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ORIGINAL RESEARCH

Forest Owner Attitudes Toward Climate-Proof Forest Management in Sweden and the Netherlands—Between Forest Strategies and Practical Measures

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Abstract

Our research targets the role of forests under the international Paris Climate Agreement, the EU Green Deal and Forest Strategy. In line with the latter objectives, Member States are expected to encourage forest owners to contribute to international climate goals via national strategic plans and new management measures. How forest owners will respond, however, to a range of climate smart forestry (CSF) measures in the near future, is not well known. After postal and email distribution in 2020, 98 Swedish (response rate 21%) and 241 Dutch forest owners (24%) filled out a forest-climate survey. Based upon specific CSF measures, several hypothetical climate-related scenarios were incorporated into the survey. Dutch forest owners are planning to introduce new tree species, more mixed species stands (a gradual shift to broadleaved species) and additional water reservoirs in anticipation of increased drought periods, all part of a hypothetical climate adaptation package for 2030. Swedish forest owners prefer earlier thinning and salvaging activities. Zooming in on Dutch scale differences, small forest owners rely less on current public subsidy packages and show significantly less interest in committing to the adaptation package than large forest owners. In Sweden, preferences for the high forest management intensity scenario is significantly affected by size class: more intensive activities are the least popular with the smallest forest owners. The greatest difference between both countries is the way in which CSF measures should be financially supported. In general, Dutch forest owners would prefer to maintain subsidy schemes but adapt them to new circumstances, while Swedish forest owners benefit from timber and bioenergy markets.

Keywords Climate action · Life on land · Natural disturbances · Forest owner's response curves · European forest strategies

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Introduction

The European Green Deal represents a comprehensive and ambitious package to achieve a sustainable green transition in the EU and combat climate change. One of the many actions under this ambition is the EU's Forest Strategy 2030 (European Commission 2021), a non-binding legislative initiative. The key objectives of the EU forest strategy are effective afforestation, restoration, and forest preservation in the EU, so as to increase the potential of forests to absorb and store CO_2, promote the bioeconomy, reduce fire impact and extent, all while protecting biodiversity. The strategy covers a wide range of possible forest activities and promotes the numerous ecological and socio-economic services forests provide. The EU Member States likewise elaborate corresponding national strategic agreements in which forests, trees and nature play an important role. Yet, national forest management practices affect future carbon cycles in living forest biomass, organic soil matter and harvested wood products (HWPs). The EU's amending and original Land Use, Land Use Change and Forestry (LULUCF) Regulations 2023/839/EC and 2018/841/EC set the general guidelines for Member State forest sector commitments in the framework of the Paris Climate Agreement (European Commission 2018, 2023).

Diverse key issues are posed by climate change like forest disturbances and forest decline, nitrogen deposition, disease, storms, pests, insects, fungi, and fire (Linser et al 2023). Three consecutive studies (Schelhaas et al 2003; Seidl et al 2014; Forzieri et al 2021) have illustrated that changing climate conditions in Europe lead to increasing natural disturbances and a decline in European forests' quality. For this reason, the forest sector is exploring new measures and incentives to adapt to changing conditions in forest ecosystems. In the context of the Paris Agreement (UNFCCC 2015), *Climate Smart Forestry* (CSF) is a necessary, but sometimes missing component in national strategies for implementing actions under the Paris Agreement (Nabuurs et al 2017; Verkerk et al 2020). The CSF concept is defined as, "*sustainable adaptive forest management and governance to protect and enhance the potential of forest to adapt to, and to mitigate, climate change. The aim is to sustain ecosystem integrity and function, and to ensure the continuous delivery of ecosystem goods and services, while minimizing the impact of climate induced impacts of (…) forests on wellbeing and nature's contributions to people*" (Bowditch et al 2020). In summary, the CSF approach should enable forest restoration, while helping society adapt to and mitigate climate-induced change (Nabuurs et al 2018; Grassi et al 2019; Kašanin-Grubin and Burton 2021; Hallberg-Sramek et al. 2022).

Climate Smart Forest Measures

The EU Forest Strategy outlines the need to improve forest biodiversity and designates a number of indicators such as deadwood volumes, the share of forests with uneven-aged structure, forest connectivity, the common forest bird index and the stock of organic carbon, to demonstrate the effectiveness of restoration measures (European Commission 2022). With respect to adaptation, countries may, for example, adopt measures with the goal of reducing vulnerability, as in the Czech

Republic to drought and bark beetle, in Ireland to storms, and in Spain to wildfires. Moreover, those measures may have additional side benefits: e.g., conversion to more natural tree species composition may have positive co-benefits for biodiversity (Nabuurs et al 2017, 2018). Mitigation measures, on the other hand, may contribute to EU Member State climate objectives. Both Ireland and Spain, for example, have adopted improved forest management strategies which aim to increase tree growth and expand the potential for roundwood harvest. The climate change mitigation potential of Europe's forests is significant. In 2021, European forest land offset approximately 8.5% of European fossil fuel-based emissions and accounted for net carbon removals from the atmosphere of approximately −281 million tonnes of CO_2 equivalents (Korosuo et al 2023). Additional climate-related contributions can also be derived from the use of HWP for product purposes and bioenergy production. When this substitutes fossil fuel consuming alternatives and contributes to storage in the HWP carbon pool, greenhouse gas (GHG) emissions can be reduced. The additional income thereby provided to forest owners acts as a stimulus for using wood in the construction of buildings (Ramage et al 2017; Nabuurs et al 2017, 2018; Hurmekoski et al 2018; Iordan et al 2018; Leszczyszyn et al 2022; Mishra et al 2022; Sikkema et al 2023).

Climate Forest Surveys Since 2010

What are the experiences of owners with climate change and their expectations for any new future management practices? One of the first climate forest surveys (Blennow et al 2012) was conducted in 2010, interviewed 1,588 German, Portuguese, and Swedish private forest owners (response rate 53%), and revealed that the largest share of respondents adopting measures to adapt forest management to climate change were found in Portugal (about 54%) and Germany (47%). The smallest share was found in Sweden (20%). One reason for the higher shares may be the more intense impact of climate change. A survey of Belgian forest owners followed up on this result and highlighted a significant gap between the awareness of climate change impacts and the extent to which adaptation measures were integrated into daily forest practice (Sousa-Silva et al 2016). In a subsequent, and broader survey with 1,131 responses across Belgium and six other EU countries, an average of 36% of forest owners reported having modified their management practices and having implemented adaptation measures. Cross country variation ranged from 14% in Portugal to 57% in Slovakia (Sousa-Silva et al 2018).

In 2018, a German climate-forest survey (with 972 responses) recommended further research on forest ownership types, climate change knowledge, and the implementation of adaptive measures beyond the stand level. This study suggested further research should develop applicable measures for all ownership types in Germany (Ehrhardt 2019). Climate change adaptation by small scale forest owners has also been studied in Austria. Austrian measures were first applied in federal forests and on large private properties, while the involvement of and uptake by smaller forest owners remained unclear. An Austrian inventory across small scale forest owners with property less than 20 ha conducted in 2015 (919 respondents) illustrated that increasing financial-economic incentives such as funding, only have a marginal influence on small scale owners' decision-making (Mostegl et al 2019). In a Swedish survey of 1,482 private forest owners (response rate 50%) in 2014, it was concluded that the Swedish Forest Agency's recommendations should be combined with economic incentives or national policy measures. This combination would strengthen incentives to apply different on-site adaptation measures (Eriksson 2018). Another survey of 1,920 Swedish small scale forest owners (response rate 34%) in 2020 concluded that the voluntary character of forest policy performs well when supported by interest in and mechanisms for timber production (Lidestav and Westin 2023). In a survey of 1,177 owners (response rate 31%) in 2022, North Swedish non-industrial private forest (NIPF) owners concluded that their knowledge of how to identify damages from insects, pathogens and other pests is quite limited. The same study (Kronholm 2023) stated that, worldwide, many countries experience such damages, partly due to climate change.

Overall, we know comparatively little about the attitudes and interests of different sizes of forest owners regarding CSF measures. The current study provides a complementary overview and new insights about the motivations of forest owners and managers for adopting climate- and sustainability-related commitments and was carried out under the umbrella of a European research project (see Acknowledgements). The accompanying survey aims to describe the views of forest owners and representative managers regarding natural disturbances and forest decline (preselected forest occurrences in 2010–2019), current management practices, near future forest strategies and preferred new measures until 2030 and beyond, in response to varied financial and economic drivers (timber markets, public subsidies, carbon taxes). The survey distinguishes the size of forest owner areas, from small scale (mostly private owners) to large scale (mostly public or industrial owners). We have selected the Netherlands and Sweden for this survey. Both countries have a large share of small-scale forest owners. Forest owners in these countries are influenced by country specific circumstances and thus may have divergent attitudes toward climate-related measures. The overall scope of our research is related to the UN's sustainable developments goals 'Life on land' and 'Climate action' (United Nations 2023).

Methodology

Country Case Studies

The Netherlands has a large population relative to the forested land area and is a net importer of HWPs. To steer forestry away from a singular dependence on economic timber production, a subsidy system is maintained by the Dutch government and Provinces for forest, landscape and nature management, recreation, and cultural historical heritage purposes (Bij12 2019). In total, the Netherlands has 0.37 million hectares of forest land of which about 0.30 million ha (81%) is available for wood supply (Forest Europe 2020a; Eurostat 2020). Most of the forest is situated on poor quality, sandy soils with a vulnerable nutrient balance disturbed by external nitrogen deposition (den Ouden et al 2010; Vos et al 2023). According to the 7th national forest inventory (NFI-7: 2017–2021), the total Dutch forest area is composed of 50% coniferous and 50% broadleaved species. The previous ratio was 52% coniferous and 48% broadleaved (NFI-6: 2012–2013). The total standing stock in Dutch forests is 81.8 million m^3 (NFI-7), an increase of 4.4% over NFI-6 (Schelhaas et al 2014, 2022). The practice of clear-felling is declining and subject to new legal restrictions (maximum 0.5 ha), while selective logging and an emphasis on increasing biodiversity are gaining attention (den Ouden and Mohren 2020). The Dutch forest strategy explicitly incorporates climate change adaptation measures: versatile and vital forests to achieve climate resilience; small scale forest management aiming at a complete set of age classes and diverse species composition; and the selection of climate resilient planting material (IPO and Ministry LNV 2020; CLO 2023). Concerning mitigation measures, the strategy aims to slightly increase harvest, with additional attention dedicated to using domestic wood as a construction material (Ministry LNV 2020) alongside imported wood. Implementation of the Dutch forest strategy is delegated to the twelve Dutch provinces, some of which have developed more sophisticated strategies than others (van Duinhoven 2023). Almost 50% of the Dutch forest area is spread out over two provinces with divergent management strategies (CLO 2023; Provincie Gelderland 2020; Provincie Noord Brabant 2020).

Sweden has long had an economically important forest and forest industry sector. Swedish forest owners benefit from domestic and export timber markets and, apart from some special cases, generally function without the provision of subsidies. A carbon tax imposed on fossil fuel-based emissions likely further promotes the use of wood for products and bioenergy (Rodrigues et al. 2021). The forest land area encompasses 28 million hectares, of which 19.6 million hectares are available for wood supply (Forest Europe 2020a; Eurostat 2020). The remaining 30% of forest land is mainly low productivity land and primarily protected for the purposes of biodiversity (Nilsson et al 2021). The total standing stock of 3.6 billion m^3 has more than doubled since 1923 and continues to increase. Scots pine (39% of standing volume) and Norway spruce (40%) are the dominant species, followed by birch (13%), other broadleaved species (7%), and other coniferous species (1%) (Nilsson et al 2021). Clear-felling is the dominant harvest practice. The Swedish forest strategy aims at strengthening or preserving a circular, bio-based economy, reducing climate impacts, biodiversity protection, cultural, environmental and aesthetic values, reindeer husbandry, hunting, berry and mushroom picking as well as outdoor recreation (Regeringskansliet 2018).

Set up and Survey Distribution

The climate-forest survey was first divided into forest size classes (see Table 1) and then sent to 1,001 forest owners in the Netherlands and 474 forest owners in Sweden. The survey was distributed between February through May 2020. The weekly collection of surveys was continued until the 1st of June 2020, with some delays due to Covid-19 regulations.

The set up and elaboration of the Dutch survey was organised in five steps:

Table 1 Overview of survey distribution by size class and response rate in the Netherlands and Sweden (survey period 1 February 2020–1 June 2020)

	Area size class	Number sent out (T)	Number responses (N)	Response rate (N/T)	Estimated area of returned surveys* (in ha)
Netherlands					
< 5 ha	**A**	264	29	0.11	125
5–25 ha	**B**	150	46	0.31	1,350
25–50 ha	**C**	155	45	0.29	2,200
50–100 ha	**D**	162	40	0.25	3,100
100–250 ha	**E**	144	29	0.20	4,600
> 250 ha	**F**	126	52	0.41	180,850
Total		1001	241	0.24	192,225 (55% coverage)
Sweden					
< 25 ha	**AB**	159	17	0.11	200
25–50 ha	**C**	99	16	0.16	600
50–100 ha	**D**	80	13	0.16	1,000
100–250	**E**	64	18	0.28	3,000
> 250 ha	**F**	44	16	0.36	20,000
> 10,000 ha	**G**	28	18	0.64	7,187,000
Total		474	98	0.21	7,211,800 (31% coverage)

*The Dutch and Swedish land use and forest registries (cadastral system) record the area size by owner. Prior to survey distribution, only forest size classes were filled out beforehand, to comply with new privacy rules in both countries. In the end, since only some respondents provided precise area details, we estimated survey coverage in terms of forest ha (NL: 40%; SE: 65%)

- Four WUR topic experts were helpful in setting up the first survey layout, which addressed four hypothetical subsidy packages. An initial list of CSF measures was compiled based on a published inventory of LULUCF actions in the EU Member States (European Commission 2013; Paquel et al 2017). Then a mix of four private and two public forest owners from each size class was selected and individual forest owners were interviewed about the draft packages and measures. Immediately following the interviews, the contacted persons were asked to test a draft version of the survey. The survey set up was further reviewed by a statistical expert and a privacy policy officer of WUR (see Acknowledgements).
- The survey was accompanied by a letter and a privacy attachment (see Appendix B for the final templates) and were sent to the postal addresses provided by the Dutch cadastral authority. The first distribution round comprised 100 surveys per forest size class, starting with the largest owners and encompassing a total of 600 surveys. In three additional rounds, another 50 surveys per size class were distributed in the same way. Size class A

required more distribution rounds, until a total of 30 responses had been received.

- In the case of public forests (communities and provinces), initially, there was a negligible return of responses. It became clear that the representatives or acting forest managers had to be approached in a different way, in part due to the Covid-19 circumstances. We chose to distribute additional surveys via email and, in some cases, to send a request using website request forms. Designating a single contact person helped to expedite survey correspondence.
- The ten largest forest owners (category F) were asked in advance to whom the survey should be sent. Only these owners received a reminder. Three of them chose to have the survey split up into regional units to obtain a more balanced representation of forest practices. These regional responses were aggregated and divided by the region number to arrive at one average answer per large forest owner. Furthermore, some owners of estates and other private forest properties forwarded their survey to a delegated, acting forest manager who responded on behalf of those owners.
- One of the attachments allowed for the provision of contact details (email, phone) in case of further questions (unclear responses, lacking data). The survey's accompanying letter promised to send a summary of the aggregated survey results if contact details were provided. For this purpose, a separate list was created with the contact details of respondents to whom the successive Dutch publication (Sikkema et al 2020a) was distributed in December 2020.

The Swedish survey was organised somewhat differently:

- First, the Dutch survey was used to derive a Swedish equivalent. A test of the Swedish questionnaire was sent to fifteen pre-selected forest owners. Their responses were used to improve and adapt the survey to the Swedish context. One single survey was made both NIPF) and large owners (Appendix C). All Swedish figures exclude national parks and other formally protected areas.
- NIPF owners are represented by area size classes A through F. The largest owners are represented by size class G, i.e., larger than 10,000 ha (see Table 1). Categories A and B were aggregated to provide a more equal distribution of responses across area classes. To deliver a broadly representative survey across all relevant climate regions, a random selection of NIPF owners distributed over the 4 geographic regions in Sweden was extracted from the Swedish cadastral system.
- All large forests owners in category G were notified in advance and were asked to whom a questionnaire could be sent.
- No additional correspondence was sent out to encourage non-respondents to reply. In case of available contact details, some forest owners were contacted for additional clarifications.

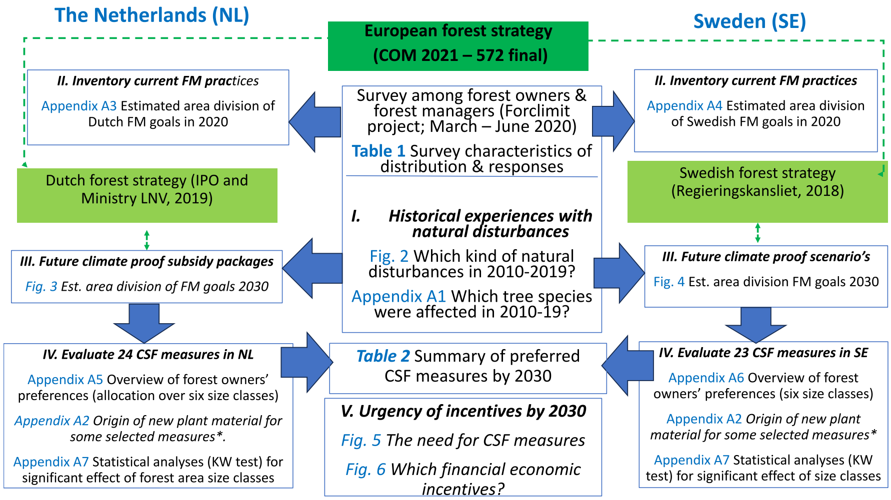

Fig. 1 Chronological flow diagram of survey set up and overview of survey elements

Inventory in Time Steps

As illustrated in Fig. 1, the surveys address five key elements:

I. The historical experience of forest owners with natural disturbances and a summary of affected tree species over the period 2010–2019. The affected tree species are highlighted in Appendix A1. Any new climate-resilient tree species are illustrated in Appendix A2.
II. A quick overview of current forest management practices (2020) divided into four objectives for both the Netherlands (Appendix A3) and Sweden (Appendix A4).
III. Forest management practices in both countries are affected by national forest strategies and climate agreements. Accordingly, we compiled four hypothetical subsidy packages for the Netherlands and seven scenarios for Sweden in 2030. Forest owner preferences for each of these elements are highlighted in the Results section.
IV. The future packages and scenarios were made up of individual CSF measures and summarized in Table 2. Appendices A5–A6 provide a more detailed overview of the proposed CSF measures in the Netherlands and Sweden.
V. The survey provides details about each owner's opinion on the relative urgency, the pace of measures, and what kind of financial-economic incentives were available (Results section).

Table 2 Which CSF measures or FM activities do you prefer to adopt by 2030 in the Netherlands and Sweden?

N	The Netherlands (24 measures) Proposed forest management activities	Average rating	N	Sweden (23 measures) Proposed forest management activities	Average rating
	A. Carbon oriented forest management (safeguard forest biomass & forest soil carbon)	**3.5**		**A1-A2. Safeguard carbon storage** (less active FM)	***2.7***
189	Less intensive management, more biodiversity	3.7**	89	Store more carbon by decreasing the ratio of felling to net growth	2.7**
180	Prolongation of rotation time	3.6**	91	Store more carbon by prolonging rotation	2.9**
187	Planting extra trees in existing, non-dense forests[1]	3.7	85	Damming of ditches to prevent carbon bound in the peat from being released into the atmosphere	2.4
177	Spontaneous regeneration on bare forest lands	3.4**		**A3. Carbon uptake** (more silvicultural activities)	***3.3***
182	Measures leading to wetter forest areas	3.2	93	Increase forest growth by fertilizing once in suitable stands before harvesting	3.0**
189	Forest with litter rich tree species[1]	3.8**	90	Increase growth by fertilizing two or more times in suitable stands between thinning and final felling	2.7**
186	Fertilisation with additional nutrients to compensate for any loss after harvest	2.7	93	Increase intensity of forest management, i.e. soil preparation, planting with large plants, refined material, early clearing and pre-commercial thinning (tending stage), to increase growth	3.9**
	B. Climate-change adaptation FM	**3.7**	89	Reforest unused arable land, preferably with fast growing tree species*	3.0
188	Alkaline rock dust to spread over forest soil: to compensate nitrogen deposition & desiccation	3.2	93	Maintain forest ditches to improve water runoff and timber production	3.9
192	Preselected planting material (same tree species)	3.5		**B. Climate risk reduction** (climate change adaptation, while safeguarding carbon)	***4.1***
197	Tree species switch (after felling)[1]	4.0	94	Strive for more diverse species mix via early clearing of shrubs, unwanted species (tending stage) to avoid monoculture pest risks	4.4**

Table 2 (continued)

N	The Netherlands (24 measures) Proposed forest management activities	Average rating	N	Sweden (23 measures) Proposed forest management activities	Average rating
191	Recovery of slash to prevent natural disturbances	2.8	94	Strive for more viable trees via pre-commercial thinning (tending stage). Less stems, more sunlight, less moisture; lower fungi risk	4.5
201	Recovery of dead, sick or dying trees	3.7	93	Regeneration by soil preparation and improved planting[1] (more, larger seedlings; suitable seedling provenance; reduce risks of damage to seedlings, saplings & other plant stages; better protection from pest insects) instead of natural regeneration with seed trees	3.7**
194	Enhance of water reservoirs in the forests	4.0	94	Regenerate with two or more tree species (fewer monocultures) to reduce the risk of climate-related damages and pests[1]	4.0**
195	Mixed forest tree species after final felling[1]	4.5**	95	Take out damaged and diseased trees to reduce the risk of fire, insect damage, fungal infestation (salvage logging)	4.2
187	Continuous cover forestry: more individual tree or group felling, and avoiding clear felling (uneven-aged FM; more diverse forests)	4.0**	94	Take out dead trees and tree parts to reduce the risk of fire, insect damage and, or fungal infestation (salvage logging)	3.9
	C. Biomass for bioenergy	**2.3**		**C. Recovery of biomass for bioenergy**	***3.2***
182	Use non merchantable trees from (non-commercial) thinning	2.4	88	Take out small trees via pre commercial thinnings (tending stage) of suitable stands[2]	3.3
183	Use of slash (branches, tops) for bioenergy	2.6	91	Take out small trees and felling debris (branches and tops) in both commercial thinning and clear-felling of suitable stands[2]	3.7
183	Use of remaining stumps for bioenergy	2.1**	90	Take out stumps after clear felling of suitable stands[2]	2.5
173	Recycling/return of ash from bioenergy plants to the forest	2.3	89	Take out dead, damaged and diseased trees (salvage logging) for bioenergy	3.5

Table 2 (continued)

N	The Netherlands (24 measures) Proposed forest management activities	Average rating	N	Sweden (23 measures) Proposed forest management activities	Average rating
	D. High quality sawlogs FM	**3.1**	88	Apply ash recovery (from central heating plants), in case of peatland stands, i.e., fertilization with return of nutrients other than nitrogen	3.3
189	Pruning of trees in the initial stage of the rotation period	3.1	86	Additional fertilization of young forest stands right after harvesting whole trees (aiming for bioenergy)	2.7
186	Designate more future trees for more sawlog qualities	3.4		**D. Higher timber quality** (more carbon storage via wooden construction in buildings)	***3.3***
182	Release future trees with surrounding, tailor-made thinning, to promote timber quality. FM aiming at Qualified Dimensions of trees (QD)	3.0	91	Delimbing or pruning of deciduous trees to increase log quality	2.5**
181	Regeneration or replanting with dry resistant tree species[1]	3.4**	91	Delimbing or pruning of conifer trees to increase log quality	2.8**
178	Maximum efforts on higher timber production (even aged forest management)	2.8	92	Thinning around future trees; aiming to promote thicker trees and reach high timber qualities (similar to QD Forest Management in NL)	4.5

N represents the respondents' number. Scores range from 1 "not favorable at all" to 5 "highly preferred"

Average rating per measure; ** = significant effect of forest size class (KW test)

Highlighted values in bold indicate the average per hypothetical package (NL) or future scenario (SE)

[1]Measures which allow for regeneration or replanting with new climate resilient tree species (see Appendix A2 for Forest Owner's preferences on species)

[2]Following actual recommendations by the Swedish Forest Agency (Skogsstyrelsen)

Data Analysis

241 Dutch respondents and 98 Swedish respondents completed and returned their surveys. After compiling two Excel databases with anonymous records, statistical tests were applied to explore the possible effect of forest area size classes on scenarios and CSF measures (Appendix A7). All non-responses and the option “I don’t know” were excluded, thereby reducing the number of responses’ to the tests. Two elements were tested:

The area distributions for current 2020 FM practices and selected future 2030 measures were first allocated to the forest area size classes as indicated in advance on the survey form, unless corrected by the respondent. The Kruskal Wallis test ($\dot{\alpha}=0.05$) was applied to see whether the 2020 and 2030 distributions were significantly affected by the six size classes. The diverse set of outcomes is further highlighted in the Results section (2030 distribution) and Appendices A3–A4 (2020 distribution). In a next step, all respondents’ forest area shares per hypothetical subsidy package (NL) and forest management scenario (SE) were summed for each size class. The area sum was then divided by the number of respondents to arrive at an arithmetic average share per package or scenario and per forest area size class. All percentages sum to 100% per size class. The error bars depict the 95% confidence interval.

Forest owner preferences for all individual measures are indicated on a Likert scale (De Winter and Dodou 2010), with scores from 1 (not favorable at all) to 5 (highly preferred). We again applied a Kruskal Wallis test ($\dot{\alpha}=0.05$), to determine whether there is a significant effect of forest size class in the Netherlands and Sweden. Eight out of twenty-four Dutch measures and ten out of twenty-three Swedish measures were significantly affected by area size class. The outcome is highlighted in Appendices A5–A6. In a next step, we summed up all scores per measure and divided these by the number of respondents, in order to arrive at an average score per CSF measure (Table 2).

Results

Table 1 shows the response rates and the unique number of forest owners, divided over six forest size area classes. Estimated based on the number of respondents, the overall response rate for the Dutch surveys was 24%, and 21% for the Swedish surveys. The response rate estimated based on the total Dutch forest area (in ha) is about 55%. The response rate for the Swedish productive forest area is estimated at about 31%.

Historical Experiences with Natural Disturbances and Affected Tree Species

We provide an inventory of forest owner experiences with natural disturbances since 2010 (Fig. 2). Based on the total number of respondents, Dutch forest owners (black

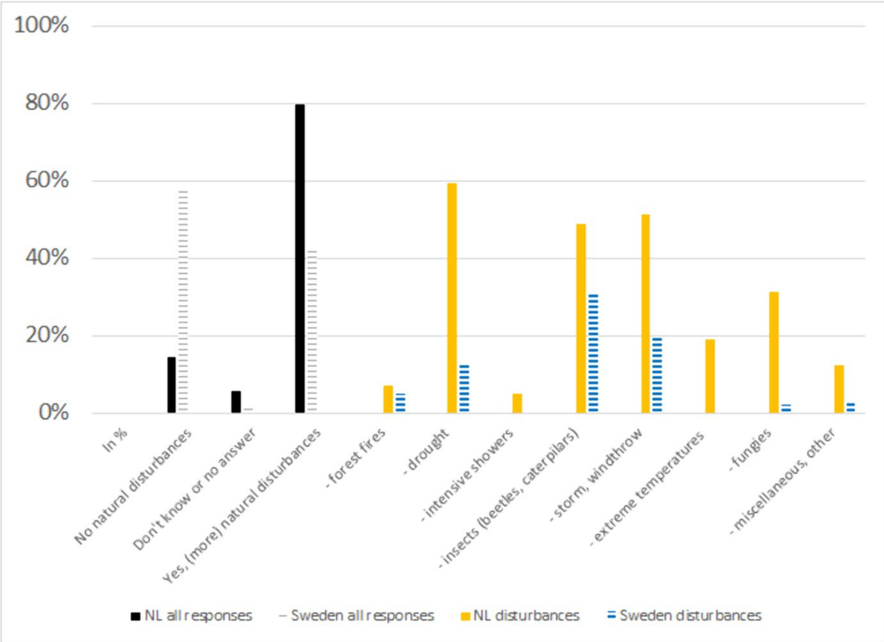

Fig. 2 Frequency distribution of the answers to the question "Have you (increasingly) experienced natural disturbances between 2010 and 2019, and, if so, of which kind?" Netherlands: 241 respondents; Sweden: 98 respondents

bars) experience comparatively more natural disturbances than their Swedish counterparts (grey bars). In the years right before the inventory (2018–2019), the Netherlands suffered from an extreme hot and dry growth season (Copini et al 2022). This may have affected the outcome. For the most part, Sweden did not experience any significant increase in natural disturbances. Focusing on the groups which did experience increased disturbances, the three main impacts in Swedish forests (blue bars) were insects (indicated by 30% of Swedish respondents), storms (20%) and drought (10%). The main disturbances in the Dutch forests (orange bars) range from drought (60%), to storms, and insect and fungi attacks (30%). In both countries, bark beetle (*Ips typographus*), which occurs in the bark of spruce, represents a major insect problem. Fungi in the Netherlands is related to the dead branches of the European ash, generally referred to as "ash dieback" (*Chalara fraxinea*). See also San Miquel Ayanz et al. (2016).

Based on the total number of respondents, the most heavily affected species is Norway spruce (*Picea abies*), followed by Scots pine (*Pinus sylvestris*), Lodgepole pine (*Pinus contorta*) and birch (*Betula* species) in Sweden, and domestic oak (*Quercus sp.),* European ash (*Fraxinus excelsior*) and larch (*Larix sp.*) in the Netherlands. Appendix A1 provides additional data.

Current Forest Management Practices

Current forest management practices differ in both countries. These are highlighted by the plotted graphs in Appendices A3 and A4 and are based on arithmetic averages per forest size class (see Methodology section). The Netherlands has three main pillars for subsidies: nature forestry, multifunctional forestry, and cultural-historical forestry (Fig. A3). Wood production is included in the multifunctional forestry graph, together with recreation and some other ecosystem services. All Dutch subsidy pillars are significantly affected by size classes (Appendix A7), largely due to a threshold for public subsidy grants. The fourth graph ("no SNL subsidies") shows the area without subsidies. The non-subsidized area decreases across small to large forest area size classes. Dutch private owners regard their forest land as a long-term investment with possible future increases of land or standing stock values.

The Swedish share of forests with voluntary nature conservation goals is smaller across all size classes (range 4.5–11%), in comparison with the Netherlands (range 13–24%). Sweden's timber production function (PG) has a dominant share and fluctuates across the size classes (Fig. A4).

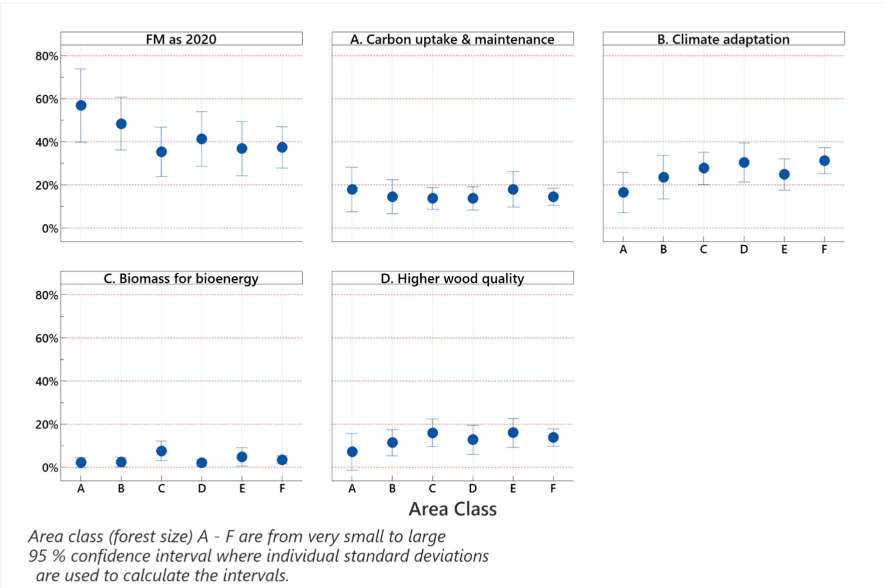

Fig. 3 Frequency distribution of the answers to the question "What will your forest management distribution look like in 2030?" The Netherlands: 221 responses. The average frequencies sum up to 100% for each area class, when all potential strategies are combined

Alternative Subsidy Packages or Possible Scenarios in 2030

Dutch owners could choose up to four hypothetical subsidy packages representing potential future management strategies (Fig. 3). Further, "unchanged forest management" ('FM as in 2020'), the fifth option, refers to the fact that current management could be continued across the same proportion of subsidized (SNL) and non-subsidized forest areas, as depicted in Appendix A3. The KW test concluded that both the choice of *Climate adaptation* (B package) and *Higher wood quality* (D package) were significantly affected by forest size, while the others were not (see Appendix A7). We observe an increasing trend from smaller to larger sizes for both affected packages.

On one end of the spectrum, Dutch small forest owners (category A: area < 5 ha) expected that fully 57% of their aggregated future forest area would remain under "FM as in 2020". The remaining 43% of their future forest area is expected to be covered by one of the hypothetical subsidy packages. On the other end, large forest owners (category F, > 250 ha), have quite different expectations. No more than 37% of the aggregated forest area was expected to remain unchanged ("FM as in 2020"). A considerable share of the large forest area (63%) is expected to be based upon new subsidy packages. In comparison with private owners (mostly allocated over smaller area size classes), large Dutch public forest owners are more exposed to public opinion. Most likely, the latter need to reflect more carefully about short-term changes in their FM plans in terms of climate change adaptation and harvested wood qualities.

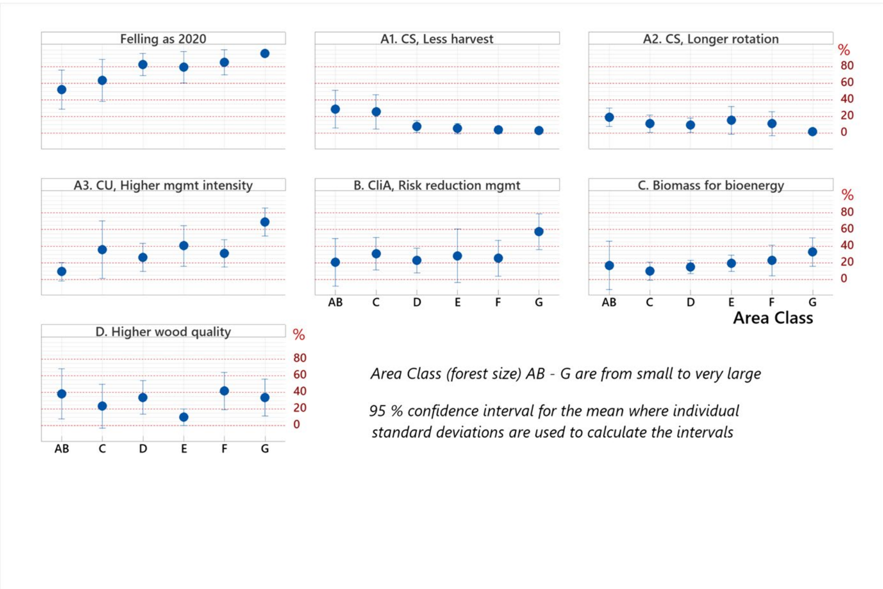

Fig. 4 Frequency distribution of the answers to the question "What will your forest management distribution look like in 2030?" Sweden: 60 responses. The average frequencies sum up to 100% for each area class, when three possible scenarios "Felling as 2020", "A1, CS less harvest" and "A2, CS longer rotation" are combined. Abbreviations CS: carbon storage; CU: carbon uptake; Cli A: Climate adaptation

The related Swedish question was phrased somewhat differently as the forest management strategy was split into two parts. First owners were asked about three possible scenarios for 2030: unchanged felling levels or felling as in 2020 (i.e., similar to the Dutch option “FM as in 2020”), reduced harvest (subscenario A1), and longer rotations (A2). The three upper plots in Fig. 4 depict this 1st stage 2030 scenario. Only “*felling as in 2020*” is significantly affected by forest size class, ranging from a 52% share for small forest owners (< 25 ha) to 96% for the largest forest owners (> 10,000 ha). Remarkably, “less harvest” has a relatively high share (around 30%) for all owners below 25 ha.

Second, the Swedish forest owners were asked about their willingness to apply four additional silviculture scenarios and the way in which harvested wood assortments should be used. These are: higher forest management intensity (scenario A3); climate risk reduction or climate change adaptation (B); recovery of biomass for bioenergy (C); and higher wood quality (D). In this first part, Swedish forest owners could choose among all alternatives. Thus, the total share can be lower or higher than 100%, as depicted in the four lower plots. Only higher FM intensity (scenario A3) was significantly affected by size class (see Appendix A7). Overall, the share of higher FM activities steadily increases from the smallest (7%) to the largest forest owners (67%). Although not significant, the relatively high shares for the largest owners for the risk reduction (55%) and biomass recovery (32%) scenarios are remarkable.

Preferred Future CSF Measures Until 2030

Table 2 illustrates the average survey outcome for 24 Dutch and 23 Swedish CSF measures. Note 1 informs about measures to introduce new or additional tree species, which are further illustrated in Appendix A2. Appendix A5 illustrates the distribution of scores across Dutch forest area size classes, including the sum of those measures significantly affected by forest size class. Appendix A6 does the same for Swedish measures, including actual recommendations by the Swedish Forest Agency. Note that, due to the second step in the Swedish survey set-up (see Methodology section), similar measures may be differently allocated over Dutch and Swedish scenarios. Examples are less and more intensive FM regimes. These are respectively allocated to safeguard carbon storage (A1-A2) and carbon uptake (A3) in Sweden and ‘as uneven aged FM’ to climate adaptation (B) and ‘even aged FM’ to wood qualities (D) in the Netherlands.

The most favorable Dutch CSF measures are all part of the climate adaptation package: i) planting of additional tree species (mixed stands) after final felling of trees in monocultures (average score 4.5), ii) enhancement of water reservoirs in Dutch forests to anticipate drought forest conditions (4.0), iii) a shift to other more climate resilient forest tree species after harvest (4.0), and iv) continuous cover forestry, with selective, individual tree or group harvesting (4.0). The least favorable measures are all part of the biomass package: i) use of remaining stumps after final felling for bioenergy (*2.1)*, ii) recycling or return of ash from bioenergy plants back to the forest (2.3), iii) use of non-merchantable trees from non-commercial thinning (2.4), and iv) recovery of slash (branches and tops) for bioenergy (2.6).

The most favorable Swedish CSF measures are; i) removal of small trees during the pre-commercial thinning stage to promote resilient tree growth (overall score 4.5), ii) selective thinning, in order to enhance the growth of future remaining quality trees (4.5), iii) striving for a more diverse trees species mix at early clearing stages (4.4), and iv) salvage of damaged of diseased trees to reduce risks of spreading disease or wildfire (4.2). Early clearing and pre-commercial thinning belong to the tending stage, which includes a broad set of management activities up to the first commercial thinning stage of young trees (Kerr 2004; Short and Radford 2008). The least favorable measures in Sweden are: i) damming of ditches (2.4), ii) delimbing broadleaved trees like birch and aspen (2.5), iii) recovery of stumps for bioenergy (2.5), and iv) additional fertilization of forest soils in between thinning and final felling stages (2.7).

Parts of our survey outcomes are confirmed in a parallel Swedish survey of 1,921 private forest owners (response rate 32%). In that survey, Swedish preferences for pre-commercial thinning and mixing tree species after final felling were also highly ranked. The reluctance toward additional fertilization was likewise confirmed by these respondents (see also, Westin et al 2023).

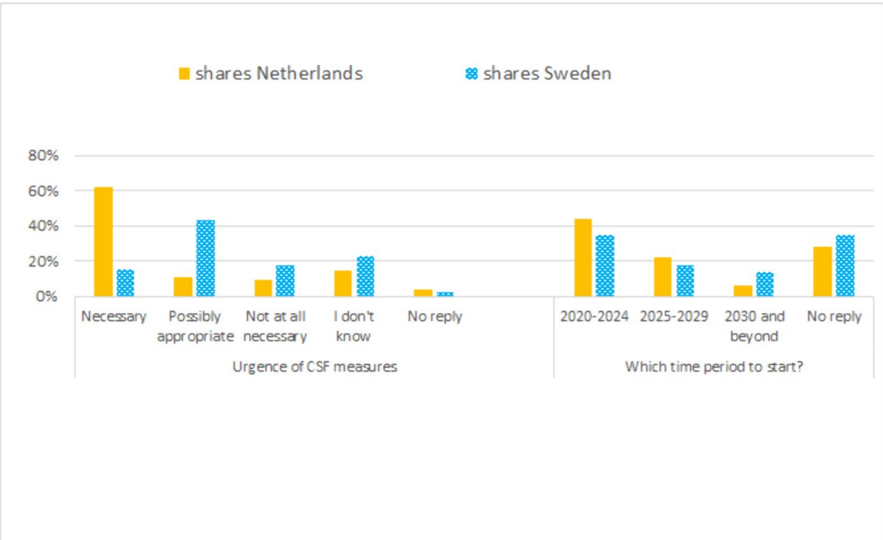

Fig. 5 Frequency distribution of the answers to the question "Which CSF measures are needed (as indicated in Table 2) and when should they be introduced?" Proportion of 241 respondents in the Netherlands and 98 in Sweden

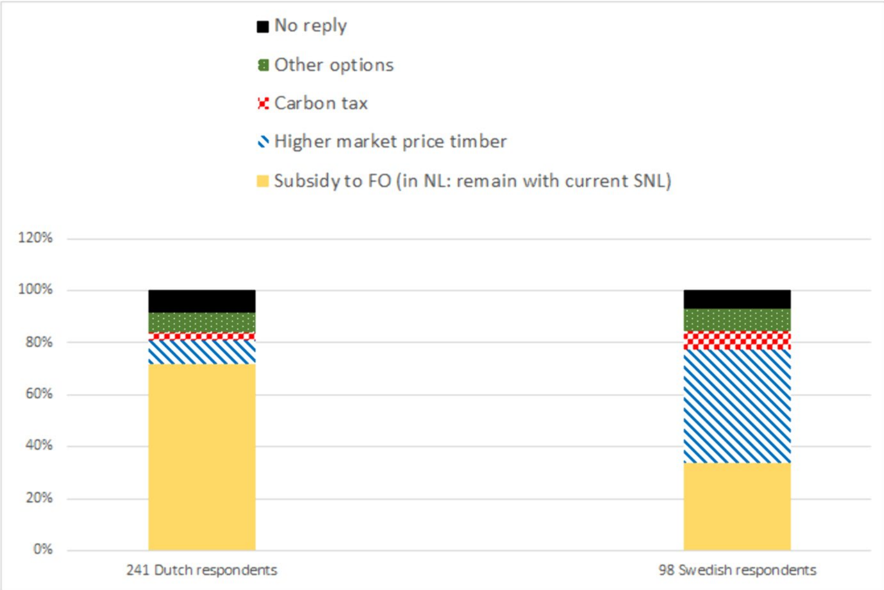

Fig. 6 Frequency distribution of the answers to the question "Which economic incentives are needed to support climate smart forestry measures?" Based on the replies of 98 Swedish respondents and 241 Dutch respondents

Urgency of Measures and Types of Incentives

At the end of the survey, the forest owners were asked about the urgency of measures and the preferred incentives. Figure 5 highlights the urgency and the time period during which the preferred CSF measures should be introduced. The majority of Dutch forest owners highlighted the urgency of 'necessary measures', whereas Swedish forest owners mainly preferred less urgent options, labeled 'possibly appropriate measures'. The time horizon required for introducing new measures is comparable for both countries. Short-term (2020–2024) and medium-term measures (2025–2029) are highly preferred in our surveys, though some of the proposed measures may already have been put into practice by a number of forest owners.

The greatest difference between both countries is the way in which CSF measures should be financially supported (Fig. 6). While Dutch forest owners prefer maintaining their current SNL subsidy scheme, Swedish forest owners prefer to benefit from timber markets, including those for bioenergy. About three quarters of Dutch forest owners applied for public subsidy schemes, while less than 10% favored higher timber market prices in the near future. Just short of 50% of Swedish forest owners opt for higher timber prices, followed by 30% for public subsidies and about 5% for a carbon tax. Though it is unclear how much this matters, the Swedish forest sector is already benefits from carbon tax advantages. By using wood residues for bioenergy instead of fossil fuels, district heating and other bioenergy plants are exempted from carbon taxes (Rodrigues et al. 2021).

Discussion

Limitations

Our research focuses on forest area size classes and overlooks types of forest owners and other factors. Dutch private forest owners make up about 46% in the total number of responses. However, small forest enterprise (< 5 ha) responses in the Dutch private sector were quite underrepresented, with only 23 responses, that is about 20% of the total number of private owner responses. According to the latest available statistics (Silvis and Voskuilen 2017), Dutch private forest owners owned about 120,000 ha in 2012, of which 50% of the number of forest parcels were smaller than 5 ha. In Sweden, 94% of the surveys were sent to NIPF owners who provided 82% of the responses (80 forest owners). The Swedish survey also had an effective area size design, with a 20% numerical share for small NIPF owners (17 responses < 25 ha). In this way, the Swedish design yields an improved sampling in comparison with the Dutch design, resulting in a slight overrepresentation of NIPF owners. According to Skogsstyrelsen (2023), Swedish individual and other private owners had 12.8 million ha of productive forest land in 2020, of which 10% of the forest parcels were smaller than 20 ha.

Our generic division into forest area size class further ignored cognitive and demographic factors. In an earlier Swedish survey of 836 NIPF owners (Vulturius et al 2018), cognitive factors like personal level of trust in climate science and belief in the salience of climate change and risk assessment, were statistically significant factors that may help explain owners' intentions to adopt climate change-related actions and their sense of urgency. Due to new privacy regulations, unless the respondent explicitly provided contact details, we were not permitted to go back and reassess additional demographic details. The owner's demographic profile, however, may be useful in predicting whether forest owners aim to manage their forest in more or less active ways. By way of example, these factors were tested in a survey returned by 1,412 NIPF owners in the United States. Among other factors, age and education exhibited statistically significant results (Aguilar et al 2014).

Perceived versus Observed Natural Disturbances

Our survey shows that the effects of a changing climate are impacting Dutch forests via more natural disturbances in the form of storms, droughts, and insect attacks (Fig. 1). We think this conclusion is also valid for Sweden, though a considerably lower share of Swedish forest owners have experienced an increase in such disturbances. Dutch forest owners are quite focused on adaptation to a changing climate, and this is significantly affected by area size. The significant effect is also true for Swedish forest owners, who focus on intensified forest management for higher production. In the Netherlands, many forest managers are considering the introduction of new and changing tree species and increasing the share of mixed forests in future stands. Currently, the share of broadleaved tree species is gradually increasing at the expense of coniferous species, as the former are better adapted to the new climate change-related forest conditions. Nevertheless, new projections with forest growth models suggest the reduced competitive strength of pedunculate oak (*Quercus robur*) under global warming (Bouwman et al 2021). This may lead to an alteration in species competition in favour of Scots pine (*Pinus sylvestris*) on the poor and dry sandy soils in the Netherlands. From the Swedish perspective, a possible tree species shift also depends on the forest zone, with relatively more coniferous species currently represented in the boreal zone and less in the temperate zone. Further, Swedish forest owners appear focused on measures that can be conducted in existing stands, e.g., thinning out unwanted or salvaging damaged trees.

What kind of natural disturbances and forest decline is occurring across Europe thus far? Forzieri et al. (2021) quantify the vulnerability of European forests to fires, windthrows and insect outbreaks over the period 1979–2018 by integrating machine learning (a new artificial intelligence approach) with disturbance data and satellite views. They illustrate that about 33.4 billion tons of forest biomass could be seriously affected by these disturbances, with higher relative losses when exposed to windthrows (40%) and fires (34%) compared to insect outbreaks (26%). Hotspot regions for vulnerability are located at the southern and northern borders of the various forest biomes in Europe. There is a clear trend in overall forest vulnerability driven by a warming-induced reduction in plant defense mechanisms to insect outbreaks, especially at high latitudes, as, for example, in Sweden (Forzieri et al 2021). Remarkably, this trend is contradicted by the responses provided in our surveys. The evidence from our survey suggests these natural disturbance phenomena are more pronounced in Dutch forests and less so in Swedish forests.

National Initiatives and EU Funding Mechanisms

Our surveys demonstrate that small scale Dutch and Swedish forest owners generally exhibit less interest in committing to any new climate-proof subsidy packages or scenarios than larger forest owners. The introduction of an easily accessible national funding mechanism for small scale forest owners could help address their reluctance (Quiroga et al 2019). From the Dutch financial perspective, Dutch authorities may wish to introduce new subsidy packages on climate change adaptation and mitigation (Sikkema et al 2020a). Small forest owners still face a comparatively large hurdle regarding the Dutch SNL ecosystem service subsidy scheme. A threshold of at least 75 ha is imposed by all provincial authorities, except for 3 ha in Flevoland (Bij12, 2023). This hurdle can be overcome by merging common forest owner interests in a regional forest group (in Dutch: 'regionale bosgroepen'). No such hurdle exists for a one-off small subsidy scheme (SKNL), which is actually more compatible for new, diverse climate investments in forests, other land uses and their maintenance in comparison with the longer-term SNL subsidy scheme (Kuneman et al 2020), unless the latter is structurally adapted in subsequent stages (Penninkhof and Thomassen 2023).

The contribution of the national forest strategies plays a role in the reformed Common Agricultural Policy (CAP) post 2020 (European Parliament 2021). At the EU level, the main EU funding source for forestry measures is the CAP, in particular the European Agricultural Fund for Rural Development (EAFRD). A survey in Austria, Finland, Germany, Slovenia and Sweden concluded that private forest owners were willing to participate in subsidy schemes designed to support environmental goals, and less so for schemes designed to mobilize wood resources for wood products (Juutinen et al 2022). In another survey in the same countries (Haeler et al 2023), data was collected on subsidies paid out for forest-related measures during the EAFRD funding period 2014–2020. Owners of small holdings (smaller than 20 ha) in particular rarely used the funding scheme of the EAFRD framework. An improved design for a dedicated forest subsidy scheme in the EU could support the implementation of the new EU forest strategy for 2030, and thus help maintain more resilient rural areas (Haeler et al 2023). Within the reformed post-2020 CAP, Member States should be able to encourage forest managers to maintain, grow and manage forests in a sustainable way (European Parliament 2021). However, from the Swedish perspective, with its focus on commercial markets, the European Commission may consider introducing a supplementary Renewable Material Directive (RMD), similar to the Renewable Energy Directive, to support the markets for construction wood and the reduction of GHG emissions when non-biogenic construction material is substituted. By means of an RMD, EU Member States would be permitted to promote wood for construction schemes, including financial support for each m^3 of wood and tonne of CO_2 emission reduction in wooden houses (Sikkema et al 2023). Such an initiative is needed at the EU level, to create a level playing-field for the EU Member States and associated countries.

International Setting of Climate Change Adaptation and Carbon Management

Are the measures proposed in our survey scientifically sound? The present rate and magnitude of climate change exceeds the natural migration and adaptation capacity of tree species (Forest Europe 2020b). Pre-designed forest measures need to adapt to these changing conditions by enhancing the adaptive capacity and resilience of managed and unmanaged forests, and other wooded lands. Appropriate measures to support adaptive resilience and disturbance risk prevention should be achieved based on the foundations of robust scientific evidence combined with practical experience and knowledge of the local conditions and species' requirements in the concerned sites. An example is increasing climate-proof genetic diversity in forest regeneration (European Commission 2021).

Worldwide, carbon stock management needs supplementary, improved reporting. Thus far, not all unmanaged land is included in current national reports on GHG emissions for the Paris Agreement. Moen et al. (2014) and Nabuurs et al. (2023) argue that CO_2 fluxes from both managed and unmanaged land must be recorded to help track progress towards global climate targets. In another, more European oriented review, it was argued that a division into forests available for wood supply and those not available for wood supply may be helpful for distinguishing different carbon dynamics in national reporting to the UNFCCC (Sikkema et al 2021). On one end of the spectrum, unmanaged forests may reach a maximum in living biomass and a corresponding maximum carbon shift from living biomass to dead trees, organic matter and forest soils (Sikkema et al 2021; Petersson et al 2022). On the other end, since the standing trees of managed forests are subject to thinning and harvesting practices, followed by a consecutive shift to the HWP carbon pool and a regrowth of the harvested areas, they exhibit strong carbon pool fluctuations, but over time a greater accumulation in total forest carbon stocks.

One possible plot twist in the forest carbon management narrative is the following: the abandonment of forestry practices could, in the long term, be unsustainable. While reduced forest use intensity can potentially and temporarily maximize carbon sequestration potential (i.e., in the shorter term), the increased presence of unmanaged forests may boost natural disturbances, potentially leading to even greater fluctuations in carbon stocks (in the longer term). In this sense, thinning and harvesting practices in private and other state-owned public forests may represent more sustainable, long-term forest management strategies. In all cases, forest sector policy represents a compromise between multiple goals, e.g., climate change mitigation, biodiversity protection, forest product-based incomes, etc. Thus, if reduced forest use intensity becomes the norm, forest (income) potential may go underutilized in the EU climate policy framework, (European Commission 2014; Ellison et al 2014: European Commission 2018; Eggers et al 2019).

Conclusions

Dutch forest owners are quite focused on adaptation to a changing climate and this is significantly affected by an increasing forest area size. Swedish forest owners, on the other hand, are strongly focused on intensified forest management for higher volume timber production, though this emphasis is again strongly affected by an increasing forest area size. In contrast to other research outcomes, in our surveys, vulnerability to and concern about climate change phenomena seem more pronounced for Dutch forest owners, and less so for Swedish forest owners. Across all Dutch respondents, the most preferred CSF measures are related to more selective harvesting, the creation of mixed forest stands, the planting of more climate resilient tree species after harvest along with a gradual shift to broadleaved species, and the enhancement of water reservoirs to anticipate drought periods. Across all Swedish respondents, the most preferred CSF measures concerned the tending stage (clearing or pre-commercial thinning) and selection of the most viable trees. And Swedish forest owners prefer more qualitative thinning for improved wood quality and the salvage of damaged and diseased trees to prevent risks of fire, insects and fungi.

Finally, small scale forest owners are clearly less responsive to the impact of subsidy schemes and market incentives and are less likely to actively introduce new CSF measures by 2030 in comparison with large forest owners. In the case of the Netherlands, however, joint initiatives for groups of forest owners (“Bosgroepen”) may help facilitate the adoption of such initiatives by small forest owners, as most provincial funding is only accessible for forest areas above 75 ha. In Sweden, with a larger reliance on timber markets, a renewable material directive at the EU level could help facilitate construction wood markets and create a more level playing field.

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Data Availability The detailed Dutch background report (Sikkema et al 2020b) is available via the ERA-GAS NET website. The anonymous datasets of from the Swedish surveys (records of 98 responses) and the Dutch surveys (records of 241 responses) used for the statistical tests (see Data analysis section and Appendix A7) are freely accessible via a repository database (https://zenodo.org/communities/forclimit/), as prescribed by the FAIR data policy of the Forclimit project sponsors.

Declarations

Conflicts of Interest None.

Code of Availability Not applicable.

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