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Ecosystem services of mixed species forest stands and monocultures: comparing practitioners' and scientists' perceptions with formal scientific knowledge

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Mixed species stands might contribute to important goals of sustainable forest management, such as higher biological diversity, more resistance and resilience to disturbances and higher carbon storage. Knowledge of stakeholders' perceptions of such ecosystem services in mixed species stands is required for effective policy development. We showed that practitioners' and scientists' perceptions of ecosystem services in mixed species stands in Belgium differed from formal scientific knowledge derived from a synthesis of published studies. The positive perception of supporting, regulating and cultural services in mixed species stands contrasted with less conclusive results from the literature, where positive, negative and neutral effects were reported. Many respondents also signified a lack of information about regulating services. Furthermore, provisioning services were perceived as equal in mixed species stands and monocultures, in contrast to higher productivity demonstrated in mixed species stands in the literature. The regional (Flanders and Wallonia) ecological and socio-economic context influenced both the perception of ecosystem services and of the importance of management objectives. Our results highlighted the need to address the lack of scientific data, to adapt communication to the ecological and socio-economic context, as well as to improve information flow on regulating services and productivity.

Introduction

Since the 1970s, the general goal of European forest policy has shifted from the provisioning of sufficient timber, the so-called 'sustained yield' concept (Chikumbo *et al.*, 2000), towards 'multiple-use forestry' and 'sustainable forest management', including broad economic, but also social, and environmental goals (Kankaanpää and Carter, 2004). The 'Second Ministerial Conference on the Protection of Forests in Europe' (Helsinki Resolutions H1 and H2) defined sustainable forest management as '*the stewardship and use of forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*' (MCPFE, 1993). This revision of priorities in forest management has been strengthened by concerns about pests, pathogens and pollutants, sometimes related to more recent issues of forest health, resistance and adaptation to climate change (Lindner *et al.*, 2010; Parks and Bernier, 2010). The principles of sustainable forest management can become operational through the concept of ecosystem services (Figure 1), defined as benefits people obtain from ecosystems (Costanza *et al.*, 1997; MEA, 2005; Cardinale *et al.*, 2012). This concept provides a structured approach to the social, economic and environmental roles of ecosystems, which is increasingly used as a framework for decision-making processes in conservation and sustainable development policies (Daily *et al.*, 2009; Thompson *et al.*, 2011).

Forest management regulations have not always been based on adequate ecological knowledge. As a consequence, management failed to sustain biological diversity and ecosystem functioning (Kimmins *et al.*, 2005) and sometimes led to undesirable

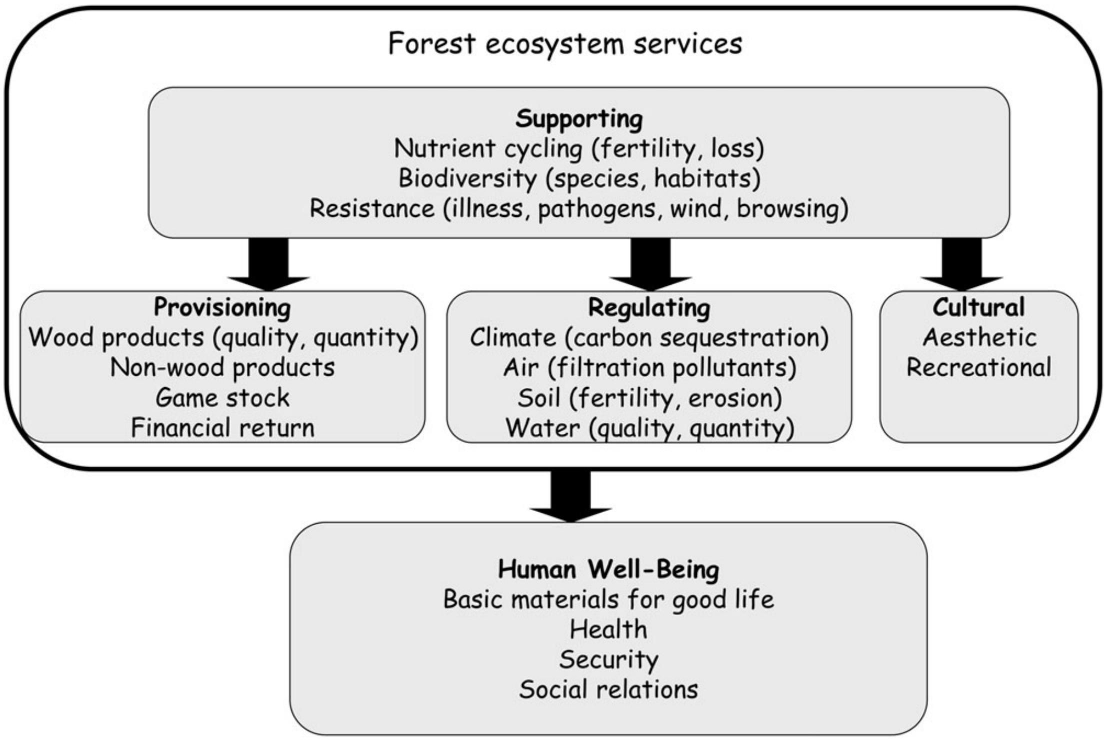

Figure 1 Forest ecosystem services addressed in this study and their relation to well-being (modified from MEA, 2005; Seppälä *et al.*, 2009).

outcomes (Van Miegroet and Johnson, 2009). For example, forest litter raking, the periodic removal of coniferous needles for use in animal stables, caused soil nutrient impoverishment, acidification and a decrease in productivity (Van Miegroet and Johnson, 2009). 'Adaptive forest management' (Chikumbo *et al.*, 2000) is a '*systematic process for continually improving forest management, in conditions of complexity and uncertainty, by learning from the outcomes of operational practice*' (Lawrence and Gillett, 2011). Sustainable, adaptive forest management should combine management, research and monitoring, through forest surveys, the assessment of ecological impact, best available scientific knowledge and practical experience (MCPFE, 1993). Consequently, forest management needs to consider different types and sources of knowledge. Raymond *et al.* (2010) distinguished three broad knowledge classes in environmental management: (1) local knowledge, referring to 'informal, lay, personal, often implicit or tacit, but possibly expert knowledge held by land managers involved in environmental decision-making'; (2) scientific knowledge, defined as knowledge derived through more formalized processes such as research and/or applying scientific methods (systematic recorded knowledge or practice), existing in widely accessible written form (explicit scientific knowledge) or passed through a strict and universally accepted set of rules (formal scientific knowledge); and (3) hybrid knowledge, referring to 'new understandings emerging through the integration of different types of knowledge' (Raymond *et al.*, 2010). In this framework, the perceptions of practitioners and scientists can be considered as local knowledge, whereas data published in the international scientific literature is considered as explicit formal scientific knowledge.

The question whether a mixture of tree species may perform better than monocultures or deliver preferred services has been discussed since the beginning of forest science in the eighteenth century, but remains controversial (Pretzsch, 2005). Recent concerns about forest health, as well as forest management adaptation and mitigation strategies to face climate change, have led to the conversion of coniferous monocultures into broadleaved or mixed species stands in several regions (Spiecker *et al.*, 2004). While there are obvious effects of specific functional traits related to tree species on some ecosystem functions (for example, nutrient cycling; see Reich *et al.*, 2005; Malchair and Carnol, 2009; Carnol and Bazgir, 2013), the question of how and to what extent an increase in tree diversity will affect a multitude of ecosystem processes simultaneously is still rather equivocal (Scherer-Lorenzen *et al.*, 2005a; Nadrowski *et al.*, 2010). Functional biodiversity research in forests requires methodological choices regarding the type of study (observational, experimental removal/addition or experimental synthetic assemblage), the kind of dilution gradient (richness, dilution, genetic, structural, functional) and the variables to measure (Scherer-Lorenzen *et al.*, 2005b, 2007b; Hector *et al.*, 2007; Leuschner *et al.*, 2009; Baeten *et al.*, 2013). The type of experimental system used, the ecosystem studied, the control of plant density and the maximum species number in the most diverse treatment influence the outcomes and interpretation of biodiversity–ecosystem functioning relationships (Balvanera *et al.*, 2006). Differences in methodology, results obtained and interpretations lead to uncertainty in 'formal scientific knowledge'. Such uncertainty can be interpreted as a lack of coherence among competing scientific understandings and often leads to environmental controversies (Sarewitz, 2004). Quantitative, unbiased information on how tree diversity affects ecosystem functioning and ecosystem services can be obtained by carefully designed studies, but is still scarce (Leuschner *et al.*, 2009;

Baeten *et al*., 2013; Gamfeldt *et al*., 2013; Verheyen *et al*., 2013). Recent data syntheses and meta-analyses allow first evaluations of forest biodiversity–ecosystem–function linkages and also discuss the implication of different methodological approaches (Jactel and Brockerhoff, 2007; Thompson *et al*., 2009; Nadrowski *et al*., 2010; Paquette and Messier, 2011).

It can be assumed that local knowledge of stakeholders is based on a range of data sources and personal experience, despite an incomplete formal knowledge and understanding of the ecology of mixed species forest stands. For example, practitioners may obtain their information principally through experience, professional journals, personal communication with colleagues and the Internet, whereas scientists may rely more on the scientific literature (Janse, 2006). The perception of both scientists and practitioners is then still formed through the interpretation of the information obtained according to personal values, beliefs and attitudes (Wyatt *et al*., 2011), a process called 'selective perception'. This process leads to different perceptions of the same information by individuals through assumptions based on past experiences, cultural expectations, motivation (needs), moods and attitudes. Other selective mechanisms include selective processes of retention, attention and exposure (tendencies of individuals to recall, pay attention, and expose themselves to information close to own interests, values and beliefs). It can therefore be hypothesized that, in addition to different information access and data sources, stakeholders' perception would depend on their regional ecological and socio-economic context. Given the importance of NGOs, forest interest groups and research institutes with an advisory role in European forest policy-making (Janse, 2006), the perceptions of stakeholders are of paramount importance in influencing forest policy (Janse and Ottitsch, 2005; Janse, 2007, 2008). Furthermore, policy change and policy implementation of formal knowledge may be impeded by beliefs of 'advocacy coalitions' (people who share a set of nominative and causal beliefs and who often act in concert; Sabatier, 1988), who could be formed by the different stakeholder groups (Van Gossum *et al*., 2011). Thus, '*adaptive forest management requires social science*' (Lawrence and Gillett, 2011), and effective policy development requires a good understanding of stakeholders' perception of ecosystem services (Lamarque *et al*., 2011).

Despite this importance of stakeholders' perception in the development of sustainable forest management policies, no information is currently available on their perception on ecosystem services in mixed species stands. We addressed this knowledge gap by studying stakeholders' perception of ecosystem services of mixed species forest stands *vs* monocultures in Belgium. The federal structure of Belgium, where forest management policies are defined at regional level, provided the opportunity for a case study in two adjacent Regions, Flanders and Wallonia. These two Regions differ in several forestry-related characteristics, including the institutional framework, forest ownership structure, forest cover and the role of forests in society (Campioli *et al*., 2009, 2012; Van Gossum *et al*., 2011). Furthermore, we focussed on two stakeholder classes: forest scientists (not necessarily specialized in tree diversity issues) and forest practitioners (managers and owners). Perceptions of these two stakeholder classes are considered to be essential, as the elaboration of management plans emerges from the discussion between scientists and non-scientists (Raymond *et al*., 2010; Fontaine *et al*., 2014). The 'Flemish Forest Decree' for Flanders (1990) is an example of such a dialogue, as its development involved numerous stakeholders, including local authorities, rural planning entities and nature conservation groups (Schmithüsen, 2000). In Wallonia, the use of species adapted to site conditions was elaborated by an inter-university team and has been included in the Walloon forest code (Laurent, 2003).

The aim of this study was to examine the common ground between 'local knowledge' of ecosystem services provided by mixed species forest stands *vs* monocultures, measured by practitioners' and scientists' perceptions and 'explicit formal scientific knowledge', derived from a synthesis of published studies. We used a large survey among forest managers and forest scientists in Belgium to explore: (1) their perceptions of ecosystem services of mixed species stands *vs* monocultures, (2) the influence of the regional socio-economic context on these perceptions and (3) whether these perceptions are in agreement with current formal scientific knowledge.

Methods

Study area

Belgium is a federal state, composed of three federal Regions: Flanders, 13 521 km^2, Wallonia, 16 844 km^2 and Brussels-Capital, 162 km^2, comprising 21.1, 78.6 and 0.3 per cent of the total Belgian forest area (692 916 ha), respectively (Vande Walle *et al*., 2005). We examined the perception of ecosystem services in mixed species forest stands compared with monocultures in Flanders and Wallonia. In Flanders, a highly urbanized area (462 inhabitants per km^2; http://statbel.fgov.be) located in the north of Belgium, the forest covers 10.8 per cent of the territory. Main forest species are pines (*Pinus sylvestris* and *Pinus nigra*, 63 550 ha), followed by poplars (*Populus* spp, 19 060 ha), indigenous oaks (*Quercus robur* and *Quercus petraea*, 14 320 ha) and mixed broadleaved species (10 250 ha) (Vande Walle *et al*., 2005; Campioli *et al*., 2012). Flemish forests are very fragmented with a private ownership of ~70 per cent; main public owners are towns (~12 per cent) and the Region (~11 per cent). The main forest area of Flanders is situated in the Kempen ecoregion situated in north-eastern Belgium at an altitude between 10 and 100 m. It is an area of poor sandy soils, mainly Podzols developed in tertiary or quaternary deposits. Land use in the Kempen ecoregion is evenly distributed between agriculture (pasture and maize), forest and heathland, and urban and industrial developments. In Wallonia, a more rural region (208 inhabitants per km^2) located in the south of Belgium, the forest covers 32.3 per cent of the territory. Main forest tree species are spruce (*Picea abies*, 35.4 per cent), followed by oak (*Q. robur* and *Quercus petraea*, 22.8 per cent) and beech (*Fagus sylvatica*, 14.3 per cent) (SPW-DGARNE-DNF, 2011). About 50 per cent are privately owned and the main public owners are towns (~74 per cent) and the Region (~22 per cent). The main forest area of Wallonia (63 per cent) is situated in the Ardennes ecoregion, situated in south-eastern Belgium at an altitude between 200 and 694 m. Soils in the Ardennes are situated on Cambrian and Devonian bedrock and poor loamy Dystric Cambisols are the main soil types, while pastures and forests are the main land uses (Weissen *et al*., 1990).

Since the regionalization of the country in 1980, forest policies are defined at regional level. In Flanders, public forests are managed by ANB ('Agentschap voor Natuur en Bos') of the Department 'Leefmilieu, Natuur en Energie' of the Flemish Administration. The matter is attached to the Flemish Ministry of Environment, Nature and Culture. In Wallonia, public forests are managed by the DNF ('Département de la Nature et des Forêts') of the DGO3 ('Direction générale opérationnelle de l'Agriculture, des Ressources Naturelles et de l'Environnement') at the SPW (Service Public de Wallonie).

Survey methodology

Web-based anonymous questionnaires (implemented with SurveyMonkey; www.surveymonkey.com) were established in Dutch for the survey in

Flanders and in French for the survey in Wallonia. Invitations to respond to the questionnaire and to forward the invitation to stakeholders were distributed by e-mail to key contact persons of forestry/nature associations, forest management organizations (private and public) and universities (with forest research departments) (Table 1). This process is referred to as 'snowballing', whereby one informant puts the researcher in touch with other important stakeholders (Valentine, 1997). A disadvantage of the snowballing technique is that it is not possible to determine a response rate. Selected organizations were targeted because their members have a potential influence on the management of forests through their profession, their involvement in forest-related research and/or environmental/forest organizations. Forest scientists contacted for the enquiry were active in general forest ecology (generally not studying tree species diversity and ecosystem functioning) and they were not authors of the studies used for the comparison with their perceptions. Each questionnaire was enclosed with a cover letter identifying the general purpose of the study and key contact persons. The questionnaire was open for 1 month in April 2009.

Questionnaire structure

The ecosystem services concept, as defined by the Millenium Ecosystem Assessment (MEA, 2005), was selected as a frame for the questionnaire (Figure 1). The questionnaire consisted of three major sections: (1) participants' professional and demographic profile, (2) respondents' ratings of the importance of selected management objectives and (3) respondent's perceptions of ecosystem services in mixed species forest stands *vs* monocultures. For the management objectives, respondents were asked to express the degree of importance they granted to provided management objectives on five-level Likert items (1: no importance, 5: very important) (Table 2). A 'Likert item', is a single statement for which the respondent expresses his level of agreement or disagreement, whereas a 'Likert scale' is a multi-item scale and refers to the sum of responses on several Likert items (Clason and Dormody, 1994). We used individual items, each consisting of one statement related to a management objective. In the latter part, respondents were asked to express their degree of agreement (five-level Likert items; 1: totally disagree, 5: totally agree) with statements related to the supporting (biodiversity, nutrient cycling, resistance), provisioning (quantity, quality and financial return of forest production), regulating (climate, air, soil, water) and cultural (aesthetics, recreation) ecosystem services, comparing mixed species stands to monocultures (Table 3). Within the questionnaire, monocultures were defined as single species stands, and mixed species stands as stands with two or more (canopy) species grown together. No distinction was made for the type of species (coniferous/deciduous, indigenous/exotic), or for the spatial pattern in the distribution of the tree species (mixing in small groups or by tree, for example). Most studies investigating the relationship between tree diversity and ecosystem functioning also use similar definitions (Nadrowski *et al*., 2010). As life on earth and its biodiversity are the basis of all ecosystem services, we classified items related to components of biodiversity within the 'supporting' ecosystem service class. Questions were presented in a random order and it was not possible for respondents to see the link between the question and the category of ecosystem service. In addition, the phrasing of the direction of questions (i.e. mixed species stands are better/poorer) was randomly attributed to minimize problems with bias.

Statistical analysis

Data collection resulted in 331 returned questionnaires. Stakeholders were grouped into practitioners-P (comprising owners and managers) and scientists-S. Scientists were grouped into 'S' regardless whether they were also owners or managers. We hypothesized that the perception of scientists is more likely to be influenced by their access to the scientific literature. Questionnaires that were not filled out completely were discarded, resulting in a total number of 267 respondents in the final dataset. For data analyses, the degree of agreement for all items was expressed towards a statement assuming a better service in mixed species stands (i.e. '1', total

Table 1 Organizations selected for forwarding the questionnaire to their members in Flanders and Wallonia

Type of organization	Flanders	Wallonia
Forestry administration	ANB ('Agentschap voor Natuur en Bos': Flemish Administration)	DNF ('Département de la Nature et des Forêts': Walloon administration) Conseil Supérieur Wallon des Forêts et de la Filière Bois (forestry council)
Forest associations	FEDEMAR-Nl ('Belgische Federatie der Bosuitbaters en Houthandelaars': association of forest loggers and wood merchants) UVB ('Unie Vlaamse Bosbouw', association of forest owners and workers) Bosgroepen (Forest groups) Landelijk Vlaanderen (Group of landowners)	FEDEMAR-Fr ('Fédération Belge des exploitants forestiers et des marchands de bois': association of forest loggers and wood merchants) SRFB ('Société Royale Forestière de Belgique': association of forest owners)
NGO	VBV – Pro Silva ('Vereniging voor Bos in Vlaanderen', now 'Bos+': forest NGO and Flemish section of Pro Silva International) Natuurpunt (NGO for the protection of nature)	Pro Silva Wallonie (Walloon section of Pro Silva International) Natagora (NGO for the protection of nature) Forêt Wallonne (forest NGO)
Forest scientists	Ghent University KU Leuven (University) INBO (Research Institute for Nature and Forest)	Catholic University of Leuven Doctoral schools: scientists and students of all Walloon universities belonging to four doctoral schools (Biodiversity, ecology, evolution, Agricultural science and bioengineer, Science, technology and environmental management, Plant science)

Table 2 Summary of survey items related to management objectives[a] within the four ecosystem service classes

Service class	Abbreviation	Items
Supporting	STORM	Decrease risk from storms
	DISEASE	Protect forests against insects and illness
	BIODIVERSITY	Maintain/protect biodiversity of associated species
	FIRE	Protect forests against fire
	SOIL	Preserve soil quality (structure and nutrients)
Regulating	CARBON	Maintain/improve carbon storage capacity
	AIR	Ensure the air purification capacity of the canopy
	EROSION	Protect soils against erosion
	FLOOD	Limit flood risks
Provisioning	GAME	Maintain game population for maximizing hunting revenues
	WOOD-PRIVATE	Ensure wood supply to individuals (i.e. firewood)
	WOOD QUALITY	Ensure the production of wood of high quality
	WOOD	Ensure the supply of wood to the timber industry
	WATER	Protect water quality
	PRODUCTS	Ensure the presence and the possibility to collect non-wood products (fruits, mushrooms, . . .)
	DECIDUOUS	Diversify deciduous and coniferous species
	PROFITABILITY	Ensure profitability
Cultural	CULTURE	Preserve a cultural heritage
	LIFE	Provide an environment where it is pleasant to live

[a]Respondents were asked to express the importance they granted to the provided management objectives on a five-level Likert item.

disagreement and '5', total agreement, that the service is better in mixed species stands). Thus, results of questions phrased in the direction of a poorer service in mixed species stands were inversed (calculated through '6-result'). As individual items within a same ecosystem service class (Table 3) may result in opposite responses, the use of a summative scale was considered inappropriate and Likert items were analyzed individually.

We used cumulative link models (also called ordinal regression models) with logit link to test the effects of stakeholders and Regions on the rating of statements, i.e. the Likert items with response Categories 1–5. A cumulative model for respondent i and response category j is $\text{logit}[P(Y_i \leq j)] = \mu_j - X_i\beta$. The model provides intercepts μ_j for each cumulative logit and a regression part where X_i is a vector of predictors and β a set of effects. An important feature is that β represents the same effects for each response category. We used stakeholders, regions and their interaction as predictors. Since the age distribution of the respondents differed between Regions (see below), the actual age was used as an additional predictor. Models were fitted in R 3.0.1 with the *clm* function in the *ordinal* package (R Core Team 2013; Christensen, 2013). The functions *convergence* and *slice* were used to check model convergence. Separate graphs of the estimated intercepts and the regression part of the models were made for interpretation. First, the intercepts were re-expressed as probabilities: $[Y_i > j] = 1 - \text{logit}^{-1}(\mu_j)$, which allowed to express the distribution of ratings across the statements and ecosystem services categories. For instance, when the majority of respondents disagreed with a particular statement, the cumulative probabilities for response categories $j > 2$, 3 or 4 were comparatively low. Second, for the regression part of the model, the exponents of the estimated effects β (and their 95 per cent confidence intervals) represent odds ratios. The odds ratio is a widely used effects size measure that allows comparison of the strength of effects across the statements. Here we used the odds ratio of the event $Y \geq j$ (the odds of rating a survey item $\geq j$) for stakeholder levels 'scientists' relative to 'practitioners' and for region levels 'Flanders' relative to 'Wallonia'. For stakeholder classes, odds ratio >1 represent higher odds rating a statement $\geq j$ for scientists, whereas odds ratio <1 represent higher odds for practitioners. For the between region effects, odds ratio >1 represent higher odds rating a statement $\geq j$ for Flanders, whereas odds ratio <1 represent higher odds for Wallonia.

Comparison to current formal scientific knowledge

We compared local knowledge, derived from stakeholders' perceptions, with best available formal scientific knowledge, based on a scientific review of studies on forest tree diversity and ecosystem function compiled by Nadrowski *et al.* (2010). These authors focussed on 31 papers published after 2007, covering a diversity gradient extending beyond two species mixtures at the stand level. We further restricted our analysis to studies related to richness (species richness gradients with different species) and dilution (species richness gradients with one species occurring in all richness levels) gradients. Stakeholders' perceptions were summarized as cumulative probabilities for response category $j > 3$ ($P[\text{rating} > 3]$) and $j > 4$ ($P[\text{rating} > 4]$), i.e. better service in mixed species stands: 4 ($j > 3$) = agree, 5 ($j > 4$) = totally agree ($n = 267$).

Results

Respondent's profile

A total of 267 responses were analyzed, 165 and 102 from Wallonia and Flanders, respectively (Table 4). For the total sample, scientists represented 39 per cent and practitioners 61 per cent of the sample population. The number of scientists responding in each Region was similar, but a higher number of practitioners responded to the questionnaire in Wallonia (117 against 47). Scientists represented 54 per cent of respondents in Flanders, against 29 per cent in Wallonia.

The age distribution of the respondents differed between the two Regions, with higher mean age in Wallonia, mainly due to the higher age of practitioners (52 years) compared with scientists (40 years) responding in this Region.

Table 3 Summary of survey items related to the perception of ecosystem services in mixed species stands (*vs* monocultures)[a] within the four ecosystem service classes

Service class	Abbreviation	Items
Supporting	STORM	Mixed stands are more unstable against storms[b]
	DISEASE	Mixed stands are more vulnerable to pathogens (insects, fungi, bacteria, etc.)[b]
	HABITATS	Mixed stands provide a greater diversity of habitats
	BACTERIA	Mixed stands provide a greater diversity of bacteria
	FUNGI	Mixed stands provide a greater diversity of fungi
	MOSSES	Mixed stands provide a greater diversity of mosses and lichens
	PLANTS	Mixed stands provide a greater diversity of flowering plants
	INVERTEBRATES	Mixed stands provide a greater diversity of insects and other invertebrates
	BIRDS	Mixed stands provide a greater diversity of birds
	MAMMALS	Mixed stands provide a greater diversity of mammals
	SOIL	Soil impoverishment in nutrients is higher in mixed stands[b]
	NUTRIENTS	In mixed stands, nutrient availability is generally higher
	BROWSING	Mixed stands are more vulnerable to game damage[b]
Regulating	CARBON	Mixed stands store less carbon[b]
	AIR	Mixed stands contribute more to air purification
	EROSION	Mixed stands reduce erosion risks
	FLOOD	Mixed stands allow a better regulation of water (quantity)
	WATER	Pollutant charge (acids, nitrates,. . .) in waters under mixed stands is higher[b]
	FERTILITY	Mixed stands improve soil fertility
Provisioning	GAME	Mixed stands maintain higher game populations
	PRODUCTIVITY	Mixed stands are generally less productive[b]
	WOOD QUALITY	Mixed stands allow the production of higher quality wood
	PRODUCTS	Mixed stands allow the collection of higher quantities of fruit/mushrooms
	INVEST	Mixed stands require higher financial investments[b]
	PROFIT	Mixed stands are less profitable[b]
	PROFIT-GAME	In mixed stands, the financial return from hunting is more important
	PROFIT-WOOD	In mixed stands, the financial return from wood production is less important[b]
Cultural	RECREATION	Mixed stands offer more recreative opportunities
	AESTHETIC	Mixed stands have a higher aesthetic value

[a]Respondents were asked to express their agreement to the provided items on a five-level Likert item.
[b]Responses of these items were inversed for data analyses ('6 − result').

Table 4 Socio-demographic characteristics of the survey sample for Flanders ($n=102$) and Wallonia ($n=165$) and the total sample ($n=267$)

	Flanders		Wallonia		Total sample	
	%	*n*	%	*n*	%	*n*
Stakeholder						
Scientist	54	55	29	48	39	103
Practitioner	46	47	71	117	61	164
Age structure						
20–34 years	45	46	24	40	32	86
35–49	36	37	27	45	31	82
50–64	18	18	30	50	25	68
65–79	1	1	17	28	11	29
80–94	0	0	1	2	1	2

Perceived importance of management objectives

Lowest importance ($P[\text{rating} > 4] < 0.15$) was given to the following management objectives: maintaining the game population, providing protection against fire, ensuring wood supply to individuals and ensuring the presence of non-woody products (Figure 2a). Highest importance ($P[\text{rating} > 4] > 0.50$) was given to maintaining the biodiversity of associated species, preserving soil quality, protecting water quality, protecting against soil erosion and diseases, and to ensure the supply of wood to the timber industry.

Cumulative link models showed significant differences between Regions and/or stakeholders in the importance given to individual management objectives within each ecosystem service class (Table 5, Figure 2b). In Wallonia, significantly higher importance was given to management objectives related to supporting services, such as decreasing the risks of storms, preserving soil quality, protection against diseases and fire, as well as those related to the provisioning services of the wood sector, such as maintaining game populations for hunting revenues, ensuring wood supply, wood quality and profitability (Figure 2b; odds ratio 'Region' < 1). In Flanders, higher importance was given to the protection of biodiversity of associated species (supporting service), the presence of non-woody products (provisioning service), and the supply of an environment where it is pleasant to live (cultural service) (odds ratio 'Region' > 1).

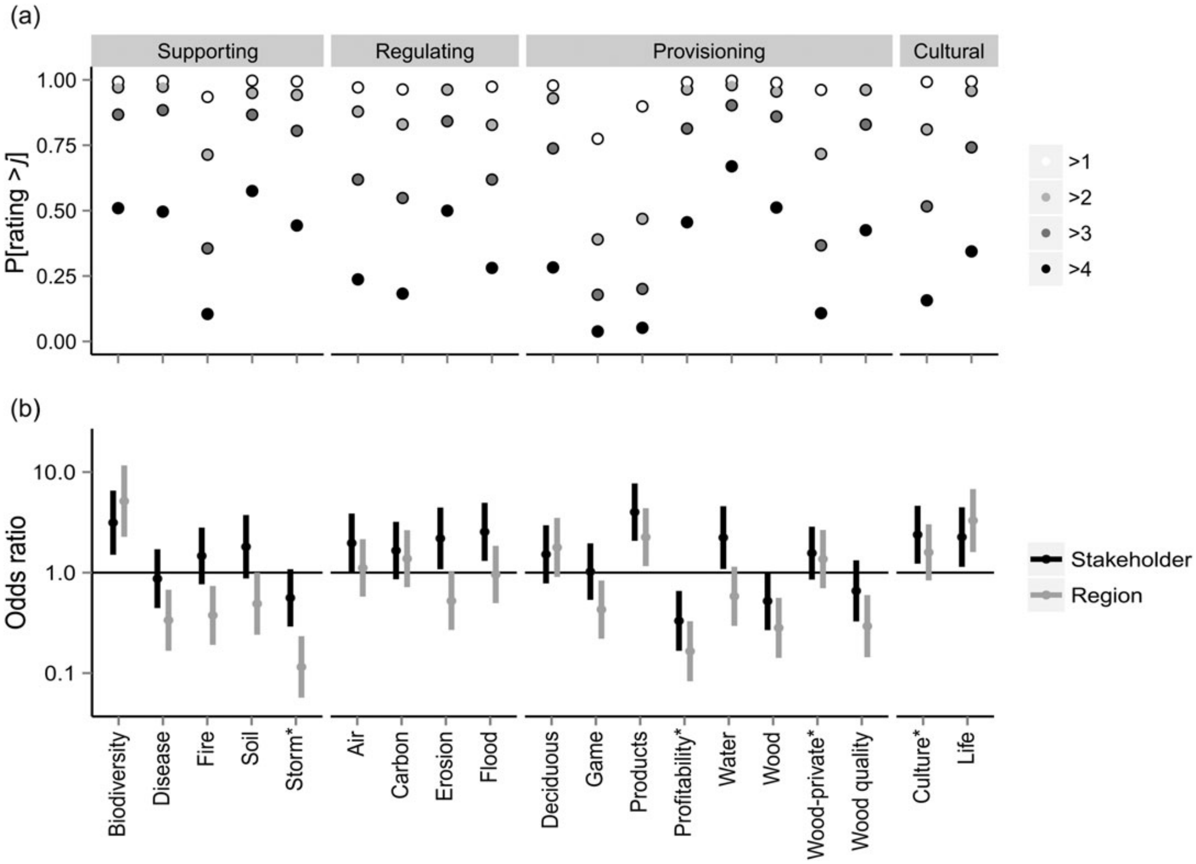

Figure 2 Results of cumulative link models, testing the effects of stakeholder categories (scientists, practitioners) and Regions (Flanders, Wallonia) on the survey respondents' importance attributed to management objectives (1 = no importance, 5 = very important). Items are presented by ecosystem services categories and they are abbreviated as in Table 2. (a) Probability of rating a statement >1, 2, 3 or 4 across stakeholder categories and Regions (b) Effects of stakeholder and Region, expressed as odds ratios (±95% confidence intervals) on a log scale. For stakeholder classes, odds ratio >1 represent higher odds rating a statement ≥*j* for scientists, whereas odds ratio <1 represent higher odds for practitioners. Between Regions, odds ratio >1 represent higher odds rating a statement ≥*j* for Flanders, whereas odds ratio <1 represent higher odds for Wallonia. *Significant stakeholder × region interaction.

In both Regions, scientists attributed a significantly higher importance to numerous objectives related to supporting (protect biodiversity of associated species), regulating (maintain air quality, limit flood risks, protect against erosion), provisioning (non-woody products, protect water quality) and cultural (preserve cultural heritage, provide an environment where it is pleasant to live) services when compared with practitioners (Table 5, Figure 2b – odds ratio 'Stakeholder' >1). Scientists assigned lower importance to ensuring profitability.

Analysis of significant interactions (Supplementary Figure 1) showed that in Flanders, scientists attributed higher importance to decreasing the risks of storms and ensuring profitability, compared with practitioners, whereas this was opposite in Wallonia. In contrast in Wallonia, scientists attributed higher importance to ensuring wood supply to individuals and preserving cultural heritage, compared with practitioners and this was opposite in Flanders.

Perceived ecosystem services in mixed species stands compared with monocultures

There was a broad agreement that supporting services would be better in mixed species stands than in monocultures (Figure 3a), as *P*[rating > 3] for items related to supporting services were generally >0.85 (except vulnerability to game damage: 0.75). Respondents also perceived regulating services to be globally higher in mixed species stands, with *P*[rating > 3] between 0.74 and 0.93, except for air purification capacity (0.69) and carbon storage (0.62). A high percentage of respondents had no opinion or did not have an answer to some items related to regulating services, particularly for the regulation of water quantity (22 per cent), pollutant charge in waters (29 per cent), air purification (22 per cent) and carbon storage (29 per cent). The opinion related to provisioning services was generally neutral (*P*[rating > 3] between 0.53 and 0.71 (except for financial return from hunting: 0.40). Cultural services, such as aesthetic value (*P*[rating > 3] = 0.89) and recreational opportunities (*P*[rating > 3] = 0.58) were also perceived to be better in mixed species stands.

Regional differences between the perception of stakeholders for the individual items (Table 6, Figure 3b – odds ratio 'Region' > 1) indicated a significantly higher score in Flanders for numerous supporting services related to components of biodiversity, for the collection of fruits/mushrooms, financial return from hunting and for recreational opportunities.

Table 5 Results (estimates on the logit scale and *P*-values) of cumulative link models testing differences in the importance attributed to management objectives between stakeholders and Regions

	Stakeholder (Scientist)		Region (Flanders)		Age		Stakeholder : Region	
	Estimate	*P*	Estimate	*P*	Estimate	*P*	Estimate	*P*
Supporting								
Biodiversity	1.144	**0.002**	1.638	**<0.001**	−0.013	0.176	−1.124	0.061
Disease	−0.139	0.686	−1.091	**0.002**	−0.006	0.509	0.716	0.155
Fire	0.383	0.247	−0.979	**0.004**	0.018	**0.039**	0.585	0.229
Soil	0.592	0.110	−0.713	**0.050**	−0.005	0.611	0.085	0.873
Storm	−0.579	0.084	−2.160	**<0.001**	0.005	0.589	1.249	**0.012**
Regulating								
Air	0.675	0.051	0.108	0.749	<0.001	1.000	−0.184	0.707
Carbon	0.505	0.132	0.318	0.338	0.005	0.578	−0.078	0.873
Erosion	0.783	**0.030**	−0.648	0.057	−0.008	0.382	0.043	0.932
Flood	0.935	**0.006**	−0.043	0.898	−0.005	0.533	−0.237	0.626
Provisioning								
Deciduous	0.418	0.218	0.576	0.095	<0.001	0.992	0.391	0.438
Game	0.022	0.946	−0.847	**0.013**	0.004	0.616	0.271	0.573
Products	1.386	**<0.001**	0.812	**0.016**	0.001	0.939	−0.851	0.078
Profitability	−1.105	**0.002**	−1.801	**<0.001**	0.005	0.561	1.553	**0.002**
Water	0.802	**0.029**	−0.544	0.116	−0.020	**0.033**	0.472	0.375
Wood	−0.652	0.054	−1.265	**<0.001**	−0.001	0.920	0.811	0.101
Wood quality	−0.419	0.241	−1.227	**0.001**	0.021	**0.027**	0.081	0.875
Wood-private	0.447	0.148	0.310	0.361	0.002	0.845	−0.961	**0.047**
Cultural								
Culture	0.868	**0.010**	0.463	0.157	0.011	0.203	−1.004	**0.039**
Life	0.815	**0.019**	1.193	**0.001**	0.001	0.953	−0.971	0.066

Significant differences ($P < 0.05$) are indicated in bold. Items are presented by ecosystem services categories and they are abbreviated as in Table 2.

A significant higher level of agreement for scientists, compared with practitioners, was found for some items in all four ecosystem service classes (Table 6, Figure 3b – odds ratio 'Stakeholder' > 1). These items were bird diversity, resistance to game damage, diversity of habitats (supporting services); air purification, reduction of erosion risks (regulating services); collection of fruits/mushrooms, financial return from hunting (provisioning services); and recreational opportunities (cultural services). A high percentage of respondents did not know whether profit from hunting would be different in mixed species stands compared with monocultures.

Significant interactions for supporting (diversity of bacteria, birds, habitats and invertebrates; resistance to game damage) and provisioning services (reduced financial investment, collection of fruits/mushrooms, financial return from hunting) showed higher values for practitioners in Flanders, but the opposite (higher values for scientists) in Wallonia (Supplementary Figure 2).

Perceptions of ecosystem services in mixed species stands and current formal scientific knowledge

Stakeholders generally believed that resistance to pathogens, biodiversity of associated species and nutrient cycling would be higher in mixed species stands, as indicated by the high probability of rating an item >3 (4 = agree) and >4 (5 = totally agree) (Table 7). For nutrient cycling, this perception was in agreement with results from the literature, as 13 out of 16 studies showed positive effects of tree diversity on ecosystem functioning. The strong positive opinion of stakeholders on the resistance to pathogens and associated biodiversity contrasted with less conclusive results from the literature: 5 of 9 studies and 11 of 23 studies reported neutral or negative effects of tree diversity on the resistance to herbivory and on properties of associated biotic communities (arthropods, earthworms, microorganisms, herbs), respectively.

Stakeholders' perception and literature results differed with regard to tree productivity. While stakeholders perceived productivity to be rather equal in mixed species stands and monocultures ($P[\text{rating} > 3] = 0.67$), the literature review indicated higher productivity in mixed species stands in 5 out of 7 studies (Table 7).

Discussion

In our enquiry, supporting, regulating and cultural ecosystem services were perceived to be better in mixed species stands. Provisioning services were generally perceived to be equal in mixed species stands and monocultures. These perceptions were significantly influenced by stakeholder group (scientists–practitioners) and Region (Flanders–Wallonia). Results showed a higher agreement towards better services in mixed species stands for scientists, compared with practitioners, and for Flanders, compared with Wallonia. However, the differences were relatively small and did not change the direction of perception from better to poorer service.

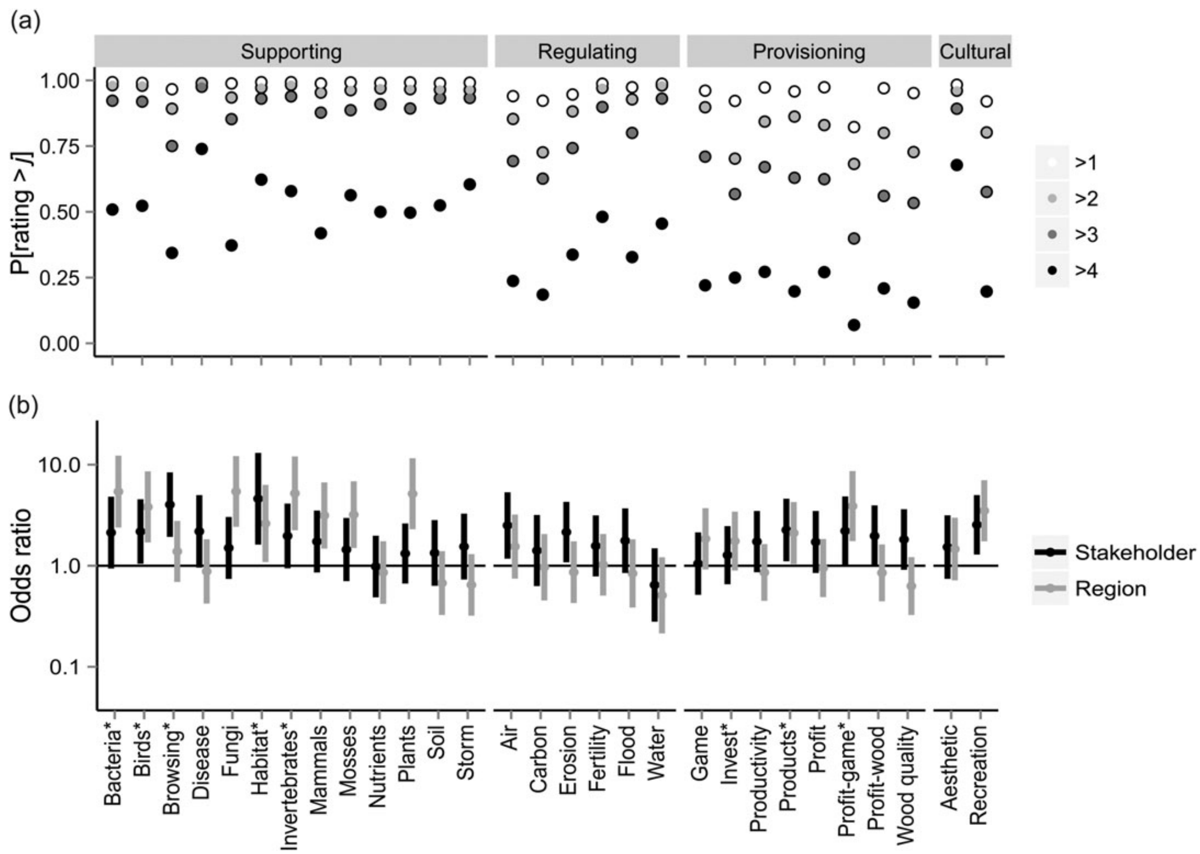

Figure 3 Results of cumulative link models, testing the effects of stakeholder categories (scientists, practitioners) and Regions (Flanders, Wallonia) on the survey respondents' perception of ecosystem services in mixed stand, compared with monocultures (better service in mixed species stands: 1 = totally disagree, 5 = totally agree). Items are presented by ecosystem services categories and they are abbreviated as in Table 3. (a) Probability of rating a statement >1, 2, 3 or 4 across stakeholder categories and Regions (b) Effects of stakeholder and Region, expressed as odds ratios (±95% confidence intervals) on a log scale. For stakeholder classes, odds ratio >1 represent higher odds rating a statement ≥*j* for scientists, whereas odds ratio <1 represent higher odds for practitioners. Between Regions, odds ratio >1 represent higher odds rating a statement ≥*j* for Flanders, whereas odds ratio <1 represent higher odds for Wallonia. *Significant stakeholder × region interaction.

Regional differences showed a significantly higher score in Flanders for supporting services related to biodiversity, for the collection of fruit/mushrooms, financial return from hunting and recreational opportunities. The perception of the supply of these services in mixed species stands was thus higher in Flanders compared with Wallonia. This tendency was also apparent in the higher importance ascribed in Flanders to management objectives related to the protection of the biodiversity of associated species, the presence of non-woody products, and the provision of a pleasant environment. The different ecological and socio-economic context in Flanders and Wallonia may explain regional and stakeholders' differences in perceptions in our study. Flanders is characterized by low forest cover, high population density and urbanization (Campioli *et al*., 2012). These factors lead to a higher emphasis in recreational and environmental functions in forest policy (Janse and Ottitsch, 2005). Furthermore, the forest code for Flanders stressed the economic, social, environmental, ecological and scientific role of forests as early as 1990, whereas the multifunctional role of forests was only included in the Walloon forest code in 2008 (Schmithüsen, 2000; Laurent, 2003). As forest policy in Flanders is more directed towards recreation and nature conservation, information towards practitioners might also emphasize these aspects.

Stakeholder group significantly influenced the perceptions in all four ecosystem service classes, with a lower score for practitioners. All significant items in supporting and provisioning service classes showed a significant stakeholder × region interaction, interpreted through a lower agreement of practitioners in Wallonia. Practitioners in Wallonia also gave the highest importance to management objectives related to the supporting service 'decreasing risks from storms' and to provisioning services related to wood production, 'ensuring production of wood of high quality', 'ensure supply of wood to the timber industry' and 'ensure profitability'. We can link these differences to the socio-economic context in Wallonia, where forest products represent an important economic resource for owners, communities and the Region (Luyssaert *et al*., 2000; Laurent and Lecomte, 2007a). Timber from conifers, the major forest product in Wallonia, is the base for numerous businesses and families dependent on the wood sector. Hunting is also a regular, non-negligible source of income. Similarly, concerns for the risk of storm may be related to the large area occupied by spruce on shallow infertile soils (Campioli *et al*., 2012), and previous

Table 6 Results (estimates on the logit scale and *P*-values) of cumulative link models testing differences in the perception of ecosystem services in mixed species stands compared with monocultures between stakeholders and Regions

	Stakeholder (Scientist)		Region (Flanders)		Age		Stakeholder : Region	
	Estimate	*P*	Estimate	*P*	Estimate	*P*	Estimate	*P*
Supporting								
Bacteria	0.754	0.070	1.689	**<0.001**	−0.016	0.129	−1.404	**0.019**
Birds	0.779	**0.037**	1.340	**0.001**	−0.003	0.773	−1.454	**0.012**
Browsing	1.391	**<0.001**	0.325	0.359	−0.003	0.778	−1.297	**0.014**
Disease	0.783	0.063	−0.130	0.728	−0.012	0.236	0.021	0.973
Fungi	0.405	0.261	1.692	**<0.001**	−0.001	0.887	−1.053	0.062
Habitat	1.526	**0.004**	0.961	**0.032**	0.004	0.753	−1.714	**0.019**
Invertebrates	0.678	0.071	1.648	**<0.001**	−0.013	0.199	−1.296	**0.029**
Mammals	0.551	0.125	1.145	**0.003**	<0.001	0.983	−0.741	0.175
Mosses	0.368	0.316	1.163	**0.003**	−0.017	0.064	−0.564	0.310
Nutrients	−0.019	0.958	−0.156	0.668	−0.017	0.069	−0.569	0.298
Plants	0.278	0.425	1.639	**<0.001**	−0.007	0.446	−0.823	0.146
Soil	0.291	0.445	−0.395	0.286	−0.002	0.866	−0.175	0.749
Storm	0.436	0.254	−0.436	0.222	−0.006	0.555	0.072	0.894
Regulating								
Air	0.918	**0.017**	0.436	0.241	−0.018	0.066	−1.054	0.060
Carbon	0.345	0.403	−0.035	0.928	0.016	0.113	−0.039	0.945
Erosion	0.766	**0.029**	−0.147	0.680	−0.007	0.454	−0.158	0.759
Fertility	0.451	0.202	0.022	0.952	−0.009	0.335	−0.866	0.094
Flood	0.571	0.128	−0.176	0.656	−0.018	0.081	−0.475	0.391
Water	−0.439	0.302	−0.676	0.127	0.012	0.286	0.618	0.322
Provisioning								
Game	0.047	0.896	0.613	0.085	0.009	0.359	−0.672	0.192
Invest	0.240	0.476	0.561	0.101	−0.016	0.081	−1.123	0.023
Productivity	0.549	0.122	−0.153	0.641	−0.017	0.054	−0.014	0.978
Products	0.814	**0.025**	0.744	0.038	−0.005	0.583	−1.118	0.035
Profit	0.541	0.132	−0.052	0.876	−0.023	0.010	−0.432	0.387
Profit-game	0.792	0.048	1.358	0.001	0.006	0.582	−1.399	0.020
Profit-wood	0.678	0.055	−0.162	0.623	−0.025	0.007	−0.480	0.335
Wood quality	0.597	0.089	−0.463	0.168	−0.015	0.109	−0.250	0.617
Cultural								
Aesthetic	0.424	0.249	0.380	0.294	−0.011	0.256	−0.500	0.355
Recreation	0.932	**0.007**	1.252	<0.001	0.006	0.511	−0.933	0.064

Significant differences ($P < 0.05$) are indicated in bold. Items are presented by ecosystem services categories and they are abbreviated as in Table 3.

damage through storms. For example, the 1990 wind storm resulted in ~11.7 Mm^3 and 0.7 Mm^3 windthrow in spruce and broadleaved stands, respectively (Laurent and Lecomte, 2007b).

The comparison of local knowledge, derived from stakeholders' perceptions, with best available formal scientific knowledge showed that better nutrient cycling in mixed forests, as demonstrated through research (Nadrowski *et al*., 2010), was also perceived as such by the stakeholders. Literature on resistance to herbivory and associated biodiversity showed positive, neutral or negative effects of tree diversity, which contrasted with the strong opinion of stakeholders, perceiving these services to be better in mixed species stands. However, in a meta-analysis covering 119 studies, Jactel and Brockerhoff (2007) observed a significantly lower level of herbivory in mixed species stands, particularly with oligophagous species. Regarding these various response patterns to tree diversity, Nadrowski *et al*. (2010) stressed that the effect of diversity *per se*, *vs* the 'identity effect' caused by the presence of specific tree species or species traits, needs to be considered and that no simple assemblage rule could be defined. For example the presence of N-fixing species, such as alder, may have specific impacts on ecosystem functioning, compared with non N-fixing species (Rothe and Binkley, 2001; Selmants *et al*., 2005; Carnol and Bazgir, 2013). Our enquiry focussed on the general perception of mixed species stands, irrespective of the spatial mixing pattern or species composition. Also, we did not distinguish between species identity, type (coniferous–deciduous) and nature (native-indigenous). This is along the line of early biodiversity–ecosystem functioning research (Scherer-Lorenzen *et al*., 2005a), investigating whether an overall link between biodiversity and ecosystem function can be established. We believe that policy development and implementation is likely to be influenced more by the general perception of practitioners than by

Table 7 Comparison of stakeholders' perceptions ($n = 267$; cumulative probabilities for response category $j > 3$ (P[rating > 3]) and $j > 4$ (P[rating > 4]), i.e. better service in mixed species stands: 4 = agree, 5 = totally agree) with best available formal scientific knowledge (Nadrowski *et al.*, 2010)[a] on ecosystem services in mixed forests (n: number of studies; numbers of negative, neutral and positive effects of tree diversity on ecosystem functioning)

Current study (probability of rating an item >3 and >4)				Best formal scientific knowledge (counts)			
Item(s)	P[rating > 3]	P[rating > 4]	Forest ecosystem functions	n	Negative	Neutral	Positive
Decreased vulnerability to pathogens	0.98	0.74	Resistance to herbivory	9	3	2	4
Biodiversity of associated species[b]	0.85–0.94	0.37–0.58	Biota community property	23	2	9	12
Nutrient cycling[c]	0.90–0.91	0.48–0.50	Nutrient cycling[d]	16	0[e]	3	13
Higher productivity	0.67	0.27	Production	7	0	2	5

[a]The following literature was used; resistance to herbivory: Vehvilainen and Koricheva, 2006; Vehvilainen *et al.*, 2007; von Don *et al.*, 2007; Sobek *et al.*, 2009a; Schuldt *et al.*, 2010; biota community property: Cesarz *et al.*, 2007; Vehvilainen *et al.*, 2007,2008; Molder *et al.*, 2008; Murphy *et al.*, 2008; Schuldt *et al.*, 2008; Ackerman *et al.*, 2009; Sobek *et al.*, 2009a,b,c; nutrient cycling: Scherer-Lorenzen *et al.*, 2007a; Guckland *et al.*, 2009; Jacob *et al.*, 2009; Talkner *et al.*, 2009; production: Liang *et al.*, 2007; Vila *et al.*, 2007; Healy *et al.*, 2008; Piotto, 2008; Potvin and Gotelli, 2008; Myster, 2009.
[b]Range for group of items: greater diversity of bacteria, fungi, mosses, plants, invertebrates, birds and mammals.
[c]Range for group of items: increased nutrient availability, improved soil fertility.
[d]Total of functions: litter production, phosphorus cycle, decomposition and element cycling.
[e]The original paper reported two negative effects (decrease in Al and Mn under mixtures) which are actually positive effects. This has been corrected in this table in agreement with K. Nadrowski.

particular situations. Nevertheless, management plans will need to recognize the role of individual species, their proportions and the influence of the spatial mixing patterns. Thus the role of individual tree species and of particular tree species combinations in providing ecosystem services still need to be further investigated.

A major discrepancy between stakeholders' perception and literature results was found for tree productivity. While literature indicated higher productivity in mixed species stands (Nadrowski *et al.*, 2010), stakeholders perceived productivity to be rather equal in mixed species stands and monocultures. After reviewing 20 studies (excluding studies with confounding factors), Thompson *et al.* (2009) concluded that diversity generally increased the productivity of forests. A recent modelling approach for Sweden also showed a positive, hump-shaped relationship for tree biomass production in relation to tree species richness, with an increase of 54 per cent at 5-species richness compared with monocultures (Gamfeldt *et al.*, 2013). Despite the scientists' better access to scientific literature, the perception of both practitioners and scientists contrasted with recent literature (no significant stakeholder effect). This discrepancy between recent formal scientific data and stakeholders' perception on productivity is a potential source of conflict originating from concerns on productivity and financial return, especially in areas where productivity is a main management objective (Niemela *et al.*, 2005). As for supporting services, it should be stressed that the identity of the species in mixtures seems also more important than diversity *per se* for the provisioning services. Indeed, the two main mechanisms identified by Kelty (1992) for affecting the outcome of productivity in mixtures (competitive reduction and facilitation), are highly tree species dependent.

Literature indicates some potential differences in regulating services, such as air purification (Berger *et al.*, 2008), water quality (De Schrijver *et al.*, 2007), carbon storage (Ciais *et al.*, 2008; De Deyn *et al.*, 2008; Díaz *et al.*, 2009; Gamfeldt *et al.*, 2013), under forest stands of different composition. However, despite the importance of regulating services in forests (Bonan, 2008), information from studies optimizing orthogonality (capacity to discriminate biodiversity effects against confounding variables), comprehensiveness (simultaneous measurement of a multitude of functions), and representativity (design reflecting 'real world' forest ecosystems), as well as explicitly comparing mixed species stands and monocultures is scarce (Nadrowski *et al.*, 2010). In spite of limited scientific information, the opinion expressed in our study assumed better water quality and higher carbon storage in mixed species stands. Opinion for erosion risks, air purification and pollutant charge in waters was more moderate. For these regulating services, >20 per cent of the respondents expressed that they had 'no opinion' or 'did not know', reflecting either the uncertainty in insufficient scientific knowledge or a lack of knowledge of the stakeholders on the topic. Similarly, Hoehn *et al.* (2003) noticed a lack of knowledge or misconceptions for regulating services, such as pollution filtering, in wetlands, and Agbenyega *et al.* (2009) reported a low appreciation of regulating services in community woodlands in the UK. The latter authors hypothesized that regulation services were under-valued as they are more 'invisible' (Lewan and Soderqvist, 2002) and that accurate assessment of the value of regulating services would depend on improved understanding. These observations call for both more research explicitly directed towards regulating services in mixed forests, as well as improved communication of the topic towards practitioners.

The integration of science into policy is hampered by many extrinsic factors to science, so that scientists often lack influence at the policy level. Decreasing uncertainties by more research is thus no guarantee for more science-guided policy (Sarewitz, 2004; Perrings *et al.*, 2011; Thompson *et al.*, 2011). However, the scientific basis of forest management has been strengthened through the assessment of past forest management practices on current forest structure and function, and as a result, science has played an important role in improving operational sustainable forest management (Thompson *et al.*, 2011). Furthermore, stakeholders are involved European forest policy making (Janse, 2006, 2008). Our study highlights a discrepancy between formal scientific knowledge and local knowledge on the issue of productivity in mixed species stands. This is of particular importance, as economic valuation of ecosystem services provides a link between science and policy (Thompson *et al*., 2011). Also, formal knowledge on regulating services is incomplete and the role of regulating services seems to be less well understood by the stakeholders. Identification and synthesis of existing formal and local knowledge, communicating the role and value of biodiversity in the provision of ecosystem services to the stakeholders, designing studies and framing research questions in relation to ecosystem services and real policy options (actual and future), and creating places and opportunities fostering quality science–policy–practice interface seem to be a way forward (Raymond *et al*., 2010; Perrings *et al*., 2011; Thompson *et al*., 2011; Cook *et al*., 2013; Stewart *et al*., 2013).

Conclusion

In conclusion, supporting, regulating and cultural services were perceived to be better in mixed species stands, compared with monocultures. This positive perception contrasted with the less conclusive results from the literature, where positive, negative and neutral effects were reported. A major discrepancy was revealed for provisioning services, which were perceived to be equal in mixed species stands and monocultures, but where the literature indicated higher provisioning in mixed species stands. Also, scientific information from well-designed studies with increasing tree diversity gradients is lacking for numerous ecosystem services. Regional differences in perceptions could be linked to the ecological and socio-economic contexts in the two Regions investigated. Higher importance was given to biodiversity and recreation related services in the densely populated, highly urbanized and low forested region of Flanders, whereas higher importance was attached to provisioning services in Wallonia. Communication towards practitioners therefore needs to consider ecological and socio-economic contexts, and special attention has to be paid to communication on productivity issues and on regulating services.

Our results also highlighted the need to address the lack of scientific data and to adjust stakeholders' perception to recent formal scientific knowledge through efficient communication and information flow. We believe that the ecosystem service framework proved to be useful for investigating stakeholders' perceptions and establishing a link between stakeholders, research and management. Tree biodiversity–ecosystem functioning research should be directed towards key ecosystem processes that can be linked to ecosystem services, as they may provide a basis for clear communication between all parties. We suggest three ways for strengthening the link between forest research, management and policy: (1) set up well-planned scientific studies with long-term funding at the relevant scale for forest management (2) synthesize available scientific literature on regular basis, in order to offer a clear view to the stakeholders and (3) establish places and opportunities for quality exchange on different knowledge types, improving the science–policy–practice interface.

Supplementary data

Supplementary data are available at *Forestry* Online.

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Conflict of interest statement

None declared.

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