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Forest managers' perspectives on environmental changes in the biosphere reserve Mura-Drava-Danube

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Riparian forests are particularly vulnerable to environmental change and anthropogenic influences because they are highly dynamic ecosystems, thus proper adaptation measures are crucial. The implementation of these measures, however, strongly depends on the actors' perceptions of the specific problems occurring in such forests. For understanding the constraints of specific interest groups toward different adaptation activities, information in this field is essential. By conducting a questionnaire survey we explore how different types of forest managers, i.e., forestry professionals, forest owners, and conservation managers, perceive the effects of environmental change on forest management in the recently established Transboundary Biosphere Reserve Mura-Drava-Danube. We show that these forest managers are highly aware of ongoing environmental changes and appraise deteriorating forest conditions, especially after observing changes themselves. Abiotic damage is expected to increase the most, followed by biotic damage, the spread of non-native species, and tree dieback. Nearly 80% of the survey respondents expect further changes and almost all of them intend to adapt their management of forests to mitigate or prepare for these changes. Nevertheless, we show differences in sensitivity to change and willingness to initiate adaptation actions by assessing adaptation thresholds: conservation managers appear generally more tolerant to changes, which results in higher thresholds to initiate management adaptation than forestry professionals and forest owners. Respondents' selection of target tree species depends on management goals and therefore, we found further differences between forestry professionals and conservation managers. These aspects need to be carefully considered to foster cooperation or develop sustainable management frameworks and adaptation strategies.

KEYWORDS

biosphere reserve Mura-Drava-Danube, forest management, sensitivity to environmental change, stakeholder perception, adaptation thresholds, riparian forest tree species

1. Introduction

Forest ecosystems are threatened by human-induced environmental impacts such as climate change and globalization (Jones et al., 2018). Changing climate results in a higher frequency and intensity of disturbance events such as storms (Beniston et al., 2007), droughts (Dubrovský et al., 2014; Hanel et al., 2018; Seidl et al., 2017), and floods (Arnell and Gosling, 2016; Dottori et al., 2018; Winsemius et al., 2016), influences habitat suitability for local forest communities (Dyderski et al., 2018), and alters interactions between pests and diseases (Bentz et al., 2010; Jönsson et al., 2009). Furthermore, globalization favors the accidental spread of non-native species (Hulme, 2009; Meyerson and Mooney, 2007; Mikulová et al., 2020) which include pests and diseases that endanger forest tree species and biodiversity (Boyd et al., 2013) as well as non-native plants (Allard and Sigaud, 2005; Nisbet et al., 2015) that create competitive pressure on native plant communities (Nadal-Sala et al., 2019). Both impacts were found to go beyond the capability of native species and ecosystems to resist (Hansen, 2008).

Riparian forests are particularly vulnerable to environmental change and other external influences because they are highly dynamic ecosystems with complex and susceptible ecological processes (Klimo and Hager, 2000; Netsvetov et al., 2019; Nilsson and Berggren, 2000; Roder et al., 2017; Tockner and Stanford, 2002). Agricultural development is believed to have destroyed 90 per cent of Europe's floodplain forests over the last century (Klimo et al., 2008). As a result, many ecosystem services provided by riparian forests are threatened, including their role as a natural buffer for flood protection (Leyer et al., 2012; Sanjou et al., 2018), their high productivity (Cartisano et al., 2013), and biodiversity (Kevey, 2018; Schnitzler et al., 2005) as well as their recreational and aesthetic qualities (Sikorska et al., 2019). Consequently, climatic, morphological, and hydrological changes (Globevnik and Kaligaric, 2005; Tadić et al., 2022; Tockner and Stanford, 2002), and the spread of non-native plants (Sikorska et al., 2019), pests and diseases (Dukes et al., 2009; Seidl et al., 2018) have enormous ecological consequences and fundamentally affect the provision of ecosystem services of riparian forests (Charles and Dukes, 2007; Nilsson and Berggren, 2000; Ramsfield et al., 2016; Vilà and Hulme, 2017).

To maintain the ecosystem services provided by riparian forests, sustainable forest management concepts will thus need to be adapted to these challenges by increasing the resilience of forest ecosystems (Funk et al., 2020; Riis et al., 2020; Rist and Moen, 2013). However, uncertainty about local changes and their magnitude is high and experiences in large-scale adaption measures are still scarce.

The implementation of proper adaptation measures depends on the actors' perceptions of the specific problems. While both the public perception of forestry (Ranacher et al., 2020) and forestry professionals' perception of climate change (Seidl et al., 2016; Sousa-Silva et al., 2018) have increasingly been investigated, the differences between forest manager types dealing with various aspects of forest management such as conservation or timber production are rarely targeted. Nevertheless, such information is crucial for understanding the attitudes of specific groups toward the development and support of different adaptation processes. Thus, due to different educational backgrounds and management goals, divergent opinions are to be expected.

Previous studies have shown that local challenges such as pests and diseases were often perceived as more pressing than the large-scale problem of climate change by private forest owners (Lawrence and Marzano, 2014), while over 70% of protected area managers across Europe consider climate change and invasive species to be relevant for their management areas (Mattsson and Vacik, 2018). Large differences between European countries in forestry professionals' beliefs about the effects of climate change on their forests were found by Sousa-Silva et al. (2018). In this context differences between stakeholder groups such as forestry professionals and small-scale private forest owners were indicated (Mostegl et al., 2019), while a segmentation based on management behavior and preferences rather than on predefined, stereotypical characteristics of stakeholder groups were found to be necessary (Mostegl et al., 2019; Seidl et al., 2016). It is also assumed that changes in management behavior are triggered by both expectations and experiences of environmental change. Therefore, when assessing the vulnerability of the forest management system, management behavior is often seen as a static component, while possible responses to former and recent experiences should be considered (Adger et al., 2009; Hajjar and Kozak, 2015; Seidl et al., 2016). Initiating such management responses to environmental changes depends on individual thresholds, i.e., tolerance limits. Low adaptation thresholds lead to early adaptation processes, while high thresholds will consequently lead to late changes in management behavior (Seidl et al., 2016). In the forest management context, low adaptation thresholds can characterize high sensitivity toward environmental changes and vice versa.

According to the current state of the art, one of the most important measures of adaptive forest management under climate change is the selection of tree species and provenances that can

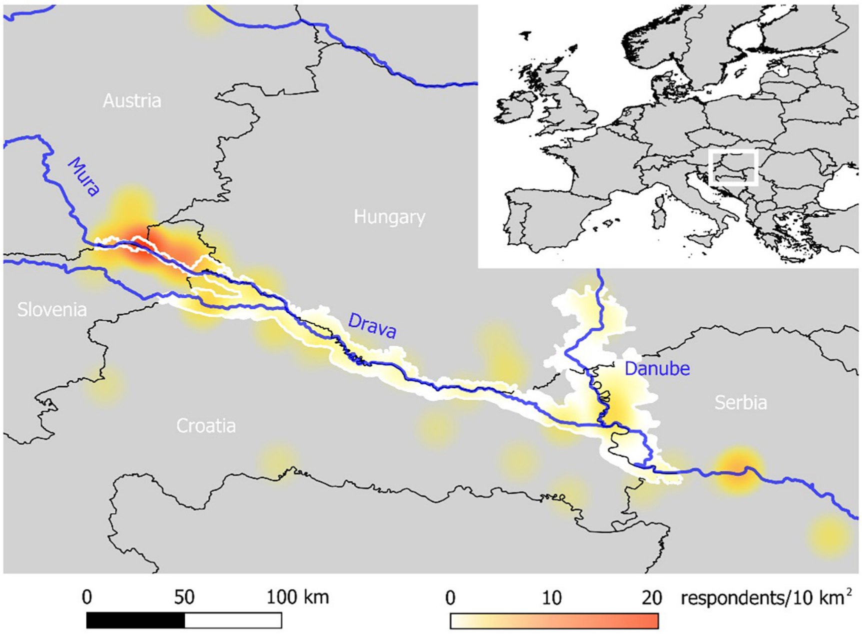

FIGURE 1
The study area across Austria, Slovenia, Hungary, Croatia, and Serbia is the transboundary Biosphere Reserve Mura-Drava-Danube. It is displayed in white, the country borders in black, and the three major rivers in blue. The geographical distribution and density of survey respondents are shown with a yellow-red color gradient heat map pattern.

increase resilience and resistance to maintain and restore ecosystem services (Buras et al., 2020; Havens et al., 2015; Konnert et al., 2015). Tree species selection is also widely recognized as an adaptation measure among stakeholders (Blennow et al., 2012; Lawrence and Marzano, 2014; Sousa-Silva et al., 2018; Yousefpour and Hanewinkel, 2015) and frequently includes the use of non-native tree species (Thurm et al., 2018). However, concerns about the ecological risks of non-native species and differences in their acceptance by forest managers and owners are common (Hajjar and Kozak, 2015; Starfinger et al., 2003; Weidlich et al., 2020). Thus, also the question of tree species selection will be a special focus of the article.

Continuous adaptation to environmental changes is a key component of sustainable development (Smit and Pilifosova, 2001). UNESCO Biosphere Reserves aim to strengthen this development in rural areas. As opposed to simply setting aside protected areas, they take a broader landscape-based approach by promoting sustainable use of natural resources around small core areas with higher levels of protection following scientific support and local engagement. By acting as role models, positive experiences should be spread beyond their borders and spur widespread changes in management standards to address the Sustainable Development Goals. Biosphere Reserves pursue the goals of conserving biological and cultural diversity, supporting sustainable economic development, and providing logistical support through research and education (UNESCO, 2021).

Established in the year 2021, the transboundary Biosphere Reserve Mura-Drava-Danube (TBR) is larger than any other riverine protected area in Europe. Spanning over five countries, differences in administrative systems and ownership structure lead to a variety of forest management systems used across the Biosphere Reserve. Forestry professionals, forest owners, and conservation managers responsible for forest management in the area may also differ in their mindsets and management goals.

Here we explore how different types of forest managers perceive the effects of environmental changes on forest management. These forest managers were grouped into forestry professionals, forest owners, and conservation managers. The specific objectives were to.

- i determine forest managers' perceptions of the direction and intensity of **expected changes** in the forests of the Biosphere Reserve.
- ii assess the **sensitivity** of the three different types of forest managers to environmental changes and understand the drivers behind different sensitivities.
- iii identify the main **tree species** of native and non-native origin preferred by the three different types of forest managers.

For this purpose, we conducted a survey among forestry professionals, forest owners and conservation managers throughout the Biosphere Reserve Mura-Drava-Danube.

2. Materials and methods

2.1. Study area

Our study focused on the riparian forests of the TBR, located in central and south-eastern Europe (Figure 1). The TBR, the world's first five-country UNESCO Biosphere Reserve, has been approved in 2021 (Köck et al., 2022). It aspires to become an international

TABLE 1 Demographic structure, highest level of completed education (1st number: overall education level, 2nd: education in forestry or conservation), connection to the Biosphere Reserve and frequency of forest visits of the types of forest managers (questions Q1, Q2, Q8, Q24, Q25, Q26, and Q27 in Supplementary material 1).

		Forester	Forest owner	Conservation professional	Other	Total
Country	Austria	6	22	4	3	35
	Croatia	24	1	2	1	28
	Hungary	8	1	6	2	17
	Serbia	13	–	8	2	23
	Slovenia	12	8	6	3	29
Age	< 18	–	–	–	–	–
	18–24	1	1	1	1	4
	25–34	13	3	4	1	21
	35–44	10	3	4	3	20
	45–54	22	8	6	3	39
	55–64	7	10	4	2	23
	65 <	1	4	1	–	6
	No answer	9	3	6	1	19
Gender	Female	8	5	5	3	21
	Male	46	24	15	7	92
	No answer	9	3	6	1	19
Education level/Education level in forestry or conservation	Primary education (ISCED 1)	–	–	1/0	–	1/0
	Lower secondary education (ISCED 2)	–	3/3	2/1	–	5/4
	Apprenticeship (ISCED 3)	1	9/5	–	–	10/5
	Upper secondary education including high school graduation (ISCED 3)	7/7	12/7	–	1/0	20/14
	Bachelor, master, doctoral or equivalent (ISCED 6–8)	46/46	5/4	17/15	9/8	77/73
	No answer	9/10	3/13	6/10	1/3	19/36
Connection to the Biosphere Reserve	Living	12	16	9	2	39
	Work within the area	24	14	8	3	49
	Forest related job (not only forestry sector)	29	14	9	5	57
	Leisure time	8	13	12	2	35
	Hunting	10	10	3	2	25
	No answer	5	1	4	2	12
Frequency of forest visits	Once per week	27	20	8	4	59
	Twice per month	7	2	6	2	17
	Once per month	12	3	3	-	18
	Once a month	13	6	4	3	26
	Other	4	1	5	2	12
Total		63	32	26	11	132

model area for long-term regional development. It consists of four recognized Biosphere Reserves in Austria, Slovenia, Hungary, Croatia, and Serbia, which are spatially interconnected (Figure 1). Inhabited by 900,000 people, 63% of the area is designated as a transition zone with a focus on sustainable economic development, 22% as a buffer zone with extensive management, and 15% as a core zone with low management intensity. Forests account for 27% (2,250 km^2) of the TBR, of which 61% are in the core zone. The TBR is dominated by fertile plains along the rivers Mura, Drava, and Danube with intensive agricultural use for cereals and pastures as well as forestry. The TBR has a climatic gradient ranging from the Illyrian climate in the west to the Pannonian climate in the east. This results in a wide range of average annual precipitation from about 1,000 mm to less than 500 mm and mean annual temperatures from 9.3°C to 11.7°C (Sallmannshofer et al., 2021a).

2.2. Survey design

We used an online survey hosted on the surveymonkey.com platform to collect quantitative information on stakeholders' perceptions and beliefs about the TBR. We began developing the survey after a preliminary research phase in 2018.

2.2.1. Preliminary research phase

First, we conducted stakeholder mapping through informal interviews with forestry and conservation experts from all five TBR countries. Then, we used this information and held a workshop for 41 experts from the key stakeholder groups across the study area to collectively identify key forest management and conservation needs and issues in the TBR. Based on the results we identified the major research needs and developed the survey.

2.2.2. Survey development

The development of the survey considered technical aspects such as the time needed to complete it and the technical competence of the participants. The survey was developed in English and translated by native speakers into five local languages: Croatian, German, Hungarian, Serbian, and Slovenian. We pre-tested the survey in English and German to see whether the questions' wording was interpreted by all stakeholder groups in the same manner. Accounting for the results of pre-testing, the survey was finetuned by the native speakers from the TBR countries to ensure consistency across languages. The questionnaire was anonymous to minimize respondents' potential attempts to hide their attitudes. Because certain words such as clearcut or monoculture may be perceived as biased or potentially offensive, we carefully considered terminology and used simple descriptions instead. The full survey contained a total of 27 questions, 18 of which were relevant to the objectives of the current study (see **Supplementary material 1**). This subset was only available to respondents who identified themselves as forestry professionals, private forest owners, and conservation managers responsible for managing forest land in the study area.

In this study, forestry professionals are defined as foresters and others working in commercial forestry and timber management, forest owners are defined as owners of all types of private forests, and conservation managers are defined as managers of forest areas primarily for conservation or biodiversity purposes – such as in areas of higher protection levels in the core zone of the TBR.

To characterize the respondents, we asked them for details about their background, complying with the EU General Data Protection Regulation (European Union, 2016). The questions aimed to assess respondents' perceptions of forest condition as well as observed and expected changes. By asking about thresholds for forest management adaptation, we assessed the sensitivity of the respondents to these changes following Seidl et al. (2016). To gain a better insight into specific forest management practices, we asked the respondents to elaborate on the preferred target tree species of native and non-native origin.

The questions included two multiple-choice questions, nine single-choice questions, and four rating-scale questions providing nominal and ordinal quantitative data. For choice questions, we offered an "other" response option, where respondents could provide free text as an answer, so as not to force them to limit their answers to the given list of options, which could bias the results. Since this option was available, all respondents were asked to answer each question to proceed to the next one. We randomized the order of items and attributes in the questions to avoid primacy or recency effects (Clark, 1956; Fagley, 1987; Tellinghuisen and Sulikowski, 2008). However, some items, such as alphabetically ordered species names or rankings had to be presented in a specific order and were therefore not randomized. For all rating scale questions, we provided the context by using descriptive labeling in combination with numbers to ensure equal intervals between response categories. Questions of high importance were conducted on individual pages as "forced single choice" rather than "select all that apply" to obtain more accurate results (Lau and Kennedy, 2019). To deal with acquiescence response bias, all response categories were tailored to be directly relevant to the questions (Höhne and Lenzner, 2018). Throughout this manuscript, specific question numbers are denoted by the letter Q.

2.2.3. Survey distribution

The survey was distributed online through a network of forest research institutions in the five countries of the TBR. Therefore, respondents were not randomly selected, and our sample was purposive. Additionally, because the survey area includes very rural areas, we distributed printed forms to reach respondents living in these areas, particularly forest owners. The survey was conducted from August 2019 to May 2020. A national contact person was assigned for each of the five language versions to coordinate the distribution of the survey to stakeholders in their countries and be available for further information.

2.3. Analysis

We used R statistical software version 3.6.2 (R Core Team, 2019) for data preparation and analysis. Data were categorical, categorically ordered, or categorically scaled. We focused on a combination of descriptive and statistical analysis, because of the small number of respondents, especially when limiting the responses to those who answered each question completely.

Correlation analysis was used to identify response patterns. In addition, we analyzed forest managers' intended responses to changes in forest dynamics, by assessing the sensitivity to various management constraints caused by environmental change. Respondents were asked to choose their thresholds until management adaptation in three categories with four sensitivity levels each. Sensitivity levels were defined according to how many target tree species were allowed to die back (Q10), the percentage of forest growth (wood increment) that was allowed to decline (Q11), or the percentage of target tree species that was allowed to fail in natural or artificial regeneration (Q13) until forest management is intended to be changed.

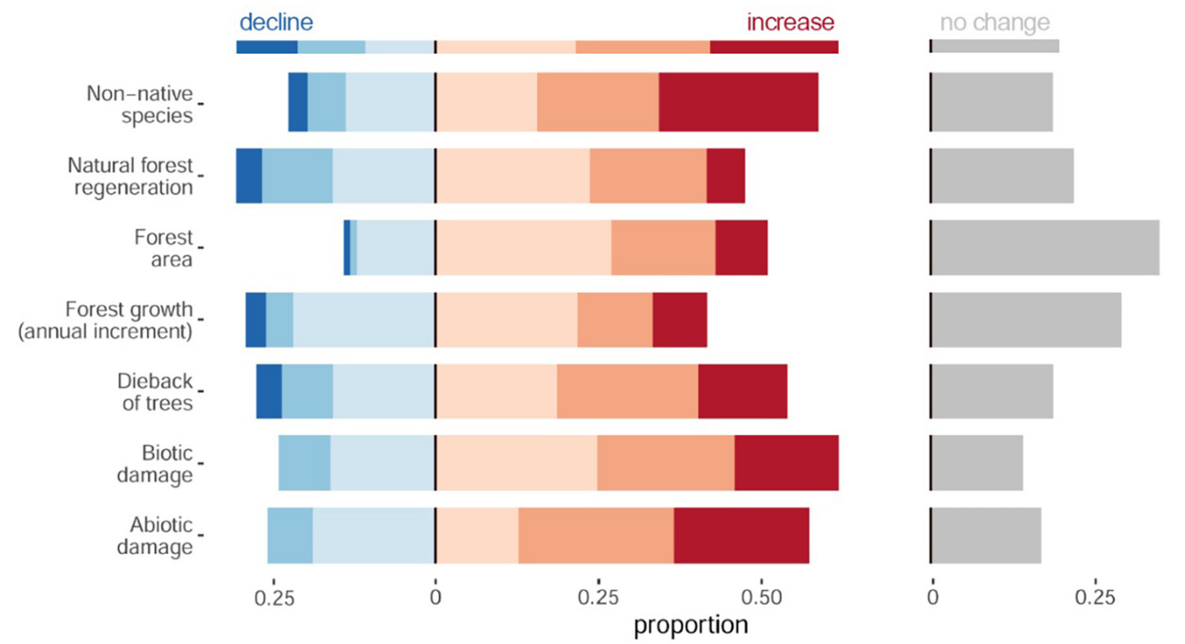

FIGURE 2
Diverging stacked bar chart showing expected forest-related changes in riparian forests of the Biosphere Reserve with their intensity and direction (Q7). The top bar represents the color scale of seven intensity classes, starting at the left with strong decline, moderate and slight decline, no change (shown separately on the far-right side), slight increase, moderate increase, and strong increase.

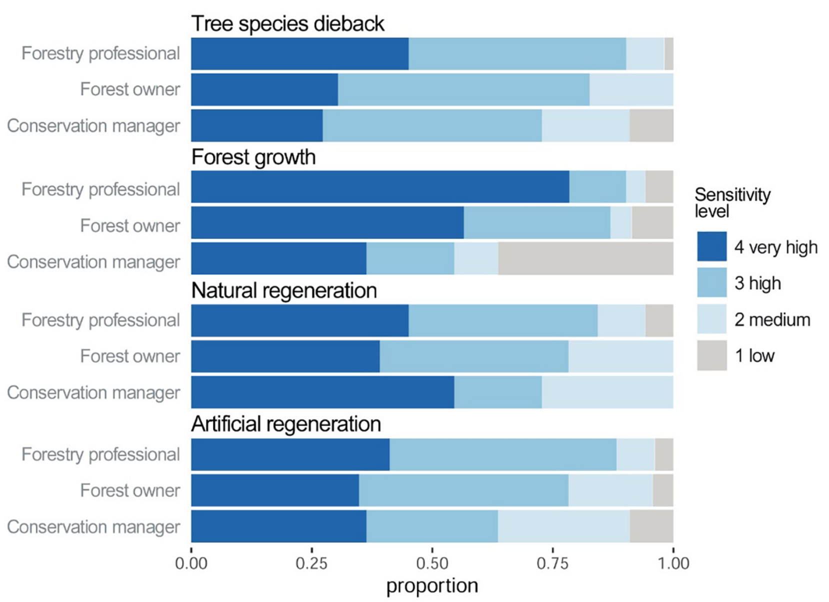

FIGURE 3
Respondents' sensitivity to forest growth, tree dieback, artificial, and natural regeneration. Sensitivity levels were defined according to how many target tree species were allowed to die back, the percentage of forest growth (wood increment) that was allowed to decline, or the percentage of target tree species that was allowed to fail in natural or artificial regeneration until forest management is intended to be changed. Sensitivity level 4 characterizes very high sensitivity with management being directly changed when one target tree species faces a serious dieback/forest growth decline by 10/10% of the target species fail to regenerate. Sensitivity level 3 is defined in the same way by two species/25/25%, level 2 by 3 species/50/50%, and level 1 by more than three species/75/75%.

To examine the differences and main drivers of the sensitivity levels, we used the random Forest machine learning algorithm version 4.6–14 (Liaw and Wiener, 2002), because of its ability to capture complex non-linear relationships with non-independent predictors and a robust, permutation-based estimation of variable importance (Cutler et al., 2007). Therefore, responses from questions that were similar in structure were combined into a single composite score. The model revealed the relative importance of

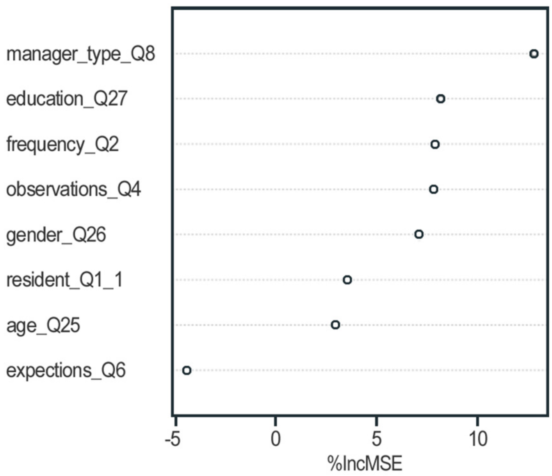

FIGURE 4
A random Forest model was built to investigate the importance of different background variables on the mean sensitivity of each respondent. The diagram displays the estimated percentage increase in mean square error (%IncMSE) when a variable was dropped from the model and the other predictors were left unaltered.

individual independent variables when scores for that predictor were randomly permuted, and all other predictors were left unchanged.

We conducted a correspondence analysis (CA) to visually examine the association between different stakeholder groups and their characteristics with their perceptions of management questions. Before conducting the CA, we summarized the response categories for ease of interpretation.

3. Results

3.1. Respondents

In total, 132 forest managers have answered the survey, of which 48% were forestry professionals, 24% forest owners, 15% conservation managers, and 8% others (i.e., forest scientists or forestry advisors responsible for area management, **Table 1**). These shares approximately match the zonation scheme of UNESCO Biosphere Reserves, with large managed areas and only 15% of core zone areas (UNESCO, 2021). The group of forest owners is mainly represented by Austrian and Slovenian respondents because the forests of the TBR in Hungary, Croatia and Serbia are mainly or exclusively publicly owned. The respondents were highly educated with 68% academics, 95% of which in forestry or nature conservation. The group of forest owners had the lowest education in this analysis with 72% being educated at the highest on the ISCED 3 level (upper secondary education) and only 17% academics. However, this group visited the forests most frequently, had the highest quote living in the TBR, and had the highest age. A share of 70% of the respondents specified to be male. Respondents were mainly from within the area of the TBR with the highest densities in Austria and Slovenia (**Figure 1**).

3.2. General perception of the state of the forests

Sixty-six ($n = 114$, Q3) respondents believed that the condition of forests is deteriorating. This correlates with 74% ($n = 117$, Q4) of respondents who have personally observed changes in forest conditions ($r = 0.54$, $p = < 0.001$). Future changes were expected by 78% ($n = 119$, Q6), of whom 98% intended to adapt their management to these expected changes in the future (Q9). The correlation between those having observed changes and those expecting future changes is low ($r = 0.11$, $p = 0.1105$).

3.3. Expected changes in the forests of the TBR

A more detailed response on expected changes was submitted by 92 respondents (Q7), who indicated an overall increasing trend for all categories of change. The greatest increase was expected for biotic damage (66% of the respondents), abiotic damage (60%), non-native species (59%), and tree dieback (55%). Thereof, a remarkable number of respondents expected very strong increases in non-native species (25%) and abiotic damage (22%). Most frequent expectations for no change were indicated for forest area (36%) and forest growth in terms of the annual increment (29%, **Figure 2**).

Comparing weighted averages of observed changes in the past (Q5) with expected changes in the future (Q7) showed that abiotic damage is expected to increase the most, followed by biotic damage, non-native species, tree dieback, increase in forest area, natural forest regeneration, and forest growth.

The intensity of observed past changes (Q5) was significantly correlated with the expected intensity of future change (Q7) for only two of the seven categories: spread of non-native species ($r = 0.63$, $p \leq 0.0001$) and tree dieback ($r = 0.33$, $p = 0.0261$). In addition, tree dieback also correlated with the expectation of increasing biotic damage ($r = 0.64$, $p \leq 0.0001$) and a reduction in forest growth ($r = -0.26$, $p = 0.0033$). Also, observed spread of non-native species correlated with expected increase of abiotic ($r = 0.42$, $p = 0.0110$) and biotic damage ($r = 0.30$, $p = 0.0017$).

Expected change of abiotic and biotic damage were significantly and positively correlated ($r = 0.64$, $p \leq 0.0001$). Expected changes of natural regeneration were negatively correlated with the spread of non-native species ($r = -0.34$, $p = 0.0058$). Additionally, there were significant positive correlations between answers for expected changes because of tree dieback and abiotic ($r = 0.63$, $p = 0.0003$) and biotic damage ($r = 0.61$, $p = 0.0018$), spread of non-native species ($r = 0.62$, $p = 0.0080$), and a negative correlation with natural regeneration ($r = -0.30$, $p = 0.0068$) (**Supplementary material 2**).

3.4. Forest managers' sensitivity

Differences in sensitivity toward negative impacts of environmental changes occurred among the respondents: Forestry professionals were found to be the most sensitive group concerning forest growth (wood increment, Q10), tree dieback (Q11), and artificial regeneration (Q13). Among all respondents,

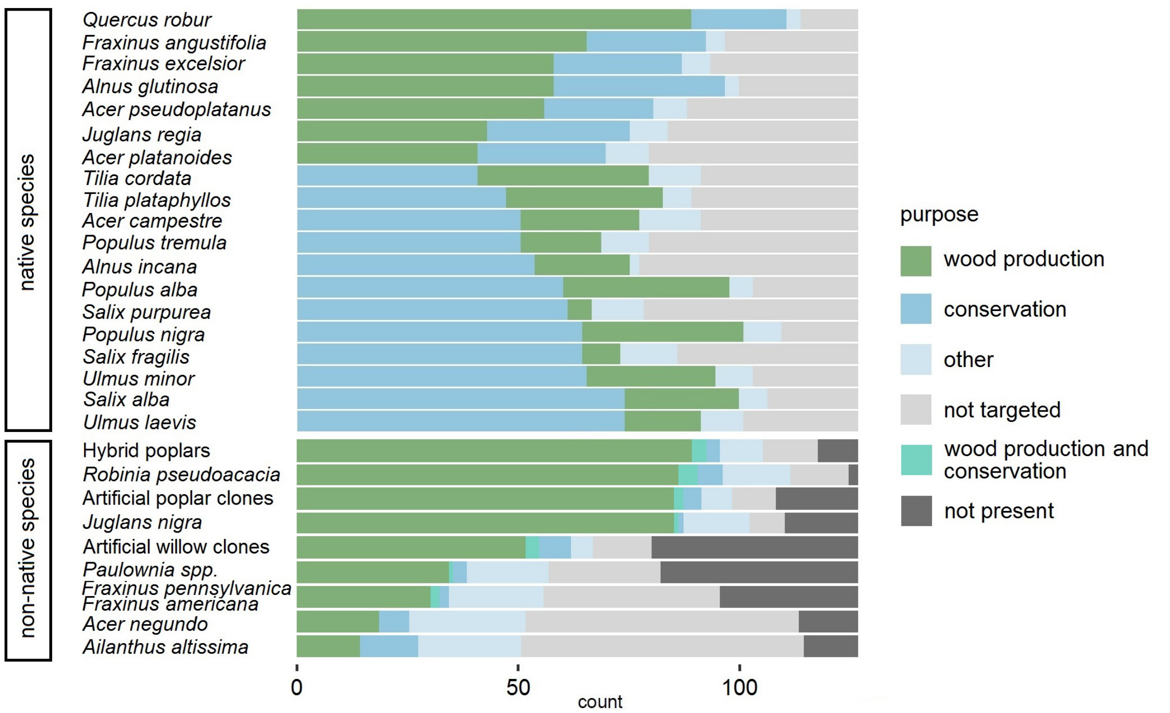

FIGURE 5
Stacked bar chart of tree species in forest management in the Biosphere Reserve Mura-Drava-Danube. Targeting a tree species for conservation means supporting native tree species or counteracting non-native tree species, while in this context not targeting a species means tolerating its presence without favoring or counteracting measures. As written by respondents in open comments, the "other purposes" option partly includes the above targets.

the mean sensitivity level was highest toward natural regeneration (Q13) with differences between the groups (Figure 3). We found a significant negative correlation between sensitivity to tree dieback and expected changes (Q7) in forest growth (annual increment) (Q11, $r = -0.22$, $p = 0.0014$), but no significant correlations between other expected (Q7) or observed changes (Q5) and the corresponding sensitivity levels (Q10, Q11, Q13).

The random Forest model of mean sensitivity helped to identify those respondent characteristics that best explain the sensitivity across the four classes (Q10, Q11, Q13, see "Section 2.3 Analysis"). The most important characteristics are (Figure 4): the forest manager type (Q8), education (Q27), the frequency of visits to the forest (Q2), having personally observed changes (Q4), gender (Q26), living in the TBR (Q1-1), and age (Q25). In contrast to having observed changes in the forests, dropping the variable expecting future changes (Q6) did not increase the Mean Square Error of the model (Figure 4).

Partial dependence plots created in random Forest showed the behavior of the model when individual variables changed. In terms of forest manager type, forestry professionals were most sensitive toward the given changes, followed closely by forest owners. Conservation managers were the least sensitive group in this context as they generally showed higher thresholds for adjusting their management. Furthermore, sensitivity increased with a higher level of education. When visiting forests once a week or more, sensitivity increased, while there was no difference between lower classes of visit frequencies. As respondents not living in the TBR generally had higher education in forestry or natural sciences, they were also more sensitive to changes. In this survey, female respondents appeared to be more sensitive than male respondents.

3.5. Target tree species

A number of 125 respondents indicated their preferences for native and non-native tree species (Q12, Q15). Among native tree species *Quercus robur* (90%) and *Populus nigra* (86%) emerged as the most common target species for management. The former was mainly selected to be used for wood production and the latter for conservation. Furthermore, *Salix alba*, *Populus alba*, *Alnus glutinosa*, *Fraxinus* sp., and *Ulmus* sp. proved to be the most outstanding multipurpose tree species/genera, very attractive for both wood production and conservation. For conservation purposes alone, *Ulmus laevis*, *S. alba* (both 59%), and *Ulmus minor* (52%) were selected even more frequently than *P. nigra* (51%). For wood production, *Q. robur* (70%) is followed by *Fraxinus* sp., *A. glutinosa*, *Acer* sp. and *Juglans regia* (Figure 5).

Among non-native species, wood production is the most frequently selected objective in the survey: hybrid poplars, *Robinia pseudoacacia*, artificial poplar clones and *Juglans nigra* were targeted for wood production by at least 68% of respondents.

For each listed non-native tree species, management for conservation was selected by only 10% of respondents or less. In combination with other purposes (that frequently included management for conservation as derived from comments), this

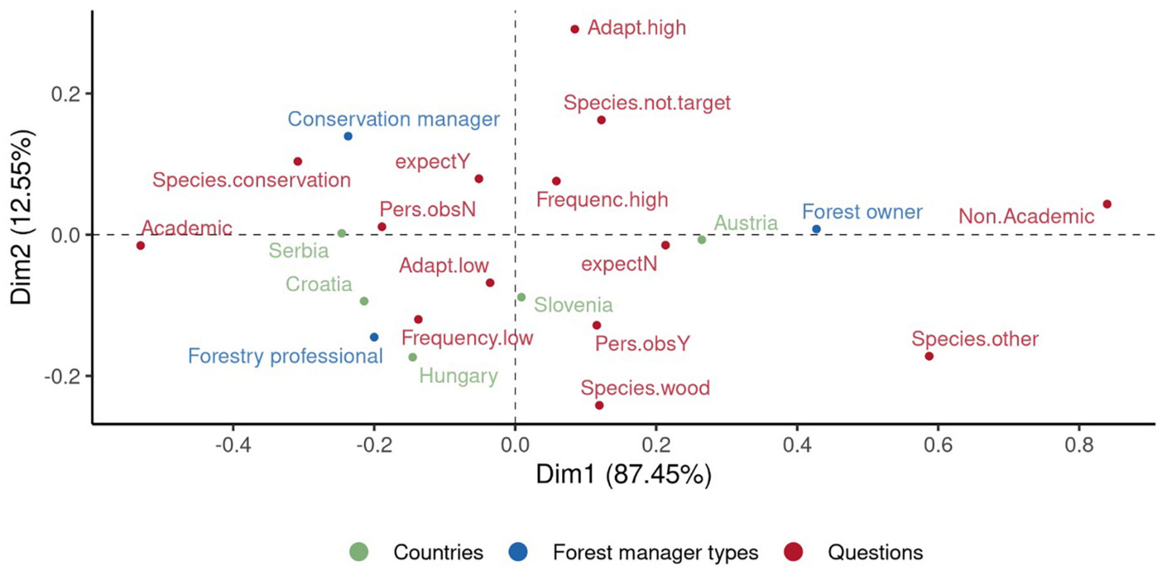

FIGURE 6
Correspondence Analysis (CA) describing the relationship between three types of forest managers (blue) and different issues related to forest management in the Biosphere Reserve Mura-Drava-Danube (red). Countries are shown as supplementary points (green) that do not influence the CA plot but aid the interpretation. The distance between any question or type of forest manager describes the similarity or dissimilarity between them. When comparing questions to types of forest managers, a small angle between the origin (center of the graph) and the labels means there is an association, a 90-degree angle means there is no association, and a 180-degree angle means there is a negative association. The length between the origin and the labels corresponds to the strength of the association.

figure reached a maximum of 26% for *Acer negundo*, followed by *Fraxinus pennsylvanica* and *R. pseudoacacia*.

There were differences between the three types of forest managers in their perceptions of native tree species concerning their management purpose. Conservation managers tended to see more species for conservation purposes (50%) than forestry professionals (40%) or forest owners (22%). As expected, forestry professionals and forest owners indicated a higher proportion of species to be used for timber production (35% and 33%, respectively) than conservation managers (17%). Forestry professionals indicated the lowest proportion of species that were not specifically managed (21%) compared to 31% for conservation managers and 35% for forest owners. Seventy-six per cent of conservation managers indicated that non-native species that do not play a major role in timber production should be considered in some form of management and so did forestry professionals (70%) and forest owners (62%). In contrast to non-native species present in the area for a long time such as *J. nigra* or *R. pseudoacacia*, conservation managers thought *A. negundo*, *Ailanthus altissima* and *F. pennsylvanica/F. americana* were more important in wood production than forestry professionals or forest owners themselves.

3.6. Species preferences and sensitivity of manager types

The relationship between the three types of forest managers and their perceptions of various management issues, as well as the country of the respondents, were analyzed using correspondence analysis (CA), with two axes explaining 100% of the variance (**Figure 6**). Before running the CA, we created contingency tables and merged the lowest sensitivity levels to "Adapt.low" and the highest two sensitivity levels to "Adapt.high." Forestry professionals would adapt their management already as a response to small changes in growth, reduced regenerative capacity, or species mortality ("Adapt.low"), while conservation managers and forest owners would more likely adapt their management later ("Adapt.high"). A difference in the groups' perceptions of woody species is also evident.

There is a positive association between conservation managers who have not seen any changes in the condition of forests in TBR themselves ("Pers.obsN") but expect them in the future ("expectY"). The opposite is true for forest owners. Furthermore, the level of education differs greatly between conservation managers and forestry professionals on the one side, most of whom have an academic education ("Academic"), and forest owners with non-academic education ("Non.Academic") on the other side. Additionally, a positive association between forestry professionals and low visit frequency ("Frequenc.high") emerged.

4. Discussion

4.1. Experiences, expectations, and forest management adaptation

The majority of forest managers in the TBR is concerned about ongoing environmental changes that pose threats to forest management, as also shown for forest managers in other areas for example, by Yousefpour and Hanewinkel (2015). The respondents in our study estimated that the conditions of forests are deteriorating, especially after observing changes themselves.

This corresponds to ecological studies in the area (de Groot et al., 2022; Sallmannshofer et al., 2021a; Tadić et al., 2022). Nearly 80% of the survey respondents expected further changes, which was significantly correlated with having observed past changes. Specific expectations were based on experiences when the investigated category of change was easy to observe by the stakeholders in the field, such as dieback of trees. Almost all forest managers that expected further changes intended to adapt their forest management while just a few forest managers were not convinced, a group that was also described by Lawrence and Marzano (2014). Most respondents expected an increase of biotic and abiotic damage, of non-native species, and of tree dieback in future. This matches the estimation that non-native species belong to the most pertinent threats to the environment (e.g., Simberloff, 2005; de Groot et al., 2022).

The group of forest owners does not tend to expect changes in forest conditions in the future although they have already personally observed changes. This is in strong contrast to conservation managers. One of the reasons for difference could be the level of education with most of the conservation managers and forestry professionals having a higher education level than forest owners within this study. Additionally, the frequency of forest visits could be relevant for not having personally observed changes: Those who self-identified as forestry professionals were positively associated with a low frequency of forest visits. This suggests that they are likely rather office workers, which is supported by their high education level, and have fewer field experiences than forest owners. Thus, they might have a higher awareness and sensitivity to expected future changes due to better access to scientific evidence for environmental change and its potential impacts. In this study, higher education and therefore rather formal knowledge appeared to be associated with management adaptation (strategic decision), whilst local ecological knowledge will play an important role for the operative implementation. A recent study (Pröbstl-Haider et al., 2020) has also indicated differences in the level of climate change adaptation between male and female small-scale private forest owners, which is confirmed by our findings among all respondents of this study.

4.2. Forest managers' sensitivity to environmental changes

Specific adaptation thresholds are proxies for adaptation goals as well as attitudes toward nature, skepticism, and trust (Adger et al., 2009; Hajjar and Kozak, 2015). These thresholds for adaptation, also called sensitivity levels in our study, were correlated with observations and expectations in only a few cases. The only significant correlation was found between expected changes (Q7) in forest growth and sensitivity to tree dieback (Q11). No other significant correlations were found between observed (Q5) or expected changes (Q7) and the corresponding sensitivity levels for forest growth (Q10), tree dieback (Q11), or regeneration (Q13). This means that sensitivity was rather stimulated by other factors: the importance of the forest manager type shows the dependence of adaptation thresholds on specific management goals and personal characteristics. Core zones in a Biosphere Reserve have been installed by the idea – among others – of letting nature take its course and thus, conservation managers in this study were more tolerant toward ongoing changes as far as natural regeneration is not limited. In line with the zonation scheme, sensitivity depended on the specific management objectives. Nevertheless, several forest functions (e.g., carbon sink, flood protection) call for high sensitivity and early adaptation of all actors across the zones. Furthermore, the individual background of the respondents, such as higher education level and frequency of forest visits, increased the sensitivity and is therefore likely to influence management adaptation behavior more than personal observation of specific changes. In addition, also the information level, which might differ from the education level, could play an important role but was not investigated. This can be also confirmed by Sousa-Silva et al. (2018), who found a lack of knowledge and information as a major barrier toward forest management adaptation for foresters' of seven European countries.

Furthermore, in our study different response patterns were found not only between manager types but also between countries. This could be a result of different legal frameworks, education, differences in ownership structure or local traditions (Sousa-Silva et al., 2018; Westin et al., 2023). When cultivating transnational cooperation in the study area or developing transnational management frameworks and strategies, these aspects need to be carefully considered: in Austria and Slovenia, for example, many forest owners need to be reached to commence changes in forest management, whereas in other countries, due to large shares of publicly owned forests high-level stakeholders and policymakers will play a key role in triggering adaptation management. Existing initiatives like the PANORAMA platform to develop and host a large portfolio of case studies on protected area management and governance can help to further promote these management actions (Mattsson et al., 2019b). The solution process considers reflection, documentation, and communication, followed by adaptation and uptake of successful management in and around protected areas.

4.3. Tree species selection in the context of environmental change

Ongoing environmental change can alter habitat conditions and pose new challenges for forest management. Our results show a high awareness of these threats; respondents expect the environmental situation to worsen. In recent decades, riparian forests in particular have suffered from a range of biotic and abiotic disturbances. For instance, oak (*Quercus* spp.) and ash (*Fraxinus* spp.), both most commonly managed for wood production by respondents in this study, have recently been affected by introduced invasive pests and diseases such as the North American oak lace bug (*Choricha arcuata* Say, 1832) (Csóka et al., 2020) and ash dieback, caused by the fungus *Hymenoscyphus fraxineus* (Kowalski, 2006). While ash is still considered one of the most important tree species for wood production in the TBR, elm species (*Ulmus* spp.) have already become a dominant target species for conservation activities after being severely affected by the Dutch elm disease, introduced a century ago and caused by the fungus *Ophiostoma novo-ulmi* (Brasier, 1991). This trend of moving from a dominant tree species to a species on the brink of extinction is also expected for ash, and survey respondents expect such biotic damages to increase the most in the future. However, not only pests and diseases but also human-induced habitat changes such as large-scale river regulations (Nilsson and Berggren, 2000; Roder et al., 2017; Tockner and Stanford, 2002) or groundwater extractions (Netsvetov et al., 2019) have had crucial long-term consequences for natural floodplain forests, evident in reduced vigor and lack of natural regeneration – two impacts to which survey respondents were most sensitive. Additionally, climate change is predicted to severely alter the habitat suitability for key tree species in riparian forests (Dyderski et al., 2018; Sallmannshofer et al., 2021a; Schueler et al., 2014). While the habitat suitability for native species may decrease, exotic species may increase in abundance (de Groot et al., 2022). The present study shows that some forest managers will aim to conserve native tree communities and counteract an invasion by non-native species, while others will support certain non-native species if this option is expected to pay off in terms of resilience or productivity in the future. These disagreements occur not only between commercial forestry and conservation but also separate between conservation approaches. Production-oriented stakeholders focus on species with excellent growth or wood characteristics such as hybrid poplars or *J. nigra*, which have been introduced long ago and are fully accepted regionally in production-oriented forestry while some focus on new non-native species such as *Paulownia* sp. (own field observation described in de Groot et al., 2022). Nevertheless, no non-native tree species can be grown without risks and professionals in forestry and conservation are fighting together against some undoubted invasive tree species, e.g., tree of heaven (*A. altissima*), suggesting the need for site-specific risk assessment (Bindewald et al., 2021). The concept of UNESCO Biosphere Reserves offers spatially separated various management options for the three zones, but the spread of species across zones and country borders demands a coherent management framework targeting at potentially invasive or harmful species (as well as other cross-border ecological interactions that were not mentioned in this study such as water dynamics or wildlife preservation). In the long term drastic environmental changes could potentially also require the acceptance of non-native species to maintain the provision of the respective ecosystem services in the respective zone. For example, the introduced black locust (*R. pseudoacacia*) has become the most common tree species in Hungary after habitat changes in former oak forests, as it copes better with warm temperatures and low water availability. In this context, the application of collaborative decision analysis could help to decompose and solve such ill-defined decision problems involving diverse stakeholder groups and considering future uncertainties (Mattsson et al., 2019a).

4.4. Data and survey constraints

Depending on the specific definition of the types of forest managers studied, individuals may belong to multiple categories such as forestry professionals who are also private forest owners. By using the single-choice option "select the category you can best identify with," respondents were grouped, although there may be overlaps between stakeholder categories. Furthermore, survey respondents were not randomly selected, as the target groups were difficult to reach, and it was impossible to create a database of all potential respondents for randomization purposes. By utilizing established networks of individuals associated with forestry and forest sciences, our sample of respondents might be biased toward rather well-educated and open-minded forest managers. The high level of education of the respondents could potentially indicate that the results derived from the questionnaire represent the opinion of decision-makers. Furthermore, there are quantitative differences in the number of respondents and group composition per country and stakeholder group. As an equal number of respondents per country was aimed for, the density of respondents was highest in Austria and Slovenia with only small parts of the TBR and lowest in Serbia, Croatia, and Hungary with the larger areas. Therefore, regional issues have potentially biased some results obtained from this study. Compared to another stakeholder survey in the area targeting at residents only (Trišić et al., 2022) our sample size was smaller but represented a very specific target group and all five countries.

4.5. Conclusion

In the Biosphere Reserve Mura-Drava-Danube forests are the main traditional source of income and hotspots of biodiversity. Moreover, resilient forests are an important prerequisite for socio-culturally and ecologically sustainable development. Nevertheless, the riparian forests are threatened, and this study shows that most forest managers, who expected further environmental changes, already intend to adapt their forest management. However, the assessed types of forest managers differed in their perceptions of forest development and management. On the one hand, this diversity might lead to a spatial (partially small-scaled) pattern of early and late, soft and strong adaptation, which might help distributing the risks of mismanagement under environmental change spatially and temporarily. On the other hand, environmental change calls for further education in this field to promote sensitivity and support adaptation management. Furthermore, due to ecological interactions between the different management zones as well as between neighboring countries exchange among the actors appears strikingly necessary. In this context, the transfer of know-how and mutual understanding between the actors could be promoted by trainings, excursion sites, and guidelines (e.g., Sallmannshofer et al., 2021b) to enhance the development of proper adaptation strategies to environmental changes and restore diverse and resilient forests.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

MS designed the survey with help of all authors and built the online survey and administered. GK, SSt, RD, PŽ, MS, MW, and TB were translated the manuscript. MS and RD analyzed and wrote the initial manuscript. SSc and HV supervised the study. MW and

SSc wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2023.1160166/full#supplementary-material

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