

Between biodiversity conservation and sustainable forest management – A multidisciplinary assessment of the emblematic Białowieża Forest case

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ABSTRACT

The tension between biodiversity conservation and multipurpose forest management may lead to conflicts. An internationally prominent example is the Białowieża Forest Massif (BFM), an extensive forest complex with high levels of naturalness. We apply a systematic, multidisciplinary assessment process to review empirical evidence on different dimensions of the BFM conflict. While there is broad consensus that this forest massif is an exceptional place worth conserving and that a way forward is a zonation system combining conservation with management, exactly how this should be done has yet to be agreed upon. Our assessment shows that the key reasons for the BFM controversy go beyond the availability of knowledge on the ecological status of the BFM and include: 1) evidence stemming from different sources, which is often contradictory and prone to different interpretations; 2) knowledge gaps, particularly with regard to socio-economic drivers and beneficiaries as well as uncertainties about future trends; 3) fundamentally different values and priorities among stakeholder groups, resulting in power struggles, and an overall lack of trust. We conclude that evidence-based knowledge alone is insufficient to cope with complex conservation conflicts. While more evidence may help assess the consequences of decisions, the actual management decisions depend on different actors' worldviews, which are rooted in their professional identities and power, and their political and legal realities. This calls for conflict management through a well-organized participatory process organized and supervised by a body deemed legitimate by the groups involved.

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1. Introduction

The conservation of forest biodiversity is dependent upon habitat retention at multiples scales (Lindenmayer et al., 2006). This objective frequently competes with forest management aimed at wood and biomass production in the same area (Angelstam et al., 2018; Mönkkönen et al., 2014; Naumov et al., 2018), which can lead to severe conflicts – from policy and governance to planning and forest management (Niemelä et al., 2005; Young et al., 2005). Consequently, there is an ongoing global debate about how to reconcile forest use, and specifically wood production, with biodiversity conservation (Bicknell et al., 2015; Borrass et al., 2017; Edwards et al., 2014; Fischer et al., 2008; Gustafsson et al., 2012; Maier and Winkel, 2017; Phalan et al., 2011).

A prominent example of the conflict between biodiversity conservation and forestry is the controversy regarding the Polish part of the cross-border Białowieża Forest Massif (BFM) (Marris, 2008; Stokstad, 2017). The BFM is characterized by remnants of forests with high levels of naturalness; including a high abundance of large and old trees (Fig. 1), high amounts of standing and lying dead-wood in diverse stages of decomposition, close-to-natural dynamics of forest stands (Angelstam and Dönn-Breuss, 2004; Faliński, 1986) and a continuity of tree cover for the last 12 thousand years (Latałowa et al., 2015). This applies in particular to the Białowieża National Park (BNP), which covers 16.6% of the Polish part of the BFM. These features support species representing a wide range of life history traits and complete species guilds. As such, for decades the BFM, particularly the strict reserve of the BNP, has been an important reference area for scientists studying natural characteristics and dynamics of European forests (Brzeziecki et al., 2016; Faliński, 1986; Jędrzejewska and Jędrzejewski, 1998; Miścicki, 2012, 2017; Wesołowski et al., 2015). At the same time, large parts of the BFM have been subject to manifold local uses. The BFM has also a significant symbolic importance for foresters and society

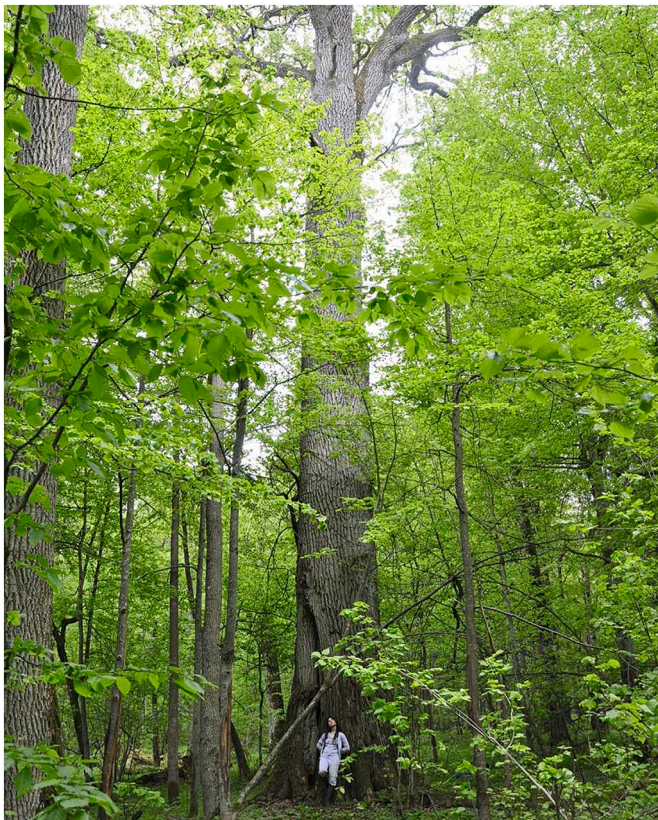


Fig. 1. Large trees in the Białowieża Forest Massif. (Photo: Janusz Korbela.)

as a whole, in Poland and beyond (Bartczak et al., 2008; Franklin, 2002).

There is a long history of conflict relating to the Polish part of the BFM (Blicharska and Angelstam, 2010; Blicharska and Van Herzele, 2015). Since the beginning of the 1990s, there have been conflicts over how to manage the BFM, specifically the parts under Polish State Forest (SF) management, which are outside the BNP (Blicharska and Angelstam, 2010). In a simplified perspective, what we call the “environmental coalition” (Niedziałkowski, 2016) – comprised of conservation biologists and ecology scientists, some forest scientists, as well as environmental activists – has called for an increase of the strictly protected area of the forest, preferably by enlarging the existing BNP to cover the whole Polish part of the BFM. In opposition to that, what we call the “forestry coalition” (Niedziałkowski, 2016) – including foresters, a majority of forest scientists and the majority of local people – argues that the present management is supportive of biodiversity conservation, as well as local need for fuelwood, non-timber forest products and jobs. The key aspects of the conflict (Blicharska and Van Herzele, 2015) include (1) the ecology of the forest, especially disturbances and how to manage them for ecological values, (2) the history of the area and resulting values (either related to an ecosystem largely formed by natural processes or through human activities), (3) the needs of local communities using the forest, and value of the BFM for the whole Polish society, and (4) the social, political and symbolic meanings of the area. The conflict has roots in different understandings of what biodiversity conservation and sustainable management mean between various groups of stakeholders, professionals and scientists (Blicharska et al., 2016; Blicharska and Van Herzele, 2015). This has invoked debates ranging from the roles of tourism and wood-based industry for local rural development to institutional and political controversies at the national and EU level. In recent years the conflict has become particularly intense: this is due to the increased logging in one of the SF districts of the BFM so as to address a large outbreak of spruce bark beetle (*Ips typographus*), and the recent decision by the European Court of Justice to halt logging related to this outbreak (ECJ, 2018; Stereńczak et al., 2019; Stokstad, 2017).

The aim of this paper is to contribute to conflict resolution in the BFM case and other conservation related land use conflicts through exploring the evidence-based knowledge. As a first objective we review the existing evidence behind the different arguments in the BFM conflict in order to better understand the controversy as a whole. In particular, we focus on the following questions: 1) What is the ecological state of BFM, key drivers that determine it, and possible effects of different management approaches on it, 2) How have humans interacted with BFM and what may it mean for today's management opportunities, 3) What is the socio-economic importance of the BFM, and 4) What are the political importance of the BFM conflict, the issues at stake and the role of different actors. As a second objective we identify the contested issues and knowledge gaps linked to these questions. As a final objective we conclude from the two previous ones on the overall nature of the conflict, and options to resolve it in the future.

To do so, we apply a systematic, multidisciplinary, evidence-based assessment process involving scientists representing a wide range of relevant disciplines and perspectives, selected to cover the key socio-ecological dimensions of the conflict. These include: ecology to understand ecosystem processes including disturbances that affect the amount of habitat for species; forest management to identify options for forest use and conservation focusing on particular objectives; environmental history and anthropology to trace human–nature interactions over time; economics to understand economic relations including aspects of distribution and efficiency; and sociology and political science to analyse values and interests as drivers of conflict and governance arrangements for handling the conflict.

Our assessment results in a summary of the arguments where compelling evidence exists and of the contested issues where evidence is weak, contradictory or unavailable. Based on these results we

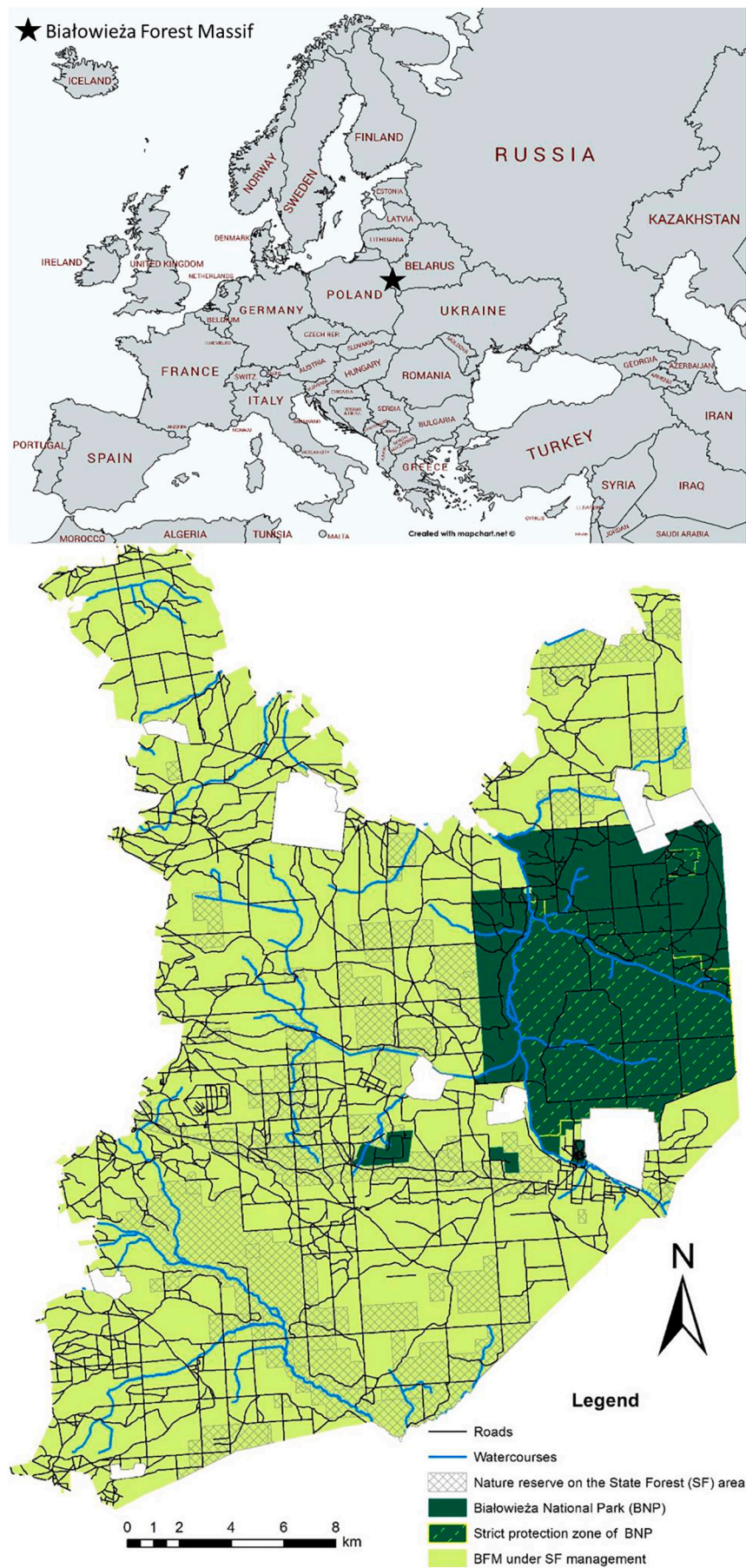


Fig. 2. The Polish part of the Białowieża Forest Massif and its protection and management zones.

elaborate on forest management challenges, particularly those entailed by the conflicts between biodiversity conservation and forest use. We discuss lessons learned from the Białowieża case that could inform other conflicts relating to conservation and forest use, with a particular focus on the role of evidence-based knowledge in addressing such conflicts.

2. Methodology

2.1. The Białowieża Forest Massif

The Białowieża Forest Massif (BFM) is located on the border between Poland and Belarus and covers approximately 1500 km². This study focuses on the Polish part of the BFM, ca. 630 km² (Fig. 2). If not indicated otherwise, we use “BFM” to refer to the Polish part of this massif. The BFM is understood here as a socio-ecological system that comprises lands allocated to various national and international management and conservation regimes, statutory categories under national law, as well as EU and international nature conservation regulations and rules, being at the same time subject to regular forest management and land use under the applicable forest legislation (Agrawal, 2000; Logmani et al., 2017; Niedziałkowski et al., 2014). The BFM is a UNESCO Biosphere Reserve, a NATURA 2000 area (both an EU Special Protection Area for birds and a Special Area for Conservation for habitats), and a part of a transboundary UNESCO World Heritage Site. Also, under Polish law, it is an Area of the Protected Landscape (which excludes only the Białowieża National Park). This means that particular areas of the BFM fall under the jurisdiction of different public administrations and are legally allocated to a variety of specific land uses according to national, EU and international regulations (Grygar, 2016; Grzeszczak and Muchel, 2018).

The BFM in Poland consists of two main parts. The first part of the BFM (105 km²) is the Białowieża National Park (BNP), of which close to 58% (ca. 60.5 km²) is strictly protected; 39% (ca. 41 km²) is subject to active protection/conservation management (excluding timber harvesting) aimed at maintaining and restoring populations of rare and threatened species (e.g. eastern pasqueflower *Pulsatilla patens*, European bison *Bison bonasus*) and natural forest structures and processes; and 3.4% (ca. 3.5 km²) is a landscape conservation zone, which includes tourism facilities and the European bison breeding centre. The second part of the BFM (525 km²) consists of three forest management units of the Polish National Forest Holding “State Forests” (SF). The politically set goal of the SF is sustainable forest management that includes the provision of multiple ecosystem services, including both wood and non-wood products, as well as regulating services (Blicharska et al., 2012; Chudy et al., 2016; Majchrowska, 2018). This part of the BFM includes many nature reserves, altogether covering about 125 km², and an additional 56 km² reference zone that has been excluded from timber harvesting since 2016.

2.2. Methods

This paper reports a systematically structured scientific assessment process conducted in three steps.

In the first step researchers from the European Forest Institute scanned the scientific literature, as well as available policy documents, press releases, internet (particularly social media debates) on the BFM controversy (in English and in Polish). To get an overview of the case, interviews were conducted with ten selected experts on the BFM. This allowed for the identification of five major topic areas of the controversy: (1) forest ecology, (2) forest disturbances and management, (3) forest history, (4) socio-economic factors, (5) forest policy and governance. Subsequently, Polish and international scholars were identified that fulfilled the selection criteria: (1) published research of relevance to the BFM case within the selected topic areas, (2) complementarity of perspectives on the BFM case (i.e., ranging from being

supportive towards active forest management to supportive towards increase in conservation), and (3) overall academic reputation (as evaluated by publication record). These top-listed scholars representing complementary perspectives were contacted and asked to join the research process. This led to the identification of twenty scientists: ten were chosen as “experts”, ten as “moderators”; for each topic area there was one expert and one moderator from each viewpoint, conservation and forestry. The moderators were asked to support the experts in identifying and discussing the existing evidence. Selecting the experts from different disciplines and representing both sides of the debate allowed us to identify the most important arguments in the BFM conflict. For details of expert selection, see Appendix A.

Experts were then asked to systematically screen the evidence existing in relation to their own discipline and to compile evidence statements for their topics. The experts followed an acknowledged scientific method by selecting, within their expertise, relevant and most recent scientific literature, reliable data and information sources, so as to provide the state of the art scientific understanding of the issues. When the task was given to participants there were almost 1200 peer-reviewed research papers or reviews listed in Scopus that mentioned Białowieża in title, abstract, or key words. Of course, only part of these were relevant to this study and the expert's role was to identify them and include in the analysis. Moreover, where evidence from BFM was insufficient, the search was expanded to other papers potentially relevant to BFM. The evidence statements aimed at summarising the current scientific knowledge on each topic, referring to empirical evidence, as well as contested issues for which the evidence either was weak or contradictory, or unavailable. The experts were also asked to include recommendations for policy and management based on the available evidence. This resulted in ten drafts of evidence statements (Appendix B).

In the second step all 20 scientists attended a workshop in Białowieża in August 2018. During the workshop evidence statements were presented by experts, commented on by moderators and subsequently discussed by the whole group. Particular attention was paid to the empirical evidence gathered in the statements. As a result, some claims that were not supported by strong evidence (i.e. peer-reviewed sources) were added to the list of contested issues. A Chatham House Rule setting was agreed upon, meaning participants committed to not reveal outside the group who had been using which argument in the debate (ChathamHouse, 2019). Two field trips were organized to facilitate the discussion of evidence in the field: one with SF representatives, the other with BNP ones. At the end of the workshop all participants agreed to contribute to this joint publication describing the outcomes of the process. The workshop resulted in written notes summarising the claims that were supported by evidence, and the claims that were not (and thus are presented in this paper as contested issues).

In the third step the experts prepared updated texts as input to the results section of the article, based on the evidence statements and the outcomes of the workshop discussion. For practical reasons the first two topics (forest ecology, and forest disturbances and management) were combined into one section, as it turned out their scopes strongly overlapped and the relevant evidence and arguments closely interrelated. Three additional experts, whose expertise was missing (with regard to forest history and forest disturbances), were added during the process; one of the experts initially included left the study, resulting in 22 authors altogether. The lead author, elected by all participants during the workshop, compiled the texts in the results section. Several iterations of the emerging manuscript were done, both among all authors and between the lead author and individual co-authors or groups of co-authors. The key aim was to refine the synthesized evidence, and to remove claims that did not have strong support in available evidence. A key criterion for the strength of the evidence was if it was published in peer-reviewed articles or books, as the peer-review process guarantees a form of quality assessment. Due to a lack of evidence in some cases, grey literature was included; this is clearly indicated in the Results

section as (potentially) weaker evidence. When refining the evidence subsections of the paper, claims that lacked compelling evidence were moved to the subsections containing contested issues and knowledge gaps. The paper was submitted when a general agreement about the evidence and the contested issues was achieved.

In the following sections we present the evidence relating to the four outlined key aspects of the BFM conflict: (1) Forest ecology, disturbances and management (Section 3.1); (2) Forest history (Section 3.2); (3) Socio-economic factors (Section 3.3) and (4) Forest policy and governance (Section 3.4). For each subsection we provide a short summary of key arguments in the conflict, the underlying evidence and a summary of the contested issues, i.e. where the evidence is unavailable, is contradictory or weak.

3. Results

3.1. Forest ecology, disturbances and management

3.1.1. The conflict

A key controversy is how the forest should be managed to maintain its biodiversity conservation values. Representatives of the environmental coalition suggest that the majority of the BFM's natural or near-to-natural forest areas (including some SF areas) should be left for natural disturbances to operate, and that no large-scale cuttings should be allowed, such as sanitary cutting invoked by an extensive bark beetle outbreak. Representatives of the forestry coalition suggest that the SF part should be actively managed by silvicultural measures to maintain its current state, including supporting existing species composition, which justifies the use of sanitary cutting to mitigate impacts of bark beetle outbreaks or other major natural disturbances (e.g. windthrows).

3.1.2. Evidence

The BFM is one of the largest and best-preserved temperate zone lowland forests in Europe (Bohn et al., 2000; Faliński, 1986). It has been shaped by complex interactions of natural disturbance factors and human activities over a long time (Bobiec et al., 2011; Latałowa et al., 2015; Niklasson et al., 2010; Samojlik et al., 2013b). The forest site types are diverse and range from rich wet to poor mesic (see Kwiatkowski's map of vegetation landscapes: <https://www.bdl.lasy.gov.pl/portal/mapy>), and are matched by several different natural disturbance regimes (Angelstam and Kuuluvainen, 2004; Bobiec et al., 2000; Brumelis et al., 2011; Faliński, 1986). These regimes range from gap dynamics with shade-tolerant broad-leaved deciduous trees (Bobiec et al., 2000; Faliński, 1986) to cohort dynamics linked to historic low-intensity fires (Bobiec et al., 2011; Zin, 2016), and succession after infrequent stand-replacing disturbances caused by fire, wind or insects (Mikusiński et al., 2018; Wesołowski and Rowiński, 2006). The majority of natural disturbances in the BFM over the past half century have been caused by biotic factors like the fungal ash and elm diseases, flooding by beavers and insect outbreaks, and to some degree by abiotic factors, mainly wind-storms (Brzeziecki et al., 2016; Keczyński, 2002). Bark beetle outbreaks have occurred in the BFM several times over the last few decades (Grodzki, 2016), which has caused substantial mortality rates of Norway spruce (*Picea abies*) in the whole BFM (Stereńczak et al., 2017; Stereńczak et al., 2020; Stereńczak et al., 2019).

In addition to natural disturbances, human activity has modified processes and patterns in the BFM, and has influenced its biodiversity over the long term (Faliński, 1986; Zin, 2016) (see also: <http://www.forbiosensing.pl/#> and Section 3.2 below). Human use of forest, including grazing and browsing of livestock and burning of the forest understory until the end of the 19th century (Zin et al., 2015), led in some places to the creation of half-open forests with specific combination of diverse flora and fauna. More open forest communities created by long-term human use (Samojlik and Jędrzejewska, 2004), thermophilous oak forest (Jakubowska-Gabara, 1996; Sokołowski, 1987) and acidophilous pine-spruce-oak forest (Matuszkiewicz, 2011)

hosted, in the past, rare species of high conservation value, for example, insects like the great capricorn beetle (*Cerambyx cerdo*) and the stag beetle (*Lucanus cervus*) (J. Hilszczański, unpubl. data). Most of these species have not been recorded in the BFM for many decades, regardless of the management intensity or protection status, most probably due to the cessation of traditional forms of forest use, especially cattle grazing, which was banned in Poland in the 1960s. Human impacts culminated in the mid-nineteenth century, when the extent of non-forested areas of anthropogenic origin within the entire BFM approached almost 30% (Mikusińska et al., 2013).

Over the past century in Poland forest management has aimed at wood production; activities related to the control of bark beetles have led to an increased proportion of Norway spruce (Faliński, 1986) (see also <http://www.forbiosensing.pl/#>) at the expense of deciduous tree species. Low intensity, partly anthropogenic disturbances by fire declined rapidly since the end of the 18th century (Niklasson et al., 2010; Zin, 2016). Subsequently, the shade-tolerant hornbeam (*Carpinus betulus*) has expanded (Kwiatkowska and Wyszomirski, 1988). This has hampered the regeneration of Scots pine (*Pinus sylvestris*) and other light-demanding tree species. In addition, spruce bark beetles have impacted Norway spruce, and especially monoculture spruce forests, in the BFM for a long time. Last decade's outbreak was the largest post-World War II (Stereńczak et al., 2020). The area impacted peaked 2012–17, which led the logging of 675 ha of older Norway spruce forest stands (around 1% of BFM) from 2016 to 2018 (Mikusiński et al., 2018). The least human altered part of the BFM with the most intact natural dynamics is found in the BNP, where no logging has been conducted in the past century. The monitoring of tree species dynamics over 76 years in the BNP shows ongoing shifts in tree species structure in favour of shade-tolerant hornbeam as part of natural dynamics (Brzeziecki et al., 2016).

The difference between the low human-impact inside the BNP and the higher impact in the rest of the BFM has resulted in different amounts of habitat components indicating forest naturalness. For example, Angelstam and Dönnz-Breuss (2004) report that the incidence of trees with diameter at breast height (dbh) > 80 cm is 58% in the BNP, compared to 16% in the rest of the BFM; the basal area of deadwood: 9.7 compared to 2.6 m²/ha, respectively; incidence of old forest stands: 96 compared to 49%, and incidence of uprooted trees: 86 compared to 65%, respectively. Also, tree cavities are four times more common inside of the BNP (Walankiewicz et al., 2014), influencing the composition and structure of the bird community (Czeszczewik et al., 2015). Moreover, focal species such as woodpeckers are less common in the managed parts of the BFM (Angelstam et al., 2002; Czeszczewik et al., 2013; Roberge et al., 2008). Notably, other managed Polish forests surrounding BFM have lower amounts of natural habitat components by an order of magnitude (Angelstam and Dönnz-Breuss, 2004). With regard to Norway spruce, research conducted in the strict reserve, other reserves and old forest stands in the managed parts of the BFM shows that average height and dbh of spruce does not differ significantly between these areas. However, there are some differences in spatial distribution of this species in these areas (Erfanifard et al., 2019).

3.1.3. Contestation and knowledge gaps

A first controversy is linked to biodiversity conservation and relates to BFM's size. It has been proposed that a minimum dynamic area is needed to maintain natural disturbance regimes that ensure the continuous presence of different habitats (Leroux et al., 2007; Pickett and Thompson, 1978). Estimates of minimum dynamic areas vary with disturbance regimes and range from 500 km² (Potapov et al., 2017) to 20,000 km² (Andrew et al., 2014). However, scientists in line with the perspective of the environmental coalition maintain that mixed-species forests in the BFM are shaped mostly by small-scale canopy gap disturbances, resulting in a shifting mosaic steady-state able to maintain biodiversity (Bobiec et al., 2000; Faliński, 1986; Jaroszewicz et al., 2017). Therefore, they suggest allowing for natural processes in most of

the BFM stands (Mikusiński et al., 2018; Wesolowski, 2005), thereby arguing that the size of the BFM is not a problem in maintaining its natural processes. At the same time, scientists representing the view of the forestry coalition consider the BFM too small to be able to maintain its current species diversity through natural processes, and suggest active management based on silvicultural interventions, e.g. artificial regeneration to support renewal of some species, e.g. pine (Brzeziecki et al., 2018; Brzeziecki et al., 2017; Brzeziecki et al., 2016). They also argue that large-scale windthrows covering many square kilometres are also likely to happen in the BFM, even though the probability of such events occurring in the Białowieża region is lower compared to other parts of Europe (Schelhaas et al., 2010).

The second controversy concerns the management of bark beetle outbreaks. On the one hand, scientists representing a forestry coalition perspective indicate that, especially in highly fragmented European forests where protected areas are adjacent to forests managed for wood production, limiting beetle expansion and preventing adverse economic effects of large-scale spruce bark beetle outbreaks is justified, and early intervention including the creation of 500 m wide protective buffer zones around strictly protected areas is effective (Fettig and Hilszczański, 2015; Stadelmann et al., 2013). According to this perspective, sanitary cuttings could have stopped the ongoing outbreak of bark beetle if the large number of relatively small protected areas (nature reserves) spread across the BFM would not have effectively limited a large-scale removal of infested trees. Consequently, protected areas are regarded as potential infestation spots that pose a threat to adjacent stands (Wermelinger, 2004). Thus, some of these scientists suggest a rearrangement of the network of protected areas in the BFM to combine them in less numerous and larger areas to allow more effective control of bark beetle populations (Holeksa 2019, personal communication). On the other hand, scientists representing the perspective of the environmental coalition claim that limiting the bark beetle population by removing infested trees is ineffective when infestation is widespread (Fahse and Heurich, 2011; Lausch et al., 2011; Sproull et al., 2017). While the respective literature partially confirms that it is particularly difficult to practice bark beetle control through management in a mosaic of managed and strictly protected areas (Dobor et al., 2019; Mezei et al., 2017), other scientists claim that protected areas did not serve as a source of the outbreak in the BFM (Gutowski and Krzysztofiański, 2005), which was also evidenced elsewhere (Schlyter and Lundgren, 1993). An additional dimension of the controversy is linked to current forest management practices in the BFM, specifically the question of what was done with trees killed by the bark beetle. While some scientists state that foresters conducted salvage logging of most of these trees to avoid economic losses and eliminate safety risks, others claim that only sanitary cuttings with an aim to stop the bark beetle outbreak were done.

The third controversy concerns the priorities for species conservation in the BFM. Scientists representing the view of the forestry coalition argue that intervention is necessary to maintain the habitats of particular species (of open forest or linked to old spruce). They claim that while a non-intervention strategy would favour late-successional species, it would at the same time lead to the disappearance of species associated with early successional stages after disturbances. For example, long-term research plots in the strictly protected part of the BNP indicate a reduction in tree species diversity (Brzeziecki et al., 2016), providing argument for active management in a majority of stands of the BFM to maintain the existing tree species composition. On the other hand, scientists representing the conservation coalition's perspective highlight the importance of the BFM being continuously forested (Kaplan et al., 2009; Latałowa et al., 2016; Mikusinska et al., 2013), and with natural disturbance regimes sufficient to maintain the full diversity of species (Jaroszewicz et al., 2017; Mikusiński et al., 2018; Wesolowski, 2005). They suggest a non-intervention strategy in most of the BFM stands to allow for gap-phase dynamics, including some larger

wind-felled areas (Bobiec et al., 2011; Jaroszewicz et al., 2017; Szwagrzyk et al., 2018).

3.2. Forest history

3.2.1. The conflict

The basic controversy relates to the question whether the BFM should be considered a natural heritage or a cultural heritage, and what implications this has for management and conservation of the forest. While the representatives of the environmental coalition highlight the naturalness of the forest and focus on the maintenance of ecological structures and processes, the representatives of the forestry coalition underline the role of people in shaping the BFM as it is now, and the need to focus on cultural values and past remains.

3.2.2. Evidence

Evidence shows that humans have been present in the BFM for at least several thousand years. Well-preserved relicts of former human activity from different time periods (e.g. ground barrows, remains of charcoal hearths, newly discovered polygonal land divides – relicts of old settlement and/or fields) have been identified on numerous sites (Górska, 1976; Götze, 1929; Hedemann, 1939; Krasnodębski and Olczak, 2012; Samojlik, 2007; Samojlik et al., 2013a; Wawrzyniuk et al., 2017; Zapłata and Stereńczak, 2016; Zapłata et al., 2018). In prehistoric times the BFM area was associated with a variety of human activities, including agricultural activities leading to the short-term deforestation of some fragments of the BFM (Zapłata and Stereńczak, 2016; Zimny et al., 2017).

Human presence in the forest has varied between periods with more intensive use and periods with little human impact (e.g. drop in anthropogenic indicators in the 6th–10th century) (Latałowa et al., 2015; Latałowa et al., 2016; Samojlik, 2007). Specifically, BFM dynamics are interrelated with the presence of animals; the human management of animals in this area has occurred in the past and occurs now in the present (Krasnodębski and Olczak, 2012; Latałowa et al., 2015; Samojlik et al., 2013a; Zapłata and Stereńczak, 2017; Zimny et al., 2017). From the 14th until the end of the 18th century, the BFM was managed as a hunting reserve of Polish kings, which contributed to shaping the forest mosaic. From the 17th century onwards human activity included local villagers and townspeople using specific parts of the forest described in the so-called “access rights” – special permissions given by the king. Such permissions incorporated mainly haymaking on forest meadows and river valleys, carving beehives and settling bees to produce honey and wax, fishing in forest rivers, harvesting berries, mushrooms or firewood, and pasturing cattle on meadows adjacent to villages (Samojlik, 2007; Samojlik et al., 2013b). However, the local people were not allowed to hunt or fell timber. At the beginning of the 20th century over 5 million m³ of wood was harvested (Więcko, 1984): around 2.6 million m³ during World War I by occupying German forces and a further 2.6 million m³ between 1924 and 1929 by the English company The Century European Corporation. According to a technical report from 1923 (Mokrzejcki, 1923), a large zone of forest was degraded during the German wood harvesting. This created a feeding base for the bark beetle, which led to the biggest outbreak of bark beetle in the BFM recorded before World War II, between 1919 and 1923, killing >1.3 million m³ of spruce (in the whole BFM, including the Belarusian side).

Nevertheless, natural regeneration of the forest was maintained. According to palynological studies, the BFM has never been fully deforested at any one time, and continuity of forest cover, at least in parts of the BFM, has not been disrupted in the last twelve thousand years. Evidence for this is based mainly on pollen analysis both for the BNP area and for the managed part of the BFM (Latałowa et al., 2015; Latałowa et al., 2016). Archaeological research on the entire BFM found the remains of agricultural systems on a total area of at least 25 km²,

the oldest initially dated 2000 years old, indicating a presence of agricultural activities in some parts of the forests in the past (Wawrzyński et al., 2017; Zapłata and Stereńczak, 2016, 2018).

3.2.3. Contestation and knowledge gaps

There is no full consensus on whether the BFM should be seen primarily as a cultural heritage or if it should be understood primarily as a natural heritage area, or in how far and with what spatial dimensions both perspectives can co-exist. Studies applying the cultural heritage framework, which aims to understand cultural dynamics in the forest, are so far underrepresented in the research regarding the BFM. Moreover, there is no consensus on the range and impact of economic activities in the BFM across time and space; for instance, whether or not, and where, pre-industrial activities significantly disturbed forest habitats before the end of the 18th century – specifically the time before the hunting reserve was established in the 14th century or what were the impacts of industrial forestry activities in the first half of the 20th century.

3.3. Socio-economic factors

3.3.1. The conflict

The main disagreement regards what the key socio-economic values of the BFM are and how this is distributed among different actors. Representatives of the forestry coalition emphasize the importance of the forest for the local people's livelihoods, through supply of wood products (Blicharska and Van Herzele, 2015) and job provision (Niedziałkowski, 2016). Environmental coalition representatives underline the value of the BFM for the whole Polish society and also locally for the possibility of increased income from employment in the tourism sector. Additionally, they emphasize the international brand of the BFM's natural heritage and existence value per se.

3.3.2. Evidence

There is limited evidence on the socio-economic importance of the BFM; however, some data exist. With 630 km², of which 525 km² is under SF management, the BFM constitutes <1% of the 92,000 km² total Polish forest cover. Thus, at the national level the BFM is a minor generator of income and employment in the forestry sector. Locally, Gołos and Zając (2007) estimate the contribution forest-based goods and services in the BFM at USD 4.8 million/year enabling 452 jobs in the forest sector and 413 outside. On top of this is the wood-processing industry. However, in such measures, substitution effects are not considered and, as a consequence, if these values and jobs are lost, the effect on the society will likely be smaller than these numbers indicate. On the other hand, it has been suggested that the limited SF profits are also related to the limitations on timber harvesting resulting from nature conservation regulations in the BFM (Janeczko, 2008; Janeczko and Parzych, 2008); however, this is not confirmed by peer-reviewed evidence.

Locally, fuelwood and the collection of mushrooms and berries are considered important in the BFM (Niedziałkowski et al., 2014). According to a local authority report (not peer-reviewed), the demand for fuelwood in the county Hajnówka, where the BFM is located, is estimated to be around 350 thousand m³/year (Brzostowski et al., 2014). At the same time local supply indicated in local forest management plans (RDLP, 2011a, 2011b, 2012) is only 48 thousand m³/year, because of conservation rules. Thus, the region is already strongly dependent on wood imported from other areas (Niedziałkowski et al., 2014). In terms of employment, jobs in the SF are more prestigious and better paid compared to the jobs in the BNP service (Niedziałkowski, 2016).

Regarding the recreational values of the BFM, Bartczak et al. (2008) estimate the average recreational value of Polish forests to be 5–8 billion € or 570–970 €/ha, with the BFM being at the high end. Giergiczyński (2009) estimates the consumer surplus for the visits in the BFM to be

2.7 million €. These benefits were 27 times greater than the profits currently generated by the SF in the BFM. Other studies indicate that the “naturalness” of the BFM is an important characteristic for tourism: one study (Janeczko and Janeczko, 2015) explores the economic benefits provided by the tourists visiting the managed part of the BFM, and estimates tourist spending at 2.1 million € per year. According to this study, 64% of the 355 respondents came specifically to the BFM because of its “unique natural character”. A recent study by Czeszczewik et al. (2019) points out that birding tourism is an important source of income for the local community (birdwatchers stay longer in the BFM and spend more money per day of visit compared to other visitors) and that those species linked to unmanaged old growth forests are the most desirable for birdwatchers visiting the BFM.

There is also agreement on the BFM's high symbolic importance for Polish society and beyond (Bartczak, 2006). Studies measuring this in economic terms find a Willingness to Pay (WTP) of 20 €/household/year (Czajkowski et al., 2009) for improving biodiversity levels in the BFM, and Bartczak (2015) confirms the high WTP even among people who have never visited the area. The BFM is frequently attributed to be unique in the larger European context. While we could not find peer-reviewed papers confirming this symbolic importance, e.g. based on empirical social science research with the European public or policy makers, the designations of the BFM as Man and Biosphere Reserve, World Heritage Site, and Diploma of Europe (awarded by the Council of Europe to protected areas of exceptional European conservation interest), as well as the rich scientific and media coverage (Marris, 2008; Stokstad, 2017) and the high amount of publications in international, peer-reviewed journals all suggest BFM's international symbolic importance (see also Bakhtiari et al., 2018; Dallimer et al., 2015).

3.3.3. Contestation and knowledge gaps

Firstly, there is substantial uncertainty on what the actual benefits of the BFM are for local people, also compared to the perceived benefits. This concerns, in particular, local benefits of timber harvest, the dependency of local people on local fuelwood and on non-timber benefits (collection of non-wood forest products and hunting), and benefits from tourism. While wood production and the forest sector have importance, especially locally, detailed input–output models for the region that also consider substitution effects would be needed to assess the de facto importance of local wood supply.

Secondly, although it is suggested that the BFM is important for tourism income, and existing studies do indicate that the “naturalness” of the forest is an important characteristic to support touristic development, the correlation remains unclear between forest value for tourism and different forest management or conservation measures (including potential tourism restrictions). Specifically, the distribution of costs and benefits of different use options – who bears costs and who receives benefits – is unknown (e.g. foregone timber value for the forestry sector or foregone tourism value for local people versus foregone options to support fuel wood for local people and foregone benefits for non-local tourism companies).

Thirdly, it is unclear what the actual costs and benefits of the (potential) increase in protection of the managed part of the BFM are. It is unclear who would benefit and who would suffer from increased protection or forest use. This relates to questions of prestige and salary level of possibly competing branches in relation to the forest (e.g. wood production sector versus tourism versus conservation work). In addition, the economic costs of the BFM controversy itself in terms of possibly decreasing interests of investors to invest in forestry/forest industry and tourism, also beyond the region, are unknown.

Finally, while the symbolic importance of the BFM has been studied and is estimated to be of high value, it is less known what symbolic meaning the forest has in terms of culture, religion and identity to different societal groups (Franklin, 2002).

3.4. Forest policy and governance

3.4.1. The conflict

The key contested issues linked to policy and governance concern the possible options for resolution of the conflict, linked to existing interests and priorities, as well as perceptions of the roles of the different parts of the BFM.

3.4.2. Evidence

The BFM controversy is driven by a political controversy between two opposing coalitions with competing interests and values (Blicharska and Angelstam, 2010; Niedziałkowski et al., 2012), the environmental coalition and the forestry coalition (for details see Introduction). Each of these groups is concerned with the attainment of their specific policy core beliefs, values and preferences (Bieńkowska et al., 2019; Niedziałkowski, 2016; Witkowski, 2017), which can be broadly aligned with either of two worldviews: conserving the biological traits of the forest or safeguarding the sustainable flow of forest provisions (Konczal, 2017; Naumov et al., 2018). To a large extent, the tensions are driven by opposing definitions of and solutions to the problems of BFM management, and the very notions of “biodiversity” and “naturalness” in particular (Konczal, 2017). While the environmental coalition believes that the BFM outside the BNP is negatively affected by timber harvesting, the forestry coalition believes that the forest has already lost its natural resilience and requires human intervention.

Apart from environmental considerations, some of the public forest managers oppose an enlargement of the BNP due to possible consequences of losing well-paid employment and professional prestige (Niedziałkowski, 2016). Others express concerns about “giving away” the BFM as a potential first step to “losing” other forest areas to conservation (Bakhtiari et al., 2018; Logmani et al., 2017; Niedziałkowski, 2016; Niedziałkowski et al., 2014; Niedziałkowski and Shkaruba, 2018), indicating the relevance of the BFM case at a national political level.

Each coalition draws on strategic power resources. In the environmental coalition, these include (1) scientific conservation knowledge and ecological data provided by scientists, (2) favourable supranational regulations at the EU level together with related implementation procedures and court rulings, as well as (3) the ability of NGOs to attract domestic and transnational public attention, to mobilize domestic and transnational conservation networks and to thereby organize protests (Blicharska and Van Herzele, 2015; Franklin, 2002; Niedziałkowski et al., 2019). In the forestry coalition these resources include (1) scientific forest research and expert knowledge providing support and legitimacy, (2) SF foresters' professional, financial and organizational resources and decision making rights at local and national levels according to domestic regulations, and (3) local residents' and communities' opposition to government initiatives restricting forest management (Blavascunas, 2014).

Since the beginning of the 1990s the debate in BFM has been dominated by attempts of the environmental coalition to convince the government to enlarge the BNP and restrict harvesting in the areas managed by the SF, as well as by attempts of the SF to prevent such changes (Blicharska and Van Herzele, 2015; Niedziałkowski et al., 2012). The government attempted to resolve the conflict but its actions were plagued by its unfulfilled promises to the local authorities, invalid implementation of support programmes and insufficient resources, as well as lacking commitment with regard to building consensus (Niedziałkowski et al., 2019). This in turn increased distrust and strategic activities aimed at distorting the communication, resulting in increased polarization. The introduction of legal veto rights for the local and regional authorities concerning a national park enlargement in 2000 shifted the venue of decision making downwards, while at the same time Poland's accession to the EU in 2004 added a new supranational level of decision making with a respective biodiversity

legislation. A meaningful, participatory dialogue did not take place among the actors involved; the possibility to organize such a dialogue decreased as the dynamic and polarization of the conflict increased (Niedziałkowski et al., 2019).

3.4.3. Contestation and knowledge gaps

A large body of social science literature (Blavascunas, 2014; Konczal, 2017; Logmani et al., 2017; Niedziałkowski, 2016; Niedziałkowski et al., 2012) points to the dominant position of the SF and its employees in the BFM conflict. It is claimed that SF managers engaged in a number of symbolic and material practices to control the BFM, and to some extent successfully defended their influence and interests against nature conservation options raised by environmentalists since the 1920s (Blavascunas, 2014; Szafer, 1957). In contrast, Franklin (2002) argues that since the 1990s the controversy has been driven by environmentalists, who have constructed an “inaccurate” vision of the BFM and want to “close” the forest for human use. According to Witkowski (2017), involved civil society groups and international organizations often lack detailed technical knowledge about the issues at stake.

Another disagreement in the reviewed literature refers to potential practical solutions proposed to resolve the controversy (Kuboń et al., 2018; Niedziałkowski et al., 2019; Niedziałkowski and Shkaruba, 2018). A widely recommended solution is to empower stakeholders to work within a participatory process (Blicharska and Angelstam, 2010; Franklin, 2002; Sadowski, 1995); this is also supported by leading SF representatives (Konieczny 2018, personal communication). However, to be successful, such a process needs to meet a number of requirements (Sabatier and Weible, 2007; Sotirov and Memmler, 2012), which are particularly difficult to fulfil during times of high-level controversy (Sotirov et al., 2017). This makes many stakeholders and commentators sceptical of such an approach, including concerns that such a process would not escape from the logic of the coalitions' fight for power, and could be misused strategically by one coalition to achieve its objectives (Niedziałkowski, 2016; Niedziałkowski et al., 2019).

A few key knowledge gaps can be identified with relation to the politics and governance of the BFM. Firstly, despite the recent involvement of the European Commission and the European Court of Justice in the controversy, the impact of Europeanisation – and the interplay between EU and national institutions and actors – on the controversy has been analysed only to a very limited extent. Secondly, the BFM case is often analysed without reference to wider socio-political struggles between conservation and forestry actors on the national (e.g. regarding designation of national parks and nature reserves) or international levels (Logmani et al., 2017). A longitudinal policy analysis is still missing, one that considers the different levels of the controversy and analyses actor coalitions as well as their strategies and power plays.

3.5. Summary

Table 1 summarizes the key scientific points of consensus found in the BFM controversy, as well as the contested issues driving this controversy and the main reasons for the disagreements.

4. Discussion

4.1. The BFM case: from a forest management and conservation perspective...

Our review has revealed that in the European context the Białowieża Forest Massif represents a unique large lowland temperate forest complex with close-to-natural structures and processes (Angelstam and Dönn-Breuss, 2004; Peterken, 1996; Sabatini et al., 2018). Notwithstanding the controversy concerning management aims and practices, the reviewed literature shows that there is broad

Table 1
Summary of key points supported by evidence and contested issues.

Expertise area	Points of agreement	Contested issues	Main reasons for disagreement ^a
Forest ecology, disturbances and management	The BFM has several unique features (species, structures, processes, scale) of an old-growth forest. Its international status as a valuable area for nature conservation is justified	Which species, habitat, processes should be prioritized in management/conservation of BFM?	Contradicting values/priorities of the main actors, partially related to contested research findings on the forest's history
	Natural dynamics and natural disturbance regimes are important to maintain many species associated with a natural forest	Is the BFM large enough to enable maintenance all aspects of biodiversity?	Contradictory empirical evidence and related interpretations
	Bark beetle disturbances are natural processes associated with ageing Norway spruce	Should natural disturbances such as bark beetle outbreaks be managed or left alone.	Contradicting values/priorities of the main actors and uncertainty due to changing (climatic) conditions
	Climate change and lowered ground water levels do alter bark beetle dynamics and other natural disturbances	Is sanitary cutting the best/most efficient way to mitigate the effects of bark beetle outbreaks and if so, should this be done in the BFM?	Contradictory empirical evidence and its interpretation
	Specific human interventions are needed to maintain some species associated with more open areas, and light-demanding tree species like pine and birch	Should salvage logging be used to prevent economic losses or should the trees killed by bark beetle be left in the forest to support biodiversity?	Contradicting values/priorities of the main actors
	There are differences in ecological structures and processes (and biodiversity) between the BNP and managed part of the BFM; and differences between the BFM and other managed Polish forests	Should active management or zero intervention be preferred, and how should these two be spatially distributed?	Contradicting values/priorities of the main actors and related interpretation of empirical evidence
Forest history	The BFM has been used for many socio-economic purposes for centuries	Should the BFM be seen as natural or cultural heritage and what should be its future management in relation to both?	Contradicting values/priorities of the main actors, partially related to contradictory empirical evidence and knowledge gaps
	There was no hunting and timber extraction by local people between 14 th and 18 th century due to royal protection	What was the range of human socio-economic activities in the past?	Contradictory empirical evidence and its interpretation
	Natural regeneration of the forest and continuity of forest cover has been kept despite human activity, and several characteristics of an old growth forest have remained	What was the impact of “pre-industrial” human activities on BFM?	Contradictory empirical evidence and knowledge gaps
		What has been the impact of 20th century forest management on natural stands and biodiversity?	Contradictory empirical evidence and knowledge gaps

(continued on next page)

Table 1 (continued)

Expertise area	Points of agreement	Contested issues	Main reasons for disagreement ^a
Socio-economic factors	Timber harvest in the BFM has only small importance for the Polish forestry sector and economy	What are the actual benefits from the BFM (wood, non-wood products, tourism) to different societal groups and at what scale?	Knowledge gaps
	Local communities perceive a dependence on local wood, mainly fuel-wood, and non-wood products from the BFM	What would the impacts of increased conservation or forest management on tourism and related benefits be, and who would benefit and who would lose?	Knowledge gaps
	The BFM is highly appreciated by the Polish people and international visitors as a place for nature-based recreation	What is the symbolic meaning of the BFM and its use in terms of culture, religion and identity to different groups in society?	Knowledge gaps
	Jobs in state forestry are more prestigious and better paid compared to jobs in the nature conservation administration (National Park Service)	What have been/are the costs of the ongoing controversy (e.g. effects on reputation of the forest sector, or tourism)?	Knowledge gaps
	The BFM has a high symbolic value for Polish society and high international prestige in the eyes of both nature conservation and forestry experts in Europe	Should the local, national or international (symbolic) value of the BFM be prioritized?	Contradicting values/priorities of the main actors
Forest policy and governance	The BFM controversy is mainly driven by a struggle over power and values between two main opposing policy actor coalitions	What are the impacts of larger policy factors, e.g. an interplay of European and domestic politics, on the BFM controversy?	Knowledge gaps
	These coalitions have diverging world views (simplified: conservation vs. sustainable forest use) that result in different management/conservation priorities for the BFM (nature conservation emphasizing non-intervention, sustainable forest use emphasizing active forest management)	What are the possible options for resolution of the conflict?	Contradictory empirical evidence and uncertainties as well as contradicting values/priorities of the main actors
	Up to now a meaningful cross-coalition participatory conflict resolution process has not taken place/succeeded		

^a Note: the main reasons of disagreement were derived based on expert judgement of all involved authors of this paper. While only the main reason (as judged by the experts) is presented, in most cases there is more than one reason behind each disagreement, and they are intertwined.

consensus that the BFM is a special place worth conserving. It has also been suggested in both ecological and forest history literature that in order to maintain the ecological value of this forest, there is a need to maintain disturbance regimes that have shaped them, both natural and human-induced. However, there is no consensus in the literature on if, and in which parts of the BFM, these regimes should be promoted by human intervention or non-intervention approaches.

A non-intervention approach based on protected areas is a common strategy for forest biodiversity conservation (Bernes et al., 2015; Peterken, 1996). Creating areas with very limited human influence has also been adopted globally as one of the key actions that can halt the further loss of biodiversity. In the European context, however, due to historical and natural conditions, protected forests frequently require active management to maintain their conservation value (Bernes et al., 2015; Sebek et al., 2015). If biodiversity values depend on legacies of past natural and human disturbances that no longer occur, active management including bringing back those traditional ways of forest use may be necessary even from a conservation perspective (see Van Meerbeek et al., 2019 on the importance of legacies for deciding on conflicting conservation strategies).

In case of the BFM, the literature evidences both natural and anthropogenic processes shaping the biodiversity values differently in different locations across the forest. Depending on the forest type and the state of a particular area, shaped inter alia by the specific environmental history, appropriate disturbance regimes in the BFM can be encouraged by either active management or non-intervention (i.e. natural processes only). For example, there is clear evidence that some parts of the BFM stand out as having high levels of natural forest properties, both when compared to neighbouring forest massifs in NE Poland (Angelstam and Dönn-Breuss, 2004) and other European forests (Faliński, 1986). This offers the potential to allow and encourage natural disturbance regimes as a way to maintain habitat for viable populations of associated species in the long term. On the other hand, other parts of the BFM are shown to be shaped by human activity and are specifically vulnerable to biotic disturbances affecting particular species and habitats (Brzeziecki et al., 2020; Spinu et al., 2020). In such areas, there may be a need for active management if such patterns are to be retained. This type of management could be oriented solely at conservation objectives or be combined with sustainable timber production.

Considering BFM's size and the spatial distribution of the areas shaped by the different disturbance regimes, there is an opportunity to have a mosaic of zones with different levels and types of site-adapted management (including both free development and active management) (Götmark, 2013). In the long term, the size of the entire protected area (with different zones of protection/the BFM) could even be enlarged by adding new multiple-use forest areas as large-scale buffers. A recent publication by Mikusiński and Niedziałkowski (in press), indicates that the use of goods and services from BFM varies spatially, so the zoning approach should carefully consider differences in the needs of stakeholders of different kinds. There is obvious potential to better connect the BFM to the protected areas in Belarus, which are currently disconnected from the Polish forest through a massive border fence. Coordinating conservation and management efforts more effectively across borders could be particularly important in response to the major disturbances that are expected to impact forests in the future due to global change (Müller et al., 2018). To conclude, the BFM as a whole in both Poland and Belarus is possibly the most suitable lowland temperate forest in Europe for developing a largely self-sustaining biodiversity conservation area supporting a wide range of ecosystem services.

4.2. ...to the necessity to understand and deal with a complex socio-ecological forest system

Although there is a general consensus that the BFM is unique and worth protecting, exactly how this should be done has not been agreed upon despite several years of debate, particularly regarding the specific distribution of zones with different management and conservation regimes (including potential enlargement of the national park). While it appears that there is enough information concerning the BFM to apply multi-criteria decision analysis techniques in a spatial context to support such zoning (Geneletti and van Duren, 2008), given the multi-faceted nature of the BFM controversy, there are possible barriers to such a rational/technical approach: (1) the fact that some ecological and historic data are contradictory and prone to different interpretation, especially if not discriminating between localities and forest site types, (2) the existence of gaps in knowledge, particularly with regard to socio-economics, and uncertainties about future trends in the portfolios of desired ecosystem services, and (3) fundamentally different policy focus, values and priorities that are present in the controversy about BFM (Table 1). In addition, the recorded lack of trust, and power struggles between the two coalitions, are impeding an evidence-based, "technical" conflict resolution.

Specifically, firstly, existing data can be contradictory and/or can be interpreted in different ways, depending on spatial scales and extents, focal interests, values and beliefs of particular actor groups, often linked to their professional identity (Redpath et al., 2015). For example, the decision whether the BFM is large enough to maintain ecological processes can be informed by empirical evidence, but is in the end a value-based decision, as it depends on the considerations of what one wants to protect and what baseline size one chooses to apply. One could, for example, argue that most protected areas in Europe are too small to be protected without intervention, if a pre-human baseline of the level of naturalness and habitat connectivity is applied. Similarly, one can argue that nature is dynamic and will develop continuously on its own and if naturalness in the process is the aim, human interventions may be unwarranted. In addition, empirical findings about ecological phenomena can be interpreted differently, resulting in different management recommendations. For example, the possibility to contain a bark beetle expansion, and what impacts it has, are controversially discussed. There is partially contradictory evidence connected to the importance of parameters such as the climate, the size and intensity of the outbreak, the importance of the distribution of spruce trees and

their predisposition to infestation, and finally the exact impact of the bark beetle expansion on the forest ecosystem, also in a long term perspective (Gutowski and Krzysztofiak, 2005; Mezei et al., 2017). Climate change and the complexity of interactions between different disturbances additionally elevate uncertainty in the accuracy of predictions concerning the impact of bark beetles (Seidl and Rammer, 2017). Given the multiple dimensions of the issue and uncertainties on one hand, and the conflicting political stakes involved on the other, the conflict concerning the management of the BFM could be considered a so-called "wicked" problem and a case of "post-normal" science, emphasizing the necessity not only to involve different scientific disciplines in developing knowledge for problem solutions, but also to extend this knowledge generation process beyond the boundaries of science and research to involve different societal groups and policy experts (Funtowicz and Ravetz, 1995).

How the empirical evidence is used and interpreted and what priorities are highlighted also depends on the spatial scale used. While there is some evidence that most of the local actors seem to pay most attention to the provisioning services and job possibilities the BFM provides, actors from outside the region seem to prioritize cultural ecosystem services (e.g., nature-based recreation) and biodiversity conservation. At the international level, a conservation view is dominating the debate, mimicking similar constellations in other environmental controversies in different countries (Winkel et al., 2015). These socio-spatial considerations raise the following question: who, at what governance level, should decide about a fate of a place such as the BFM, where both international and local people's values are important.

Secondly, up-to-date socio-economic evidence is largely missing. This is surprising as the BFM is one of the best studied forests of the world (almost 1200 publications in Scopus that mention "Białowieża"). This lack of knowledge and the resulting uncertainty regarding potential costs and benefits of different management options for the different actor groups fuel the controversy.

Finally, an important part of the BFM controversy is its political element, particularly (but not only) the ongoing struggle over power and the different beliefs between the environmental and forestry coalitions involved. Changing societal values threaten traditional forestry trajectories and support conservation interests (Sténs and Mårald, 2020). The described long history and polarization of the controversy has led to severe distrust among the conflicting coalitions, making attempts to broker the controversy very difficult. Political science literature (Sabatier and Weible, 2007) shows that a negotiated agreement through mediation between opposing policy coalitions in a polarized stalemate like the one in the BFM is possible if: (1) the continuation of the status quo is seen as problematic for both sides, (2) all relevant groups involved in the controversy are present, (3) there is a credible policy broker with a mandate from the two coalitions to negotiate future solutions, and all major conflict groups have enough trust in the person and process, (4) both sides can agree on rules and the boundaries of what can be negotiated, (5) commitment is long-lasting, and (6) there are relatively few alternative options for both sides to succeed with their interests by circumventing the process. It remains an open question in our assessment if these preconditions can be met. While it was not an aim of our study to analyse the potential for such preconditions in the BFM case, future studies on that would be important for further steps in conflict resolution. There is an indication that at least some of the conditions may be difficult to fulfil, e.g. there is seemingly no legitimate broker who could organize a constructive dialogue and produce a policy option that is acceptable for both parties. Also, it is not clear in how far there is a shared interest by all major involved actors to move beyond the status quo. However, the long-lasting and increasingly polarized conflict, together with the considerable reputational damage for the region and the responsible administrations, accompanied with a substantial "fatigue" among many of the involved conflicting parties,

may be preparing the ground for initializing such a process, supported by credible scientific knowledge and data, to develop a resolution of the BFM controversy. Using a game theoretical approach to understand the conflict may be one of the ways ahead, as suggested by Redpath et al. (2013) in their study on conservation conflicts in the rainforests of the Pacific North-West.

When designing such a collaborative process aimed at trust-building, the issue of spatial scale is important. As this paper has demonstrated, the BFM has ecological features that are unique and irreplaceable in the European lowlands (Hannah et al., 1995; Sabatini et al., 2018). These features are the basis for the international dimension of the controversy, with respective European (Natura 2000) and global (UNESCO World Heritage) legislative and protective frameworks coming into play. This means that the BFM controversy is not only a local or even national issue, but has an international dimension that needs to be recognized in any dialogue process.

The growing uncertainty of how to best conserve and manage the BFM in light of future climate change calls eventually for an adaptive management approach. This approach has been suggested for approaching forest management and conservation in complex settings that encompass both social and ecological systems (Nordin and Sandström, 2016), building on an ongoing assessment of the effects of interventions, and learning from successes and mistakes. In the case of the BFM, adaptive co-management that involves representatives of both the forestry and environmental coalitions in the interpretation of data and decision making could enable both trust building and handling the existing uncertainties (Rist et al., 2016). Similarly, planning that adopts the rules of a strategic choice approach, which helps participants to develop a capacity to creatively cope with complex multidimensional situations characterized by uncertainty and considers interconnected agendas in the decision making, could be beneficial (Friend and Hickling, 2004).

5. Conclusions

As the result of a systematic interdisciplinary scientific assessment process about the BFM in Poland we show that the interrelation of knowledge and decision making in conflicts about the conservation and management of nature remain complex. Evidence-based knowledge about ecological, social and economic systems is necessary but insufficient to cope with such conflicts. This stresses the need for humbleness regarding claims that empirical evidence can directly resolve complex environmental controversies, or that more research will clarify contested issues in polarized conflicts such as around the BFM. There can be important knowledge gaps where systematic research could generate new evidence (e.g., socio-economic information in the BFM case). Yet for other issues, a large amount of studies does not per se decrease the contestation, including within the academic community. This is because different scientific communities represent different paradigms for knowledge production, and thus partially distrust and distance themselves from each other per se, thus questioning the validity of each other's findings and interpretations. In the highly emblematic case of the BFM, this has led to a certain stalemate, polarization and frustrations not only among policy makers, but also among scientists. To bridge this polarization has been one main motivation for this paper. The approach taken – testing a novel approach to assess the evidence, engaging both sides in one publication reviewing the state of knowledge, and having a constructive debate about the BFM case – may merit repetition in other similar settings. Even more, one lesson learnt from this study is that it could be a promising strategy for knowledge generation to encourage scholars with distinct perspectives to not only jointly review existing evidence, but also work together to conduct empirical research (data gathering and analysis) to generate new evidence on contested issues after having agreed on adequate joint

research designs.

However, while better evidence may help to make the consequences of decisions more visible, the actual decisions depend on different actors' worldviews rooted in their personal situations (e.g. dependence on forest resources), power and professional identities, and the political and legal settings (Redpath et al., 2015) that shape, for instance, who has the right to decide about a particular area. The role of research is then not to say what is the right decision, but to describe the consequences for different aspects and to clarify how far arguments in the debate can be based on empirical evidence, but also to openly acknowledge uncertainties and contestations, and finally, to point towards the necessity to take decisions over partially conflicting values and interests which goes beyond the realm of science and research. We hope that our study will be useful in that respect for supporting decision making and inform readers from both science and policy dealing with forest management and biodiversity conservation issues in and beyond the Białowieża Forest.

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Author statements

First and last author (MB and GW) developed the idea of the study and led the whole process. MB has synthesized the texts provided by other co-authors and wrote the manuscript. All other authors contributed with gathering the evidence base, writing parts of Results and providing inputs to all parts of the manuscript. KS prepared a map (Fig. 1).

Declaration of competing interest

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

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