3.5. Evaluation of actors' participation in the workshop

Of the 21 actors who responded to the questionnaire, 33.3% had never been involved in participatory approaches, while 14.3% had already been involved more than ten times, 42.9% had been involved in two to five participatory approaches, and 9.5% only once. All actors confirmed their willingness to participate in future participatory approaches.

The results (Fig. 2) highlight that about 85.7% of the respondents rated *Other actors' participation in discussions* as of strong to very strong importance. It reveals the value of social interaction to share points of view and opinions. *Actor learning during the workshop* was also highly rated (85.8% strong to very strong importance), indicating that the information available and the discussions contributed to actor's understanding and knowledge.

Regarding the evaluation of their participation, around 71.4% of the actors indicated that they had been able to clearly share their ideas and opinions during the workshop. Although, the rating of their *Participation in discussions* was somewhat lower, about 66.6% considered it strong to very strong. Less than half of the actors (42.8%) indicated strong to very strong importance to changes in initial opinion because of the discussion. It means that the remaining actors considered that they slightly changed their initial opinion (57.1%). No actor rated any of the items as of very low importance. Only 4.8% of actors rated as of low importance some questions (*Actor ideas and opinions clearly shared* and *Actor participation in discussions*).

The workshop discussions and the actors' comments in the evaluation questionnaire revealed that most actors considered that this approach contributed to (a) their learning from the information provided; (b) their discussion with actors who had different preferences in forest management, and (c) their understanding of other actors' opinions and points of view.

4. Discussion

This approach was not intended to model actors' opinions. Moreover, we did not aim to reach a consensus on FMMs, forest management post-fire options, forest functions, or ecosystem services to be considered in forest management planning. The objectives were to quantify actors' preferences, identify alternative FMMs and capture the multiplicity of actors' points of view. The findings can support ZIF managers better orient forest management planning. Also, we sought to understand if the workshop environment leads actors to change their opinion and promotes social knowledge and learning. The main advantage of this approach is the ease of application and its time and data processing cost effectiveness.

4.1. Actors preferences and opinion change

In general, actors' preferences and opinions regarding current forest management did not change significantly since the observed differences are not statistically significant ($p > 0.05$). Also, the actors' evaluation of their participation in the workshop confirmed that most of them did not strongly change their opinion. However, results highlight some opinion shifts from pre- to post-questionnaire that may be due to the workshop participatory discussions and are noteworthy.

The main actors' preferences for FMMs were first for *Pure maritime pine* and second for *Pure eucalypt*. In addition, actors assigned a higher percentage of area to the *Pure eucalypt* model, which increased significantly from pre- to post-questionnaire, followed by *Pure maritime pine*. These results confirm and strengthen the current preference of forest managers for these two FMMs. Besides, these species occupy most of the area in Vale do Sousa. According to the actors opinions during workshop discussions, the preferences for *Pure eucalypt* and *Pure maritime pine* FMMs are based on (a) the income that can be obtained in the short term

Table 6

Pre- and post-questionnaire results and differences of preferences for forest functions and ecosystem services (n=24). Rank according to the post-questionnaire.

	Pre-questionnaire		Post-questionnaire		Pre- and post-questionnaire differences				Z	*p*-value
					Variation		95% Confidence interval			
	Mean (SD)	Rank	Mean (SD)	Rank	Mean (SD)	Rank	Lower	Upper		
Forest function (frequency of yes, %)										
Wood production	91.67 (28.23)	1	75.00 (44.23)	1	↓ -16.67 (38.07)	→ 0	0.59	32.74	-2.000	**0.046***
Water quality protection	20.83 (41.49)	4	33.33 (48.15)	2	↑ 12.50 (33.78)	↑ 2	-26.77	1.77	-1.732	0.083
Biodiversity promotion	20.83 (41.49)	4	29.17 (46.43)	3	↑ 8.33 (40.82)	↑ 1	-25.57	8.91	-1.000	0.317
Soil protection	25.00 (44.23)	3	25.00 (44.23)	4	→ 0.00 (0.00)	↓ -1	na	na	0.000	1.000
Cultural services promotion	29.17 (46.43)	2	20.83 (41.49)	5	↓ -8.33 (40.82)	↓ -3	-8.91	25.57	-1.000	0.317
Carbon sequestration	12.5 (33.78)	6	16.67 (38.07)	6	↑ 4.17 (20.41)	→ 0	-12.79	4.45	-1.000	0.317
Non-wood forest products production	8.33 (28.23)	7	12.50 (33.78)	7	↑ 4.17 (20.41)	→ 0	-12.79	4.45	-1.000	0.317
Other forest function	8.33 (28.23)	7	12.50 (33.78)	7	↑ 4.17 (20.41)	→ 0	-12.79	4.45	-1.000	0.317
Ecosystem service (8 to 1)										
Wood	5.63 (2.856)	1	6.42 (2.466)	1	↑ 0.79 (2.226)	→ 0	-1.732	0.148	-1.699	0.089
Biodiversity	5.29 (1.488)	3	5.38 (1.715)	2	↑ 0.08 (1.586)	↑ 1	-0.753	0.586	-0.215	0.830
Wildfires resistance	5.04 (2.476)	5	5.13 (2.092)	3	↑ 0.08 (1.998)	↑ 2	-0.927	0.760	-0.024	0.981
Water quality	5.33 (2.120)	2	5.04 (2.156)	4	↓ -0.29 (2.177)	↓ -2	-0.627	1.211	-0.952	0.341
Soil erosion protection	5.17 (2.078)	4	4.92 (2.062)	5	↓ -0.25 (1.939)	↓ -1	-0.569	1.069	-0.394	0.694
Carbon sequestration	4.25 (2.172)	6	4.38 (2.163)	6	↑ 0.13 (1.569)	→ 0	-0.788	0.538	-0.257	0.797
Cultural services	4.13 (1.918)	7	3.96 (2.331)	7	↓ -0.17 (2.278)	→ 0	-0.795	1.129	-0.344	0.731
Resin	2.92 (2.448)	8	2.42 (2.205)	8	↓ -0.50 (1.978)	→ 0	-0.335	1.335	-1.222	0.222

* significant at $p < 0.05$; SD – standard deviation; na – not applicable; ↑ increase; ↓ decrease; → no variation

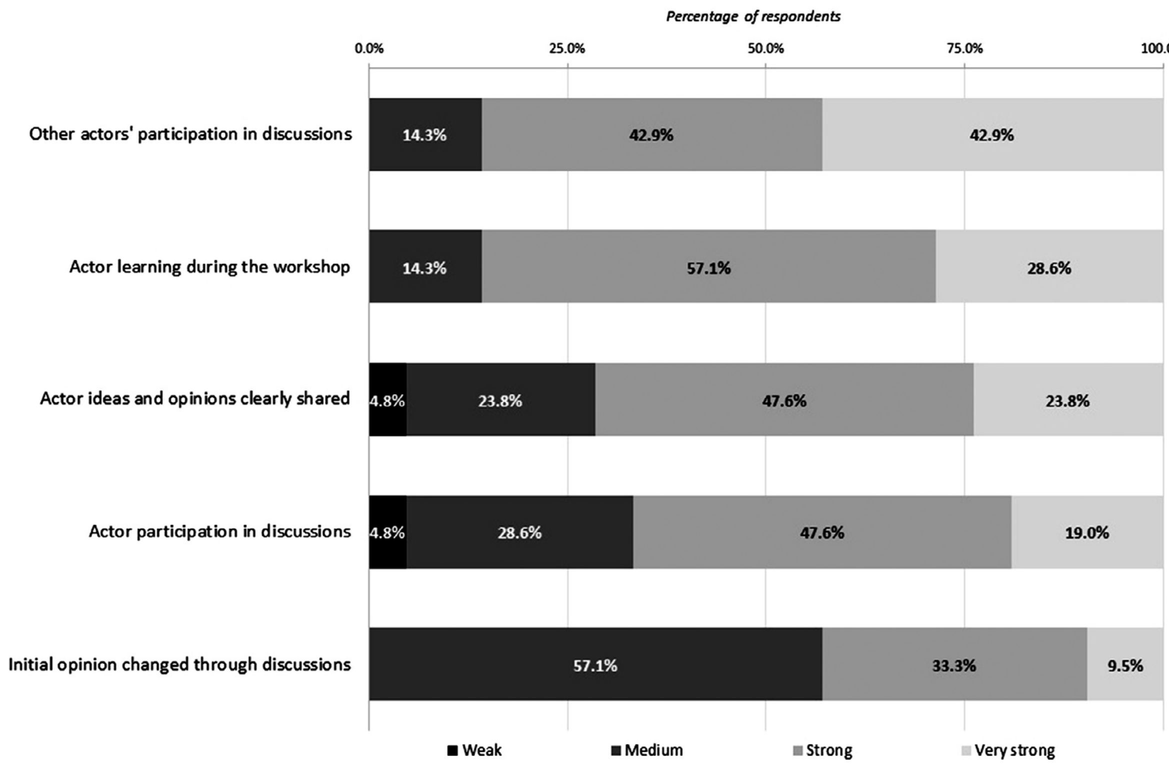

Fig. 2. Aggregate results (n=21) of actors' perceptions about their and others' participation in workshop discussions, measured on a 5-point Likert-scale ("very weak" to "very strong" importance).

(e.g., eucalypt is harvested every 10-12 years and maritime pine at 35-50 years); (b) the wildfire recurrence period (about ten years); and (c) the market demand. Throughout discussions actors stressed that FMMs with extended rotation ages are not attractive to forest owners and managers. Further, actors from the Market Agents group stated that market demand for pine wood is less than 35 years. Therefore, actors required an adjustment of the *Pure maritime pine* and *Pure pedunculate oak* models to shorten the rotation age and anticipate revenues.

During the discussions, some forest owners reported a high mortality of trees of *Pure chestnut* model. This situation can be caused by ink disease (*Phytophthora cinnamomic*) or by chestnut cancer (*Endothia parasitica* And & And). This sharing of information may explain the actors' opinion shift on the area to be allocated to this model. The preferences for *Pure chestnut* decreased significantly from pre- to post-questionnaire, changing from the third preferred FMM to the least preferred.

Most forest owners and managers depend on the forest economic returns, directly or indirectly. During the workshop discussions, actors reinforced that one of the most important concerns is the profitability of forestry investment. Moreover, actors revealed the importance they assign to the diversification of income sources and to the evenness of revenue flows. According to the actors, in Vale do Sousa, these economic criteria depend on the *Wood production,* classified as the most important forest function while *Wood* is the preferred ecosystem service. These findings reinforce the preference of actors for *Wood* provisioning in Vale do Sousa, as reported by Borges et al. (2017), Juerges et al. (2017), and Marques et al. (2020).

To achieve a profitable and multifunctional forest, that can minimize the wildfire problem, during participatory discussions, actors debated the inclusion of two alternatives FMM: (a) cork oak (pure or mixed); and (b) riparian broadleaves. Discussions about these alternative models may have led to the actors' opinion shift since the preference for *Other forest management model* increased significantly from the pre- to the post-questionnaire. In the pre-questionnaire the cork oak FMM was proposed by a single actor while in the post-questionnaire it was proposed by four actors. In addition, forest managers emphasized that wildfires may dissuade them from choosing species with longer rotation age. Actors stressed that the cork oak FMM may be an adequate alternative to respond to concerns (namely with income even flow and with losses due to wildfires) that influence forest management decisions in Vale do Sousa. Besides the cork oak regularity of income (every nine years), the actors also highlighted the cork oak's excellent ability to regenerate in the post-fire conditions in Vale do Sousa.

Another notable opinion shift, from pre- to post-questionnaire, was a significant decrease in preference for the forest function *Wood production*. This opinion change may be related to the information that speakers (researchers) presented about the range of available ecosystem services and forest functions in Vale do Sousa. The graphical comparison of the available ecosystem services by FMM brought a new vision and helped promote discussions about the possibility of diversifying forest functions and ecosystem services as this may contribute to decrease losses by wildfires. Also, some actors stressed the importance of diversify the forest functions for a sustainable forest management.

Despite the fact that actors continue to consider *Wood production* as the most important forest function, the decrease in their preference evidence a willingness to change current forest management practices. In fact, during the participatory discussions, actors expressed their interest in a multifunctional forestry. It appeared that actors are available to consider alternative FMMs and to diversify the forest functions and ecosystem services in forest management planning. Forest managers interested in profitable forests were not opposed to alternative FMMs (e.g. riparian broadleaves), forest functions (e.g., water quality protection), or ecosystem services (e.g., biodiversity) since they can receive payments for that forest management change.

These findings suggest an opportunity for ZIF managers to enhance forest management planning, since there is an openness of the forest managers to accept changes to the current forest management practices. This reveals that if more information is provided about scenarios involving changing social demand, market fluctuations and wildfires recurrence, actors may adjust their preferences to better address the new challenges.

4.2. Actors knowledge and social learning during the workshop

An evaluation questionnaire should complement the pre- and post-questionnaire approach to assess (a) the quality of workshop and participatory approach and discussions; (b) the interaction between actors; (c) actors self-learning and knowledge. Most actors stated that they viewed themselves as having learned during the workshop, increasing their knowledge in a social context. Moreover, the actors acknowledged that with the participatory discussions they better understand the points of view of other actors regarding forest management. Also, they highlighted the increased knowledge of opportunities and alternatives to diversify forest functions, ecosystem services and FMMs, that they may consider in forest management planning.

Thus, there is evidence that in our approach the participatory discussions contributed to social learning, confirming the findings by Reed et al. (2010) and Voinov and Bousquet (2010). Most actors did play an active role during the workshop; they discussed forestry issues and learned with social interaction. Furthermore, the workshop also demonstrated its utility in improving the relationships between actors. Some evidence of this social learning was the interactions after the workshop, with questions and requests for more information related to the workshop discussions. For example, two forest owners, one actor from wood industry association and another from forest certification contacted us to ask for more information about the alternative FMMs and the assortment of ecosystem services in Vale do Sousa. Another example was the contact by an actor from the forest authority with whom we discussed the improvement of the cork oak FMM proposed during the workshop discussion session.

The results from the application of pre- and post-questionnaire to actors' preferences for forest management, can be compared to other similar studies in natural resources management. As demonstrated by this research, the participatory approach that involves social interaction between actors can (a) impact their knowledge and learning (Fatorić and Seekamp, 2017; Mayer et al., 2017; Upton et al., 2019); and (b) in some situations, can contribute to actors opinion change (Canfield et al., 2015; Lafon et al., 2004).

4.3. Participatory approach limitations and future improvements

The application of this approach provided valuable information that may be used by future research. We identified five issues to address. Firstly, the time available for the actors to interact with researchers and to discuss among them might be extended to support further their reflections and the learning process. This would be influential to examine further whether in forest management planning, opinions change quickly or if, as Smith (1994) points out, actors' opinions and interests do not change rapidly or unpredictably.

In this framework, in future research, we might apply the same questionnaire in four steps, to quantify and confirm the impact of the workshop and participatory discussions in a long-time frame. In the first step, we would send the pre-questionnaire by email or mail to the actors one week before the workshop so that they could examine it comfortably without the workshop social environment time constraint. In the second step, actors would answer the pre-questionnaire in the first session of the workshop. In the third step, actors would respond the post-questionnaire at the end of the workshop. And in the fourth step, we would send the post-questionnaire by email or mail to the actors one week after the workshop, so that they have more time to absorb, reflect and think about all the information provided by the speakers (researchers) and the participatory discussions. Thus, we can compare a pre-questionnaire and two post-questionnaires and assess the effect of participatory discussions and social interaction in actors' initial opinion, according to the time given for reflection (on the day and one week later).

The drawback of this four steps approach can be a low response rate as outside the workshop environment since it may be more difficult to ensure actors' commitment and availability. In addition, it may be challenging to ensure that a suitable number of the same actors answer the three questionnaires so that we may get matched questionnaires. In order to circumvent potential shortcomings of the four steps approach, the questionnaires should be sent to a wide range of stakeholders, ensuring diversity and representability of interest groups. In addition, follow-up work with the actors will be necessary in the first and fourth steps. Researchers should contact actors, by phone or in person, to motivate them to answer the questionnaires, emphasizing the importance of their participation in the study.

Secondly, in future research the structure of the questionnaires might be adjusted to explore further the actors' points of view. Although actors could add other unlisted features, they had little time to justify their preferences and explain their perceptions. Also, not all actors feel comfortable to freely express their opinions in participatory discussions. Thus, in future research, we may add a field to each question for actors to express themselves anonymously, without restrictions that the social environment may impose on them.

Thirdly, future research should address further the weak participation of some actors in the discussion and the need to strengthen their involvement. Therefore, we should identify the most passive or shy actors and enhance their participation so that they can present and share their ideas and opinions. Fourthly, future research should address the fact that actors with the same interests or from the same entity or interest group may speak to each other and agree on some responses to the questionnaires. So, to guarantee individual and independent responses, actors' seats are distributed in advance, ensuring that actors sitting side by side have different interests. Moreover, before starting to fill up the questionnaire, the researcher can reinforce that the answers are individual.

Fifthly, future research should develop strategies to ensure sufficient actors for statistical analysis, assuring the representativeness of interests. We identified and invited 46 actors representing the diversity of interests in forest management in Vale do Sousa. Actors were categorized into four groups, according to their interests in forest management (Juerges and Newig, 2015; Marques et al., 2020): civil society, forest owners, market agents and public administration. Knowing at the outset that not all actors would be available to participate in the workshop, we invited more actors (46 actors) than we thought it would be interesting to have present (30 to 35 actors). Although 13 actors were not available to attend, those who participated in the workshop were representative of the four interest groups from Vale do Sousa. However, only 24 actors were available to attend the full day workshop. So, further research is needed to develop and explore strategies for engaging more actors in the participatory approaches. This will be influential to draw more information from the perspective of each group.

5. Conclusions

This study provides information about actors' preferences and points of view to support landscape-level forest management planning. It is the first evaluation of actors' preferences for FMMs, forest functions and ecosystem services for Vale do Sousa. Our findings reveal the importance of involving actors to discuss alternatives to current forest management practices.

Vale do Sousa forest management planning encompassed four FMMs and three species, eucalypt, maritime pine and chestnut. In the workshop, researchers proposed two alternative FMMs (*Pure maritime pine* and *Pure pedunculate oak*), that were well accepted by the actors. However, they asked for an adjustment to these FMMs to shorten the rotation age and anticipate revenues. An important outcome from this participatory approach was the inclusion of two new alternative FMMs - *Cork* *oak* and *Riparian broadleaves* - in forest management planning in Vale do Sousa. During participatory discussions actors considered that these two models are suitable for Vale do Sousa as they meet their economic goals (income flow) and environmental concerns (biodiversity and wildfire protection). Due to discussions, actors changed their opinion about these alternative FMMs, and their preference for them increased significantly from pre- to post-questionnaire. With this participatory approach, we went from four to eight FMMs, thus contributing to diversify the forest management options in Vale do Sousa.

The integration of actors' preferences and participatory discussions outcomes from this study in ZIF forest management planning can (a) facilitate its social acceptance and implementation; (b) the development of more consensual forest management plans; and (c) contribute to enhance actors' knowledge and learning. The proposed approach can be easily applied or replicated in other ZIF or forest management areas. This systematic collection of information (quantitative from questionnaires and qualitative from participatory discussions) may be useful to support ZIF managers, when developing collaborative forest management plans, or policymakers, when designing effective forest policy programs that can address the actors' demands and preferences. Moreover, comments by actors reported in the self-evaluation questionnaire confirmed that they found the workshop and participatory discussions useful. This approach enables actors to enhance their knowledge about the range of FMMs, forest functions and ecosystem services that can promote a multifunctional and sustainable forestry.

The survey of actors' preferences for forest management using pre- and -post-questionnaires is a useful, practical, low-cost, and straightforward way for evaluating their opinions and perceptions. However, further research can improve this approach by (a) giving actors more time to reflect in their preferences and choices (before and after workshop); (b) asking actors to justify their preferences in questionnaires so we can better understand their opinion change; (c) assessing the social learning using an evaluation questionnaire with more questions to quantify it; (d) extending the workshop to a broader interest groups; and (e) developing strategies to attract more actors and motivate them to participate in the workshop throughout the day.

This research was developed in the framework of a participatory process that is being developed with actors with interests in forest management of Vale do Sousa. In the next stage of the process we will take advantage of the actor analysis research (Juerges et al., 2017; Marques et al., 2020) and the results from this workshop with a participatory approach to develop further the assessment of actors' preferences applying other participatory techniques in the framework of multiple criteria decision analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 676754 with the title 'Alternative models for future forest management' (ALTERFOR), as well as from the project LISBOA-01-0145-FEDER-030391 - PTDC/ASP-SIL/30391/2017 with the title 'Forest ecosystem management decision-making methods - an integrated bio-economic approach to sustainability' (BIOECOSYS). The authors would like to thank the Fundação para a Ciência e a Tecnologia (Portugal) for funding the Ph.D. grant of Marlene Marques (PD/BD/128257/2016) and for support the Forest Research Center Project UIDB/00239/2020. We warmly thank all the actors who have participated in the workshop and answered the questionnaires. We want to thank Carlos Caldas and Susete Marques for testing the questionnaires.

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CHAPTER IV

Multicriteria decision analysis and group decision-making to select stand-level forest management models and support landscape-level collaborative planning

Paper published in *Forests*

Marques, M., Reynolds, K. M., Marto, M., Lakicevic, M., Caldas, C., Murphy, P. J., Borges, J. G. 2021. Multicriteria Decision Analysis and Group Decision-Making to Select Stand-Level Forest Management Models and Support Landscape-Level Collaborative Planning. Forests. 12, 399. https://doi.org/10.3390/f12040399

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Article

Multicriteria Decision Analysis and Group Decision-Making to Select Stand-Level Forest Management Models and Support Landscape-Level Collaborative Planning

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Citation: Marques, M.; Reynolds, K.M.; Marto, M.; Lakicevic, M.; Caldas, C.; Murphy, P.J.; Borges, J.G. Multicriteria Decision Analysis and Group Decision-Making to Select Stand-Level Forest Management Models and Support Landscape-Level Collaborative Planning. *Forests* **2021**, *12*, 399. https://doi.org/10.3390/f12040399

Academic Editor: Isabella De Meo

Received: 6 March 2021
Accepted: 25 March 2021
Published: 28 March 2021

Abstract: Forest management planning is a challenge due to the diverse criteria that need to be considered in the underlying decision-making process. This challenge becomes more complex in joint collaborative management areas (ZIF) because the decision now may involve numerous actors with diverse interests, preferences, and goals. In this research, we present an approach to identifying and quantifying the most relevant criteria that actors consider in a forest management planning process in a ZIF context, including quantifying the performance of seven alternative stand-level forest management models (FMM). Specifically, we developed a combined multicriteria decision analysis and group decision-making process by (a) building a cognitive map with the actors to identify the criteria and sub-criteria; (b) structuring the decision tree; (c) structuring a questionnaire to elicit the importance of criteria and sub-criteria in a pairwise comparison process, and to evaluate the FMM alternatives; and (d) applying a Delphi survey to gather actors' preferences. We report results from an application to a case study area, ZIF of Vale do Sousa, in North-Western Portugal. Actors assigned the highest importance to the criteria income (56.8% of all actors) and risks (21.6% of all actors) and the lowest to cultural services (27.0% of all actors). Actors agreed on their preferences for the sub-criteria of income (diversification of income sources), risks (wildfires) and cultural services (leisure and recreation activities). However, there was a poor agreement among actors on the sub-criteria of the wood demand and biodiversity criteria. For 27.0% of all actors the FMM with the highest performance was the pedunculate oak and for 43.2% of all actors the eucalypt FMM was the least preferable alternative. The findings indicate that this approach can support ZIF managers in enhancing forest management planning by improving its utility for actors and facilitating its implementation.

Keywords: forest management planning; ecosystem services; cognitive mapping; AHP; SMART; Delphi; participatory planning

1. Introduction

Contemporary planning for sustainable management of forest resources is a very complex problem, mainly due to the multiplicity of wide-ranging criteria involved in the underlying decision-making process (e.g., income, soil erosion, wildfire risk) (e.g., [1–3]). Forest management also needs to consider additional challenges such as climate change, dynamics of global markets, and societal demand. Practically, all such decision problems are inherently multicriteria in nature [1,4]. Joint collaborative forest management, e.g., ZIF (the acronym for *Zona de Intervenção Florestal* in Portuguese) is complicated further by the need to consider the diverse perspectives of numerous actors (e.g., forest owners, forest managers, public administration, market agents, and civil society) who bring different interests, concerns, preferences, values, and goals to the decision problem [5,6]. Thus, traditional decision-making approaches to stand-level forest management in North-Western Portugal with a primary focus on economics are unlikely to ensure the sustained provisioning of desired ecosystem services (ES) [7,8]. Innovative methods are needed for forest management decision-making in ZIF.

This innovation may encompass the use of multicriteria decision analysis (MCDA) methods. Belton and Stewart ([4], p. 2) define MCDA as "*an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter*." They involve several approaches that aim to support the systematic evaluation of alternatives with multiple, and often conflicting, objectives [4,9–11], thus helping actors and other decision-makers organize and synthesize complex information to facilitate confident decision-making [4], while accounting for diverse criteria. MCDA supports the evaluation and prioritization of alternatives that best reflect the actors' goals and preferences even when consensus among actors is not possible [12].

There have been a significant number of research articles on, and scientific reviews of, the application of MCDA in natural resources management planning. For instance, Mendoza and Martins [13], reviewing MCDA methods from 1970–2006, reported Finland as the country with more publications referring to the use of MCDA in natural resource management (18 out of 57), followed by the USA with 16 publications and Australia with five publications. For additional scientific reviews and application examples, the reader is referred to [1,12–18].

So, how can we work with actors with different interests to identify their preferences, to understand the importance that actors assign to them, and thus support forest management planning using MCDA? Group decision-making (or equivalently, participatory planning) is widely used when many conflicting interests and goals are involved [13]. Group decision-making has become increasingly important in natural resource management because multiple values are treated simultaneously in time and space, and multiple actors can be involved in the decision process [19,20]. Thus, the group decision-making technique allows actors to participate and contribute actively to forest management decisions, promoting a more transparent, simple, and easily accessible participatory planning process [3,13].

There are several group-interaction techniques in the fields of behavioral science and decision analysis (e.g., workshops, questionnaires, cognitive mapping, Delphi surveys, focus groups, etc.) that help structure group goals, criteria, and preferences. For example, workshops with participatory discussions promote and broaden the actors' social learning and their understanding of other actors' opinions contributing to reducing conflict of interests [21]. The group decision-making approaches can support (particularly small-scale) forest owners of ZIF, by promoting learning in the group context, and improving group understanding of forest management alternatives. Mainly, participation can be used to increase the legitimacy of a decision and to facilitate the implementation of the chosen forest management models (FMM), as well as to improve the substantive quality of the decision in terms of total social benefit. Moreover, participation can be an end in itself, fulfilling democratic or other local empowerment objectives in the context of forest management [22].

Although the application of the group decision-making approach to forest planning is a relatively recent research area, Diaz-Balteiro and Romero [1] identified a substantial number of research studies related to this approach, confirming an increasing interest in the use of this technique with MCDA. Similarly, Marttunen et al. [10] confirmed that actors' involvement in MCDA has become relatively common, particularly in environmental decision-making. Borges et al. [6] and Maroto [23] note that MCDA and group decision-making are powerful techniques for dealing with strategic decision problems and divergent interests, while Ortiz-Urbina et al. [3] highlight the potential of the hybridization of both techniques.

There are few examples in the literature of the application of MCDA to forest management planning in Portugal. Borges et al. [6] applied a combined methodology of participatory workshops and multicriteria decision methods to support the development and negotiation of targets for the supply of ES in two ZIF areas in Portugal—ZIF Chouto Parreira (Chamusca) and ZIF Paiva and Entre-Douro e Sousa (Vale do Sousa). While Xavier et al. [24] employed a methodology based on the multicriteria approach to support decisions for mitigating wildfire risk in a ZIF in the Algarve region, in southern Portugal. However, to our knowledge, a combined MCDA and group-decision making approach has not yet been applied to joint management planning of a forested landscape to help forest actors rank and select the stand-level FMM that best reflect their preferences regarding the supply of ES. This research aims at addressing this gap.

For that purpose, our approach encompasses four stages. First, it uses cognitive mapping [4,25] in a participatory planning session to identify (and discuss with actors) the most relevant criteria and sub-criteria when selecting among forest management alternatives. Second, it evaluates and quantifies the importance of criteria and sub-criteria and the utility of FMM that are better suited to the actors' preferences and concerns, by using a multicriteria questionnaire to address the analytic hierarchy process (AHP) method to judge the importance of criteria and sub-criteria by pairwise comparisons [26,27], the simple multi-attribute rating technique (SMART) to rate the attributes of the alternative FMM [11,28], and a Delphi survey to gather actors judgments [29–31]. Third, it analyzes the convergences and divergences among actors with respect to FMM preferences. Finally, it explores the potential value-added for informing a participatory group decision-making process with a structured decision model that explicitly addresses actors' preferences with respect to criteria, sub-criteria, and FMM alternatives compared to simple questionnaires that actors have previously used to directly rank FMM preferences without the benefit of an explicit decision model [21].

2. Materials and Methods

2.1. Case Study Area

The Vale do Sousa case study area is located in the North-Western region of Portugal and extends over an area of 14,840 hectares (Figure 1). It includes two joint collaborative management areas: ZIF of Entre-Douro-e-Sousa and ZIF of Paiva. The forests are the primary land use. The predominant species are pure and mixed stands of eucalypt (*Eucalyptus globulus* Labill) and maritime pine (*Pinus pinaster* Aiton). The forestland is mainly privately owned, small-scale, and fragmented into multiple blocks. Vale do Sousa is representative of forest management performed in North-Western Portugal, because (a) it has a very large number of small-scale forest owners, (b) eucalypt is the main species, (c) forest management is decided mainly according to individual economic criteria; and (d) the actors interested in forest management have different goals, points of view, concerns, and expectations about forest management planning.

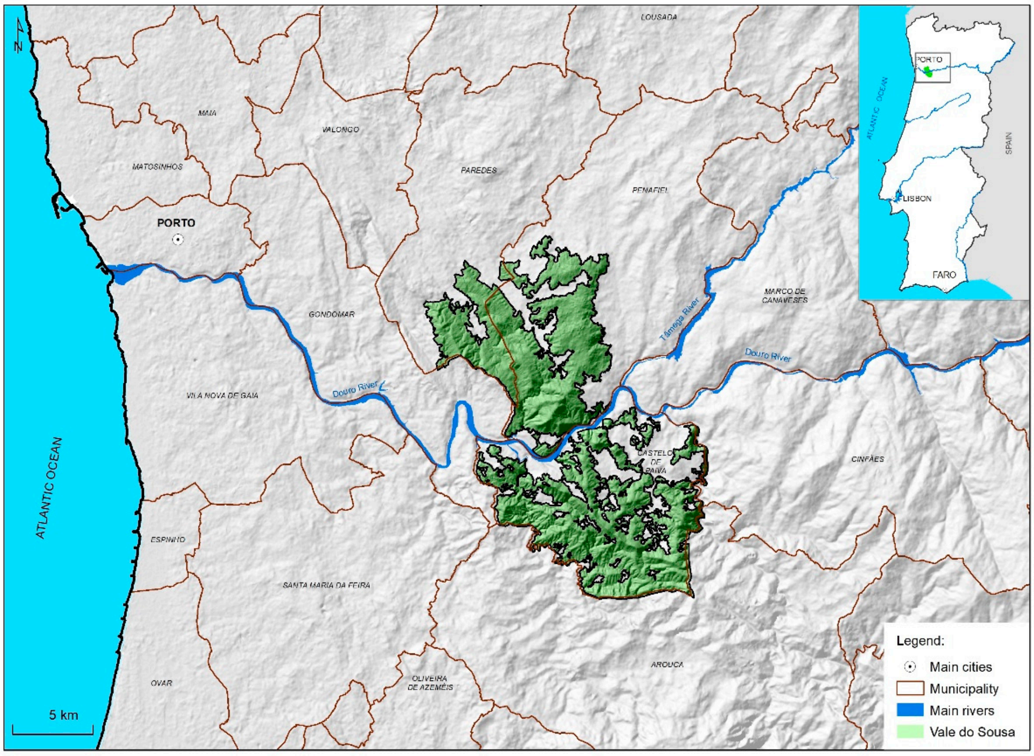


Figure 1. Location of Vale do Sousa case study area.

2.2. Research Design

We used a combined MCDA and group decision-making approach to identify the FMM that best reflected the actors' preferences regarding the supply of ES process. We implemented the MCDA process in four stages (Figure 2). The choice of participatory techniques was based on its potential to integrate actors' opinions and preferences in forest management planning.

2.2.1. Problem Structuring

We started (stage 1) by structuring the problem based on the information and knowledge gained from former interviews and actor analysis [29,30] and participatory workshop discussions [21].

Our overall problem formulation was motivated by the proposition that the traditional approach to selecting FMM, driven primarily by economic considerations, is unlikely to ensure the sustained long-term provisioning of a broader and balanced range of ES and the diversification of income sources to forest owners and managers [7]. Actor analysis [32,33] identified the problems and conflicts, and the actors that can affect or influence the forest management decisions. A subset of these actors deemed as representative of Vale do Sousa forest management interests was invited to a participatory workshop where they highlighted that the greatest management planning difficulty was to identify the FMM that best respond to their preferences and concerns, in addition to the financial objective [21]. This was influential to characterize the decision context, identify goals and trigger the second stage with key actors.

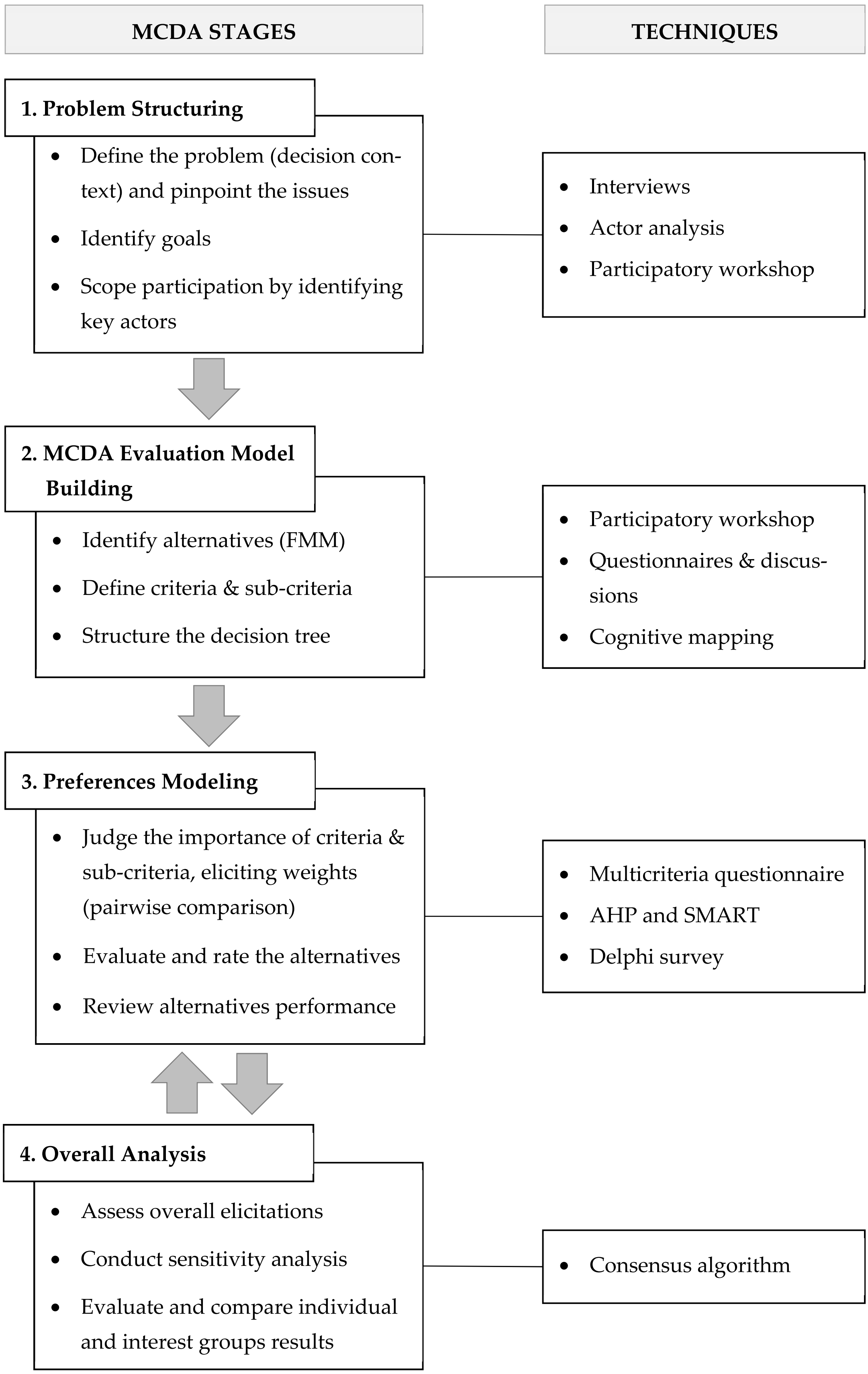


Figure 2. General stages of the multicriteria decision analysis methodological process and techniques applied. Modified from [4,11,34].

2.2.2. MCDA Evaluation Model Building

In the participatory workshop, the actors identified and agreed further on eight stand-level FMM for Vale do Sousa: mixed maritime pine and eucalypt, mixed eucalypt and maritime pine, pure chestnut, pure eucalypt, pure maritime pine, pure pedunculate oak, pure cork oak, and riparian broadleaves [21]. For this study, we considered all FMM except the riparian broadleaves as this option is only applied to very restricted areas, namely the waterways to provide specific ES (e.g., soil protection, biodiversity).

The problem under analysis was decomposed in a structured way into simple components that could be easily analyzed by the actors. During the workshop, we conducted a half-day session, applying a cognitive mapping technique. A total of 28 actors attended this session (Table 1).

Table 1. Identification of the actors who attended the cognitive mapping session by interest group.

Interest Group and Type of Actor	Attended the Cognitive Mapping Session
Civil Society	***5***
Environmental NGO	2
Forest Certification	3
Forest Owners	***9***
Forest Owners' Association	2
Forest Owners (Non-Industrial)	6
Parish Council with Community Areas	1
Market Agents	***10***
Forest Investment Fund	1
Forest Services Provider	1
Forest Services Provider and Wood Buyer	3
Wood Industry	3
Wood Industry Association	2
Public Administration	***4***
Forest Authority	2
Municipality	2
Total	**28**

Two experienced facilitators conducted the cognitive mapping session. They tried to conduct the session in an impartial, independent, and unbiased way. With this technique, all actors have an equal chance to share and contribute to the discussion.

The session started by asking actors to identify and write on a supplied post-it, their most important criterion in forest management decision-making. We clarified that the purpose was not to reach a consensus but to have a shared understanding of the different criteria. The post-its were placed on a large board and a facilitator read out loud all of them. The facilitator and actors clustered the post-its based on their similarity.

Next, facilitators opened the discussion to analyze each group of criteria, asking actors, "Which criteria should we choose?" and "What is the importance of each group of criteria?" Several opinions, concerns and points of view arose from the lively discussion.

During the session, a researcher assisted the facilitators in organizing the cognitive map using the software Mental Modeler (www.mentalmodeler.org, accessed on 7 December 2020). The actors approved a consensus cognitive map with five groups of criteria and 17 sub-criteria (Figure 3).

To structure the decision tree (stage 2), we converted the cognitive map into a hierarchical structure and complemented it with information from the problem structuring stage. We used the software Criterium DecisionPlus—CDP (InfoHarvest, Inc., Seattle, WA, USA, 1996–2018), a component of the ecosystem management decision support (EMDS) system, [35]), to structure the decision tree which was divided into three parts: six criteria, 12 sub-criteria, and seven alternatives (Figure 4). In structuring the decision tree, we followed a set of key properties highlighted and described by Goodwin and Wright [28] and von Winterfeldt and Edwards [36], namely: completeness, operationality, decomposability, essentiality, understandability, non-redundancy, conciseness, and independence.

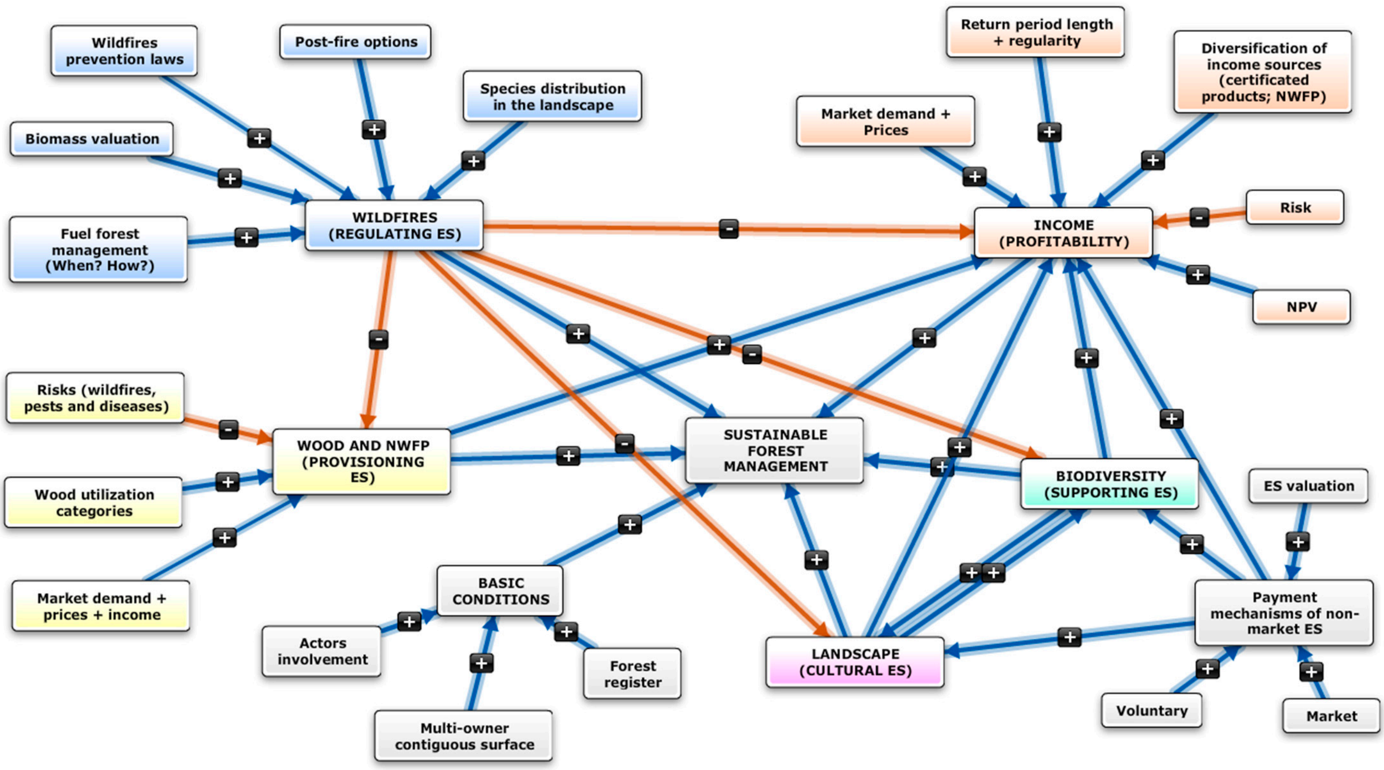


Figure 3. Cognitive map developed with actors during the workshop.

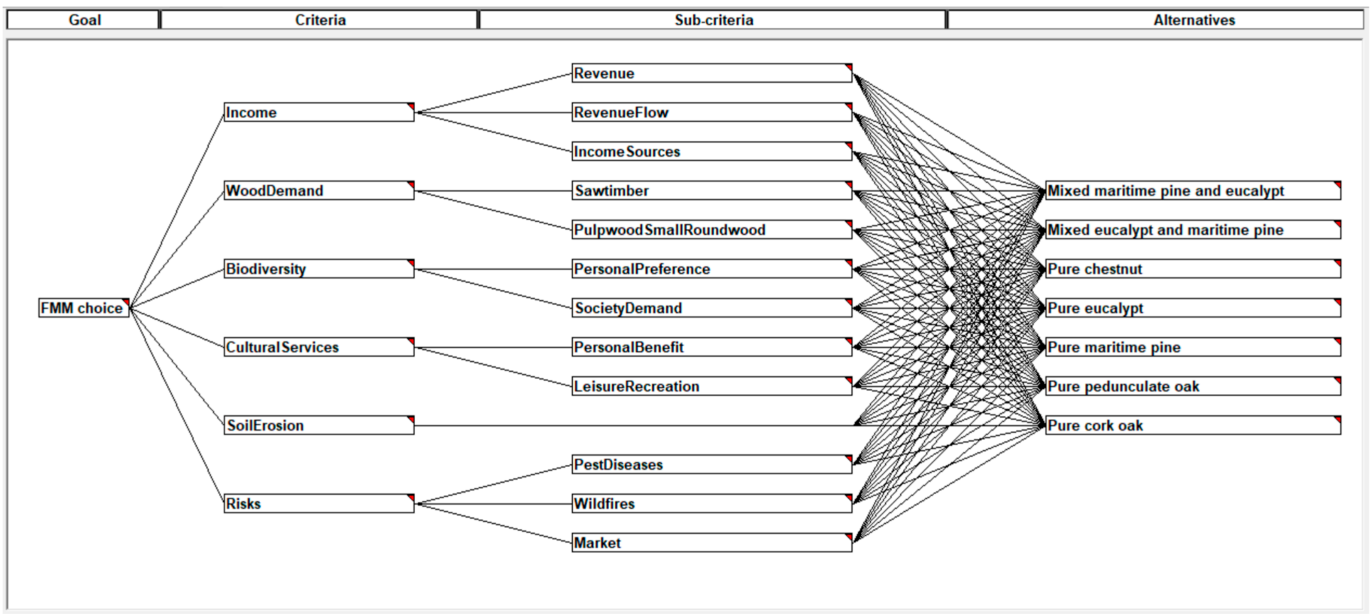


Figure 4. Decision tree (designed by the authors, using the software CDP).

2.2.3. Preferences Modeling

Because the actors were not familiar with CDP, we used Excel to structure the multi-criteria questionnaire, based on CDP, to facilitate weighting the criteria/sub-criteria and rating the alternatives on the criteria and sub-criteria (utility). The questionnaire was organized in three parts, according to the decision tree. We used the AHP to judge the importance of criteria and sub-criteria by pairwise comparisons, and SMART to rate the attributes of the alternatives.

First, in Part I (criteria) and Part II (sub-criteria), we asked each actor to assign the relative importance of each criterion (or sub-criterion) relative to all others, by pairwise comparison on the AHP's standard 9-point scale (Figure 5). We provided a range of nine numerical values (with corresponding verbal descriptions) ranging from 1 (equal) to 9 (absolutely better) to characterize how much more important one criterion was over another. We used the abbreviated pairwise comparison technique in CDP that skips some comparisons to decrease the number of comparisons needed [37], thus expediting actor responses. This method is based on the axiom of transitivity of preference [11].

For each criterion and sub-criterion, a text box with a question was presented to support the analysis. The elicitation was facilitated by a dynamic graph. Therefore, they could change the elicitation if the result did not comply with their expectations, or if they wanted to explore how selecting a different value affected the result. This form of interactive response was provided to ensure that actors understood their elicitation correctly.

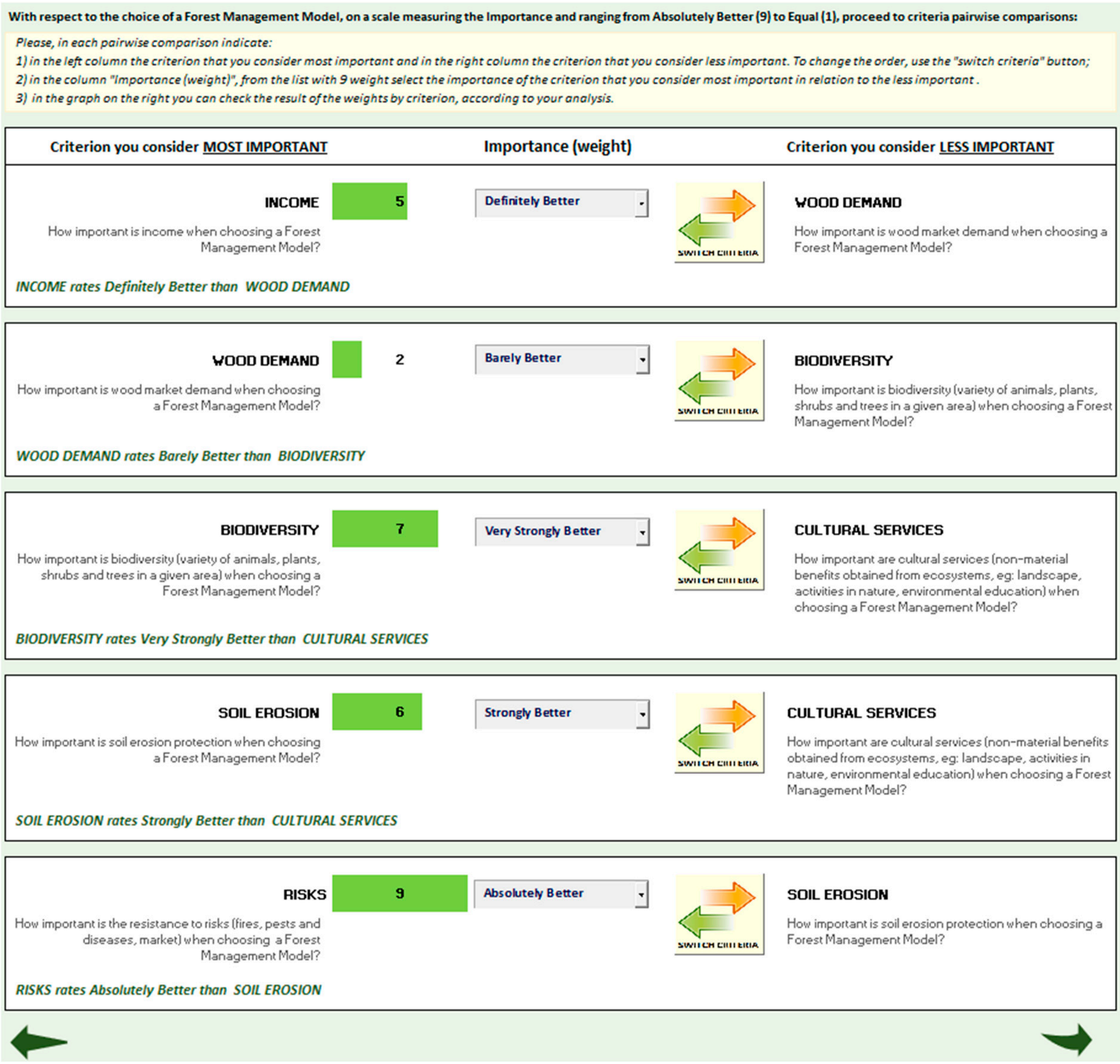


Figure 5. *Cont.*

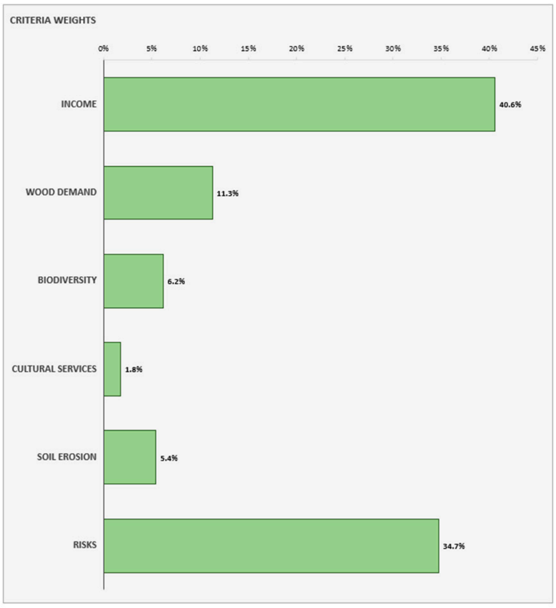
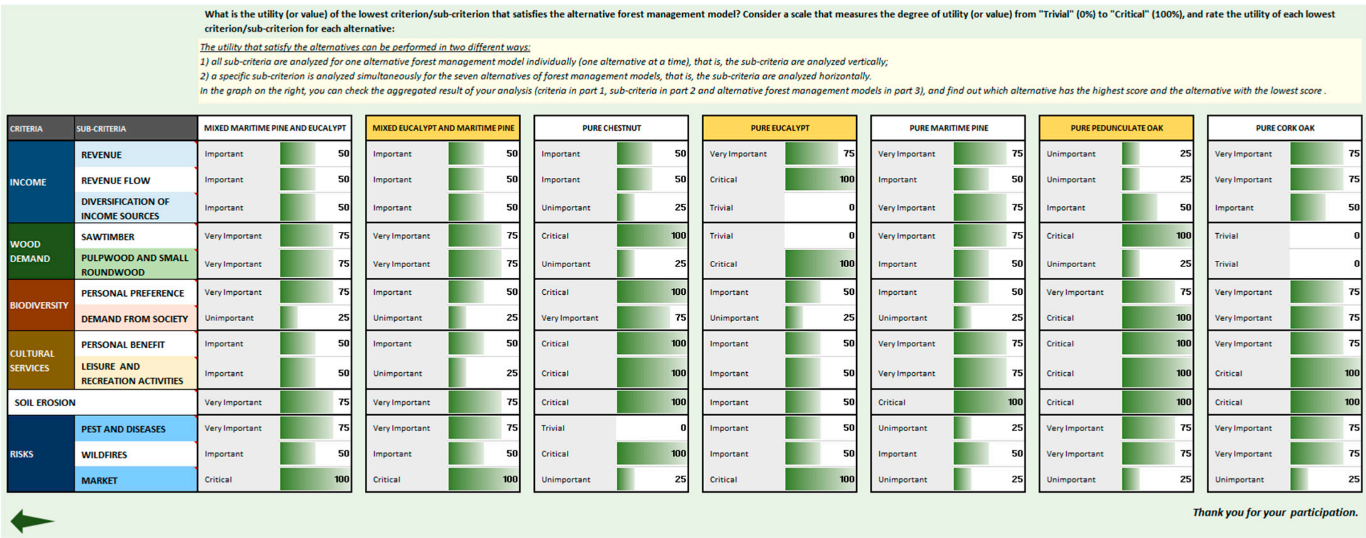


Figure 5. Multicriteria questionnaire: judging the importance of criteria by eliciting weights by pairwise comparisons.

In Part III (alternatives) of the questionnaire, we asked each actor to evaluate each FMM against the lowest-level criteria or sub-criteria (Figure 6), assigning it a utility value, ranging from 0 (very low) to 100 (very high). We asked, "How well does this alternative address or satisfy this sub-criterion?" The goal is to measure the performance of each alternative on that sub-criterion. This gives a measure of how well a FMM performs over all the lowest-level criteria or sub-criteria.


What is the utility (or value) of the lowest criterion/sub-criterion that satisfies the alternative forest management model? Consider a scale that measures the degree of utility (or value) from "Trivial" (0%) to "Critical" (100%), and rate the utility of each lowest criterion/sub-criterion for each alternative:

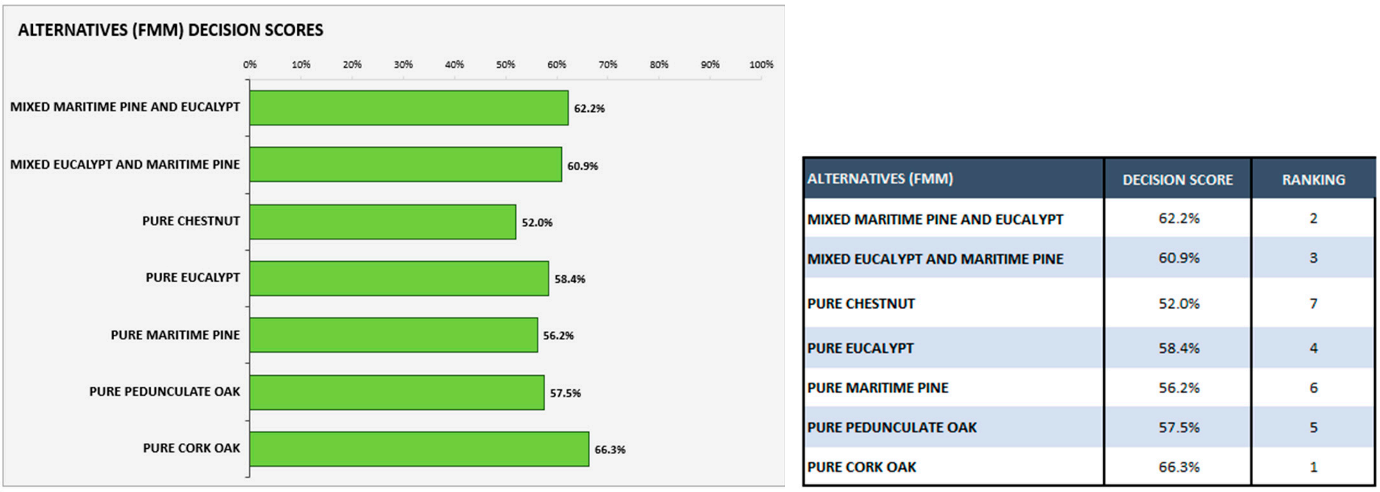
The utility that satisfy the alternatives can be performed in two different ways:
1) all sub-criteria are analyzed for one alternative forest management model individually (one alternative at a time), that is, the sub-criteria are analyzed vertically;
2) a specific sub-criterion is analyzed simultaneously for the seven alternatives of forest management models, that is, the sub-criteria are analyzed horizontally.
In the graph on the right, you can check the aggregated result of your analysis (criteria in part 1, sub-criteria in part 2 and alternative forest management models in part 3), and find out which alternative has the highest score and the alternative with the lowest score .

CRITERIA	SUB-CRITERIA	MIXED MARITIME PINE AND EUCALYPT		MIXED EUCALYPT AND MARITIME PINE		PURE CHESTNUT		PURE EUCALYPT		PURE MARITIME PINE		PURE PEDUNCULATE OAK		PURE CORK OAK	
INCOME	REVENUE	Important	50	Important	50	Important	50	Very Important	75	Very Important	75	Unimportant	25	Very Important	75
	REVENUE FLOW	Important	50	Important	50	Important	50	Critical	100	Important	50	Unimportant	25	Very Important	75
	DIVERSIFICATION OF INCOME SOURCES	Important	50	Important	50	Unimportant	25	Trivial	0	Very Important	75	Important	50	Important	50
WOOD DEMAND	SAWTIMBER	Very Important	75	Very Important	75	Critical	100	Trivial	0	Very Important	75	Critical	100	Trivial	0
	PULPWOOD AND SMALL ROUNDWOOD	Very Important	75	Very Important	75	Unimportant	25	Critical	100	Important	50	Unimportant	25	Trivial	0
BIODIVERSITY	PERSONAL PREFERENCE	Very Important	75	Important	50	Critical	100	Important	50	Important	50	Very Important	75	Very Important	75
	DEMAND FROM SOCIETY	Unimportant	25	Unimportant	25	Very Important	75	Unimportant	25	Unimportant	25	Critical	100	Very Important	75
CULTURAL SERVICES	PERSONAL BENEFIT	Important	50	Important	50	Critical	100	Important	50	Very Important	75	Critical	100	Very Important	75
	LEISURE AND RECREATION ACTIVITIES	Important	50	Unimportant	25	Critical	100	Important	50	Very Important	75	Critical	100	Critical	100
SOIL EROSION		Very Important	75	Very Important	75	Critical	100	Important	50	Critical	100	Critical	100	Critical	100
RISKS	PEST AND DISEASES	Very Important	75	Very Important	75	Trivial	0	Important	50	Unimportant	25	Very Important	75	Very Important	75
	WILDFIRES	Important	50	Important	50	Critical	100	Important	50	Important	50	Very Important	75	Very Important	75
	MARKET	Critical	100	Critical	100	Unimportant	25	Critical	100	Unimportant	25	Unimportant	25	Unimportant	25

Thank you for your participation.

Figure 6. Multicriteria questionnaire to evaluate and rate the utility of the attributes of alternatives (columns) with respect to the lowest-level criteria or sub-criteria (rows).

In the questionnaire, we also provided a dynamic graph with the aggregate outcome of the analysis (Figure 7). We added commentaries to all lowest-level criteria and sub-criteria, so actors could get more information about that topic. The multicriteria questionnaire was pre-tested by three researchers.



ALTERNATIVES (FMM)	DECISION SCORE	RANKING
MIXED MARITIME PINE AND EUCALYPT	62.2%	2
MIXED EUCALYPT AND MARITIME PINE	60.9%	3
PURE CHESTNUT	52.0%	7
PURE EUCALYPT	58.4%	4
PURE MARITIME PINE	56.2%	6
PURE PEDUNCULATE OAK	57.5%	5
PURE CORK OAK	66.3%	1

(**a**) (**b**)

Figure 7. Multicriteria questionnaire: (**a**) performance of alternatives; (**b**) ranking of alternatives.

Finally, we used the Delphi technique to give actors an equal opportunity to reflect on and revise their previous answers and preferences and to facilitate the group dynamic process. For the first Delphi round, we sent the multicriteria questionnaire to 60 actors with different interests in case study area (Table 2). About 15 days before the deadline for the submission of the questionnaire, we sent a reminder to the actors who did not respond, explaining how important their contribution was to our participatory approach. We obtained 37 valid questionnaires, i.e., a response rate of 61.7%.

Table 2. Identification of the actors to whom the Delphi questionnaire was sent and those who answered in both rounds, by interest group.

Interest Group and Type of Actor	Questionnaire Sent	Delphi Round 1	Delphi Round 2		
			Did Not Change the Responses	Changed the Responses	Did Not Answer
Civil Society	***10***	***7***	***6***	***1***	***0***
Environmental NGO	5	4	4		
Forest Certification	3	2	2		
Energy Sector [1]	1	1		1	
Forest Owners	***19***	***9***	***7***	***1***	***1***
Forest Owners' Association	4	1	1		
Forest Owners (Non-Industrial)	11	5	4		1
Parish Council with Community Areas	4	3	2	1	
Market Agents	***23***	***15***	***9***	***2***	***4***
Biomass Industry [1]	1	1		1	
Forest Investment Fund	2	2	2		
Forest Services Provider	1	0			
Forest Services Provider and Wood Buyer	6	3	3		
Wood Industry	6	4	3		1
Wood Industry Association	6	4		1	3
Non-Wood Forest Products Association [1]	1	1	1		
Public Administration	***8***	***6***	***2***	***2***	***2***
Forest Authority	5	3		1	2
Municipality	3	3	2	1	
Total	**60**	**37**	**24**	**6**	**7**

[1] Additional categories of actors involved in the Delphi rounds that were not present in the cognitive mapping session.

After one month, we sent the questionnaire and a report with the results from the first round to the 37 actors who answered the questionnaire for a second Delphi round. As with the first round, 15 days before the deadline, we sent a reminder to the actors. Six actors changed some of their answers and 24 confirmed that they did not wish to make any changes. We assumed that the seven participants who did not respond did not want to change their responses.

Because of the high rate of unchanged answers (64.9% confirmation of no change) and the low rate of changed responses (16.2%), we did not send the questionnaire for a third Delphi round because we considered that the process had achieved a suitable level of group stability. The goal was not to reach group consensus, but simply to gather well reflected and consolidated actors' preferences and viewpoints.

2.2.4. Overall Analysis

The results of the preferences modeling stage were used to complete a CDP model for each actor. Abbreviated pairwise comparisons do not allow for tests of consistency [38]. Thus, to evaluate how robust the actors' responses were to changes in the weights, and for a more transparent analysis, we performed sensitivity analyses, by assessing what would happen if we made small changes in the weights. CDP prioritizes the list of sub-criteria in a model in order of "most sensitive" to "least sensitive", facilitating the analysis of criteria that can influence the decision the most.

A decision model is considered robust when "very substantial changes in the criterion weights are required before another alternative would become selected as the preferred alternative" ([37], p. 191). We considered a model to be robust and stable when the percentage to crossover was greater than 5% for the most sensitive criterion or sub-criterion (crossover in CDP refers to the absolute change in weight on a criterion that would result in the top-ranked alternative being replaced by another alternative). CDP does not accept simultaneous inputs from multiple participants, so we exported each actor's results (AHP weights and SMART utilities) to Excel to analyze differences among actors. Additionally, to characterize the decision model results by interest group, we synthesized individual judgments on criteria and sub-criteria weights by interest group and overall actors, by applying a consensus convergence algorithm [39] implemented with RStudio (Appendix A).

In our version of the convergence algorithm (Appendix A), we chose to equally weight the contribution of each actor in each group synthesis, whereas a more general implementation of the algorithm would also provide the possibility for actors to rate the importance of each other's weight inputs. We opted for the simpler version of the algorithm as it is both much simpler for actor participation and more egalitarian (e.g., each actor in a group contributes equally to the consensus convergence result). To complete the synthesized CDP model for each group of actors, we calculated the SMART utility score for each attribute of the FMM as the median response of the actors in the group. Finally, to produce a synthesis of the FMM ratings across all interest groups, we calculated a group-weighted CDP utility score for each FMM as:

$$FMM_i = \frac{(FMM_{i,CS} \times 7) + (FMM_{i,FO} \times 9) + (FMM_{i,MA} \times 15) + (FMM_{i,PA} \times 6)}{37} \quad (1)$$

where: FMM_i = the group-weighted CDP utility score of the i-th FMM for a group, and the groups are civil society (CS), forest owners (FO), market agents (MA), and public administration (PA).

3. Results

We analyzed the actors' weights and rating results at three levels: (a) individual; (b) aggregated by interest group; (c) aggregated overall actors. The analysis of individual results highlights the subjectivity of the preferences and their variation even when actors are in the same interest group (intra-group analysis). Moreover, it indicates a variation in the ratings attributed by the 37 actors. The aggregated analysis provides information about the differences between interest groups as well as about the overall preferences.

3.1. Criteria

The criteria that are assigned a greater weight by individual actors are income (56.8% of all actors), risks (21.6% of all actors) and soil erosion (5.4% of all actors) (Figure 8a). Individual actors provide their second and third highest weight to wood demand (32.4% of all actors) and biodiversity (16.2% of all actors), respectively. The smallest weight was given to cultural services (27.0% of all actors rank it as the least preferred criterion).

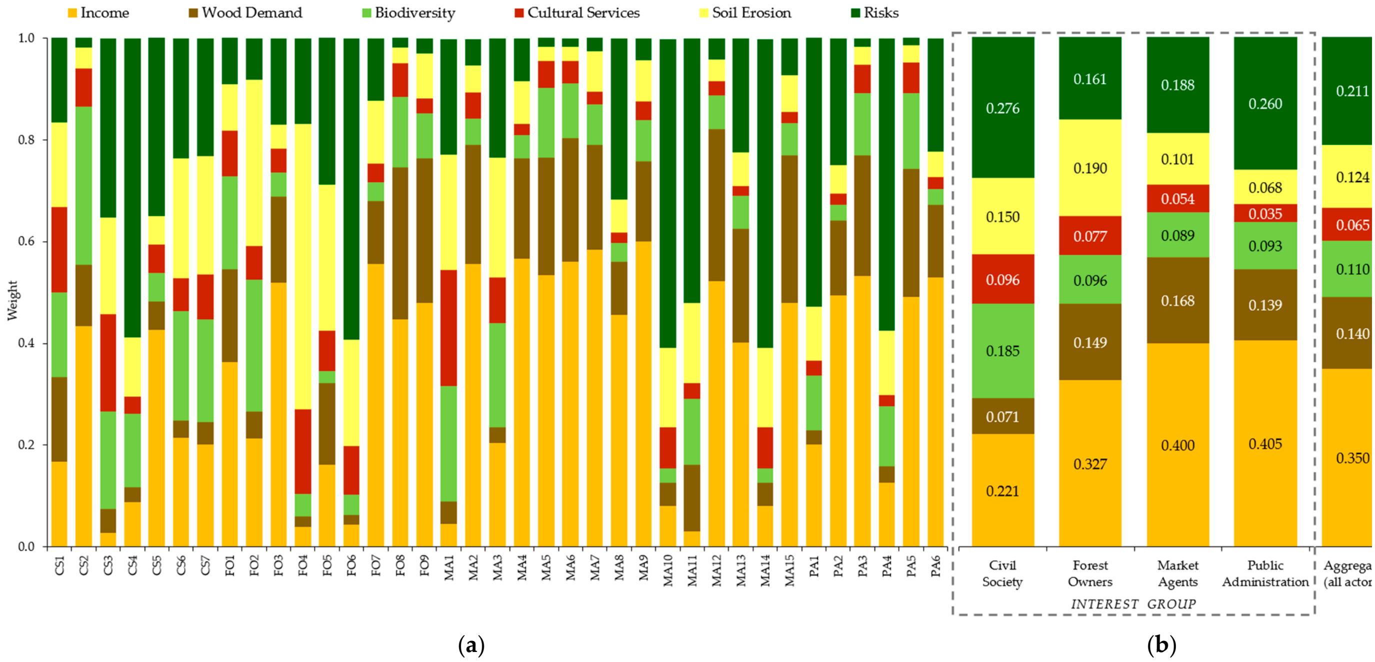


Figure 8. Weights of criteria: (**a**) Weights assigned by each actor (CS—civil society; FO—forest owners; MA—market agents; PA—public administration); (**b**) Aggregated weights by interest group and aggregated all actors. Criteria weights for each interest group were calculated with the consensus convergence algorithm which is presented in the Appendix A and the aggregate weights of all actors' criteria were calculated with Equation (1).

Analyzing the intra-group differences, we found that 10 out of 15 actors from market agents and four out of six actors from public administration agreed to provide the highest weight to the income criterion, while five out of 15 actors from market agents and two out of six actors from public administration agreed to assign the highest weight to the risks' criterion. The actors in these two groups also agreed on the least preferred criterion, assigning the lowest weights to the cultural services (seven out of 15 actors from market agents and three out of six actors from public administration). The actors in the forest owners' group assigned the highest weight to the income criterion (five out of nine actors). The actors from the civil society group considered income (two out of seven actors) and risks (two out of seven actors) as the most important criteria.

Regarding the inter-group analysis (Figure 8b), based on the consensus convergence algorithm, we found that the income criterion was assigned the highest weight by public administration (0.405), market agents (0.400), and forest owners (0.327). In the case of the civil society group, the criterion with the highest weight was risks (0.276) followed closely by income (0.221). In the aggregate analysis of overall actors, we found that the income criterion was assigned the highest weight (0.350) followed by risks (0.211), and the criterion receiving the lowest weight was cultural services (0.065).

3.2. Sub-Criteria

3.2.1. Income

The income criterion had three sub-criteria: revenue, revenue flow, and diversification of income sources. About 37.8% of all actors attributed the highest weight to the diversification of income sources (Figure 9). The intra-group analysis highlighted that in all groups there was a general agreement on the preference for diversification of income sources. In the inter-group analysis, based on the consensus convergence algorithm, the diversification of income sources had the highest weight across the four interest groups, highlighting public administration with the highest value (0.523). In the case of the market agents' group, the difference in weight between the sub-criteria of diversification of income sources (0.379) and revenue flow (0.360) was small, indicating a more or less equal preference for these two sub-criteria. For the overall aggregate results, the diversification of income sources had the highest weight (0.455).

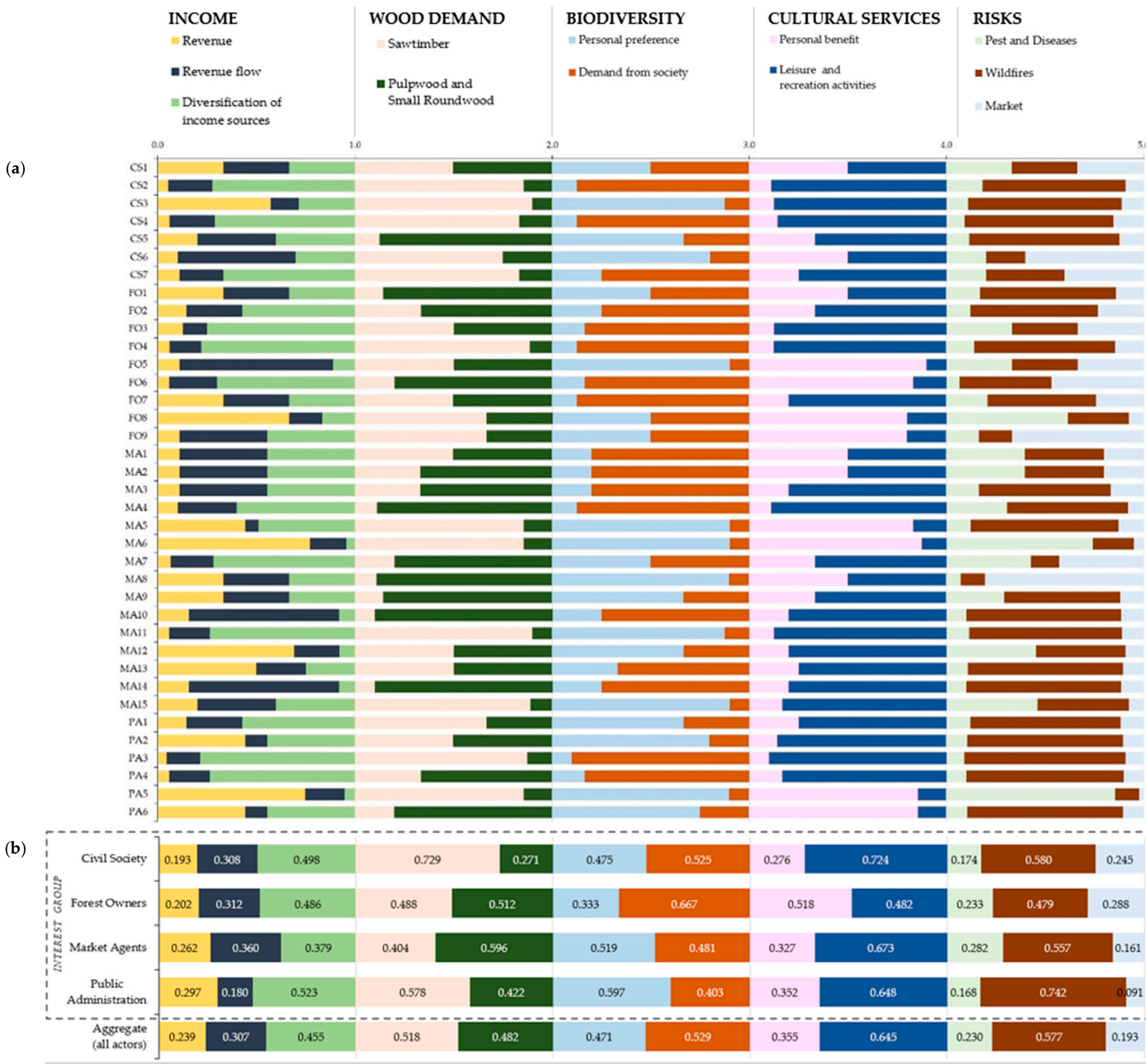


Figure 9. Weights of sub-criteria: (**a**) Weights assigned by each actor (CS—civil society; FO—forest owners; MA—market agents; PA—public administration)—absolute weights for each sub-criterion can be computed as the product of the relative weight shown here and the associated criterion weight from Figure 8; (**b**) Aggregated weights by interest group and aggregated all actors. Sub-criteria weights for each interest group were calculated with the consensus convergence algorithm which is presented in the Appendix A and the aggregate weights of all actors' sub-criteria were calculated with Equation (1).

3.2.2. Wood Demand

The preferences for the type of wood are variable among the actors, with preferences divided between the two types of wood: 40.5% of all actors assigned the highest weight to sawtimber and 37.8% of all actors to pulpwood and small roundwood (Figure 9). The intra-group analysis highlights a stronger preference for sawtimber by actors in the civil society and public administration groups. In contrast, actors of the market agents group assign the highest weight to pulpwood and small roundwood. Weights for these sub-criteria were variable among actors in the forest owners' group. The aggregate results, based on the consensus convergence algorithm, demonstrate a difference of preferences between the interest groups, with two groups giving highest weight to sawtimber (civil society and public administration) and the other two groups showing a preference for pulpwood and small roundwood (market agents and forest owners). The overall aggregated results indicate the highest preference for sawtimber (0.518) but with only a small difference for pulpwood and small roundwood (0.482), demonstrating a divergence in preferences among actors.

3.2.3. Biodiversity

Actors' preferences for the two sub-criteria of biodiversity were highly variable, thus demonstrating low agreement (Figure 9). Results show that 45.9% of all actors assigned the highest weight to the sub-criterion demand from society and 40.5% of all actors to personal preference. The intra-group analysis revealed a divergence of opinions in the civil society and market agents' groups. However, there was a higher degree of agreement on preferences in the other two groups. The inter-group analysis by the consensus convergence algorithm, highlights a division between groups. The sub-criterion demand from society has the highest weight in the forest owners and civil society groups, whereas personal preference has the highest weight in the public administration and market agents' groups. The overall aggregated result across all actors revealed that there was poor agreement on preferences among actors, with only a minor difference between demand from society (0.529) and personal preference (0.471).

3.2.4. Cultural Services

In the case of the sub-criteria of cultural services, we observed good agreement among actors on their preferences, with 62.2% of all actors attributing the highest weight to leisure and recreation activities (Figure 9). The intra-group analysis shows that there was a good agreement in the preferences of the groups civil society, market agents and public administration for the sub-criterion leisure and recreation activities. Conversely, there was no agreement in the group of forest owners.

The inter-group analysis by the consensus convergence algorithm showed greater weight of leisure and recreation activities in the case of the civil society, market agents, and public administration groups. The forest owners group assigned the highest weight to personal benefit (0.518), but with a minor difference to leisure and recreation activities (0.482). The aggregate overall result across all actors, shows that the highest weight was attributed to leisure and recreation activities (0.645), with a markedly lower weight assigned to personal benefit (0.355), this demonstrating a reasonable consensus in the preferences of the actors.

3.2.5. Risks

Actors' preferences for the three sub-criteria of the criterion risks highlight the importance of the sub-criterion wildfires, with 56.8% of all actors assigning the highest weight to wildfires (Figure 9). The intra-group analysis showed that there is an agreement in preferences for the wildfires.

The inter-group analysis by the consensus convergence algorithm, highlighted that the highest weight of wildfires across all interest groups. Actors in the public administration group showed the highest level of agreement in their preference for this sub-criterion, followed by civil society and the market agents. In the overall aggregate result across all actors, sub-criterion wildfires was weighted 0.577, with a markedly higher preference compared to pests and diseases (0.230).

3.3. Alternatives (FMM)

We evaluated the performance rank of the alternatives to identify which were preferable or desirable by the actors. The analysis of individual preferences showed that for 27.0% of all actors the FMM with the highest performance was the pedunculate oak (Figure 10a). Also, for 21.6% of all actors the eucalypt was the FMM with the highest performance. However, 43.2% of all actors considered this FMM as the least preferable alternative, demonstrating a divergence of opinions among actors.

The intra-group analysis of FMM performance indicates a divergence in preferences. In the civil society group, of the seven actors, two preferred pedunculate oak, two chestnut, and the other two cork oak. Of the nine actors in the forest owners' group, three assigned the highest performance to pedunculate oak and two to cork oak. In these two groups, however, there was an agreement about eucalypt being the least preferred. In the public administration group, two of the six actors gave the highest performance to the eucalypt, while the other four actors had different preferences for FMM. However, there was no agreement regarding the least preferred FMM.

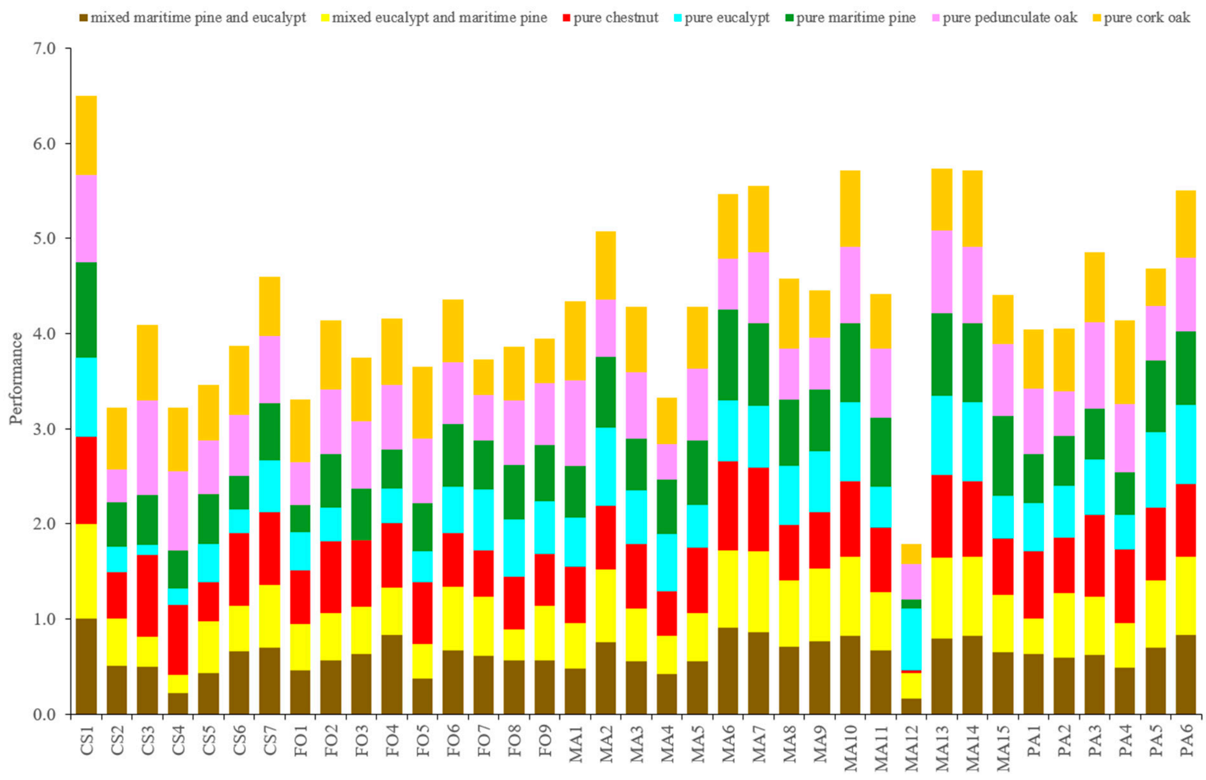
In the market agents group there was a divergence of preferences between the FMM of eucalypt and pedunculate oak. Thus, of the 15 actors, five gave the highest performance to eucalypt, four to pedunculate oak, and three to maritime pine. However, the least preferred FMM were eucalypt (for four out of 15 actors), pedunculate oak (for four out of 15 actors), and chestnut (for three out of 15 actors).

From the aggregated results by interest group (Figure 10b), the highest performance of the pedunculate oak was found in the groups of civil society (0.788) and forest owners (0.631). The lowest performance of FMM for these two groups was the eucalypt (0.314 and 0.411, respectively). For the group of market agents, the highest performance was the maritime pine (0.686) and the lowest the chestnut (0.562). For the public administration group, the alternative with the highest performance was chestnut (0.827) and the lowest was mixed eucalypt and maritime pine (0.644). For the overall aggregate result, the FMM with the highest performance was pedunculate oak (0.668) followed by chestnut (0.637). The FMM with the lowest performance was eucalypt (0.514).

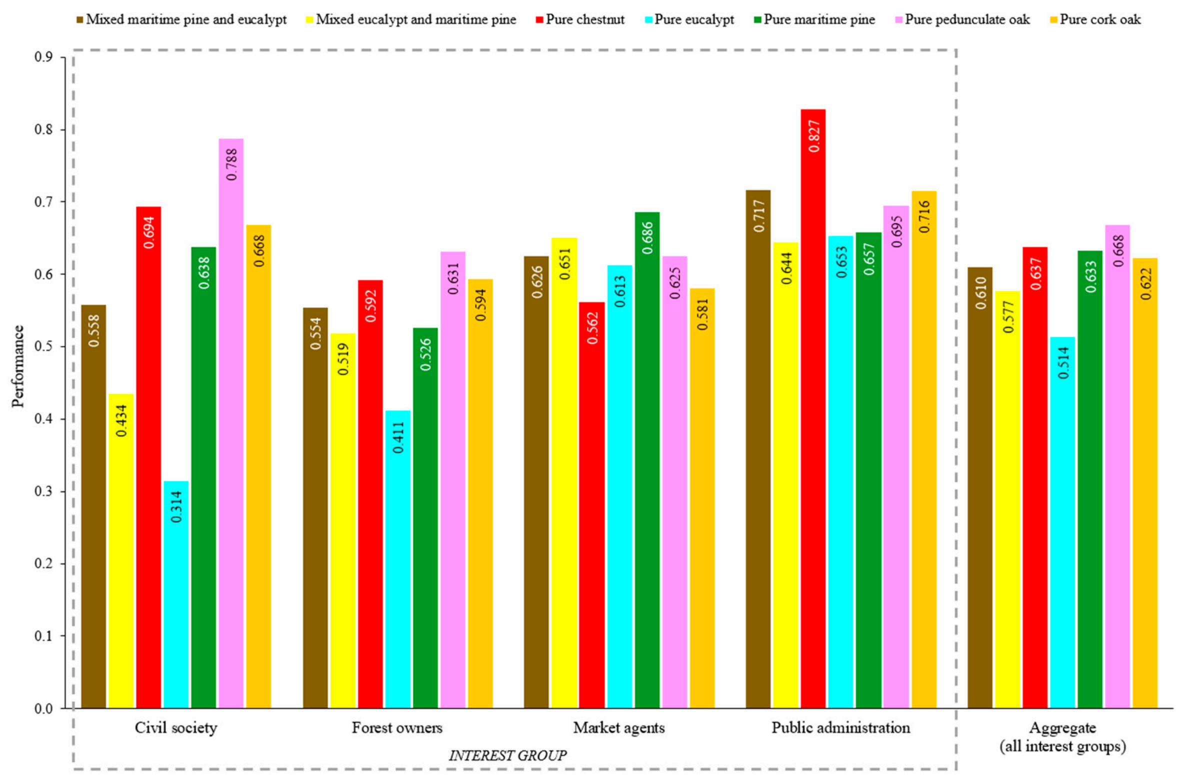
Contributions by Criteria

To further evaluate the results of the assessment of FMM by the actors, we analyzed the contributions by criteria to understand which criteria contributed most to the actors' decision and which contributed less. To simplify, we analyzed the contributions by interest group.

For the civil society group (Figure 11a), the criteria that most contributed to the alternative with the highest performance, pedunculate oak, were risks (0.230), biodiversity (0.185), and soil erosion (0.150). Regarding eucalyptus, which received the lowest FMM performance rating in this group, the biodiversity and cultural services criteria were assessed as making no contribution to the performance.



(**a**)



(**b**)

Figure 10. Performance of alternatives: (**a**) Performance according to each actor; (**b**) Performance aggregated by interest group and aggregated across all interest groups. We calculated the SMART utility score for each attribute of the alternative FMM as the median response of the actors in the group. The group-weighted CDP utility score for each FMM was calculated with Equation (1).

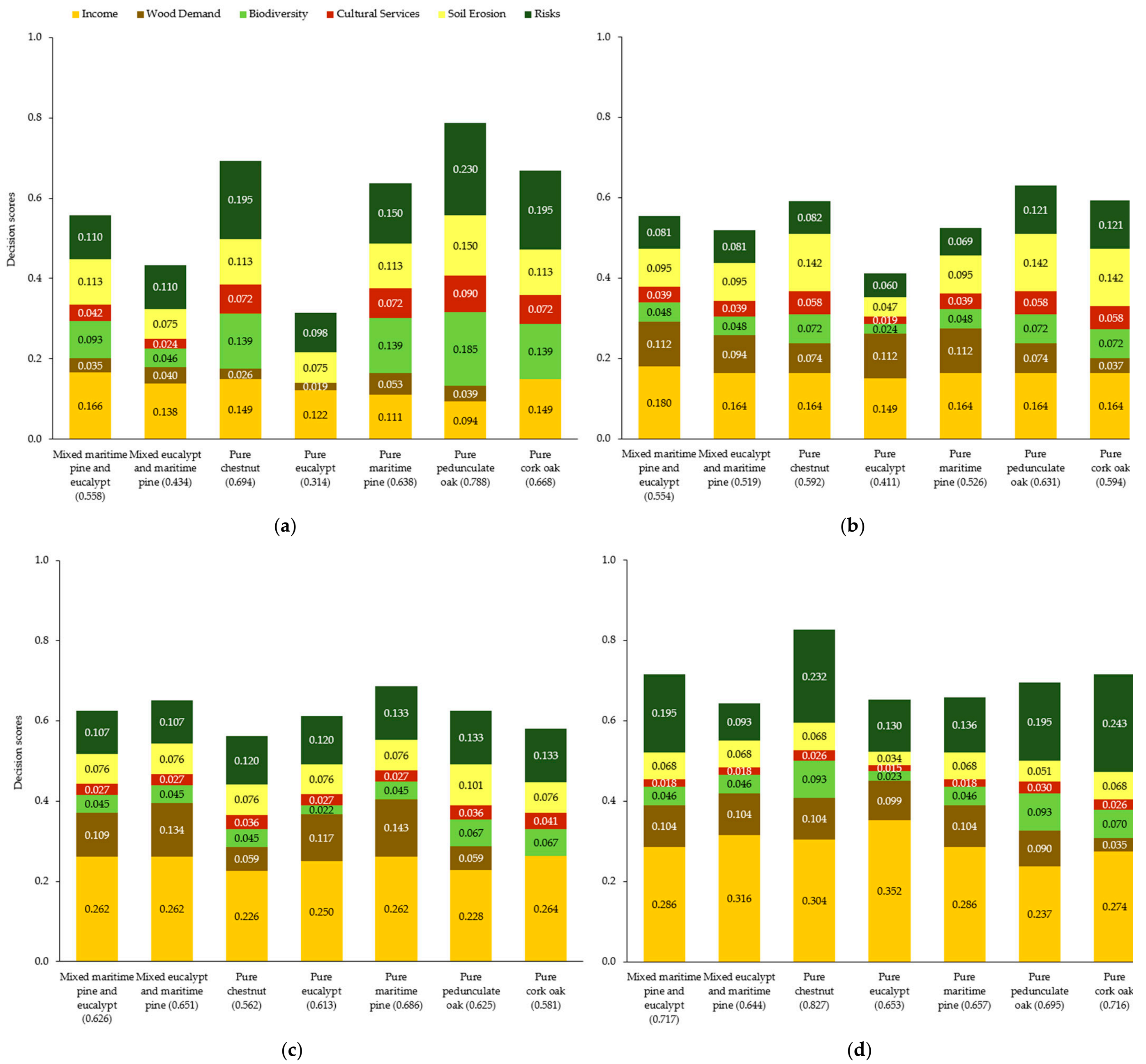


Figure 11. Contributions by criteria to alternative (FMM) performance as assessed by each interest group: (**a**) civil society; (**b**) forest owners; (**c**) market agents; (**d**) public administration.

In the case of the forest owners' group (Figure 11b), the criteria that most contributed to the performance rating of pedunculate oak were income (0.164), soil erosion (0.142), and risks (0.121). The cork oak (0.594) and chestnut (0.592) alternatives had very similar performance ratings because the criteria income, biodiversity, soil erosion, and cultural services were assessed as making the same contribution to performance by these FMM. In the case of eucalypt, except for the criterion wood demand, the remaining criteria were assessed as making the lowest contributions to the performance rating compared to the other alternatives.

For the market agents' group (Figure 11c), the three criteria that most contributed to the performance of the preferred FMM, maritime pine, were income (0.262), wood demand (0.143), and risks (0.133). For all alternatives, the criterion with the highest contribution to performance was income, while the one with the least contribution was cultural services.

For the public administration group (Figure 11d), the criteria of income (0.304), risks (0.232), and wood demand (0.104) are those that were assessed as most contributing to the performance of chestnut, the preferred FMM.

3.4. Sensitivity Analysis

Sensitivity analysis can assess the robustness of a decision model by identifying how much the most sensitive criteria in a model would need to change in absolute value (the crossover or criticality value) such that the top ranked FMM is replaced by another FMM due to a change in criteria weights. For this analysis, we considered that a model was robust if the crossover value of the most sensitive criteria was greater than 5%. According to this crossover criterion, among the decision models of individual actors, 32.4% of all individual actor decision models cannot be considered robust, with a percentage crossover value ranging between 1.0% and 4.1%.

Analyzing robustness of individual actor decision models by interest group, six of the seven models in the civil society group were considered robust, with minimum crossover values between 11.2% and 27.1%. In the forest owners' group, seven of the nine models were robust, with minimum crossover values ranging between 5.3% and 21.8%. In the market agents' group, nine of the 15 actor models were robust, with minimum crossover values ranging from 6.2% to 56.8%. In the public administration group, half of the actor models were considered robust, with minimum crossover values ranging between 8.1% and 14.8%. Despite the variability in robustness among individual actors' models when summarized as above by interest group, the aggregate models for the four interest groups all evaluated as robust, with minimum crossover values ranging between 11.6% (market agents) and 24.8% (public administration).

4. Discussion

In Vale do Sousa, a first assessment was carried out with a simple and direct questionnaire, by asking actors to rank the FMM and ES [21]. In the present study, we further analyzed the actors' preferences to understand which, and by how much, different criteria contribute to their decision or are important when choosing a FMM. The combined MCDA and group decision-making approach supports the actors' participation and incorporates their values and preferences in a structured way, ensuring a certain degree of transparency [40]. The actors who participated in our research represent the forest management interests of Vale do Sousa.

This methodology relied on the values and judgments of actors and their willingness to participate. It allowed for a systematic evaluation of criteria and sub-criteria by abbreviated pairwise comparison and by their perceptions of the utility of seven FMM (mixed maritime pine and eucalypt, mixed eucalypt and maritime pine, pure chestnut, pure eucalypt, pure maritime pine, pure pedunculate oak, and pure cork oak). It provided information about the overall performance of FMM and the relative priorities and ranking of the seven FMM. It further provided a transparent overview of the preferable and consensual FMM and an insight into convergent and divergent preferences, perspectives, and opinions. These outputs can help ZIF managers enhance forest management planning in Vale do Sousa.

Actors need an opportunity to express their concerns and interests, and to learn together [21,40,41]. Thus, the development of the cognitive map during the workshop broadened the actors' perspectives on the issues related to forest management decisions, promoting discussions about which criteria were relevant to their choice and should be included in forest management planning. With the cognitive mapping technique, all actors have an equal opportunity to contribute their ideas, while ensuring anonymity when expressing their opinions on the post-its [4]. Hierarchically structuring the decision tree is one of the most important phases of the MCDA process. Thus, we asked actors to reach a consensus on the cognitive map and to validate it in order to bring transparency to the development of the decision tree and the multicriteria questionnaire.

Next, the weight and rate elicitation process through the multicriteria questionnaire allowed the actors to confirm, through dynamic graphics, the impact of their criteria and sub-criteria preferences on the ranking of the FMM. The Delphi survey technique allowed the actors to think, reassess, and change their opinion, considering the responses of the interest group and the overall actors' answers. It also allowed them to freely contribute to the questionnaire without restrictions or influence from other actors. However, few actors changed their responses in the second round (six out of 37 actors). This suggests that the actors were confident and comfortable with their answers in the first round.

Rather than a simplistic ranking of FMM based on a direct question [21], the MCDA process helped the actors justify their choices as the result is an aggregation of criteria and sub-criteria weights and utilities. Most of the actors who participated in this research had rarely used modern tools or approaches to planning forest management (e.g., MCDA, computerized decision support systems). Use of an MCDA approach was intended to improve the evaluation of the importance of decision criteria and sub-criteria in a participatory decision process. The difference in the weights and utilities emphasized the subjectivity of the actors' preferences. By comparing the overall weights and utilities of different actors it was possible to explore the agreement or disagreement on each criterion, sub-criterion, and alternative.

4.1. Criteria

In the cognitive map session, most of the discussion addressed the profitability of the FMM. Of the 28 actors who participated, 11 wrote income on the post-it as the most important criterion in their decision to choose an FMM. The preference for this criterion was confirmed in the multicriteria questionnaire results, with 56.8% of the actors giving it the highest weight. Because most of the ZIF area is privately owned, the main objective of forest owners is profitability. In contrast, actors from the parish council, who manage community areas with the objective of a recreational forest for local populations, considered soil erosion the most important criterion.

Most actors stated that if a forest management unit is not profitable, the forest owners would tend to abandon it. The results of the multicriteria questionnaire also revealed that 21.6% of actors placed a high weight on risks because it could lead to significant losses of forest investment. Overall, these findings led us to conclude that there was a consensus among the actors on the preference for the criteria of income and risks. The civil society group considered risks as the most important criterion and biodiversity as the third. In the interviews [33], the actors of this group defended the importance of biodiversity as an ES to be promoted in Vale do Sousa. However, this was not verified in the results. Moreover, the actors also agreed on the least preferred criterion being cultural services, reinforcing the findings by Marques et al. [21,33]. This may be due to conflicting interests between the outdoor motorized recreation activities, particularly the unorganized activities, and the forest owners and managers [33].

4.2. Sub-Criteria

Overall, the actors agreed on their preferences for the sub-criteria of the income, risks, and cultural services criteria, but there was poor agreement among actors on the sub-criteria of the wood demand and biodiversity criteria.

For the sub-criteria of income, most actors assigned the highest weights, first, to diversification of income sources and, second, to revenue flow. These results confirmed participatory discussions. Due to the risks of wildfires and pests and diseases, the actors highlighted the importance of ensuring diversification of income sources, particularly through a multifunctional forest. Forest management requires several maintenance interventions with associated costs, and actors stressed that ensuring a revenue flow made it easier to meet these expenses and manage the forest.

For the risks' criterion, there was agreement on the preference for the sub-criterion wildfires. This can be explained by the frequency of wildfires. The substantial financial losses that resulted from wildfire occurrences in Vale do Sousa in 2016 and 2017 even led to the abandonment of forest management by some forest owners due to the lack of financial resources. Actors gave the second-highest weight to pests and diseases. In the last decade, forest owners and managers had to deal with two pests, which have affected the forest stands of Vale do Sousa. First, the pine nematode (*Bursaphelenchus xylophilus*), and second the *Gonipterus platensis* in the eucalyptus stands. The recurrence of wildfires and pests, in combination with low financial incentives and investments, may be discouraging forest owners and managers from managing the forest. These findings confirm the actor analysis results [33].

For the cultural services criterion, most actors attributed a higher weight to leisure and recreation activities. This preference can be explained by the importance that forests have for recreational activities in the ZIF. There is a growing demand in Vale do Sousa for natural spaces by society and by sports enthusiasts and urban people (e.g., from Porto). However, half of the actors from the forest owners' group considered that forests should be for personal benefit because it is private, as opposed to public forest land.

There was no agreement among actors about the type of wood because half preferred sawtimber and the other half preferred pulpwood and small roundwood. Currently, the dominant FMM in Vale do Sousa is eucalypt (pure or mixed) for pulpwood to address the market demand of the pulp and paper industries, but sawtimber from forest stands over 40 years old commands higher prices than pulpwood and small roundwood. However, due to the high frequency of wildfires in Portugal, the availability of sawtimber on the national market is limited. This divergence of opinion on the type of wood can be explained by a conflict between short-term financial needs and longer-term concerns with forest diversity.

Although there was a diversity of actors' preferences for biodiversity during the cognitive mapping discussions, actors emphasized that this was an important ES in Vale do Sousa. Moreover, they were in general agreement regarding the need for adequate policy tools to promote and protect the supply of biodiversity. Some forest owners stated that although society demands biodiversity, people are not willing to pay for this ES, thus compensating forest owners for their income loss. These two sub-criteria were perhaps the most controversial among actors.

4.3. Alternatives

The findings demonstrate that actors' preferences are divided between native broadleaf species (pedunculate oak, cork oak, and chestnut) and exotic species (eucalypt), and similarly between the forest product types, sawtimber (pedunculate oak and chestnut) and pulpwood (eucalypt).

In Vale do Sousa, there are four dominant FMM: pure maritime pine, pure eucalypt, mixed maritime pine and eucalypt, and mixed eucalypt and maritime pine. In the simple FMM questionnaire [21], actors ranked these FMM as the first, second, third, and fourth preferred models, respectively, confirming the current forest management options implemented in Vale de Sousa. However, in the multicriteria questionnaire, preferences for the eucalypt FMM were contrasting, because 21.6% of all actors assigned the highest performance to this model and 43.2% of all actors assigned to it the lowest performance. These results suggest that there are actors, mainly from the market agents' group, who prefer to maintain the same FMM (eucalypt) due mostly to its shorter rotations and the frequency and severity of wildfires. In addition, since eucalypt and maritime pine are the dominant species in Vale do Sousa, we expected a higher ranking of these FMM by forest owners' group. However, they ranked these FMM low, in contrast to the current land use. The latter are prone to increase due to climate change [42]. Thus, climate change has an indirect impact on the ranking of FMM by forest owners and managers.

More than half of actors attributed the highest performance to FMM that encompass native species and longer rotations (pedunculate oak, cork oak, and chestnut). These preferences suggest a willingness to implement conversion of species in the ZIF of Vale do Sousa. When the actors answered the multicriteria questionnaire, the Portuguese government had already published legislation that restrict the expansion of eucalypt plantations. This constraint may lead some actors to consider other FMM. Moreover, during the cognitive mapping discussions, forest owners and managers stressed that they are open to the possibility of converting forest species, replacing eucalypt with native species if they are financially compensated for the loss of income. Such a change in species choices would tend to promote a diversification of forest species and ES in Vale do Sousa. These findings reinforce the actors target for a multifunctional and profitable forest [21,33].

4.4. Comparison to Other MCDA and Group Decision-Making Studies

The few examples of the application of MCDA to forest management planning in Portugal do not allow an in-depth comparison with our results. Borges et al. [6] used a multicriteria decision-making approach combined with a decision support system to support the negotiation of targets for the supply of ES. Most of the actors who participated in their study also participated in our research. Nevertheless, the authors did not analyze the actors' preferences for criteria or ranked the ES or FMM. However, our results can be compared with studies from other countries reported in scientific publications. For example, Fontana et al. [43] used MCDA to rank three land-use alternatives and their ES provision in the Eastern Alps, Italy. While in our research the actors weighted income highest, in Italy the profitability ranked lowest and protection against avalanches, landslides and rock fall high. However, in both countries, the actors gave the lowest weight to cultural services. Nordström et al. [40] used AHP for planning an urban forest in Sweden. The authors worked with four social groups (timber producers, environmentalists, recreationists, and reindeer herders) to identify the criteria, elicit the preferences and ranking three forest plans. The authors concluded that actors' participation in the decision process promoted a better structuring of the problem and more transparency for actors, which was also confirmed in our research. Segura et al. [44] implemented a collaborative management process and assessment of ES in Valencian Community (East Spain). They worked with three groups (decision makers, technical staff, and other stakeholders) by identifying ES and eliciting preferences using the AHP method. All actors considered the maintenance of ES as the most important function. In our research and in cognitive map session, the actors also discussed this topic and agreed that ES should be maintained, and their diversification promoted in Vale do Sousa. In Valencia, actors from the three groups considered the forest products (cork, timber, biomass, mushrooms) as the most important provisioning services. In our research, wood provision was considered as the third most important criterion (aggregate results).

4.5. Limitations of the Study and Future Improvements

The participatory MCDA process can be time-consuming and demanding for the research team. One year went by, since the first workshop, in which the cognitive map was developed with the actors until the presentation of the MCDA results in a second workshop. During that time there were several interactions with the actors, not only by sending out the questionnaire, but also follow ups to encourage response. Moreover, identifying and contacting forest owners who were willing to answer the questionnaire was both challenging and time-consuming.

We identified three issues throughout the combined MCDA and group decision-making process that can be improved by future research. First, not all actors were proactive during the cognitive mapping discussion. Some actors talked more freely during the personal interview for actor analysis [33] than in the workshop open discussion. In the interviews, the actors were very comfortable sharing their experiences, preferences, and concerns related to forest management. Although the facilitators tried to get every actor to participate in the discussion, in some situations, some actors were more vocal and tended to dominate the discussion. This behavior tends to inhibit other actors from participating out of concern for how their contribution may be received by their peers. In this framework, it is necessary to develop strategies that allow every actor to participate equally in the discussions without hesitation.

Second, a relatively small number of private non-industrial forest owners responded to the multicriteria questionnaire. We sent 11 questionnaires to private forest owners, but we only received five responses. We asked the local Forest Owners Association (AFVS) to identify more forest owners who could answer the questionnaire, and we contacted them by email or telephone to find out if they were willing to answer the questionnaire. Yet, many forest owners were either not available or did not want to participate. Of the eight forest owners that participated, three managed only eucalypt and five have eucalypt and yet they are converting the stands at the end of the rotation to native species. Thus, the forest owners' group in our research may not be fully representative of the forest owners who keep the eucalypt FMM in ZIF of Vale do Sousa. Thus, to guarantee more responses from a more diversified set of forest owners to the multicriteria questionnaire, future research can encompass personal visits to gain the forest owners' trust, engagement, and willingness to participate in the multicriteria questionnaire.

Third, although we had designed the questionnaire to be relatively simple and intuitive, with dynamic graphs to provide information about the implications of choices, some actors may have had difficulties understanding it, and because of that they may have not responded. Due to budget constraints, it was not possible to visit the actors individually, to explain the questionnaire and how to fill it out. These limitations are typical of current MCDA approaches [19]. Thus, to promote a higher level of responses, future research may expand our approach to include personal visits to the actors who did not understand the questionnaire to explain the questions so that they may feel more confident and comfortable to provide answers. Alternatively, it may be expanded to include a decision conference (as explained by Phillips, [45]), creating a multi-voiced decision model (as described by Murphy, [11]), to allow actors to discuss and interactively visualize the impact of weights and utilities on the performance of the alternatives. In that decision conference, a facilitator may conduct the brainstorming, help actors with eliciting and rating the decision model, analyze and discuss the outcomes, and refine the model if necessary [11].

5. Conclusions

This study successfully combined MCDA and group decision-making processes as an approach to rank seven FMM and enhance joint forest management planning. Consensus was not the main goal of this research, but, rather, the understanding of actors' opinions and interests, and its variability among individuals and groups. The development and application of this approach requires an effort of conceptualization, time for data gathering, to interact with the actors and to analyze all the information collected. Nevertheless, it fully achieved its objective to select FMM and support landscape-level collaborative planning.

Income was the criterion with the highest level of agreement among actors in a decision on the choice of FMM. This result led us to conclude that actors generally depend on the eucalypt FMM for its ability to provide a short-term flow of income. Yet, they expect to change this paradigm. They also want a more multifunctional forest with more diversity of species that may contribute to diversify their income sources, with a revenue flow, that is resilient to the risks of wildfires and pests and diseases. According to the participatory discussion, wildfires are the risk that actors considered the most impactful to forest management, and, as stated by some actors, broadleaves FMM may contribute to reducing this risk. Some actors argued that a forest with a diversity of species could slow the progression of pests and diseases. These reasons may explain the higher and similar performances of the broadleaves FMM (pedunculate oak, chestnut, and cork oak).

Forest owners and managers are open to possibility of replacing eucalypt FMM with other FMM, if they are financially compensated. Moreover, forest owners argued that they should also be financially compensated for promoting other ES, such as biodiversity and cultural services, from which society benefits most. These ES are non-marketable services, so it is not easy to calculate the corresponding financial compensation. In general, there is an openness to change the selection of FMM in Vale do Sousa to achieve a multifunctional forest.

We believe that three key elements contributed to the success of the application of the combined MCDA and group decision-making process. First, the choice of actors to represent a wide variety of interests and points of view on the forest management of Vale do Sousa. Second, the promotion of participatory and interactive discussion in the identification of criteria and alternatives to be considered in MCDA. This stage also promoted social learning and a shared understanding of the actors' different points of view. The consensual cognitive map was crucial in structuring the decision tree and the multicriteria questionnaire. Third, the opportunity for actors to reassess and change their responses, considering the results of other actors' responses.

The MCDA and group decision-making process allowed actors to explore the impact of criteria and sub-criteria weights and FMM utilities on the performance of each alternative. It contributed further to better understand the opinions and preferences of other actors. A forest management plan for the entire ZIF that integrates these preferences and opinions is likely to be more easily accepted by the ZIF members who participated in this decision-making process. Participatory forest management decisions raise the actors feeling of belonging, social awareness, and shared influence, potentially improving the changes of implementation of better forest management. The combination of MCDA and group decision-making is thus a useful approach towards the fulfillment of one of the ZIF objectives—joint forest management. The application of this methodology demonstrated that actors are interested in a profitable and multifunctional forest that is resilient to the risks of wildfires and pests and diseases. ZIF managers may want to consider integrating these findings into the next revision of the forest management plan of Vale do Sousa.

The results from this study will be used in the next step of ongoing research of participatory processes. When several FMM alternatives provide different levels of ES, there should be a consensus-building exercise among actors before its implementation by a plan. Ideally, a decision would be taken by consensus and only then implemented by ZIF managers and forest owners. In a subsequent study, we will apply a focus-group technique to discuss negotiable and consensual forest management solutions for Vale do Sousa. At this stage, the actors are already aware of the results obtained from the participatory process undertaken to date, namely the preferences and points of view of other actors and the potential conflicting interests.

Author Contributions: Conceptualization, M.M. (Marlene Marques), K.M.R. and J.G.B.; methodology, M.M. (Marlene Marques), K.M.R., M.M. (Marco Marto), M.L., C.C., P.J.M. and J.G.B.; software, M.M. (Marlene Marques), K.M.R., M.M. (Marco Marto) and P.J.M.; validation, M.M. (Marlene Marques), K.M.R., C.C. and J.G.B.; formal analysis, M.M. (Marlene Marques) and K.M.R.; investigation, M.M. (Marlene Marques), K.M.R., M.M. (Marco Marto), M.L. and J.G.B.; resources, M.M. (Marlene Marques), K.M.R. and J.G.B.; writing—original draft preparation, M.M. (Marlene Marques); writing—review and editing, K.M.R., J.G.B., M.M. (Marco Marto), C.C., M.L. and P.J.M.; project administration, J.G.B.; funding acquisition, J.G.B., M.M. (Marlene Marques) and M.M. (Marco Marto) All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Union's Horizon 2020 Research and Innovation Programme (grant agreement number. 676754) (ALTERFOR), by the Marie Skodowska-Curie Research and Innovation Staff Exchange (RISE) within the H2020 Work Programme (H2020-MSCA-RISE-2015) (SUFORUN), by the Portuguese Science Foundation (FCT) namely through the Ph.D. grant of Marlene Marques (PD/BD/128257/2016), the Ph.D. grant of Marco Marto (SFRH/BD/108225/2015), the Forest Research Center Project UIDB/00239/2020, and the BIOECOSYS project (grant number LISBOA-01-0145-FEDER-030391, PTDC/ASP-SIL/30391/2017).

Disclaimer: The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon request.

Acknowledgments: We thank Susete Marques for testing the questionnaire and helping during the workshop and Brigite Botequim for helping during the workshop. We thank Sandra Pinto for helping identify and contact forest owners from Vale do Sousa. We warmly thank all the actors who have participated in the Workshop and/or answered the Multicriteria Questionnaire.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Code A1. R code to calculate the consensus convergence algorithm.

```
rm(list=ls())

library(Rfast)

## Loading required package: Rcpp

## Loading required package: RcppZiggurat

#options(digits=22)


data <- read.table("C:/MCDA/Weights_Criteria.csv", header=TRUE, sep=";")


wi <- data.matrix(data, rownames.force = NA) #Transform the dataframe into a matrix
wf <- wi


for(k in seq(1:ncol(wi))){


P0 <- wi[,k] # starting values of P0 (columns of matrix)
x <- runif(nrow(wi))
P <- x/sum(x) # starting values of P (normalized random uniforms (0,1))


W <- matrix(rep(0, nrow(wi)*nrow(wi)),nrow(wi),nrow(wi)) # declaration of matrix W


# criterion 1
for(i in seq(1:nrow(wi))){
 for(j in seq(1:nrow(wi))){

 W[i,j] <- 1 - abs(wi[i,k]-wi[j,k]) # calculate of the numerator of each cell in matrix W

 }
 W[i,] <- W[i,]/sum(W[i,]) # Normalize by the sum of each row
}


diff <- max(abs(P-P0)) # calculate the maximum distance between P and P0


while (diff > 1e-10){


 P <- W %*% P0 # calculate the matrix product between W and P0, P


# print(P)
```

```
 diff <- max(abs(P-P0)) # calculate the maximum distance between P and P0

 P0 <- P

}

wf[,k] <- P # The kth (column) vector P of consensus weights

}

wf.norm <- wf/sum(wf [1,]) # Normalization of consensus weights (to sum up exactly 1)

print(wf) #sum 0.9849123

print(wf.norm) #sum 1

rowSums(wf) # Verification of the sum of consensus weights

rowSums(wf.norm) # Verification of the normalized of consensus weights (to sum up exactly 1)
```

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CHAPTER V

A Participatory and Spatial Multicriteria Decision Approach to Prioritize the Allocation of Ecosystem Services to Management Units

Paper published in *Land*

Marques, M., Reynolds, K.M., Marques, S., Marto, M., Paplanus, S., Borges, J.G. 2021. A Participatory and Spatial Multicriteria Decision Approach to Prioritize the Allocation of Ecosystem Services to Management Units. Land. 10, 747. https://doi:10.3390/land10070747

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Article

A Participatory and Spatial Multicriteria Decision Approach to Prioritize the Allocation of Ecosystem Services to Management Units

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Abstract: Forest management planning can be challenging when allocating multiple ecosystem services (ESs) to management units (MUs), given the potentially conflicting management priorities of actors. We developed a methodology to spatially allocate ESs to MUs, according to the objectives of four interest groups—civil society, forest owners, market agents, and public administration. We applied a Group Multicriteria Spatial Decision Support System approach, combining (a) Multicriteria Decision Analysis to weight the decision models; (b) a focus group and a multicriteria Pareto frontier method to negotiate a consensual solution for seven ESs; and (c) the Ecosystem Management Decision Support (EMDS) system to prioritize the allocation of ESs to MUs. We report findings from an application to a joint collaborative management area (ZIF of Vale do Sousa) in northwestern Portugal. The forest owners selected wood production as the first ES allocation priority, with lower priorities for other ESs. In opposition, the civil society assigned the highest allocation priorities to biodiversity, cork, and carbon stock, with the lowest priority being assigned to wood production. The civil society had the highest mean rank of allocation priority scores. We found significant differences in priority scores between the civil society and the other three groups, highlighting the civil society and market agents as the most discordant groups. We spatially evaluated potential for conflicts among group ESs allocation priorities. The findings suggest that this approach can be helpful to decision makers, increasing the effectiveness of forest management plan implementation.

Keywords: forest management planning; MCDA; multicriteria Pareto frontier methods; focus group; EMDS; GIS

Citation: Marques, M.; Reynolds, K.M.; Marques, S.; Marto, M.; Paplanus, S.; Borges, J.G. A Participatory and Spatial Multicriteria Decision Approach to Prioritize the Allocation of Ecosystem Services to Management Units. *Land* **2021**, *10*, 747. https://doi.org/10.3390/land10070747

Academic Editor: Christine Fürst

Received: 13 June 2021
Accepted: 14 July 2021
Published: 16 July 2021

1. Introduction

Forest management planning is a multilayered process because it involves numerous actors and occurs at different spatial and temporal scales [1]. Multifunctional forestry requires a landscape-level management planning approach to integrate different actors' preferences and goals and to provide a wide range of ecosystem services (ESs) that can address the pillars of sustainable forest management [2]: economic—ensuring profitable forest management; environmental—diversifying ESs; and social—integrating different interests, objectives, and preferences.

An important challenge in contemporary forest management planning is integrating different actors' preferences and objectives for ESs to produce a forest plan that they have a sense of ownership in and are comfortable implementing [3,4]. In addition, forest owners and managers typically need to deal with various resource limitations to implement a forest management plan [5,6]. So, a central question for forest owners, managers, and other interest groups is how to allocate ESs to forest management units (MUs) that best fulfill the objectives and preferences of multiple competing interests.

To support forest owners, managers, and other interest groups in prioritizing the allocation of ESs to MUs, we developed a Group Multicriteria Spatial Decision Support System approach, combining Multicriteria Decision Analysis (MCDA), multicriteria Pareto frontier methods [7–10] and EMDS—Ecosystem Management Decision Support [11]. We used the Feasible Goal Method to generate the Interactive Decision Maps (Pareto frontier) based on previous research applied to forest management planning developed by Borges et al. [12,13], Marques et al. [14,15] and Marto et al. [10,16]. This approach can facilitate data visualization and spatial analysis and promote a better understanding of actors' preferences and the landscape-level impacts of their choices [17–19].

Several applications of Group Multicriteria Spatial Decision Support System have been developed within the scope of spatial prioritization of natural resources management. For example, Caglayan et al. [2] combined a participatory MCDA, mixed integer programming, and a Geographic Information System (GIS) approach to assign ESs priority to MUs based on ESs sustainable development goals. Reinhardt et al. [20] created landscape-level prioritization for the management of five invasive forest plants, using a spatial MCDA methodology, whereas Povak et al. [21] developed a combined approach of MCDA and logic models, using EMDS, to prioritize landscape treatment units for invasive species removal and native forest protection from non-native species invasions. Bottero et al. [19] applied an MCDA and GIS to identify suitable areas for biodiversity conservation to be included in spatial planning decision support processes. Uribe et al. [22] used a participatory GIS-based MCDA approach to identify priority areas for forest landscape restoration. There are some applications of prioritizing landscape restoration, using MCDA and EMDS. For example, Cannon et al. [23] prioritized restoration areas for the development of stand treatments (e.g., forest tree thinning, prescribed fire), and Reynolds et al. [24] identified the priority landscape units for treatment (e.g., restoration) and the priority treatment actions to be implemented there.

According to the last National Forest Inventory (IFN6) [25], in 2015, forests were the main land use in Portugal mainland, accounting for 36.2% of the total land area. Public ownership (state and other public entities) represented only 3% of the forest land, with the remainder held by local communities (about 6% of the total forest land) and by private owners (91% of the total forest land, of which 4% were managed by industrial companies) [26]. In 2005, in order to address concerns with the increase of burned forest area the Portuguese Government created a legal regime to promote the cooperation of non-industrial small-scale forest owners through the creation of joint collaborative management areas, ZIF (the acronym for *Zona de Intervenção Florestal* in Portuguese) [6]. The main objective of ZIF is to promote a sustainable, profitable and wildfire resilient landscape-level forest management. In December 2020, there were 245 ZIF in Portugal mainland, representing more than 23,000 forest owners and extending over 1697 thousand ha, corresponding to 19.0% of the country's mainland area [26,27].

However, not all ZIF have forest management plans implemented. ZIF managers find it difficult to integrate the different interests and objectives of the forest owners in the planning or implementation of forest management, due to the conflict of interests [5] and to delays in public funds availability [6]. In this context, ZIF managers need participatory approaches that may facilitate the understanding and the integration of the different interests and objectives of forest owners and contribute to the effectiveness of forest management planning. In addition, ZIF forest management and the corresponding allocation of the provision of ESs to MUs is complicated by the large number of forest owners and the fragmentation of forestland into multiple blocks. Thus, ZIF managers and other decision-makers with similar contextual challenges to forest management can benefit from tools that can prioritize the allocation of ESs to MUs, given the competing priorities of multiple interest groups, minimizing potential conflict of interests. Uhde et al. [1] have observed that the research and application of hybrid methods of MCDA and trade-offs between different ESs and their optimization are rare. To our knowledge, no research has focused yet on the use of a Group Multicriteria Spatial Decision Support System to prioritize the allocation of ESs to MUs in a joint management area, such as ZIF, dealing with multiple actors with different interests and objectives.

To fill this gap, we developed and applied a Group Multicriteria Spatial Decision Support System approach to two ZIF areas in Vale do Sousa for allocating bundles of ESs to MUs, according to interest groups' preferences and objectives. The emphasis was on the facilitation of a transparent participatory forest management planning, integrating different actors into forest decisions of a ZIF, as well as on the promotion of sustainable landscape-level forest management planning in joint management areas (ZIF).

2. Materials and Methods

2.1. Case Study Area

The Vale do Sousa case study area extends over 14,840 hectares in the northwestern region of Portugal (Figure 1a). It is located about 50 km East of Porto, so it is popular for recreational activities in nature. Vale do Sousa includes two joint collaborative management areas separated by the Douro River: ZIF of Entre-Douro-e-Sousa (north of the Douro River) and ZIF of Paiva (south of the Douro River). It is a forested area, where the predominant species are pure and mixed stands of eucalypt (*Eucalyptus globulus* Labill) and maritime pine (*Pinus pinaster* Aiton). Vale do Sousa is divided into 1373 MUs (Figure 1b). A MU is a delimited contiguous and homogeneous area in terms of land use, type of forest stand (species, age), and physical characteristics (type of soil and slope).

Wildfires have been frequent and severe in Vale do Sousa in the last six years (2013 to 2018), with the accumulated burned area covering 7175 ha [28] (Figure 1c). The years with the largest burned area were 2016 (1763 ha, 11.9% of the total area) and 2017 (4006 ha, 27.0% of the total area). During this period, 7135 ha (48.1% of the total area) of Vale do Sousa burned once and 40 ha (0.3% of the total area) twice (Figure 1d). Before conducting the analysis of MUs, we used the satellite imagery from late 2017 and verified the land occupation in areas that burned before that year. In the case of areas burned in 2017, we simulated alternative land occupation, according to actors' preferences identified in previous interactions (interviews and workshops; [5,29]), regarding the species to use for regeneration.

The ownership is mainly private, small-scale, and fragmented into numerous small blocks. There are also community areas managed by the local parish councils and private areas managed by the pulpwood industry. Vale do Sousa is also characterized by actors with distinct interests, goals, and concerns in forest management. Therefore, Vale do Sousa is considered representative of forest management in northwestern Portugal.

2.2. Research Design

We implemented a Group Multicriteria Spatial Decision Support System approach that encompasses four-step integrating decision support methods (Figure 2) to spatially prioritize the allocation of ESs to MUs that best reflects the competing preferences, priorities, and objectives of the interest groups. First, we applied MCDA to weight the criteria and sub-criteria of the decision models by interest group [30]. Second, we organized a group decision-making session, applying a focus group technique [31] to negotiate consensual solutions, using a multicriteria Pareto frontier method for ESs trade-offs and multi-objective optimization [16,32]. Third, we normalized the Pareto frontier solutions' data. Fourth, we integrated the decision models and the normalized Pareto frontier solutions into EMDS [11] to estimate the spatial priority scores of interest groups for alternative bundles of ESs. A final phase of the analysis presents a simple approach to spatially evaluating the potential for conflicts among group ESs allocation priorities for ZIF management.

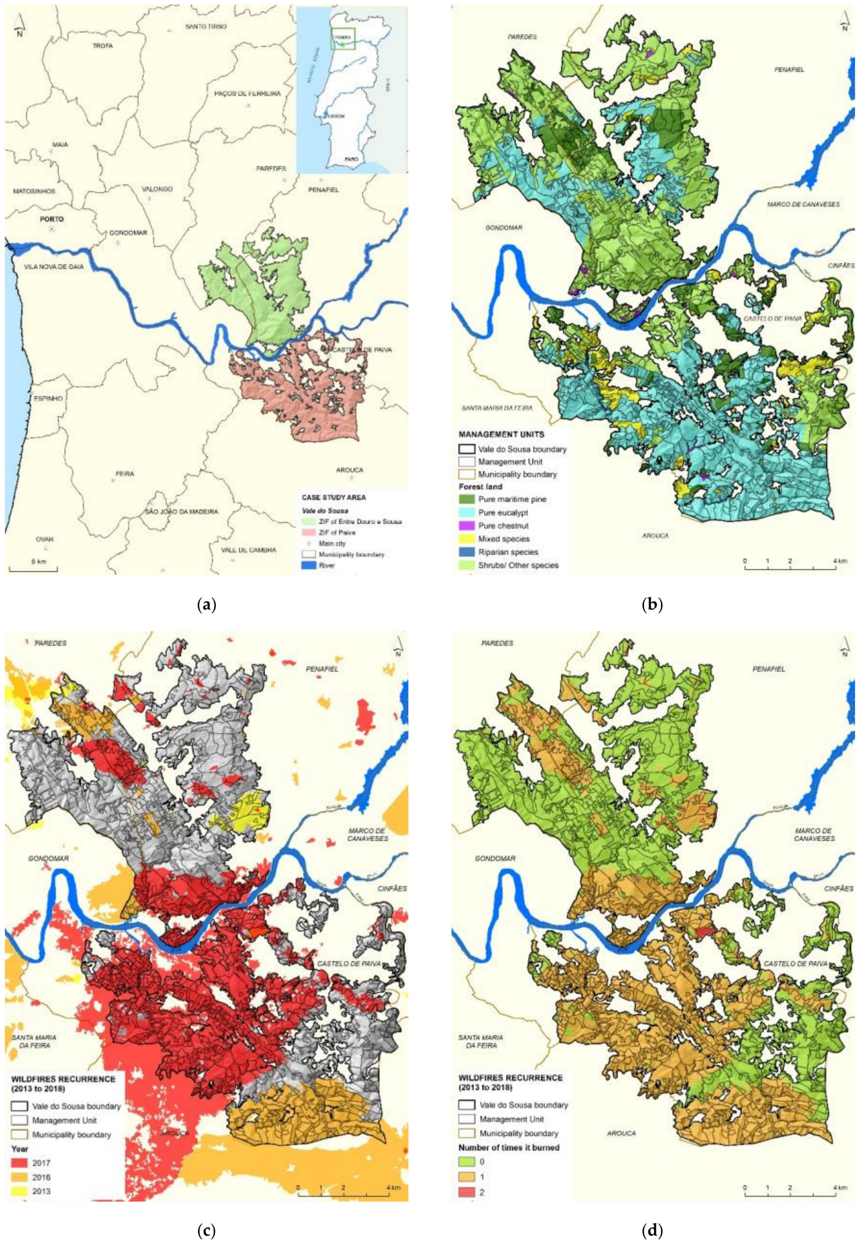

Figure 1. Vale do Sousa case study area: (**a**) location of ZIF of Entre-Douro-e-Sousa and ZIF of Paiva in northwestern Portugal; (**b**) forest land of 1373 management units by cover type; (**c**) burned area over the period of 2013 to 2018; (**d**) wildfires recurrence (2013 to 2018).

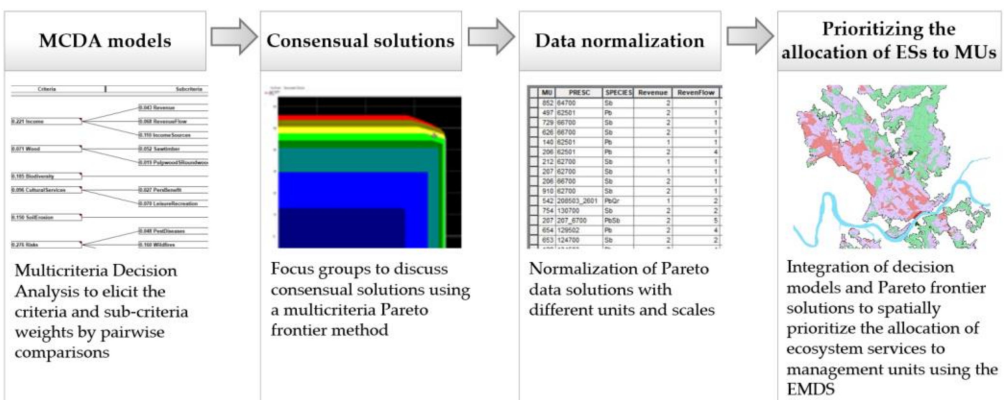

Figure 2. General steps of the methodological process and techniques applied.

2.2.1. MCDA Models

In a previous study [30], four interest groups participated in the designing of MCDA models to evaluate the priority of forest management models in terms of meeting performance criteria for the provision of ESs. A forest management model identifies the rules of conducting a species according to its defined goals and constraints, within a specific period. All groups' models shared a common structure in terms of the criteria and sub-criteria used to evaluate performance, and the derived weights of the decision models by interest group (example available in Supplement S1, Figure S1) were obtained through a combined MCDA and group decision-making approach. The criteria and sub-criteria weights were assigned by 37 actors applying analytic hierarchy process (AHP) pairwise comparisons [33,34], using the software Criterium DecisionPlus—CDP (InfoHarvest, Inc., Seattle, WA, USA), a component of the EMDS system (Table 1). The reader is referred to Marques et al. [30] for details about how the actors weighted criteria and sub-criteria and how weights were achieved by the interest groups.

Marques et al. [30] obtained a ranking of the forest management models, according to the actors' preferences. However, in our study, we did not consider the priority scores from that ranking, but only the weights of the criteria and sub-criteria since the solution obtained through the Pareto frontier method assigns to each MU the forest management model that best meets the actors' objectives (Section 2.2.2). The alternative of the decision model (Supplement S1, Figure S1) represents the MUs. The criteria and sub-criteria weights for each interest group reflect each group's preferences for the provision of ESs in a MU, so a group's priority score for a MU reflects how well the forest management model (FMM in Supplement S1, Figure S1) meets the group objectives, given its allocation of ESs criteria weights. In other words, a MU has high priority for an interest group when the MU has high scores on the ESs most important to the group. Given the relation between a group's MU priority score and the weights allocated to ES criteria, this has immediate application to the allocation of bundles of ESs to MUs.

Table 1. Criteria and sub-criteria weights of the MCDA model by interest group [30]. In each group, criteria weights sum to 1. At the sub-criterion level, criteria weights are shown as distributed to the sub-criteria under each criterion (e.g., the sub-criteria weights under a criterion sum to the criterion weight). Lowest level criteria evaluate the attributes of the alternatives. The priority score for an alternative (a management unit) is calculated as the sum of products of the lowest level criterion weights and the utility scores of each attribute for the alternative (note that biodiversity and soil erosion are also lowest level criteria).

Criteria/*Sub-Criteria*	Civil Society	Forest Owners	Market Agents	Public Administration
Income	0.221	0.327	0.400	0.405
Revenue	*0.043*	*0.066*	*0.105*	*0.120*
Revenue flow	*0.068*	*0.102*	*0.144*	*0.073*
Diversification of income sources	*0.110*	*0.159*	*0.151*	*0.212*
Wood	0.071	0.149	0.168	0.139
Sawtimber	*0.052*	*0.073*	*0.068*	*0.080*
Pulpwood and Small Roundwood	*0.019*	*0.076*	*0.100*	*0.059*
Biodiversity	0.185	0.096	0.089	0.093
Cultural Services	0.096	0.077	0.054	0.035
Personal benefit	*0.027*	*0.040*	*0.018*	*0.012*
Leisure and recreation activities	*0.070*	*0.037*	*0.037*	*0.023*
Soil Erosion	0.150	0.190	0.101	0.068
Risks	0.276	0.161	0.188	0.260
Pest and Diseases	*0.048*	*0.038*	*0.053*	*0.044*
Wildfires	*0.160*	*0.077*	*0.105*	*0.193*
Market	*0.068*	*0.046*	*0.030*	*0.024*

2.2.2. Consensual Solutions

We designed the focus group session with 4 to 6 participants each, i.e., a total of 16 to 24 participants, so that every actor could contribute with their opinion and have time for discussion [31]. A potential drawback of a focus group approach is a lack of participants. Thus, we over-recruited and invited 45 actors who are representative of the forest management interests of Vale do Sousa to participate in a one-day workshop. Twenty-three actors attended the workshop and of these, 19 participated in the focus group session. Of 19 actors, 14 assigned the criteria and sub-criteria weights of the MCDA models [30]. First, we presented and discussed the results of the MCDA participatory process [30]. Next, we explained how to work with the Pareto frontier method. Then, we grouped the actors, according to their interests in forest management. As a result, we assembled four interest groups of four to six actors into civil society, forest owners, market agents, and public administration (Table 2).

A trained facilitator and an observer supported each group. The facilitator started the session by explaining their and the observer's role, highlighting that they would not interfere in the group discussion. The facilitator conducted the discussion, clarified any questions related to the use of the Pareto frontier method, and ensured that all the group actors participated in the discussion. The facilitator asked actors to discuss the question, "*What matters most to us as a group?*", and then to negotiate a consensus solution that best achieved their goals. The observer registered the main conclusions of the discussions and controlled the time throughout the session, periodically indicating the remaining time available. The groups were allowed 90 min to reach a consensus.

The actors applied the Pareto frontier method to negotiate a consensual bundle of seven ESs—biodiversity, carbon stock, cork, cultural services, soil erosion, wildfire resistance, and wood—over a 90-year planning horizon. We considered 90 years in order to be able to check the impact of forest management models on the supply of ESs, especially in the species usually managed with longer rotations (e.g., pedunculate oak and cork oak), due to their slow growth rate.

To avoid an overly complex analysis and to facilitate selecting a solution, we limited the analysis to these seven ESs, where first and second ESs are represented in the X and Y axes, respectively. The third ES is represented by decision maps with different colors that correspond to slices of the three-dimensional Pareto frontiers. The fourth and fifth ESs are represented as columns and in rows, respectively, while the sixth and seventh as scroll bars (Figure 3). Each group of actors selected how they wanted to see the ESs represented (order of ESs) for their interactive and collaborative decision process (Table 2). The interactive use of the Pareto frontier method [35] and the analysis of trade-offs between ESs allowed actors to select the solution that they agreed to be the most appropriate and representative of group interests and objectives. To select a consensus solution each group analyzed the set of Interactive Decision Maps and selected a point in the Pareto frontier. In the negotiation process, the actors discussed and negotiated the following:

1. The level of the ESs represented in the scroll bars, fixing them.
2. The level of the ESs represented in columns and rows.
3. The level of the third ESs represented in decision maps.
4. Finally, the desired level on ESs in Y and X axis.

After the group reached the consensus solution and fixed this selection, the tool displayed the management plan associated with the solution, thus identifying the forest management models and the corresponding prescriptions to be assigned to each MU.

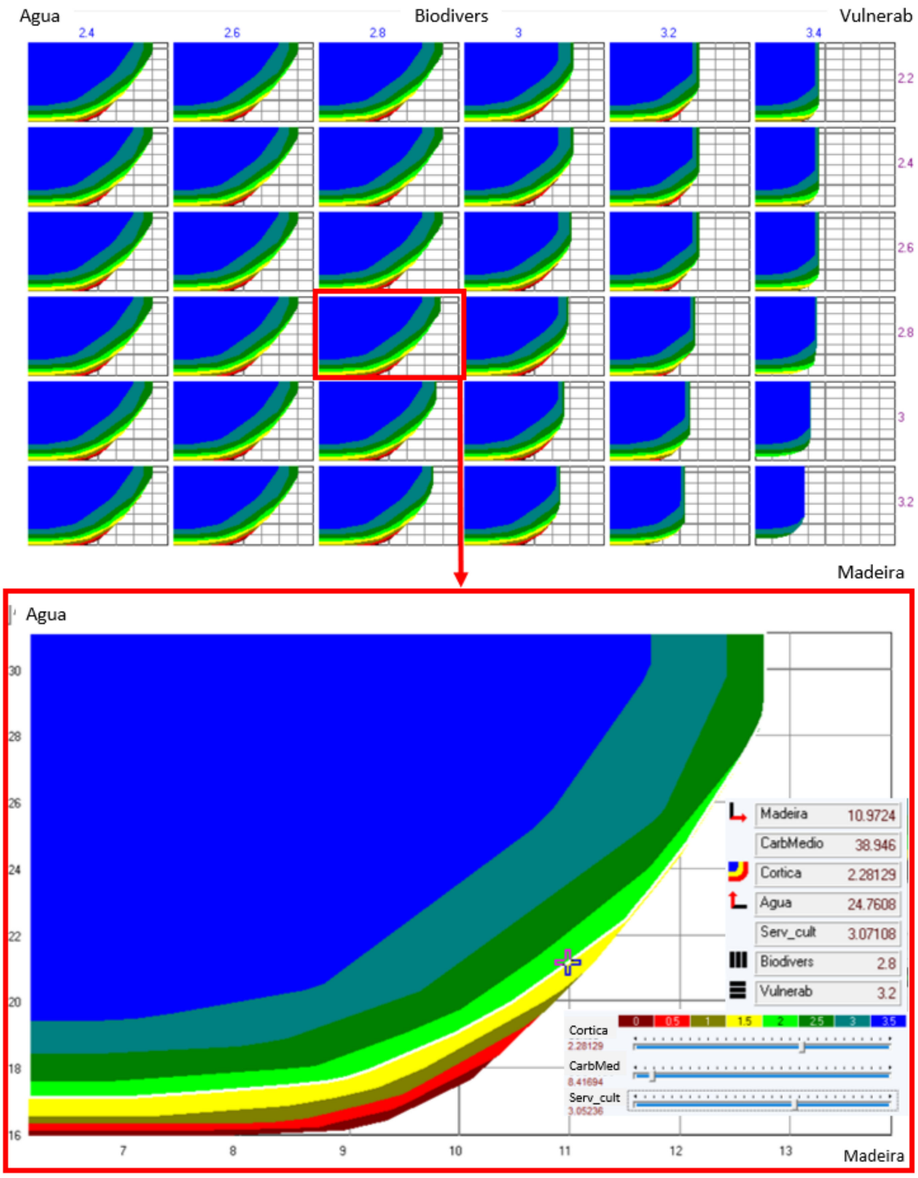

Figure 3. Example of group solution considering the trade-offs for seven ecosystem services using the multicriteria Pareto frontier method. Madeira (wood) refers to the total amount of harvested wood in the case study area in the planning horizon (*10^6 m^3), represented in the X axis; Agua (soil erosion) is the total soil loss caused by the rainfall (*10^5 t) (in Y axis). Each of the eight decision maps (in colors) represents Cortica (cork), being the amount of removed cork (*10^5 arroba; arroba = 14.7 kg); Biodivers (biodiversity) is the average biodiversity level represented in columns; Vulnerab (vulnerability) represents the average wildfire resistance represented in rows. In the scroll bars are represented the sixth and seventh ecosystem service (CarbMedio and Serv_Cult), where CarbMedio (average carbon) represents the average carbon stock for the whole landscape (*10^5 t), and Serv_Cult (cultural services) represents the leisure and recreation computed thru RAFL index. The plus sign represents a selected point in the frontier.

Table 2. Identification of the actors who attended the focus group session and number of iterations to reach a consensus solution by interest group.

Interest Group and Type of Actor	Attended the Focus Group Session	Number of Tested Solutions to Select a Consensus Solution
Civil Society	***4***	3
Environmental NGO	3	
Forest Certification	1	
Forest Owners	***6***	1
Forest Owners' Association	1	
Forest Owners (Non-Industrial)	4	
Parish Council with Community Areas	1	
Market Agents	***5***	4
Biomass Industry	1	
Forest Investment Fund	1	
Wood Industry	3	
Public Administration	***4***	4
Forest Authority	3	
Municipality	1	
Total	**19**	**12**

2.2.3. Data Normalization

Most data from Pareto frontier solutions had different units and scales (e.g., revenue was in EUR and soil erosion was in t/year). So, to integrate the contributions of the lowest criteria and normalize data inputs, we defined a common scale ranging between 1 (very poor) and 5 (very good) (Table 3). Then, we assigned this scale to the MU Pareto frontier database solutions (Figure 4 and Supplement S2, Figure S2.1 to Figure S2.4). However, it was not necessary to normalize the values of three ESs—biodiversity, leisure and recreation (cultural services), and wildfires (risks)—as they were already ordinal indices ranging between 1 and 5.

MUs_CivilSociety

MU	PRESC	SPECIES	Revenue	RevenFlow	IncomeSour	Sawtimber	Roundwood	Biodiv	PersBenef	LeisureRec	SoilErosion	PestDiseas	Wildfires	Market
852	64700	Sb	2	1	4	1	2	4.071982	2	2.700006	3	4	3.990005	5
497	62501	Pb	2	1	3	4	3	2.754779	1	3.400001	5	3	2.099992	4
729	66700	Sb	2	1	4	1	2	3.914554	2	2.710001	1	4	3.950005	5
626	66700	Sb	2	1	4	1	3	4.051633	1	2.709993	3	4	3.960004	5
140	62501	Pb	1	1	3	4	3	2.628014	1	3.022223	3	3	1.800004	4
206	62501	Pb	2	4	4	5	3	2.431664	1	3.000019	4	3	2.800011	4
212	62700	Sb	1	1	4	1	2	4.24727	1	3.011115	4	4	4.888892	5
207	62700	Sb	1	1	4	1	2	4.152504	2	3.011111	4	4	4.88889	5
206	66700	Sb	2	1	4	1	3	4.045443	2	2.710006	5	4	3.869997	5
910	62700	Sb	2	1	4	1	2	4.555193	1	2.999999	4	4	4.644448	5
542	208503_2601	PbQr	1	2	3	2	2	3.879597	1	2.808942	5	4	2.664663	3
754	130700	Sb	2	2	4	1	2	4.043691	1	2.710006	4	4	3.550012	5
207	207_6700	PbSb	2	5	5	3	3	3.081174	2	2.937748	5	3	3.461723	4
654	129502	Pb	2	4	4	3	3	2.442128	1	2.699981	4	3	1.530003	4
653	124700	Sb	2	2	4	1	2	4.033926	1	2.709999	4	4	4.430002	5
122	134503	Pb	2	4	4	3	3	2.281152	1	2.720003	4	3	1.72001	4
669	124700	Sb	2	2	4	1	2	4.033856	1	2.710001	3	4	4.409999	5
191	134	Ec	3	1	2	1	4	2.01575	1	2.999976	3	2	1.699987	5
123	124503	Pb	2	4	4	3	3	2.296167	1	2.709979	4	3	2.040004	4
666	129700	Sb	2	2	4	1	2	4.003539	1	2.71	3	4	4.380004	5
123	129700	Sb	3	2	4	1	3	4.315195	1	2.710008	5	4	4.119987	5
123	134	Ec	4	1	2	1	5	2.007821	1	3.000032	3	2	1.388872	5
123	129700	Sb	3	2	4	1	3	4.315192	1	2.710003	3	4	4.229993	5
122	134	Ec	1	1	2	1	5	1.69303	1	2.999998	5	2	3.977766	5
123	134	Ec	3	1	2	1	5	1.693028	1	2.999979	5	2	3.999972	5
135	124503	Pb	2	1	3	3	3	2.606157	1	2.710048	4	3	0.910016	4
102	129503	Pb	2	1	3	3	3	2.28584	1	2.750004	5	3	1.830002	4
985	129503	Pb	2	4	4	3	3	2.285839	1	2.700002	3	3	1.970002	4
974	129502	Pb	2	1	3	3	3	2.620755	1	2.700001	4	3	1.62	4

Figure 4. Example of a normalized management units Pareto frontier solution database from 1 (very poor) to 5 (very good).

Table 3. Normalization of Pareto frontier database solutions into five classes for a 90-year planning horizon according to the lowest criteria.

Criterion	Sub-Criterion	Units	Classes					Data References
			1 (Very Poor)	2 (Poor)	3 (Moderate)	4 (Good)	5 (Very Good)	
Income	Revenue	€/ha	≤ 0	]0–4000]	]4000–8000]	]8000–12,000]	>12,000	Net Present Value (NPV) using 3% discount rate
	Revenue flow	nr.	[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10]	]10–20]	]20–30]	]30–40]	>40	Frequency of revenue
	Diversification of income sources	nr.	0	1	2	3	≥4	No. of profitable wood and non-wood forest products
Wood	Sawtimber	m^3/ha	0	]0–200]	]200–400]	]400–600]	>600	Species volume [36–45]
	Pulpwood and small roundwood	m^3/ha	0	]0–150]	]150–300]	]300–1000]	>1000	Species volume [46–52]
Biodiversity		index *	1 to 5 (where 1 is associated with less biodiversity and 5 more biodiversity)					Biodiversity scores [53]
Cultural Services	Personal benefit	nr.	1	2	3	4	≥5	No. of recreational activities
	Leisure and recreation	index *	1 to 5 (where 1 is associated with less appealing for leisure and recreation and 5 more appealing for leisure and recreation)					Recreation aesthetics forest landscape (RAFL) index [54]
Soil Erosion		t/year	≥75	[55–75[	[25–55[	[10–25[	[0–10[	Universal soil loss equation (USLE) [55]
Risks	Pest and diseases	nominal	chestnut and eucalypt (elevation ≥ 500 m)	eucalypt (elevation < 500 m)	maritime pine	cork oak and pedunculate oak	riparian species	Species according to actors' interviews [5]
	Wildfires	index *	1 to 5 (where 1 is associated with less fire resistance and 5 more fire resistance)					Wildfire resistance (RAit) index [14]
	Market	nominal	riparian species	chestnut	pedunculate oak	maritime pine	eucalypt and cork oak	Species according to actors' interviews [5]

* Continuous variable.

In CDP, the normalized input ratings on the 1-to-5 scale (Table 3) are linearly transformed to utility scores such that a rating of 1 has a utility of 0, and a rating of 5 has a utility of 1. Lowest level criteria evaluate the attributes of the alternatives (Table 1). The priority score for an alternative (a management unit) is calculated as the sum of products of the lowest level criterion weights and the utility scores of each attribute for the alternative. Given that the weights of lowest level criteria sum to 1, and utilities are on a [0, 1] scale, the resulting priority scores for MUs likewise are on a [0, 1] scale.

2.2.4. Prioritizing the Allocation of Ecosystem Services to Management Units

In the final step of the analysis, we used the EMDS 7.1.0.22 system (Mountain View Business Group, San Marcos, TX, USA) with the ArcGIS 10.6 geographic information system (Environmental Systems Research Institute, Redlands, CA, USA) to prioritize the allocation of ESs to MUs given the competing priorities of interest groups. In EMDS, we started by creating a new assessment and loading the normalized Pareto frontier solution geographic database (Supplement S2, Figure S2.1 to Figure S2.4). Next, we created a new analysis for the assessment by selecting CDP from the list to create a task and loading the corresponding decision model weights (Table 1; Supplement 1, Figure S1). Then, we mapped the MUs database fields to the CDP decision model names (Figure 5a) and calculated the priority score for each MU (Figure 5b). Given the discussion in Section 2.2.1, the output effectively prioritized the allocation of ESs to MUs based on the group criteria (Table 1) and objectives for the Vale do Sousa landscape.

2.3. Data Analysis

We conducted a spatial analysis using the software ArcGIS 10.6 and a statistical analysis using the software IBM SPSS Statistics, version 26 (IBM Corp., Armonk, NY, USA), to understand the priority scores of the allocation of ESs to MUs at the landscape level and to compare results between the interest groups. First, we used descriptive statistics to understand the distribution of ESs priority scores at the MU level and their spatial distribution by interest group. Next, we applied statistical tests to compare the results between groups and to determine which groups had the most concordant and the most discordant results. We established the inference with a significance level of $\alpha = 0.05$. Because the assumptions of normality and homogeneity of variance were not met, we applied the non-parametric Kruskal–Wallis Rank Test to determine if there were statistically significant differences between groups.

To determine which groups were different after the Kruskal–Wallis Test rejected the null hypothesis, and because the groups were independent, we used a post hoc test for each group pair, the Mann–Whitney U-Test (also known as Wilcoxon Rank Sum Test).

Both non-parametric tests replace all priority scores by their rank numbers. So, higher priority scores get higher rank numbers. Additionally, we calculated the effect size (Cohen's d) to compare and analyze the size of differences between groups [56,57].

2.4. Identifying Management Units in which There Is Low Conflict among Interest Groups

To assess if there were MUs on the landscape that could fulfill the objectives of one group without compromising the objectives of the other groups, we developed two analyses. Compromise, in this case, means that meeting the objectives of one group can only occur at the expense of realizing the objectives of one or more other groups. In other words, there is conflict among at least two groups with respect to satisfying their respective objectives. For example, MU 1597 had a priority score of 0.60 for civil society and 0.62 for market agent, that is, this MU is classified in the high class by both groups, which represents a conflict of interest between them, as these groups have different criteria and objectives for the Vale do Sousa landscape.

In both analyses, we began by assigning the Boolean value 1 to each group in each MU if a group's priority rating was high or very high and 0 otherwise (Supplement S3, Figure S3.1). In this Boolean classification, a group value of 0 (not high or very high) was interpreted as an indicator that there was room for compromise with other groups, thus reducing the potential for conflict.

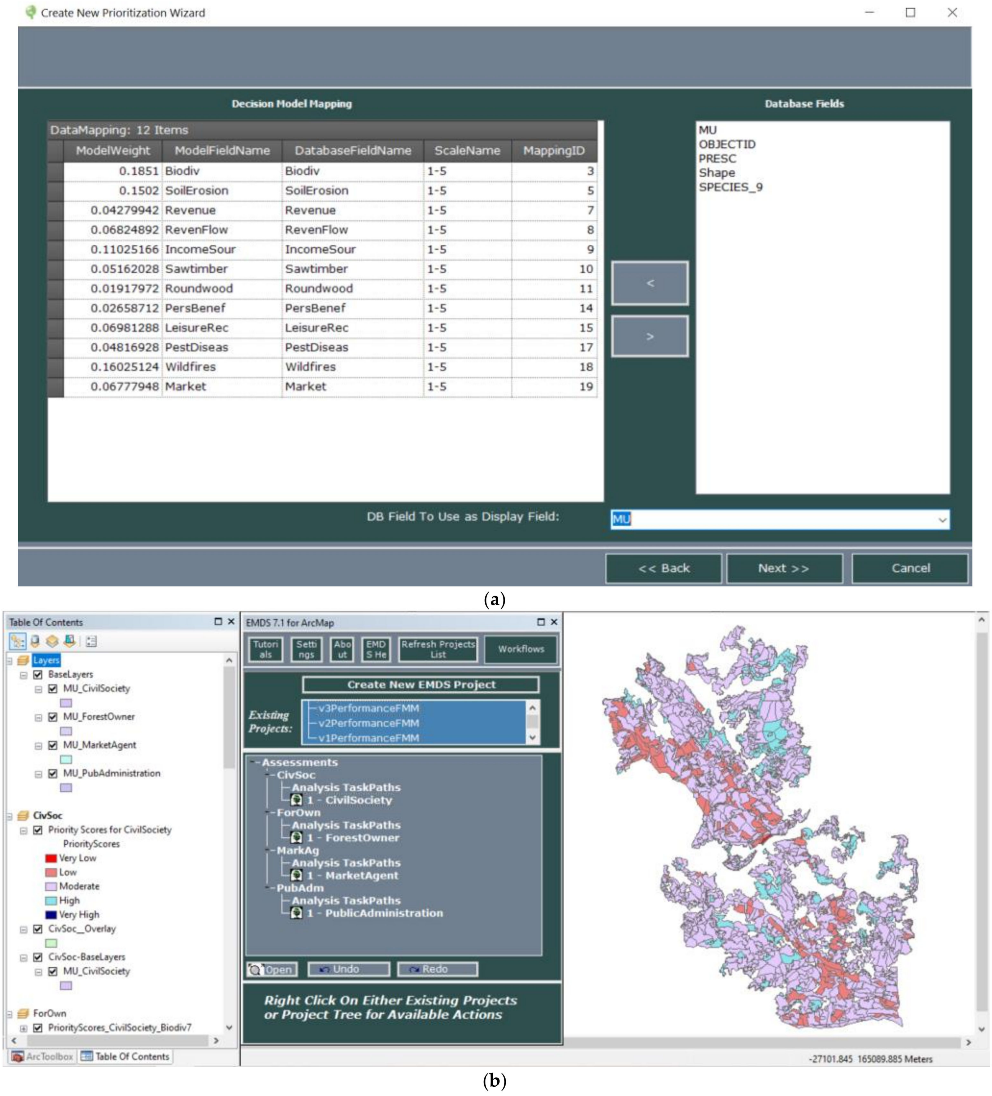

Figure 5. Example of the EMDS assessment of an interest group: (**a**) map the management units database fields (column "DatabaseFieldName") to the CDP decision model (column "ModelDecisionName"); (**b**) results of priority scores. Per Section 2.2.1, these priority scores have immediate application to ESs priorities.

In the first analysis, we summed the Boolean values in each MU to count how many groups assigned high or very high priority in the same MU. We used the resulting count as an indicator of potential group conflicts, with a count of 0 or 1 indicating no or low potential for conflict among groups, and values from 2 to 4 indicating increasing potential for conflict among groups.

The second analysis is a refinement of the first in which we used the NetWeaver logic modeling component of the EMDS system to evaluate four specific cases that can create potential conflict if one or more groups rate the same MU as high or very high (Supplement S3, Figure S3.2). The design of the logic model was informed by the results presented in Section 3.3. Case 1 assumes the priorities of forest owners and public administrators are basically compatible (e.g., there is no or low conflict in these two groups when both rate a MU as high or very high priority). Cases 2 and 3 test for high priority in only civil society or market agents, respectively. Case 4 tests that no group rates the priority high or very high in a MU so there is at least the potential for compromise among groups.

3. Results

3.1. Consensual Solutions

During the focus group session, each group worked to reach a consensus, discussing the bundle of ESs. All groups discussed wood volume provisioning and wildfire risk resistance in depth. However, only the market agents discussed carbon stock more deeply, while the civil society group addressed biodiversity broadly. The forest owners group had the most difficulty managing the discussion of trade-offs, having tested only one consensual solution, in contrast to the other groups who analyzed between three to four solutions until arriving at a consensus (Table 2). The forest owners also had some difficulty interpreting the Pareto frontier solution, while the other three groups were relatively comfortable with the tool and its outputs.

We obtained four consensual solutions, according to the preferences of each interest group (Table 4). Comparing the different ESs values achieved by each group, the forest owners group selected wood provisioning (11.10×10^6 m^3) as the main ES, so the trade-offs were lower values for the other ESs. The civil society group selected the highest values for biodiversity (3.26), cork (3.30×10^6 arroba), and carbon stock (54.09×10^5 t/year), the trade-off being the lowest value for wood provisioning (8.44×10^6 m^3). The market agents group selected the highest value of wildfire risk resistance (3.84) and public administration, the highest value of soil erosion (22.50×10^6 t of soil loss).

Table 4. Consensual Pareto frontier solutions for a 90-year period, by interest group.

Ecosystem Services	Unit	Interest Group			
		Civil Society	Forest Owners	Market Agents	Public Administration
Biodiversity	index: 0–7	3.26	3.07	3.14	3.20
Carbon stock	10^5 t/year	54.09	47.51	53.87	53.55
Cork	10^6 arroba *	3.30	2.15	3.26	3.19
Cultural services	index: 1–5	3.07	3.06	3.09	3.08
Soil erosion	10^6 t	20.34	22.36	21.92	22.50
Wildfire risk resistance	index: 1–5	3.67	3.01	3.84	3.50
Wood	10^6 m^3	8.44	11.10	9.39	9.84

* arroba = 14.7 kg.

3.2. Priority Scores of the Allocation of Ecosystem Services to Management Units

The result of the prioritization of the allocation of ESs to MUs were priority scores for each MU. These priority scores differed among the interest groups (Figure 6). Given potential priority scores between 0.0 (very low) and 1.0 (very high), the civil society group had the smallest difference between the minimum (0.20) and maximum (0.72) values. In contrast, the public administration group had the greatest range between the minimum (0.15) and maximum (0.76) values. The mean of priority scores varied between 0.43 (market agents) and 0.51 (civil society).

Keeping in mind that each interest group developed its own set of criteria weights, some care is needed in comparing priorities across groups. For example, civil society and forest owners may assign roughly the same priority to a MU, but each group has its own rationale for that priority as determined by their respective criteria weights. Conversely, but by the same reasoning, if civil society rates the priority of an MU higher than the forest owners, this, per se, does not mean that the allocation of ESs by civil society should take precedence over that of forest owners. Nevertheless, large differences in interest group can be helpful as a rough guide to minimizing conflicts among interest groups as we discuss further in Section 3.4 below.

To spatially analyze the priority scores, we defined five classes: very low ≤ 0.25; low]0.25–0.40]; moderate]0.40–0.55]; high]0.55–0.70]; very high > 0.70. Analyzing the spatial distribution of scores (Figure 7), all groups classified most of the area in the moderate class, with the forest owners classifying the largest area as moderate (60.5% of total area, corresponding to 791 MUs) and civil society classifying the smallest area as moderate (46.5% of total area, corresponding to 699 MUs). Among all groups, market agents classified the largest area to the very high priority class (0.9% of total area, corresponding to 11 MUs) and low (32.8% of total area, corresponding to 524 MUs) classes. The civil society group classified the largest area in the high priority class (39.5% of total area, corresponding to 492 MUs). In comparison, the public administration group classified the largest area in the very low priority class (1.3% of total area, corresponding to 42 MUs).

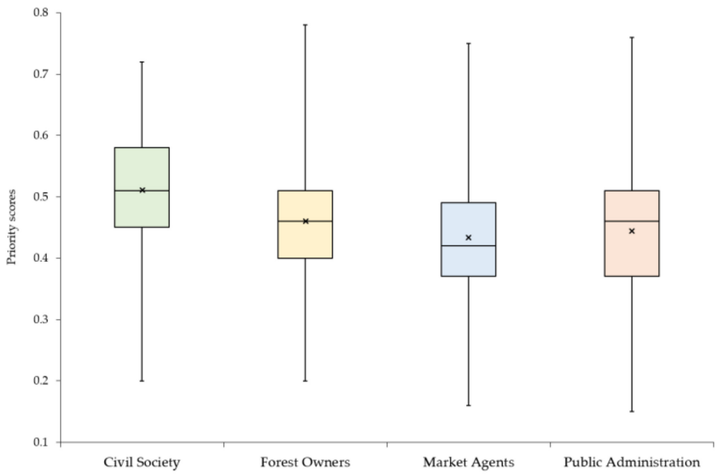

Figure 6. Boxplots of priority scores of the allocation of ecosystem services to management units by interest group. The middle line of the box represents the median between the first quartile (lower end of the box) and the third quartile (upper end of the box). The symbol × represents the mean. The lower and upper bars represent, respectively, the minimum and maximum values of the priority scores.

3.3. Differences between Interest Groups

The Kruskal–Wallis Rank Test revealed that the differences in priority scores of the allocation of the ESs to the MUs among groups were statistically significant ($H(3) = 545.96$, p-value = 0.000). The test also indicated civil society had the highest mean rank (3564.53), followed by forest owners (2689.83) and public administration (2500.85), while the market agents had the smallest mean rank (2230.80).

The post-hoc Mann–Whitney U-Test compared all pairs of interest groups, and the results demonstrated statistically significant differences in priority scores among all pairs of groups (Table 5). The most noteworthy differences were between civil society and the other three groups, highlighting the pair civil society and market agents ($U(1373) = 507{,}800$; $z = -20.939$; p-value < 0.05) as the most discordant groups, with a statistically large effect size (0.87). The sum of ranks for civil society was more significant than the sum of ranks for market agents. Conversely, the most concordant groups, with the smallest significant differences, were forest owners and public administration ($U(1373) = 881{,}588$; $z = -2.937$; p-value < 0.05), with a very small effect size (0.11), which means a negligible difference between these groups.

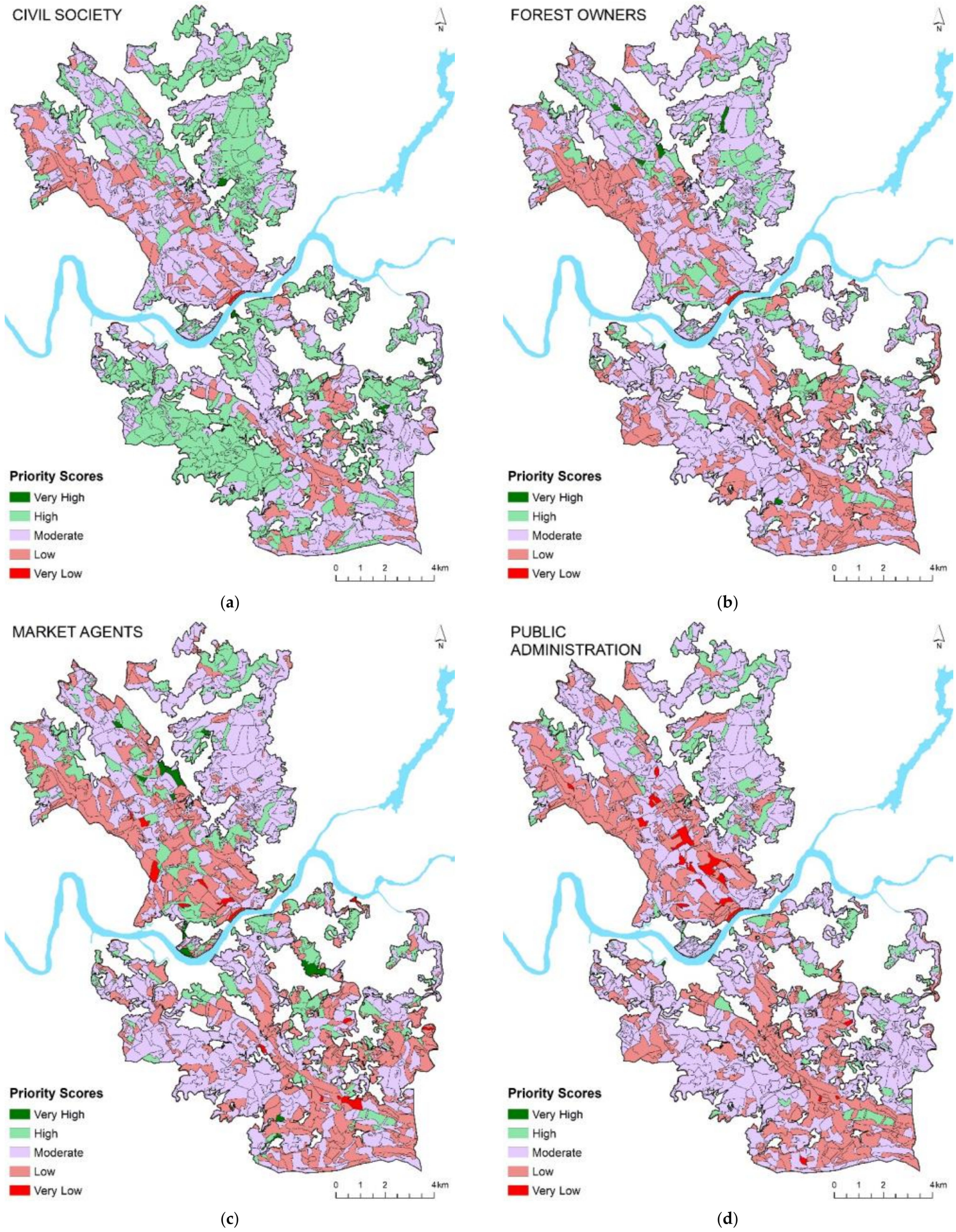

Figure 7. Priority scores of the allocation of the ecosystem services to the management units by interest group: (**a**) civil society; (**b**) forest owners; (**c**) market agents; (**d**) public administration. The priority scores were classified into five classes: very low $\leq$ 0.25; low]0.25–0.40]; moderate]0.40–0.55]; high]0.55–0.70]; very high > 0.70.

To spatially analyze and compare the differences of allocation priority scores between groups, we calculate the absolute difference for each MU by group pairs. As demonstrated by the Mann–Whitney U-Test, the groups civil society and market agents had the most extensive area with the largest differences in priority scores, i.e., above 0.20 difference (371.78 ha, corresponding to 91 MUs) and between 0.15 and 0.20 difference (2940.05 ha, corresponding to 286 MUs) (Figure 8a). In contrast, the forest owner and public administration groups had the largest concordant area, i.e., no differences between the priority scores of 1270.45 ha (corresponding to 70 MUs) (Figure 8b). The group pair with the next largest concordant area were market agents and public administration, with 815.75 ha (corresponding to 116 MUs) with no differences (Supplement S4,Figure S4d).

Table 5. Results of the Mann–Whitney U-Test for ranks of priority scores for the 1373 management units and effect size (Cohen's d) by pair of interest groups.

Interest Group Pairs	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	*p*-Value	Effect Size (Cohen's d) [1]	
Civil Society Forest Owners	1604.89 1142.11	2,203,508 1,568,123	624,872	1,568,123	−15.302	0.000	0.61	medium
Civil Society Market Agents	1690.15 1056.85	2,320,581 1,451,051	507,800	1,451,051	−20.939	0.000	0.87	large
Civil Society Public Administration	1643.49 1103.51	2,256,514 1,515,118	571,867	1,515,118	−17.854	0.000	0.72	medium
Forest Owners Market Agents	1503.80 1243.20	2,064,717 1,706,914	763,663	1,706,914	−8.617	0.000	0.33	small
Forest Owners Public Administration	1417.91 1329.09	1,946,793 1,824,839	881,588	1,824,839	−2.937	0.003	0.11	very small
Market Agents Public Administration	1304.75 1442.25	1,791,422 1,980,210	848,171	1,791,422	−4.546	0.000	0.17	small

[1] Benchmarks according to the classification of Sawilowsky [57].

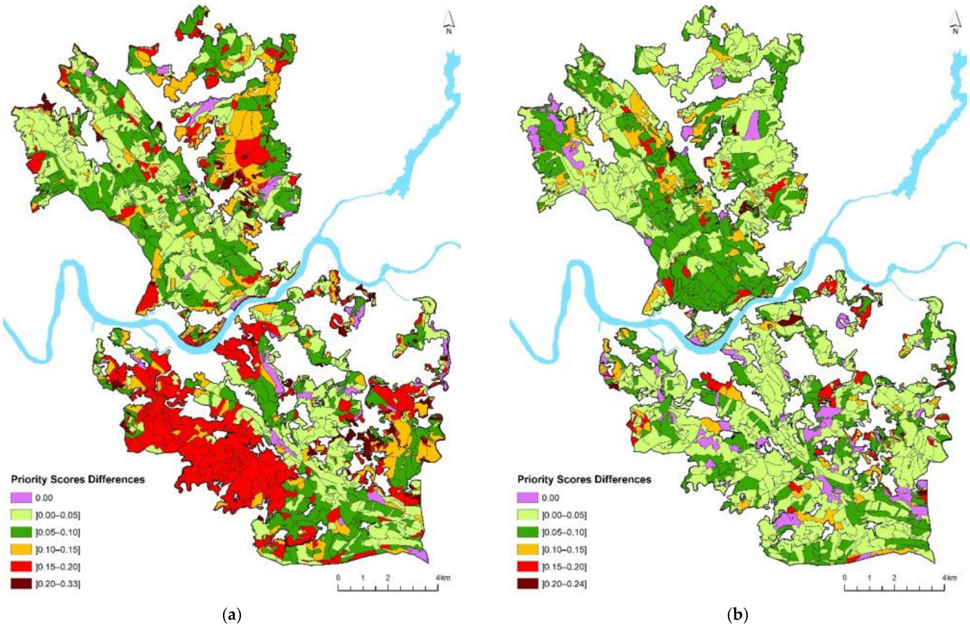

Figure 8. Most meaningful differences in priority scores of the allocation of the ecosystem services to the management units between the most significant group pairs: (**a**) the most discordant groups, with the most significant differences—civil society and market agents; (**b**) the most concordant groups, with minor differences—forest owners and public administration.

3.4. Opportunities to Minimize Conflicts among Interest Groups

MUs with high and very high priority scores were those that best matched the criteria and objectives of the interest groups. Based on the simple counts of group priority scores of high and very high in each MU, in Vale do Sousa, 30.4% of the total area (396 MUs) was classified as high to very high priority by only one group, and 51.3% (736 MUs) was classified as moderate to very low priority by all groups (Figure 9), both of which suggest low potential for conflict among the groups. The total percentage of the MU area with potential for conflict among the two, three, and four groups was 10.1% (136 MUs), 4.9% (71 MUs), and 3.2% (34 MUs), respectively.

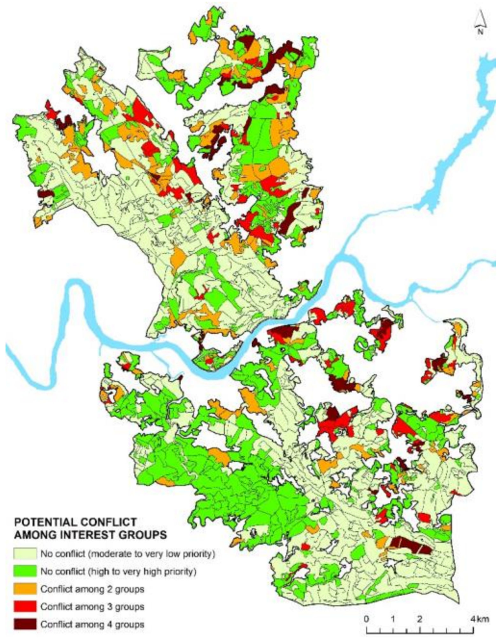

Figure 9. Most meaningful differences in priority scores of the allocation of the ecosystem services.

The results of Case 1 from the logical model (Supplement S5, Figure S5a) showed that 3.1% of the total area (49 MUs) was compatible for forest owners and public administration. Cases 2 and 3 showed that 24.0% of the total area (292 MUs) was high or very high priority only for civil society (Supplement S5, Figure S5b), and 3.5% of the total area (60 MUs) was high or very high priority only for market agents (Supplement S5, Figure S5c). Case 4 corroborated that, for 51.3% of the total area, no group rated the priority high or very high in a MU (Supplement S5, Figure S5d). We also note that, in EMDS, users can query these maps to show which specific groups rate a MU as high or very high priority, and therefore, which specific groups are potentially in conflict.

4. Discussion

The combined Group Multicriteria Spatial Decision Support System approach allowed the successful integration of actors' preferences, priorities, and objectives to prioritize the allocation of ESs to MUs at the landscape level, providing a more informed forest management plan. The results were four solutions at the landscape-level for Vale do Sousa, identifying the MUs according to each interest group ESs priorities. Civil society had the highest mean rank of priority scores, followed by forest owners, public administration, and market agents with the lowest value. The ZIF manager of Vale do Sousa can use these solutions as four proposed plans to present and discuss with ZIF forest owners' members and select the solution that best represents the interests and objectives of the joint forest management, considering the broader perspectives of the four interest groups.

4.1. Convergence and Divergence among Interest Groups

The analysis of Pareto frontier solutions goals allowed a perception of each interest group's priorities for Vale do Sousa. While the forest owners wanted to maintain current forest management, focused on wood provision, civil society proposed to change it in order to increase the diversification of ESs (more biodiversity and cork oak), and the trade-off was less wood provision. The other two groups had similar goals. In previous research [5,29], most actors supported the diversification of ESs. Even the forest owners group accepted the change to a multifunctional forest as long as this was profitable [30].

During the focus group discussion, the actors from the forest owners group reinforced the importance of a profitable forest. Otherwise, they would lose interest in forest management. Although cork is a non-wood forest product with a periodic income, the forest owners revealed some skepticism, as the recovery of investment in cork oak takes longer when compared to eucalypt. Conversely, market agents, who also manage forest areas in Vale do Sousa, had different goals, and considered a lower priority for wood provision to increase the priority of cork, revealing that they may be interested in diversifying forest market products in Vale do Sousa.

The iterative Pareto frontier method helped actors visualize and understand the impact of their preferences and goals and thus, facilitated negotiations to reach a consensus. However, the forest owners' group had more difficulties arriving at a consensual solution and interpreting it than other groups, which is perhaps because forest owners have not used this type of tool in their forest management decisions heretofore. Indeed, after the focus group session, some forest owners contacted the research team asking to access this tool to support their forest management decisions or whether the ZIF manager could use it to help them in forest management decisions. Thus, the forest owners revealed interest and openness for enhancing the current forest management, diversifying the ESs so they can better understand the impact of their choices and ensure profitable forest management.

The priority scores resulting from the allocation of forest management models and the corresponding provision of ESs to MUs by interest group provided a perception of the convergence and divergence between their preferences and goals. We found significant differences in MUs priority scores between groups (Figure 8). The civil society group was the most discordant of the four groups because one of its main objectives was biodiversity, giving less importance to wood provision and income when compared to other groups. The differences of interests and goals among the groups suggest a need to continue participatory discussions among actors to understand each other's priorities, goals, and preferences in order to minimize potential conflicts of interests and outline joint strategies for forest management.

4.2. Opportunities to Avoid Conflict

The identification of MUs with low potential conflict can facilitate negotiation among groups and thus, enable the implementation of forest management by avoiding, or at least minimizing, conflicts among groups. The ZIF forest owners may be more comfortable implementing forest management in MUs in which their priorities and goals are guaranteed, but not in conflict with the priorities of other groups. The results from this portion of the study also may present an opportunity for the ZIF manager to manage these MUs as model areas for building consensus by providing a way to explore the similarities and differences among interests and objectives. For the remaining area, the potential for conflict may be an opportunity to develop additional participatory discussion sessions among interest groups to explore the differences that may be the subject of conflict and to try to negotiate a consensus solution.

Our analysis of potential group conflicts was based on simple Boolean logic that identifies MUs in which multiple groups with potentially competing values rate a MU as being of high or very high priority. The results (Figure 9 and Supplement S5) are easy to understand, and thus may be a good starting point for negotiations among interest groups. However, the logic-based approach (Supplement 5, Figure S5.2) is also easily refined by use of fuzzy logic in the NetWeaver model, thus enabling a more quantitative evaluation based on degrees of conflict among groups.

4.3. Limitations of the Study and Future Improvements

Borges et al. [13] organized three groups of actors to reach a consensual solution, using the Pareto frontier method for five ESs of Vale do Sousa—eucalypt pulpwood, pine saw logs, chestnut saw logs, the volume of ending inventory, and average carbon stock. This research extends this approach to include biodiversity and wildfire resistance and to prioritize the allocation of ESs to MUs. Comparing our approach with similar studies ([2,19–24]), it innovates by developing a participatory process that involves actors in different stages of decision, and by integrating the solutions from a trade-off analysis and criteria weights from MCDA. The trade-off analysis allowed actors to have a greater sense of what they would sacrifice to maintain their goals.

We identified two main drawbacks of the methodology that can be improved. First, forest owners were not comfortable with the Pareto frontier method, and some of these actors did not express their doubts or concerns to the facilitator. Thus, this group took a long time to reach a consensus, compared to the other three groups. Forest owners also demonstrated difficulties analyzing the seven ESs on the Pareto frontier and understanding the solution. More research may be needed to simplify the analysis presented by the tool so that it is more intuitive for forest owners. Alternatively, training sessions with forest owners might be organized ahead of a broader actors meeting, using data from their forestland, to familiarize them with the Pareto frontier method analysis process.

Second, although the Pareto frontier method provides a spatial visualization of the solution [13,35], it was not practical to integrate the MCDA results [30] and the consensual Pareto frontier solution during the focus group session because it was necessary to normalize the Pareto solution database, which is the most time-consuming step of our methodology. Therefore, additional research into ways to optimize the integration of solution results in the Pareto frontier method would be useful for actors to see and discuss results in the same session.

We started by working with groups of actors with the same interests because sharing similar goals and concerns can promote empathy among actors and can facilitate discussions and negotiation, leading to consensus. Indeed, we found this to be generally true of the four groups involved in this study. Moreover, once a group of actors with the same interests understand each other's points of view, it may be easier to work with groups of actors with different interests. Thus, a two-step participatory process that begins with seeking consensus within relatively homogeneous groups and proceeds to seeking consensus among groups with diverse interests and perspectives may be an effective way to deal with complex management problems involving diverse actors.

Another improvement that could be introduced in our methodology is creating portfolios of alternative sets of forest management actions based on a given budget (e.g., [58,59]). Thus, the MUs priority scores could be complemented by creating portfolios based on a specific budget, which could assist ZIF managers with managing the forest more efficiently with a specific budget in mind.

The analysis of potential conflicts revealed a significant area of MUs with low conflict for negotiation among interest groups. These results suggest that the group decision-making enhances understandings and convergence of interests. However, more participatory sessions are needed so that the actors' interests and goals can be discussed and understood in greater depth, facilitating the negotiation, and thus contributing to the consensus of the allocation of ESs to MUs for Vale do Sousa.

In addition, aiming for a more transparent landscape evaluation and group decision-making, the four landscape priority scores, complemented with portfolios, could be presented as landscape forest management proposals and discussed in a wide-ranging event with ZIF's forest owners' members, asking them to vote on the proposal with which they identify most. So, the proposal that obtained the most votes would be integrated into the forest management plan of the Vale do Sousa ZIF. Thus, this plan combines different preferences, priorities, and objectives for a landscape that actors intend to be sustainable and multifunctional.

Moreover, the ZIF manager of Vale do Sousa was recognized as the most influential actor in forest management decisions when actors ask for forest management support [5]. ZIF managers in general may wish to consider applying or adapting our approach to negotiating consensus solutions for multi-objective landscape-level planning to integrate the different forest owners' interests and goals, while providing a wide range of ESs.

5. Conclusions

This research successfully applied the Group Multicriteria Spatial Decision Support System approach, combining MCDA, focus groups, the Pareto frontier method, and EMDS spatial integration to prioritize the allocation of ESs to MUs, given the competing priorities of the four groups. The result was a map of MUs priorities by interest group, representing four consensus solutions for Vale do Sousa. This combined approach is a helpful tool in forest management because it integrates multiple criteria and objectives to spatially model different actors' preferences, interests, and goals.

There were two key elements to success in applying this approach. First, the diversity of interests involved in the analysis enabled four solutions. ZIF managers can use the solutions as four proposals to be discussed with ZIF forest owners' members to select the forest management plan for Vale do Sousa that is best suited to ZIF interests and goals. Second, the willingness and commitment of all actors to participate in the process with several steps (workshops, multicriteria questionnaire, and focus group), and the cooperation to reach consensus solutions in the focus groups session enabled social learning among the actors and the research team. Such participatory processes are rich in promoting understanding and sharing knowledge, interests, and experiences that allow forest management planning to be closer to those who implement it, thus promoting a feeling of sharing and a common good.

This Group Multicriteria Spatial Decision Support System approach can be applied by ZIF managers, forest owners, forest managers, and other decision makers dealing with different interests and goals to support decision making in forest management planning. Because the output spatially shows the priority MUs at the landscape scale, it is easier to visualize and understand by the forest owners and other actors.

In an era of new technologies, it is crucial that the ZIF managers in Portugal, or in other forest management situations dealing with actors with different interests, can support their forest management decisions with participatory techniques and apply these combined tools, contributing to an easier understanding of the impact of the decisions at the landscape level by forest owners and managers. This can increase the confidence of forest owners in forest management planning decisions, thus facilitating their implementation.

Supplementary Materials: The following is available online at https://www.mdpi.com/article/10.3390/land10070747/s1, Figure S1. Criteria and sub-criteria weights of the MCDA model. The following are available online at https://www.mdpi.com/article/10.3390/land10070747/s2, Figure S2.1. Data normalized from the Pareto frontier solution for the civil society group; Figure S2.2. Data normalized from the Pareto frontier solution for the forest owners' group; Figure S2.3. Data normalized from the Pareto frontier solution for the market agents' group; Figure S2.4. Data normalized from the Pareto frontier solution for the public administration group. The following are available online at https://www.mdpi.com/article/10.3390/land10070747/s3, Figure S3.1. Priority scores classified into two Boolean classes of "high and very high" (value 1) and "moderate to very low" (value 0) by interest group: (a) civil society; (b) forest owners; (c) market agents; (d) public administration; Figure S3.2. NetWeaver logic model: (a) arguments of conflict case 1, where priority scores are high for either forest owners and public administration or both, but priority scores are not high for civil society and market agents; (b) arguments of conflict case 2, where priority scores are only high for civil society; (c) arguments of conflict case 3, where priority scores are only high for market agents; (d) arguments of conflict case 4, where priority scores are not high for any interest group. The following is available online at https://www.mdpi.com/article/10.3390/land10070747/s4, Figure S4. Differences of priority scores between pairs of interest groups: (a) civil society and forest owners; (b) civil society and public administration; (c) forest owners and market agents; (d) market agents and public administration. The following is available online at https://www.mdpi.com/article/10.3390/land10070747/s5, Figure S5. The four cases of NetWeaver logic model: (a) case 1, the priorities of forest owners and public administrators are basically compatible; (b) case 2, high priority in only civil society and any other group's high priority is a potential conflict; (c) case 3, high priority in only market agents and any other group's high priority is a potential conflict; (d) case 4, no group rates the priority high or very high in a MU.

Author Contributions: Conceptualization, M.M. (Marlene Marques), K.M.R. and J.G.B.; methodology, M.M. (Marlene Marques), K.M.R., S.M., S.P., M.M. (Marco Marto) and J.G.B.; software, M.M. (Marlene Marques), K.M.R., S.M., S.P., M.M. (Marco Marto) and J.G.B.; validation, M.M. (Marlene Marques), K.M.R., S.M. and J.G.B.; formal analysis, M.M. (Marlene Marques) and K.M.R.; investigation, M.M. (Marlene Marques), K.M.R., S.M., M.M. (Marco Marto) and J.G.B.; resources, M.M. (Marlene Marques), K.M.R. and J.G.B.; writing—original draft preparation, M.M. (Marlene Marques); writing—review and editing, K.M.R., S.M., S.P., M.M. (Marco Marto) and J.G.B.; project administration, J.G.B. and S.M.; funding acquisition, J.G.B., M.M. (Marlene Marques), S.M. and M.M. (Marco Marto). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Union's Horizon 2020 Research and Innovation Programme (grant agreement number 676754—ALTERFOR project and grant agreement number 773324—NOBEL project, which is part of the ERA-NET Cofund ForestValue), by the Marie Skodowska-Curie Research and Innovation Staff Exchange (RISE) within the H2020 Work Programme (H2020-MSCA-RISE-2015) (SUFORUN), by the Portuguese Science Foundation (FCT), Portugal, namely through the Ph.D. grant of Marlene Marques (PD/BD/128257/2016), the Ph.D. grant of Marco Marto (SFRH/BD/108225/2015), in the scope of Norma Transitória—DL57/2016/CP1382/CT15, the Forest Research Center Project UIDB/00239/2020, the BIOECOSYS project (grant number LISBOA-01-0145-FEDER-030391, PTDC/ASP-SIL/30391/2017) and the MODFIRE project (grant number PCIF/MOS/0217/2017).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon request.

Disclaimer: The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Acknowledgments: We thank the researchers Brigite Botequim, Carlos Caldas, Catarina Tavares and Patrícia Pécurto for helping during the focus group session. We warmly thank all the actors who have participated in the focus group. Finally, we thank the journal's reviewers who provided a number of very useful criticisms and helpful suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

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MDPI

Supplement S1

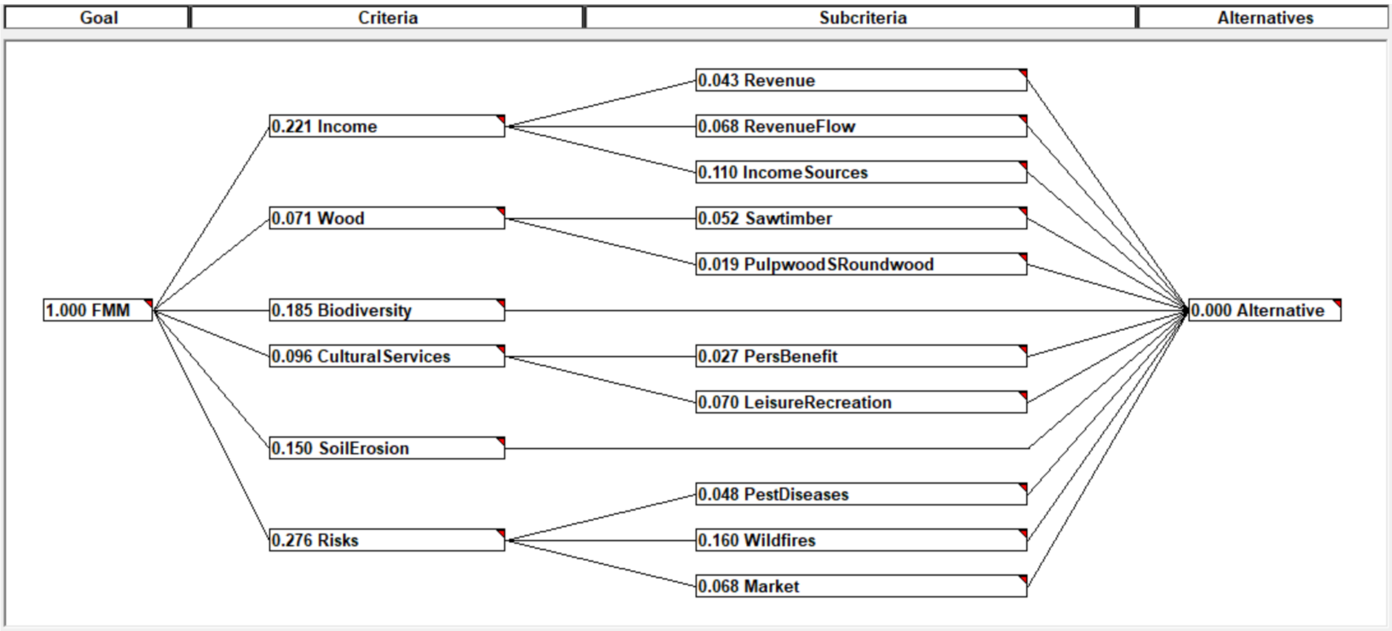
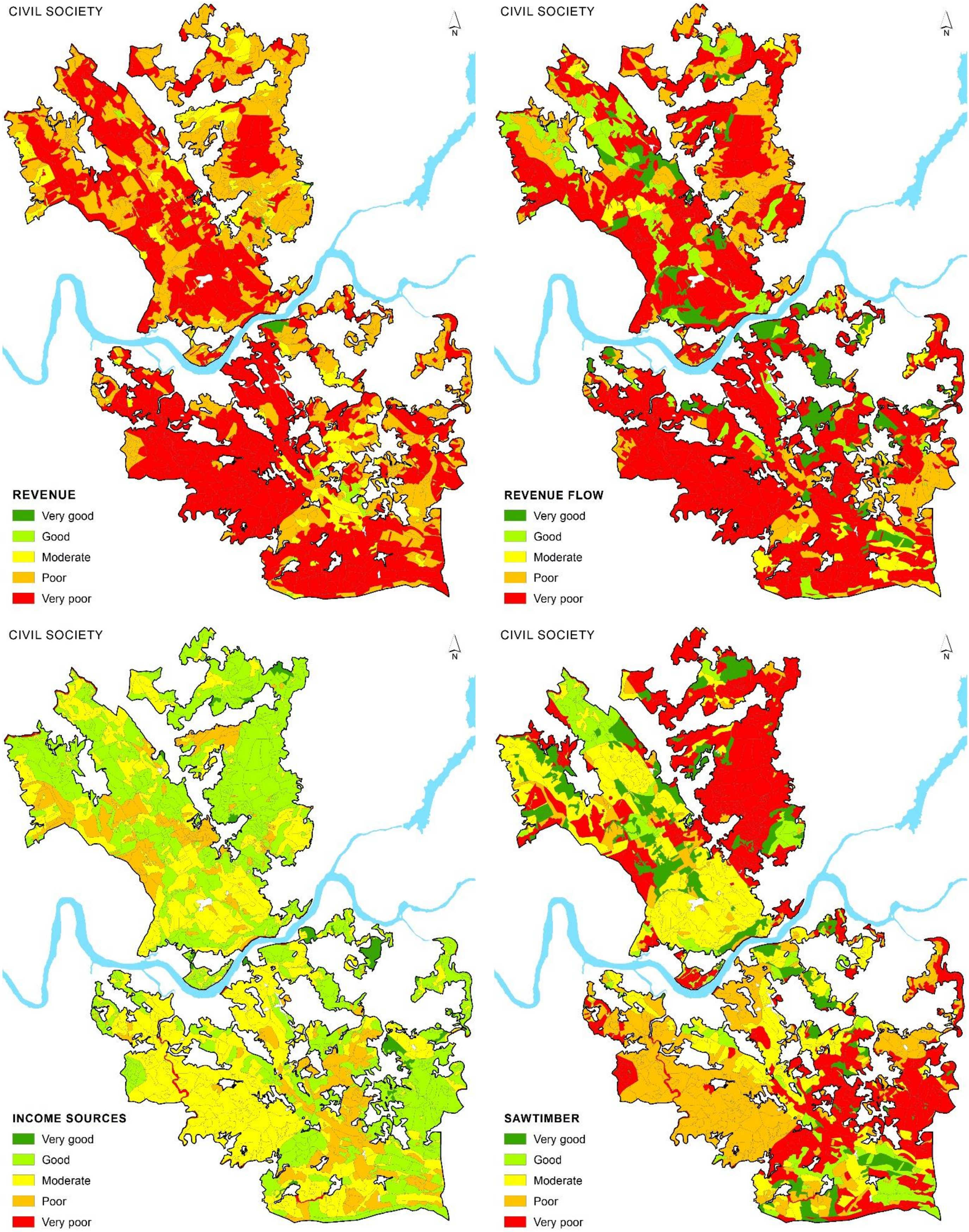


Figure S1. Criteria and sub-criteria weights of the MCDA model. Example from civil society group [25]. Criteria weights sum to 1. At the sub-criterion level, criteria weights are shown as distributed to the sub-criteria under each criterion (e.g., the sub-criteria weights under a criterion sum to the criterion weight). Lowest level criteria evaluate the attributes of the alternatives. The priority score for an alternative (a management unit) is calculated as the sum of products of the lowest level criterion weights and the utility scores of each attribute for the alternative (note that Biodiversity and Soil Erosion are also a lowest level criteria). As implemented in EMDS, the single alternative is simply a placeholder that is replaced at runtime by the list of management units contained in the analysis area.

Supplement S2



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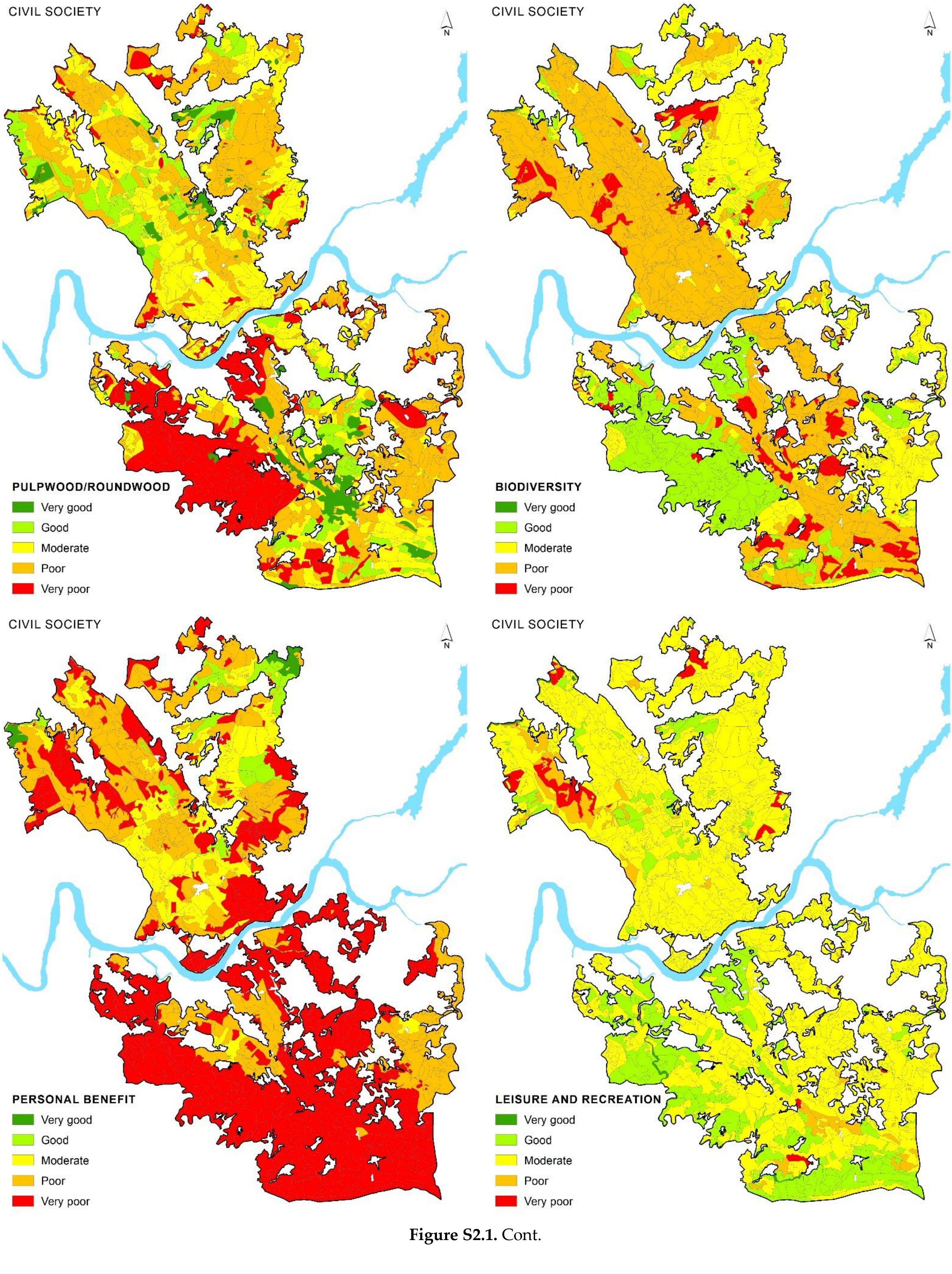

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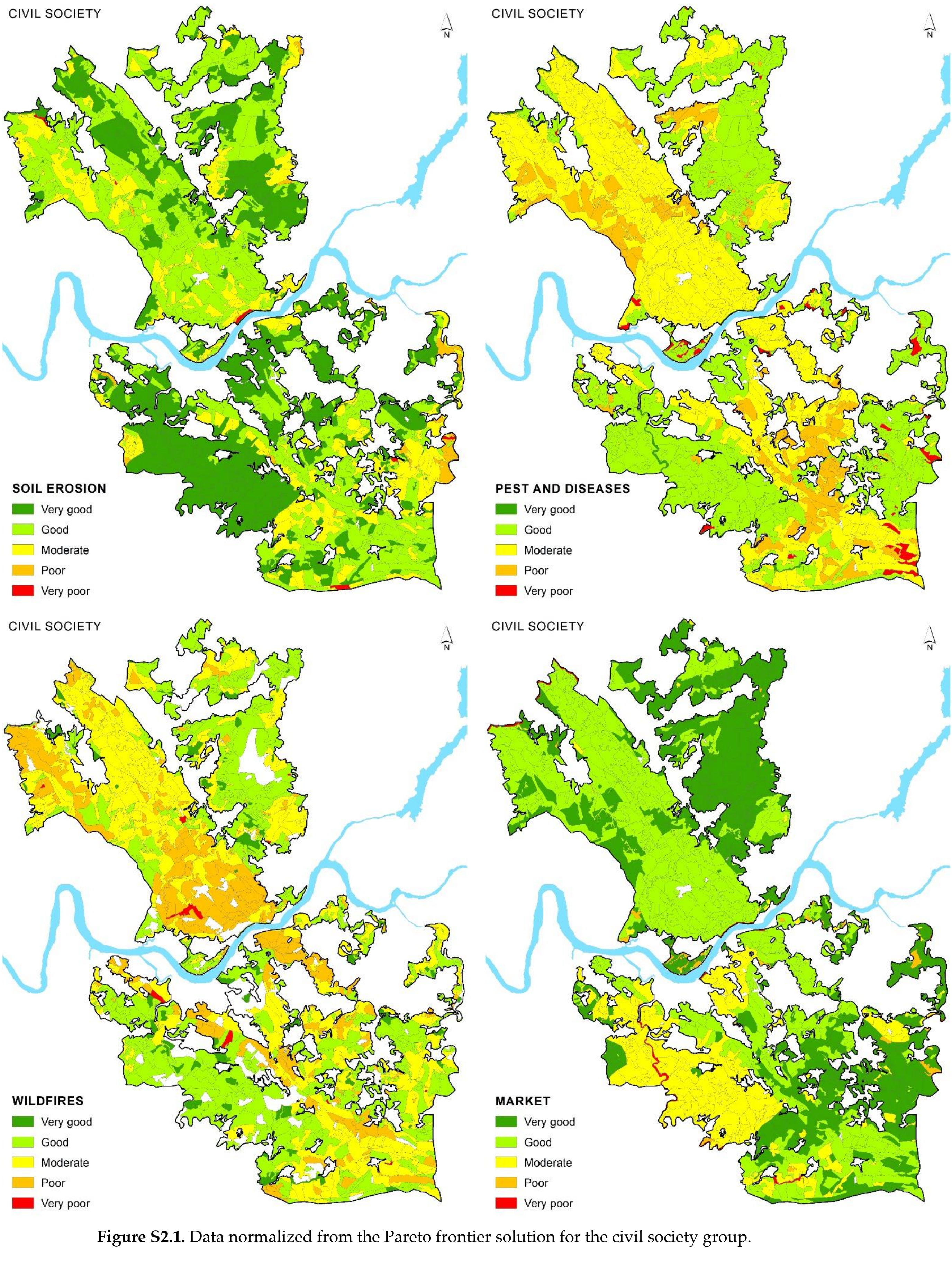
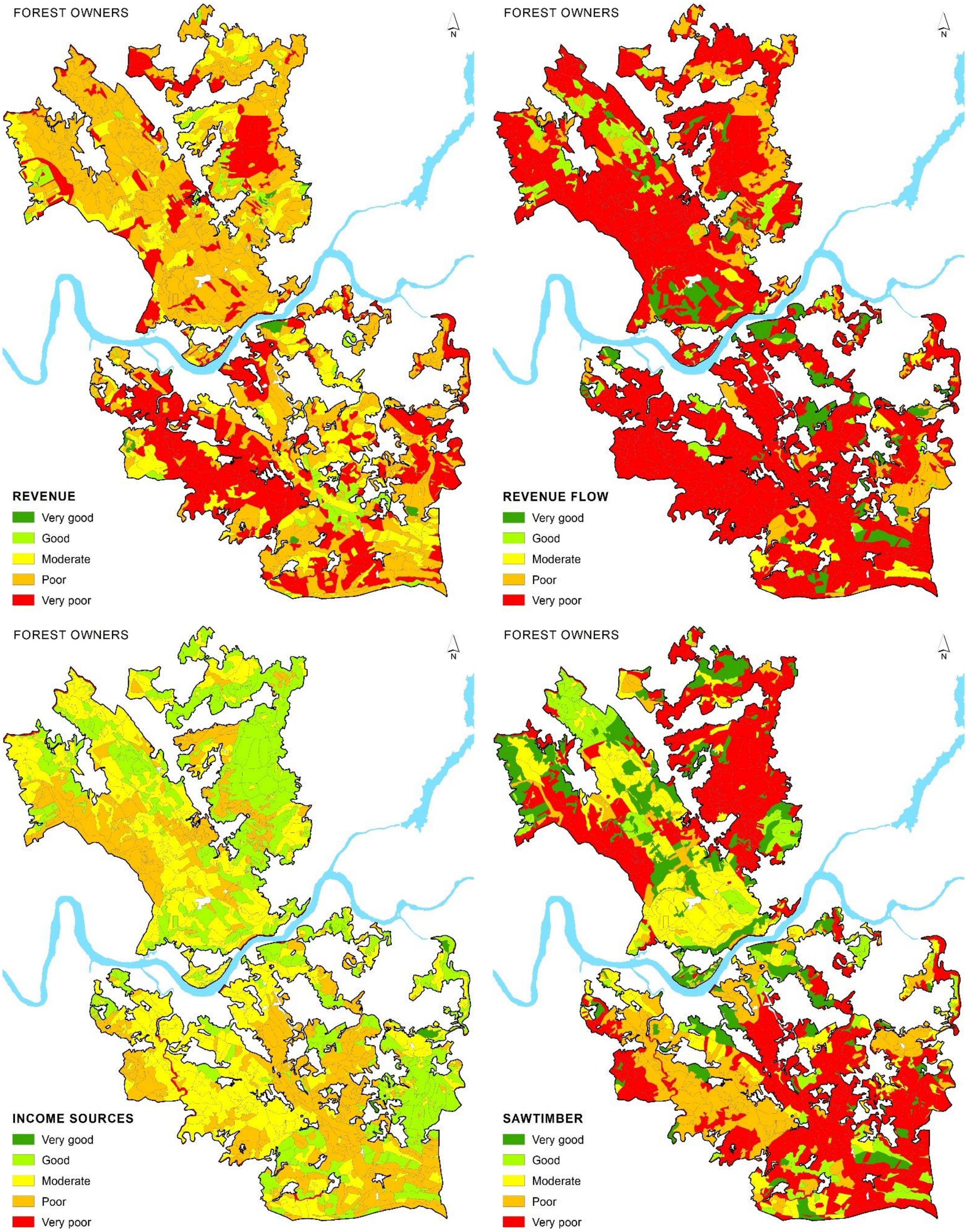


Figure S2.1. Data normalized from the Pareto frontier solution for the civil society group.



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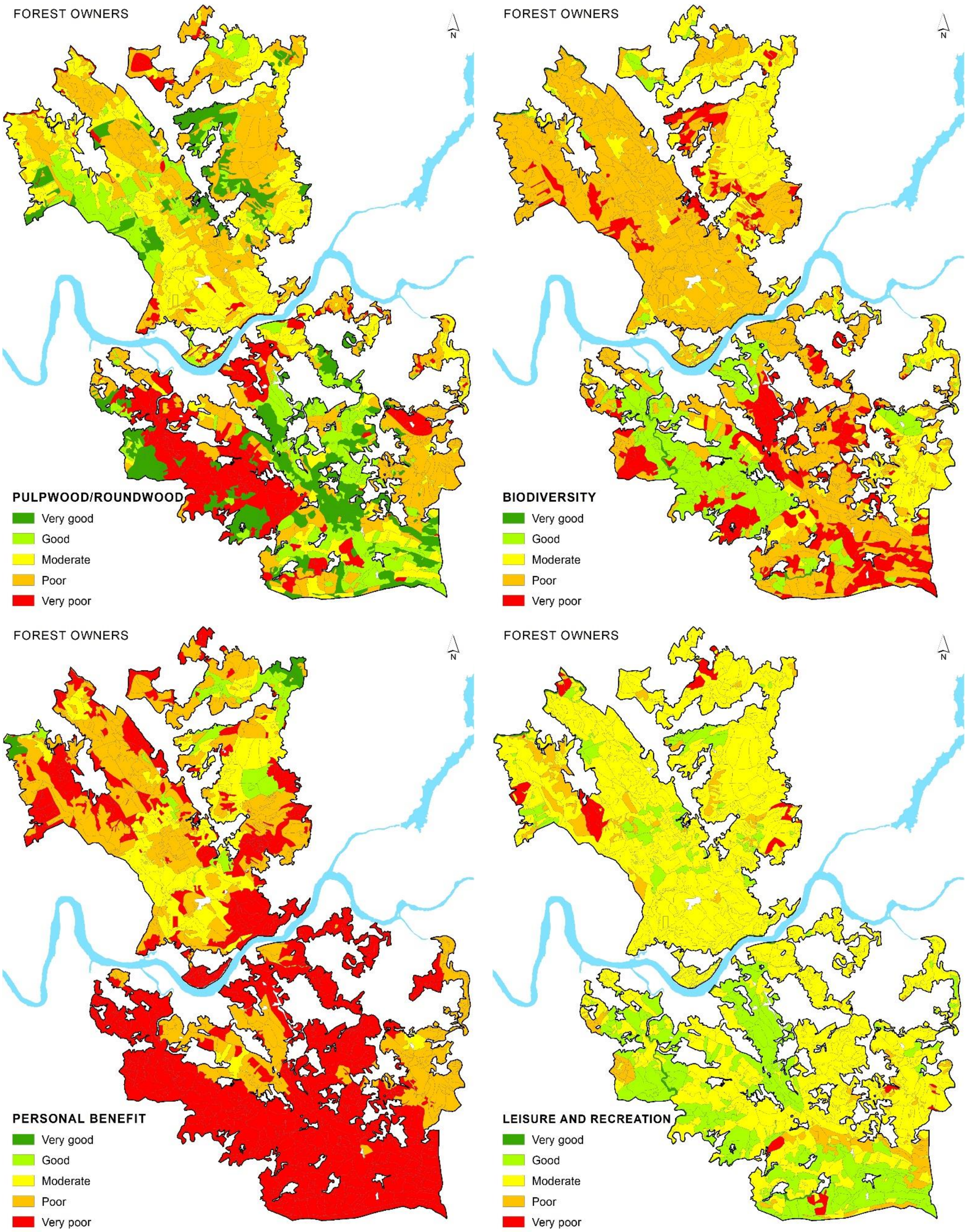

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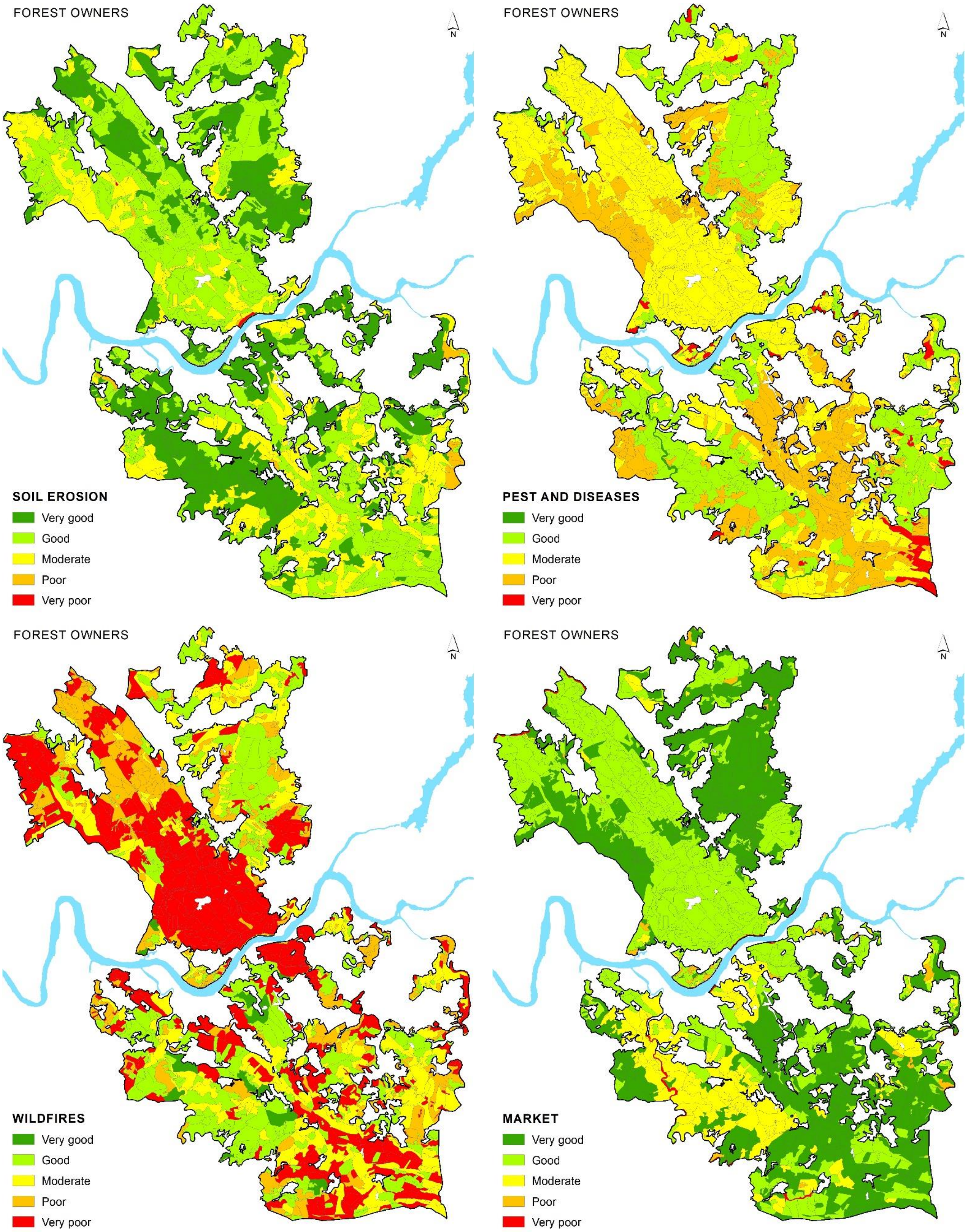

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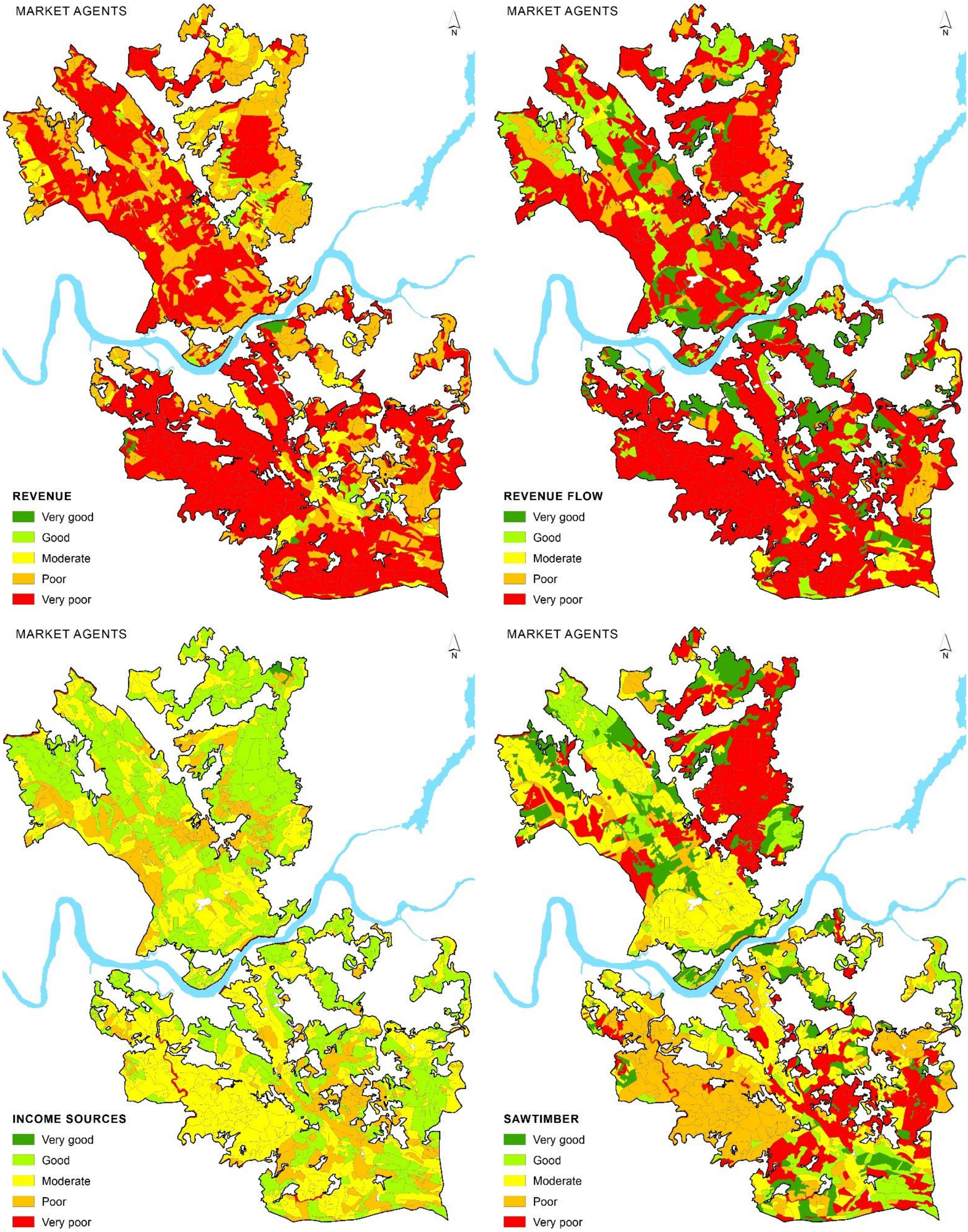

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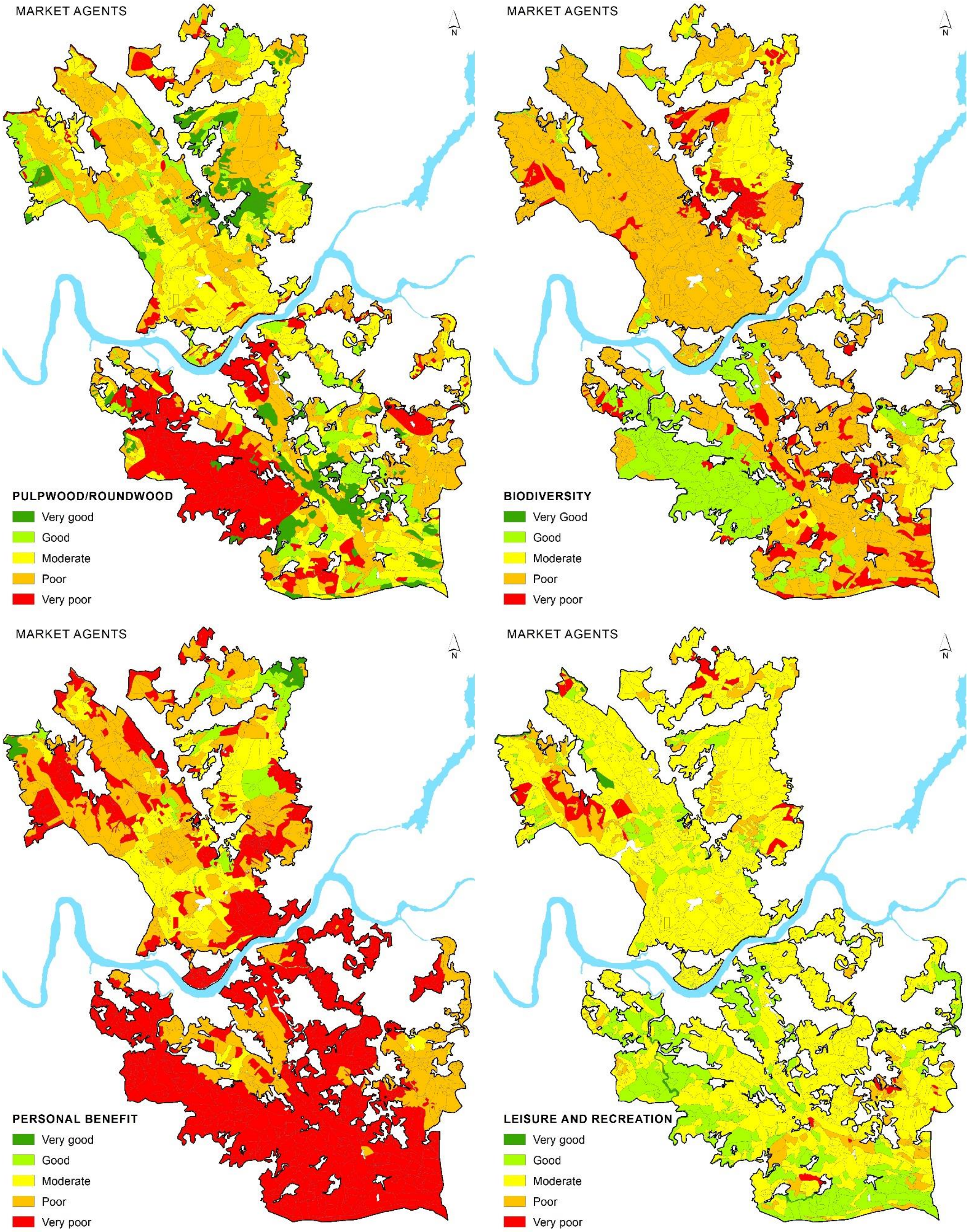

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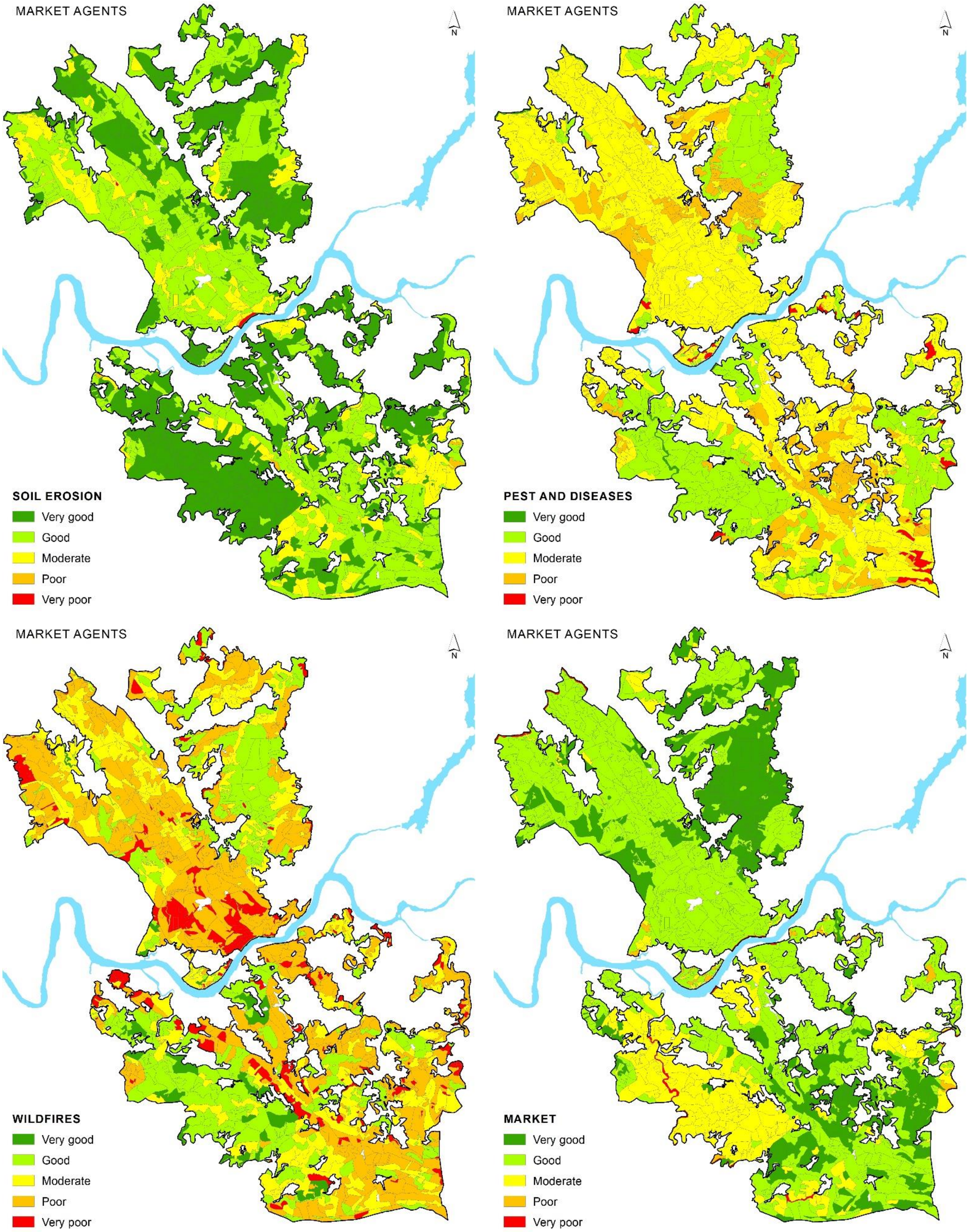
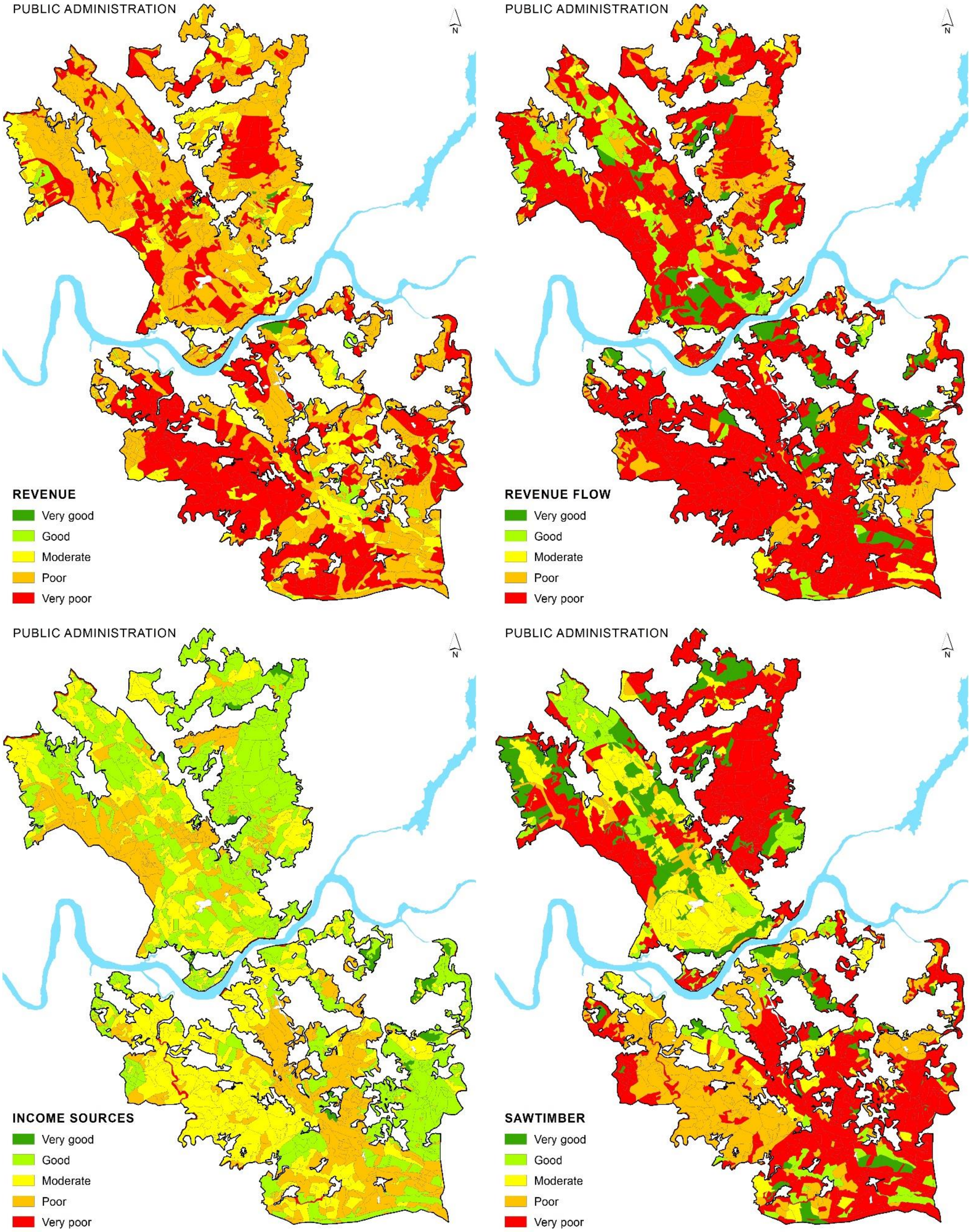


Figure S2.3. Data normalized from the Pareto frontier solution for the market agents' group.



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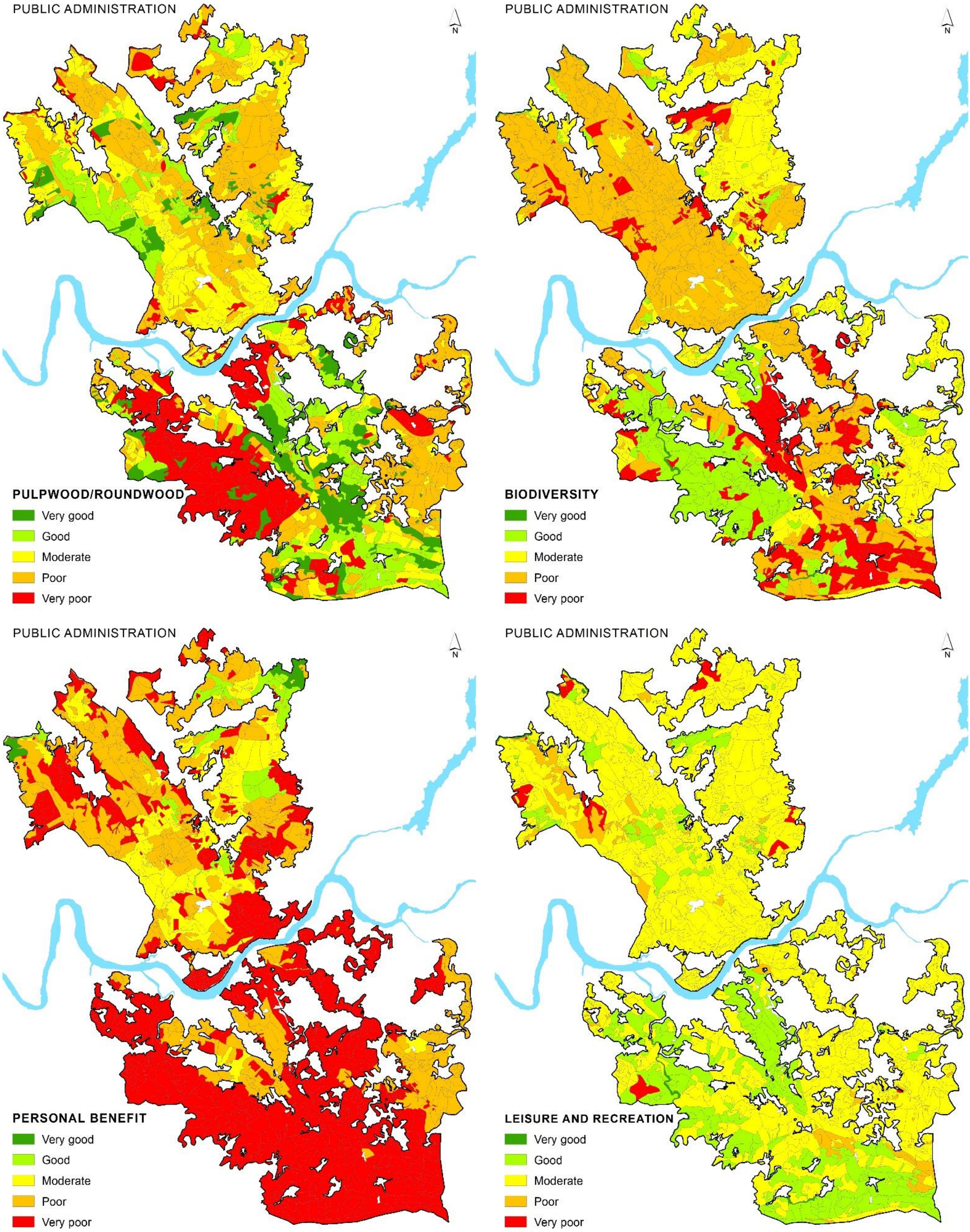


Figure S2.4. Cont.

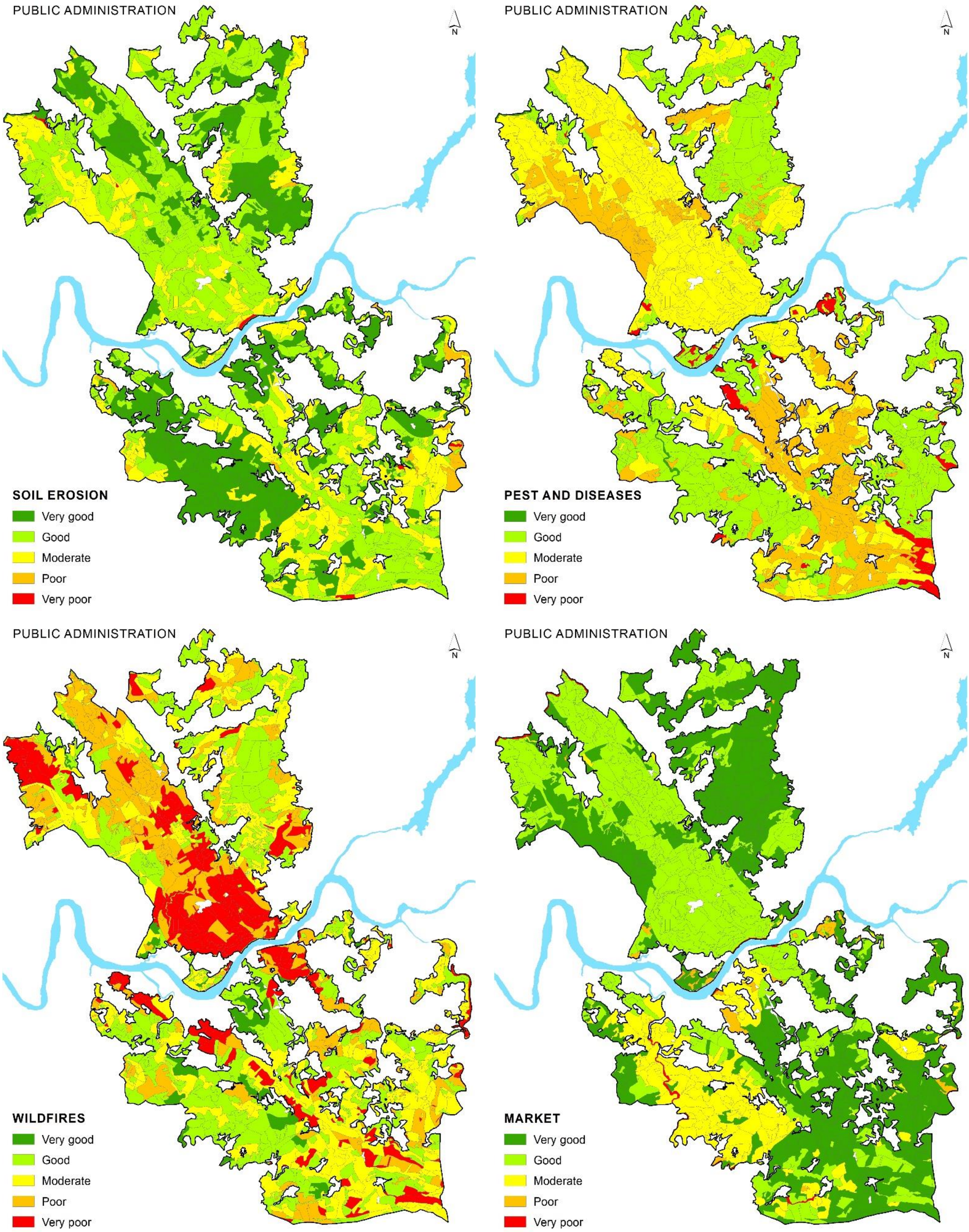


Figure S2.4. Data normalized from the Pareto frontier solution for the public administration group.

Supplement S3

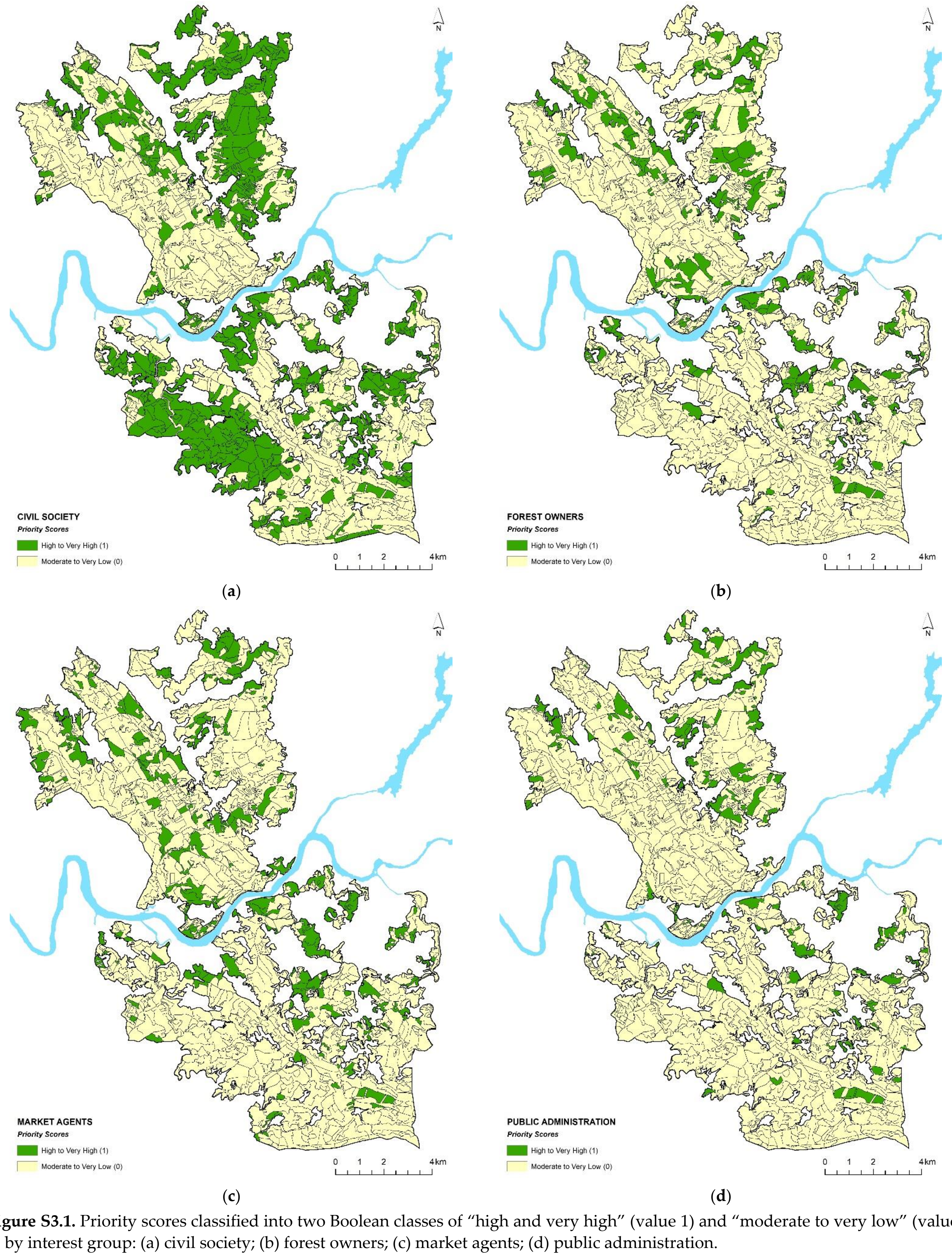


Figure S3.1. Priority scores classified into two Boolean classes of "high and very high" (value 1) and "moderate to very low" (value 0) by interest group: (a) civil society; (b) forest owners; (c) market agents; (d) public administration.

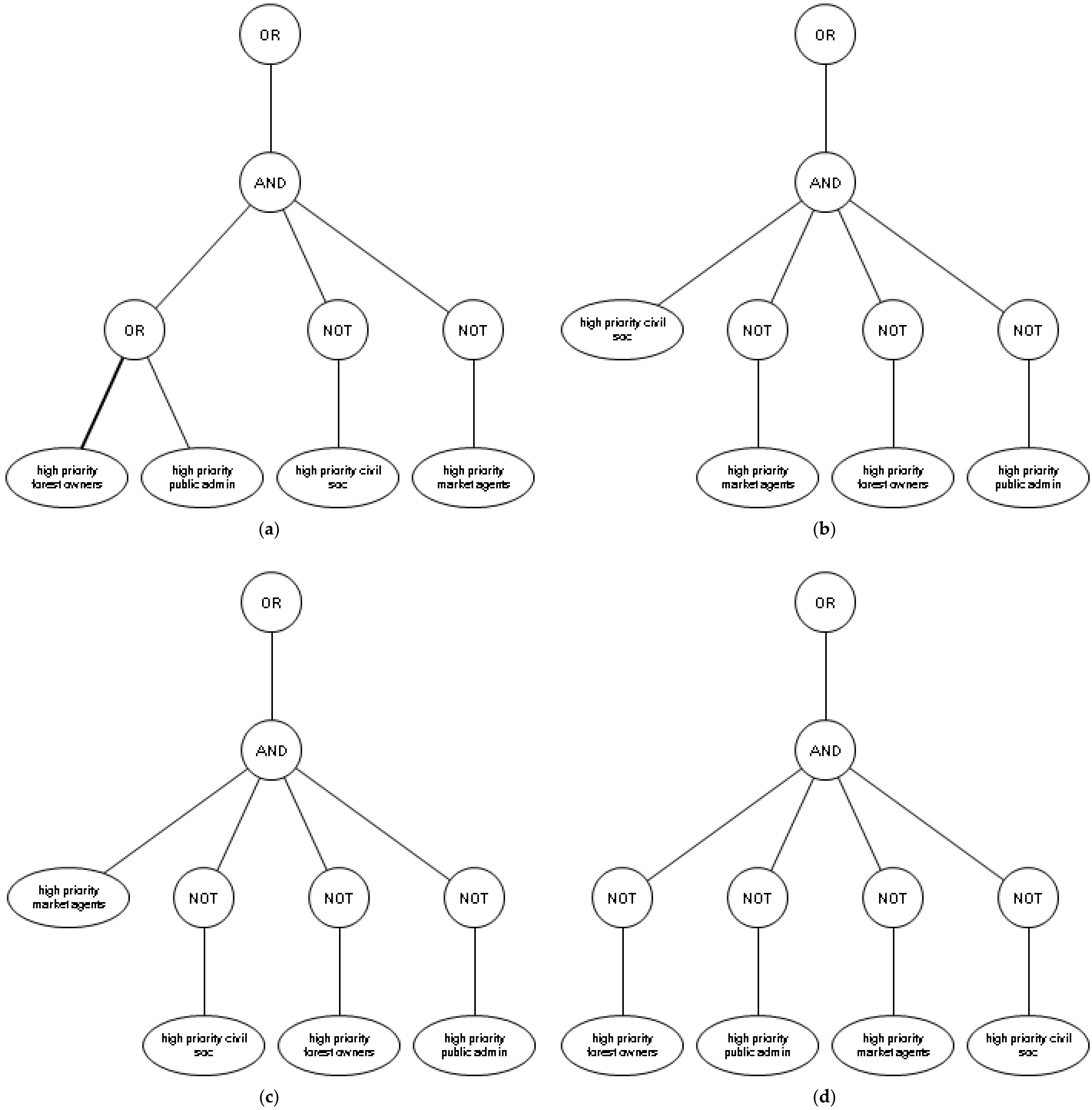
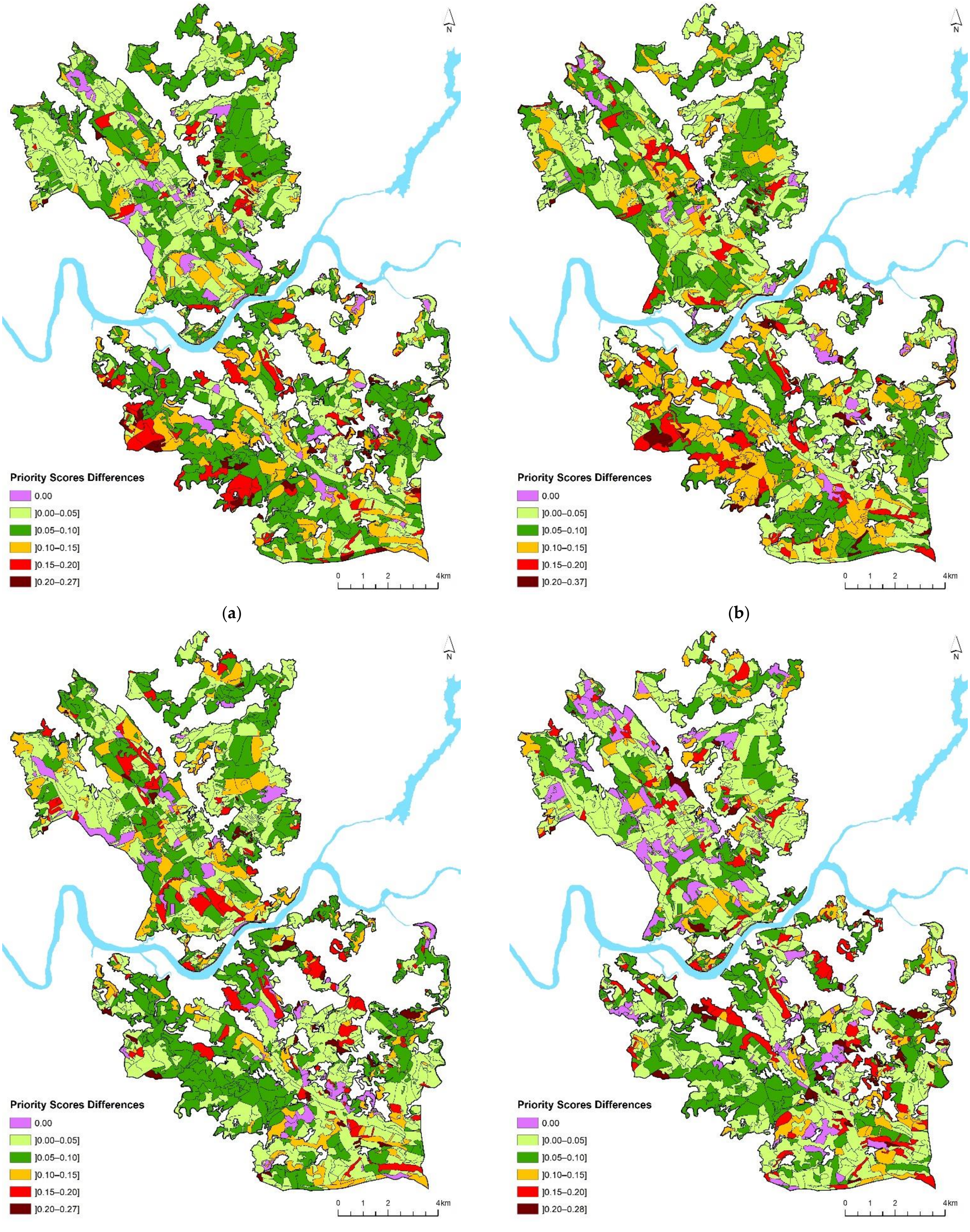


Figure S3.2. NetWeaver logic model: (a) arguments of conflict case 1, where priority scores are high for either forest owners and public administration or both, but priority scores are not high for civil society and market agents; (b) arguments of conflict case 2, where priority scores are only high for civil society; (c) arguments of conflict case 3, where priority scores are only high for market agents; (d) arguments of conflict case 4, where priority scores are not high for any interest group.

Supplement S4

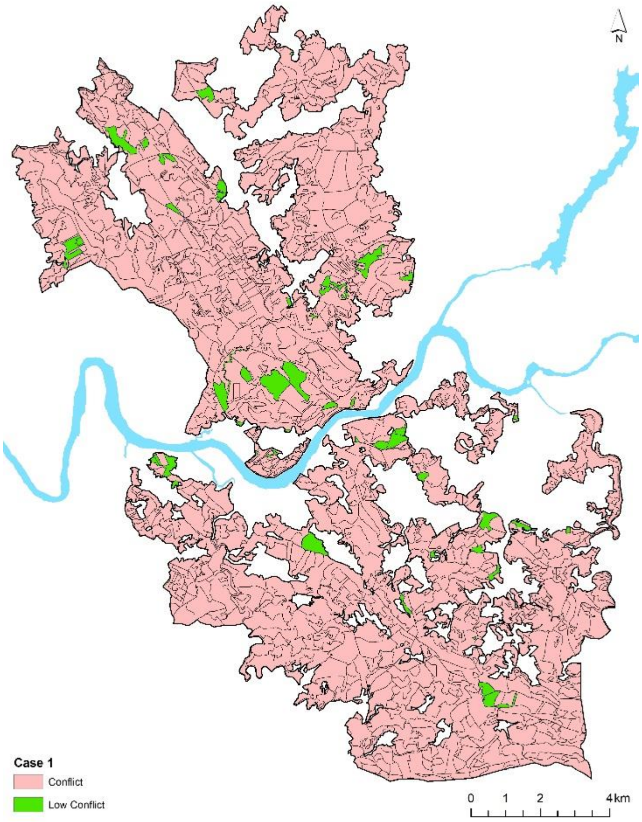


(**a**) (**b**)

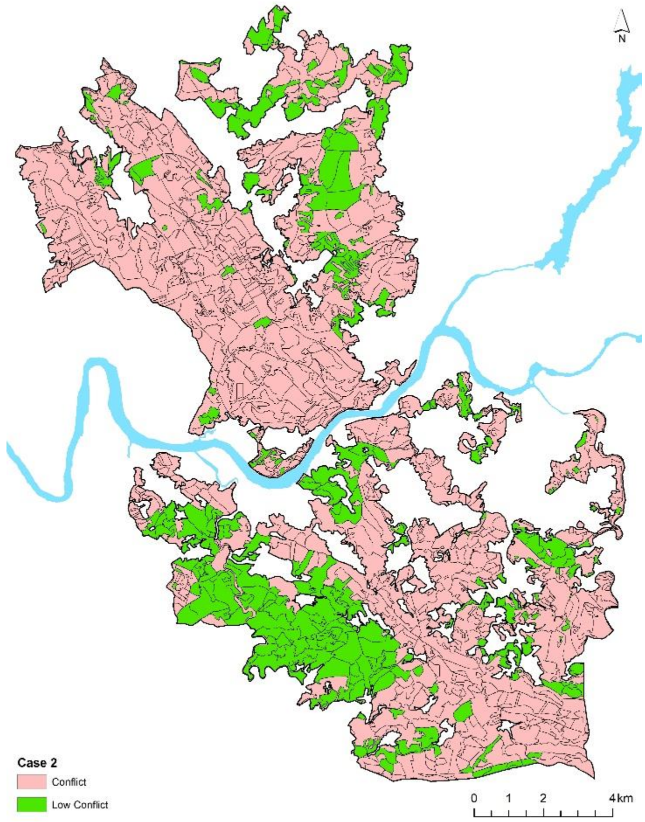
(**c**) (**d**)

Figure S4. Differences of priority scores between pairs of interest groups: (a) civil society and forest owners; (b) civil society and public administration; (c) forest owners and market agents; (d) market agents and public administration.

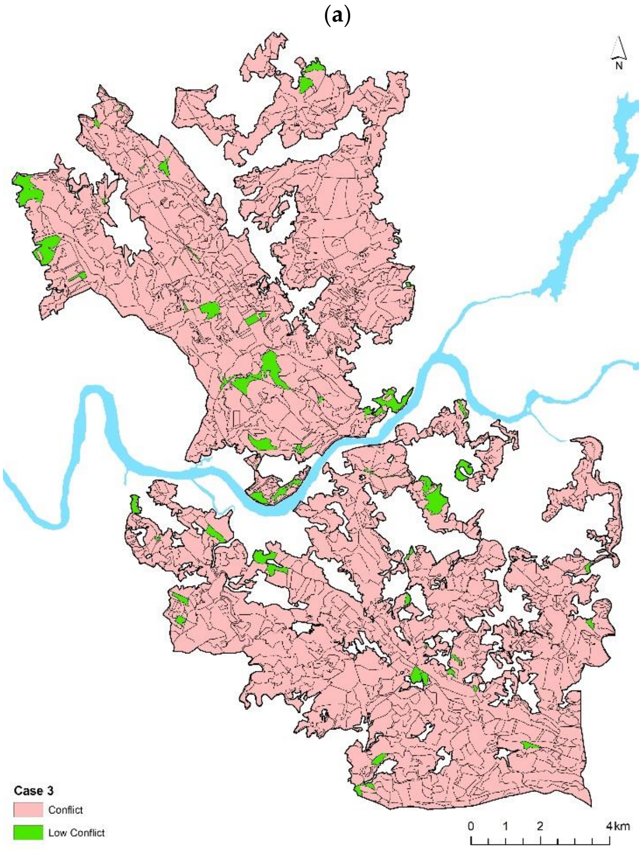
Supplement S5



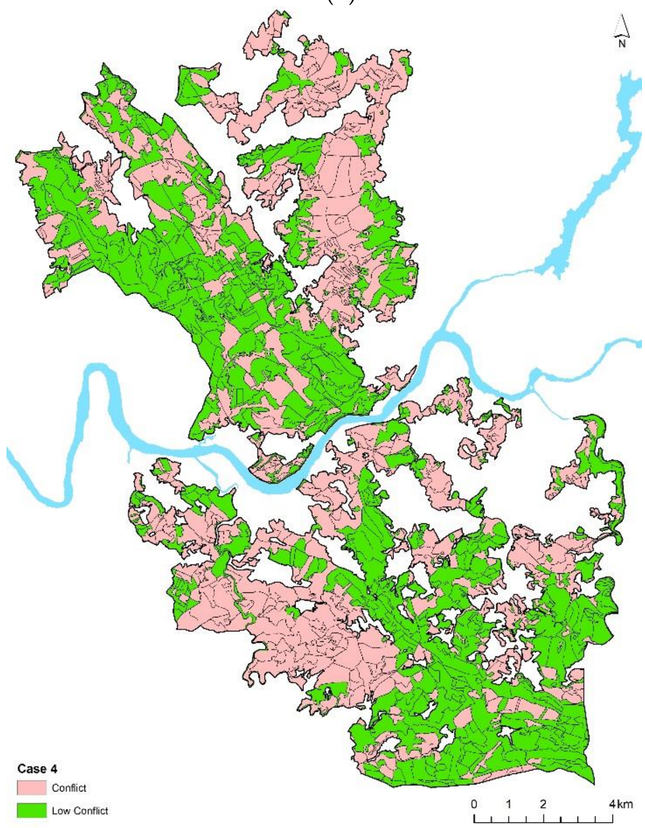
(**a**)



(**b**)



(**c**)



(**d**)

Figure S5. The four cases of NetWeaver logic model: (a) case 1, the priorities of forest owners and public administrators are basically compatible; (b) case 2, high priority in only civil society and any other group's high priority is a potential conflict; (c) case 3, high priority in only market agents and any other group's high priority is a potential conflict; (d) case 4, no group rates the priority high or very high in a management unit.

CHAPTER VI

Final Remarks

VI.1. General conclusions

The use of participatory and multicriteria approaches and group decision-making techniques successfully answered the main research question of this thesis. The involvement of actors with different interests in all phases of the participatory process granted a knowledge of their concerns, goals, and priorities, as well as their understanding of other actors’ points of view. Moreover, the participatory discussions and multicriteria approaches explored and quantified actors' preferences, considering decision criteria of sustainable forest and natural resource management (economic, environmental, and social), and targeting the provision of a wide range of ES and the challenges of the 21st century.

Although there has been significant research in the scope of the application of MCDA or hybrid models of MCDA and group decision-making in natural resources at a world level, there is little research and few applications in joint management areas or other case studies involving many private small-scale forest owners. This thesis has addressed this gap, improving the knowledge that best reflects actors’ interests and goals for forest management by applying approaches and techniques that can support ZIF managers and other decision-makers with similar forest management decisions.

All stages of the applied methodology were characterized by constant actors’ involvement and a flow of information included in the ongoing analysis and discussions. During the interviews and the two workshops, we explained to actors all the phases of the participatory process, what was expected from their participation and how they would be asked to participate (in questionnaires, Delphi survey, and focus groups). In the interviews, all actors confirmed their willingness to participate. This motivation was confirmed again in later questionnaires. The quality of participatory forest management decisions depends on the quality of the process used to achieve it. In a participatory process, the selection of actors to involve, and the choice of multicriteria approaches, are crucial for the success of the group decision-making process.

The actor analysis provided a snapshot of the forest management context of Vale do Sousa, including valuable information about the actors and factors (interests, conflicts, problems, and power resources) that impact the forest management decisions of ZIF. The interviews were a crucial technique to create empathy between the actors and the research team, facilitating the invitation to participate in the workshops, focus groups, and multicriteria questionnaire. These initial contacts and findings were relevant to the preparation of the following phases of the participatory processes.

The hybridization of MCDA and group decision-making promoted meaningful discussions regarding the decision problem of forest management in Vale do Sousa that was intended to be solved, integrating different interests and preferences that are important for each actor. In the participatory discussions, actors questioned and defended their points of view and learned about those of other actors, debating the most important criteria to consider in MCDA, testing and adjusting the trade-offs between ES and, when agreed or satisfied with the result, deciding. The Group Multicriteria Spatial Decision Support System approach facilitated the integration of groups' preferences and objectives to prioritize the allocation of ES to MUs, promoting a sustainable forest management planning of Vale do Sousa landscape.

Throughout the participatory process, there was a consensus among the actors regarding their preferences for a forest resilient to wildfires and profitable forest management, as well as for cultural services as the least preferred ES. The frequency of wildfires and the extent of burned area in Vale do Sousa were widely discussed by actors, particularly the wildfires of 2016 (interviews) and 2017 (workshop and cognitive mapping) that burned more than 5769 ha (38.9% of total area). These can explain the consensual preference, as wildfires affect both actors' investment and the availability of ES and have influenced the forest management decisions of forest owners and managers.

The actors emphasized the importance of participatory forest management planning for Vale do Sousa, which should be carried out at the landscape and not at the stand-level, to minimize the major risks they identified, namely wildfires, invasive alien species, pests and diseases. According to the discussions and the findings, a multifunctional forest that offers a diversity of ES could be a solution for a more resilient landscape to those problems and the impacts of climate change, but it must be also profitable. In general, actors aim for the diversification of ES in Vale do Sousa. But forest owners and managers stressed that they seek a profitable forest as they directly or indirectly depend on the forest economic returns. However, they do not oppose to a change of their current forest management as long as they have financial compensation for that, or they can be paid for the non-market ES.

Actors identified outdoor motorized recreation activities as the major conflict of interests in Vale do Sousa (Chapter II), which may explain the actors' lower preferences for cultural services. This conflict involves all the affected actors, directly or indirectly, and the sports enthusiasts. Despite having been invited to the workshops, the associations representing these activities were not available to participate and get to know the concerns of forest owners and managers and negotiate a consensual forest management solution integrating both interests.

In the analysis of the preferred FMMs, the results were distinct when actors were directly questioned for their preferences or needed to consider multicriteria in their decision analysis. While in the simple questionnaire (Chapter III), the preferred FMMs were for pure maritime pine and pure eucalypt, and the least preferred FMMs were chestnut and pedunculate oak, in the aggregated results of the multicriteria questionnaire (Chapter IV), the preferences were contrasting, with the FMMs of pedunculate oak and chestnut obtaining the best performances and the FMM of pure eucalypt the lowest performance. These findings suggest that the approaches used to identify the actors' preferences can achieve different results. In the multicriteria questionnaire, actors needed to consider multiple criteria that affect their decisions instead of thinking about one simple criterion (e.g., species choice).

When actors answered the multicriteria questionnaire (Chapter IV), the Portuguese Government had published legislation that limited the expansion of eucalypt plantations. This constraint may have led some actors to consider alternative FMMs. Moreover, the multicriteria findings also suggest a willingness to change the current forest management in Vale do Sousa to implement a diversification of forest species and ES, aiming for more sustainable forest management and contributing to the Sustainable Development Goals of the United Nations 2030 Agenda for Sustainable Development (particularly the 15th goal).

All these findings - a broad understanding of the different actors' interests, preferences, concerns, goals, priorities, and points of view - as well as the participatory approaches and techniques applied, can support ZIF managers in developing joint collaborative landscape-level management planning, considering a range of ES and aiming at multifunctional forest, increasing the effectiveness of its implementation.

Likewise, for a successful implementation of joint collaborative forest management, the local Forest Owners Association (AFVS, *Associação Florestal do Vale do Sousa* in Portuguese) and Wood Industry, identified by actors as the most influential (Chapter II), can work together to delineate common strategies to support forest owners and managers with good examples of ZIF forest management, as most of the forest owners practice "forest management by example." In addition, all these findings and approaches can support policymakers (municipal, regional, and national levels) in understanding the interlinked forest problems and conflicts of interests and actors' expectations, thus supporting policymaking closer to the actors' goals in facilitating a plan's application and anticipating problems and conflicts.

The multicriteria approaches and group decision-making techniques applied in this research can readily be replicated and adapted to different contexts. The results can be used to recommend or develop natural resource planning, activities, or strategies. The managers of ZIF or AIGP can replicate the process presented in this research work, starting from the most accessible participatory techniques (i.e., time and data processing cost-effectiveness but with simpler results based on simple questionnaires and interviews), and extending to a complete approach with detailed outcomes (but requiring more time and budget for workshops, focus group, cognitive mapping, multicriteria questionnaire, Delphi, Pareto frontier, and EMDS).

This research confirmed the importance of involving actors in forest decisions because the perception of ZIF managers may not be the same as those who carry out the forest management or those who influence the forest management decisions. ZIF managers or other decision-makers cannot develop a forest management plan assuming they know what the interests or objectives of the forest owners are, because they only have a perception of it. Therefore, we recommend that ZIF managers involve the actors in elaborating the forest management plan using participatory approaches.

These actors-focused approaches were applied to empowered actors in joint collaborative forest management planning. Actors' involvement and engagement in the decision-making process increases their trust and the legitimacy of forest management decisions, contribute to the transparency of the decision process, reduce potential conflicts of interests, and promote the feeling of the common good, all attributes relevant in ZIF areas, where joint forest management is the goal. Thus, with successful participation, actors will be part of a more consensual forest management process rather than having a passive role.

The most critical stages of the methodology were when actors worked with more demanding techniques (multicriteria questionnaire – Chapter IV and multicriteria Pareto Frontier tool – Chapter V). To keep a high level of actors' engagement, a permanent contact, such as phone calls and workshops discussions, was necessary, even though it was time-consuming. Also crucial was ensuring that all actors had equal opportunity to participate and share their viewpoints, giving them time to reflect and discuss so they could reach a shared understanding of forest management goals for ZIF. The actors' commitment in all research stages was critical to the success of the participatory process and this research.

Finally, based on the general experience of researching and applying multicriteria approaches and group decision-making techniques, we highlight some relevant learning points that can be considered when using this methodology or other participatory techniques:

- The selection of actors is an essential and primary task for all participatory processes as different actors can produce different results. Thus, the selection process should be transparent. Actors must be selected according to their interests and have a vested interest to the case study area, inviting actors with different interests to have distinctive opinions.

- This methodology can be costly in terms of actors' time to participate because it requires their involvement and commitment throughout the various phases of the participatory process. Thus, it is crucial to have good contact with the actors, sharing and discussing the results (e.g., workshops), the reports, and scientific publications to which they contributed. In this way, they will be more accessible to participate in similar processes in the future.

- The actors felt very comfortable sharing their opinion and knowledge during the interviews. However, during the participatory discussions (workshops and focus groups), some did not feel comfortable "fighting" to share their opinions. Thus, the facilitator must ensure that the group discussion is not led by one or two dominant participants, being aware of the group dynamics to allow the most passive or shy actors to share their opinions. In addition, workshops and focus groups can be complemented with other techniques (e.g., anonymous questionnaires or interviews) so that actors can share their viewpoints without group pressure.

- Most actors recognized the importance of group discussions either by sharing or by learning and understanding the points of view of other actors, whereby participatory group discussions should be promoted even if not all actors participate in the same way.

- The MCDA and group decision-making process can be time-consuming and demanding. So, the research team must be aware and prepared for constant interactions with actors, encouraging questionnaire response and workshop participation.

- To promote a higher level of responses to multicriteria questionnaires using the Delphi survey technique, it is essential to consider in the approach personal visits to the actors who did not understand the questionnaire and to explain the questions so they can feel more confident and comfortable to answer.

VI.2. Future research

The actors of Vale do Sousa will change over time, as well as their roles concerning forest management. Therefore, the actor analysis tool must be repeated over time in the application of future participatory processes in order to update the actors' network to be involved, analyze their interests, and assess the actors and factors influencing forest management decisions. Throughout this research, we identified future potential research to further improve the approaches, and the techniques that can support managers of ZIF or AIGP, decision-makers, and policymakers to enhance forest management decisions:

- Explore deeply the relationships between actors and potential actors' coalitions using their questionnaire answers and assess the similarities of interests that could form a coalition using, for example, a dendrogram analysis to cluster actors, influence matrices, actors-linkages, or knowledge mapping analyses techniques.

- Apply pre- and post-questionnaires in four steps to assess the effect of participatory discussions and social interaction in their initial opinion according to reflection time, giving actors more time to reflect. They should know the questionnaire before the workshop, on the day they would answer a pre-questionnaire in the first session, a post-questionnaire at the end of the day, and a post-questionnaire a week later.

- Develop strategies to increase the representation of non-industrial forest owners in participatory approaches. For example, actors were open to face-to-face interviews but resistant to moving away from home (e.g., Porto city) to participate in the workshops or focus groups. Future participatory workshops could be held locally in Vale do Sousa municipalities (Penafiel, Paredes or Castelo de Paiva) to overcome this constraint.

- Implement decision conferences of one or two days, using real-time interactive tools (e.g., creating a multi-voiced decision model using CDP), inviting actors with different interests who represent a diversity of perspectives, and facilitating by an impartial team of experts. This interactive technique can improve the criteria weight elicitation as actors can visualize the impact of weights in alternatives performance and promote the discussion of a consensual group solution.

- Organize more participatory sessions (workshops or focus groups) to promote actors discussions and understanding about their and others interests and objectives, facilitating negotiation and contributing to the consensus on the attribution of ES to MUs.

- Create portfolios of alternative sets of forest management actions to assist the ZIF managers in managing the forest more efficiently according to different budget thresholds representing ZIF constraints.

- Present and discuss with the ZIF actors (forest owners and managers), in a wide-ranging event, the four landscape priority scores from the prioritization of the allocation of ES to MUs, complemented with portfolios, and test voting techniques to identify the landscape forest management proposal with which they identify most and the reasons for the selection. ZIF managers could use these actors input to recommend a few different portfolios that achieve the best results for the broader landscape management of a ZIF.