



Expert-Based Evaluation of Ecosystem Service Provision in Coastal Reed Wetlands Under Different Management Regimes

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A characteristic feature of lagoons and estuaries along the Baltic Sea is the dominance of reed (*Phragmites australis*) along their coasts. Reed wetlands are ecologically valuable ecosystems and play an important role for nutrient and matter cycling as well as for biodiversity. They provide a broad spectrum of ecosystem services and have been utilized by humans already for centuries. We assess the ecosystem service provision of reed wetlands and analyze how this is affected by different management scenarios and how the results of an expert-based ecosystem service assessment can be used in practice. Because of strong internal gradients and interactions with the surrounding, coastal reed belts show a higher ecosystem service provision compared to homogeneous inland reed. The three different coastal management scenarios are (1) winter harvest of reed, (2) summer harvest of reed, and (3) grazing by livestock. According to the views of 18 involved experts from Lithuania, Poland, and Germany, winter harvest is regarded as the scenario with the lowest conflict potential between nature protection and reed utilization. Experts expect no changes or even slight increases for regulating and cultural services. However, experts see the need to establish a sustainable and regionally anchored winter harvest concept. Summer harvest and grazing entail the risk to change the ecosystem structure and could lead to a shift in vegetation pattern toward short salt marsh grassland. Experts expect a slight decrease in regulating services. In particular, erosion control, biodiversity, and nutrient sequestration are rated controversially. To our experience, these expert-based ecosystem service assessments can support policy implementation (e.g., NATURA 2000, European Water Framework Directive or Marine Strategy Framework Directive). It can serve as a tool that allows stakeholders to visualize trade-offs, analyze patterns and processes at regional scales, and hence facilitate decision-making.

Keywords: *Phragmites australis*, CICES, transitional waters, ecotones, expert-based assessment, Baltic Sea

INTRODUCTION

Historically, wetlands along the Baltic Sea used to be very heterogeneous with a wide range of species due to strong gradients in salinity, climate, or water level fluctuations (Dijkema, 1990). The biodiversity also resulted partly from human interventions: Many Baltic coastal wetlands were traditionally grazed, mown for hay-making, or harvested for construction material. Since

the decline of such activities due to economic reasons or nature protection goals, common reed [*Phragmites australis* (Cav.) Trin. ex Steud.] has replaced other halophytes in many wetlands and expanded heavily (Dijkema, 1990; Jutila, 2001; Köbbing et al., 2013). *Phragmites* is a perennial grass (family Poaceae) that can grow up to 4 m and overtops most other emergent macrophytes in wetlands such as *Typha*, *Scripus* or *Spartina* (Cronk and Siobhan Fennessy, 2001). Although reed is principally a freshwater plant, it is well-adapted to brackish water conditions because it is able to cope with a wide range of salinities (Karsten et al., 2003; Meriste et al., 2012; Altartouri et al., 2014). Reed wetlands act as bio-engineers of their own environment: They can grow vertically and horizontally by litter accumulation and can trap sediments by buffering wind and wave energy. Reed has thus the potential to sequester nutrients or heavy metals, to stabilize soils, or to provide habitats in urban or industrial areas where many plants would not thrive otherwise (Kiviat, 2013; Karstens et al., 2016). However, reed also tends to form near-monocultures with only few accompanying species and thereby limits biodiversity at the landscape scale (Prach and Pyšek, 1994; Wanner, 2009; Sweers et al., 2013).

The benefits that reed systems deliver to human well-being can be regarded as ecosystem services (ESs). ESs are defined as the tangible and intangible goods from nature's processes and functions to humans (Millennium Ecosystem Assessment, 2005). The concept has been increasingly used as a holistic approach to support management and decision-making processes (Baker et al., 2013; Posner et al., 2016; Bouwma et al., 2018; Geneletti et al., 2018). ES analysis allows one to disentangle complex interdependencies in socio-ecological systems (Bouwma et al., 2018) and brings a more sustainable perspective into decision-making and policy outputs (Geijzendorffer et al., 2017). To achieve both human well-being and nature conservation, it is important to understand the dynamics and relationships (trade-offs) of ESs (Raudsepp-Hearne et al., 2010; Daw et al., 2015; Renard et al., 2015; Geneletti et al., 2018). In particular, the analysis of trade-offs has gained attention in policy and decision-making processes (Bennett et al., 2015; Bennett and Chaplin-Kramer, 2016). To assess the impact of management options in ESs provision, expert-based matrix approaches (e.g., Burkhard et al., 2012; Schernewski et al., 2018) can be used for their simplicity. Such approaches can easily be integrated in a stakeholder meeting, and the results can be used as a starting point to extract valuable information that can eventually influence the implementation and design of policies and management approaches. While ES provision is fairly well-studied in seagrass meadows, mangroves, or freshwater wetlands (e.g., Bowden, 1987; Moore et al., 1994; Ewel et al., 1998; Reddy et al., 1999; Moberg and Rönnbäck, 2003; Holmer et al., 2006; Deborde et al., 2008; Delgard et al., 2013), very few studies have addressed ESs in coastal wetlands colonized by *Phragmites*, and to our knowledge, no studies so far investigated the impact of different management options (e.g., grazing, reed harvest) on ES provision.

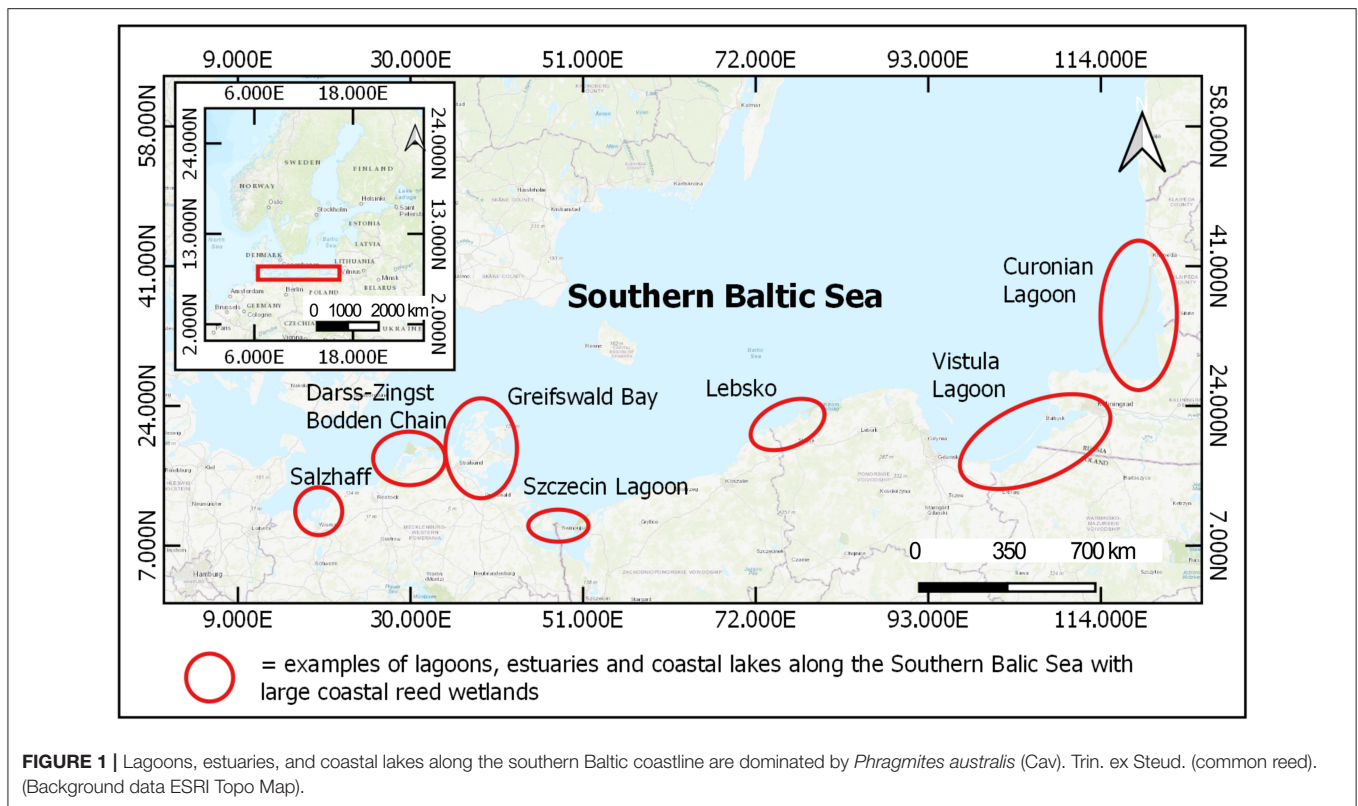
Main research questions for this study are as follows: (1) How does ES provision differ in transitional and homogeneous

reed systems? (2) How do different management scenarios impact the ES provision in reed wetlands along the Baltic Sea? In order to approach these questions, different methods were applied: In a first step, the ESs based on the CICES v5.1 were assessed for homogeneous reed wetlands around shallow inland waters and transitional reed belts along coastlines (e.g., Baltic Sea) by the authors. In a second step, an expert-based ES assessment was applied in order to evaluate changes in service provision due to three different management scenarios: (1) winter harvest, (2) summer harvest, and (3) grazing. Both steps were accompanied by an extensive literature study to allow a diverse discussion of the authors' and experts' assessments. This study shall test whether ES assessments can be applied in facilitating and visualizing management decisions in transitional systems like coastal reed belts.

MATERIALS AND METHODS

Study Site: Transitional Reed Wetlands Along the Southern Baltic Sea

Large areas of the southern Baltic coastline are dominated by *P. australis* (Cav.) Trin. ex Steud (Figure 1). These coastal reed wetlands are transitional systems that possess stronger internal gradients than homogeneous reed areas around shallow inland waters (see Figure 2). Various abiotic stress factors impact ecological gradients and thus vegetation patterns, *inter alia* salinity, flooding, desiccation, erosion, ice scouring, nutrient availability, or human activities such as livestock grazing in wetlands (Wanner, 2009). Several studies showed that flooding seems to be the most controlling factor for species distribution and diversity (Gough et al., 1994; Sanchez et al., 1996; Grace and Jutila, 1999; Jutila, 2001). The interior zone of reed wetlands that borders the hinterland is rarely flooded, and *Phragmites* is often accompanied by plant species such as *Calystegia*, *Urticaceae*, *Trifolium fragiferum*, or *Crataegus monogyna*. In wetter and more saltwater influenced areas, *Aster tripolium*, *Carex* spp., or *Bolboschoenus maritimus* occurs besides *Phragmites*. In the fringe zone with permanent high water levels, submerged macrophytes such as *Stuckenia pectinata*, *Potamogeton* spp., and *Chara* sp. can grow alongside *Phragmites*. The zone in between interior and fringe is often characterized by dense monocultures of *Phragmites* (www.umweltkarten.mv-regierung.de; Paulson and Raskin, 1998; Berthold et al., 2018). Values for salt tolerance of *P. australis* vary in different studies, e.g., up to 6‰ (Raabe, 1981; Jeschke, 1987), 13‰ (Ranwell, 1972), 15–20‰ (Esselink et al., 2000), 5–25‰, and even up to 60‰ for individual clones (Lissner and Schierup, 1997). However, even if low salinities are not limiting *Phragmites* occurrence, it still affects productivity and plant performance (Hellings and Gallagher, 1992) and above salinities of 5‰ growth rates and leaf production decline (Lissner and Schierup, 1997). Besides salinity, limiting factors for reed along the southern Baltic coast are waves and other mechanical stressors such as ice scouring or wild boar grubbing and deer grazing (Krisch, 1989, 1992; Dijkema, 1990; Puurmann et al., 2002; Wanner, 2009).



Comparison of Ecosystem Service Provision in Different Reed Wetland Types

Most studies about ES provision in reed wetlands focus firstly only on inland reed wetlands, and secondly, they cover mainly regulating services such as erosion control or nutrient dynamics, but do not take into account cultural services such as the role of reed to coastal heritage, the landscape aesthetics, and values for tourism and recreation. As a consequence, we included not only all sections (regulating–provisioning–cultural) in our study but compared also the ESs potential and use for two different reed wetland types: homogeneous reed wetlands around shallow inland waters (e.g., Neusiedler See) vs. transitional reed belts along coastlines (e.g., Baltic Sea; **Figure 1**). An extensive literature research about ES provision in transitional reed wetlands along coastlines was conducted to allow a complex discussion of the results.

According to Burkhard et al. (2012), ES potential refers to the maximum potential yield of an ES in a spatial unit. ES use (generally known as flow) is the actual use of ES over a period of time. Our aim is to evaluate whether differences in ES potential exist between these two types of reed. We chose a qualitative matrix-like approach similar to Burkhard et al. (2012), common and widely used in the research field of ES, to assess potential and use of ES. To define which services to tackle, we screened through the new version of the Common International Classification on Ecosystem Services, CICES v5.1 (Haines-Young and Potschin, 2018) and discussed based on our background knowledge and the conducted literature study which ESs are relevant in reed

wetlands. The CICES classification was chosen for its wide use in ES assessments and because it is the “official” classification used in EC. Services such as cultivated terrestrial plants grown for nutritional purposes were excluded, and the CICES list was narrowed down to 30 ESs relevant for reed wetland (see **Table 1**). Each service was then assessed by us regarding the potential (in percentage) of ES provision for the two reed types (transitional and homogeneous). We used six categories: 0% (no potential), 1–20% (slight potential), 21–40% (considerable potential), 41–60% (medium potential), 61–80% (high potential), and 81–100% (very high potential). The highest potential (100%) was defined having in mind an ecological system that could deliver the maximum provision of each service. The last step was then to assess the real use of each ES also for the two reed types. The use is defined as a percentage of the potential that is currently being exploited: 0% (no use), 1–20% (slight use), 21–40% (considerable use), 41–60% (medium use), 61–80% (high use), and 81–100% (very high use). We, the authors, belong to different institutions and have distinct academic backgrounds ranging from geography, marine ecology, marine biology and conservation, economics, and coastal and marine management. Working in different fields of research, we have different expertise in the topic of ES.

Expert-Based Ecosystem Services Assessment

To understand how different management scenarios could potentially influence the provision of ES, an expert-based approach was used, similar to Schernewski et al. (2018). During

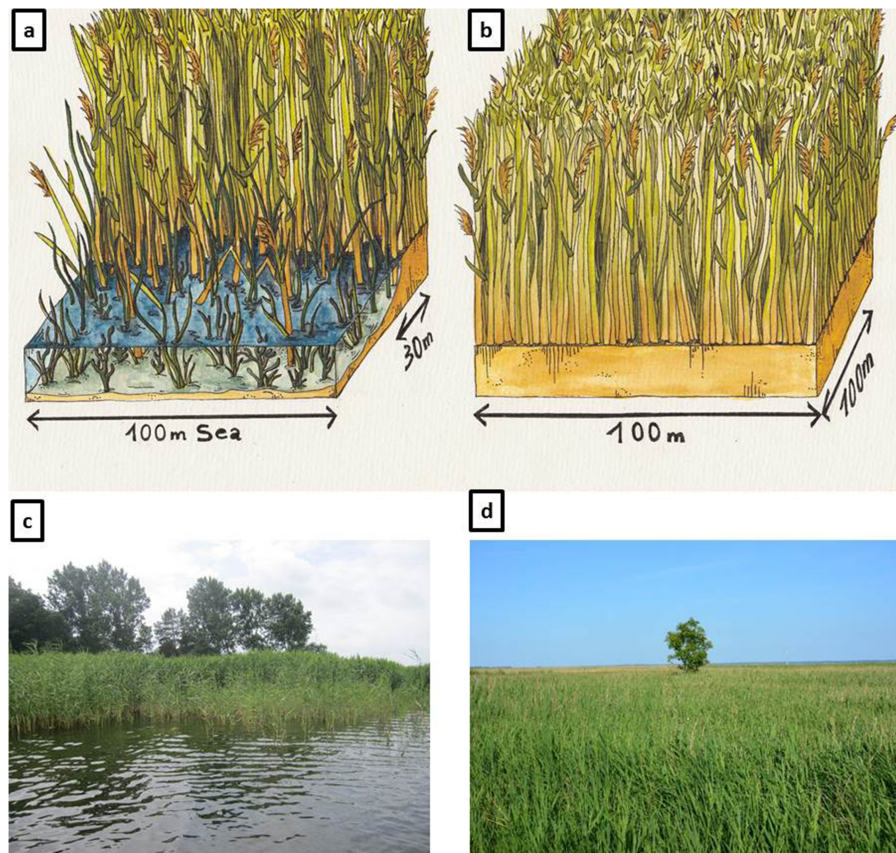


FIGURE 2 | Schematic representation and photos of transitional reed wetlands along coastlines (a,c) and homogeneous reed wetlands around shallow inland waters (b,d). (Drawing by Ronja Trübger, with permission).

the cross-border workshop “Coastal biomass: Combining nutrient reduction in coastal waters with blue-growth opportunities” (14th of November 2018, Wieck, Germany) a total of 18 invited experts from the field of coastal management were asked to conduct an ES assessment. The Baltic Lagoons Network (BALLOON, www.balticlagoons.net) as well as a stakeholder mapping conducted within the Interreg South Baltic Project LiveLagoons helped to identify relevant stakeholders. Invited experts were representatives of science institutions (10), state authorities (3), and NGOs (5) and came mostly from Germany (7), Poland (6), or Lithuania (4). Three scenarios were presented to the expert audience: (1) winter harvest in coastal reed wetlands, (2) summer harvest, and (3) grazing by livestock. Reed is a wetland plant that has been utilized by man since ancient times. Harvested reed can be used for a variety of products, *inter alia* as insulation material for walls or as roofing material when harvested in winter, as energy source (combustion, biogas, biofuel), or as fodder and fertilizer when harvested in summer (Köbbing et al., 2013). However, harvest and grazing activities are declining nowadays due to economic reasons or nature protection (Wanner, 2009; Köbbing et al., 2013). In nature conservation, two diverging concepts exist: the “wilderness” concept, where no human intervention

shall take place, vs. the “biodiversity” concept, where human management aims at reaching pre-fixed goals such as high species richness or maintaining target communities (Kiehl and Stock, 1994; Bakker et al., 1997; Wanner, 2009). We asked ourselves whether a conflict between reed utilization and nature protection exists *per se*.

The experts were asked to give their opinion on how the different management scenarios [(1) winter harvest, (2) summer harvest, and (3) grazing] impact the ES provision in reed wetlands along the Baltic Sea. Information regarding background knowledge on wetland functioning and nationality were collected from the experts and included in the results (see **Tables 4–6**). In order to reduce the duration of the assessment during the workshop to <2 h and thereby ensure the motivation of participants, the number of services was shortened to a total of 14 services (see **Table 4**). The services were described using a less technical and more user-friendly language, and indicators were used to give examples for each service. Each management scenario (winter harvest, summer harvest, and grazing) was presented with one PowerPoint slide describing the process and subsequent utilization of reed. Photos were shown additionally to visualize management scenarios (e.g., harvest machinery). The experts were asked to choose a category regarding the changes

TABLE 1 | Results of the authors' ecosystem service assessment for regulating services in transitional and homogeneous reed wetlands.

Section Class		Potential MEAN (potential compared to possible maximum)		Use MEAN (% of potential)	
		Transitional reed (%)	Homogeneous reed (%)	Transitional reed (%)	Homogeneous reed (%)
R&M	Bio-remediation by micro-organisms, algae, plants, and animals	61–80	41–60	61–80	61–80
R&M	Filtration/sequestration/storage /accumulation by micro-organisms, algae, plants, and animals	61–80	41–60	61–80	61–80
R&M	Smell reduction	1–20	1–20	41–60	41–60
R&M	Noise attenuation	1–20	1–20	41–60	41–60
R&M	Visual screening	21–40	21–40	41–60	61–80
R&M	Control of erosion rates	61–80	21–40	61–80	81–100
R&M	Buffering and attenuation of mass movement	61–80	41–60	61–80	81–100
R&M	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	61–80	41–60	61–80	61–80
R&M	Wind protection	61–80	61–80	61–80	61–80
R&M	Seed dispersal	41–60	21–40	61–80	61–80
R&M	Maintaining nursery populations and habitats (Including gene pool protection)	61–80	21–40	61–80	81–100
R&M	Pest control (including invasive species) and disease control	41–60	21–40	61–80	61–80
R&M	Weathering processes and their effect on soil quality	41–60	41–60	61–80	61–80
R&M	Decomposition and fixing processes and their effect on soil quality	61–80	41–60	61–80	81–100
R&M	Regulation of the chemical condition of fresh- and salt -waters by living processes	61–80	41–60	61–80	61–80
R&M	Regulation of temperature and humidity, including ventilation and transpiration	41–60	41–60	81–100	81–100

that each management scenario might have on ES provision compared to an unmanaged coastal reed wetland. The scale ranges from -3 to 3 where -3 (high), -2 (medium), and -1 (low) represent a decrease in services provision, 0 no change in provision and +3 (high), +2 (medium), and +1 (low) represent an increase in services provision.

RESULTS AND DISCUSSION

Comparison of Ecosystem Services Provision by Transitional and Homogeneous Reed Wetlands Regulating Services

The potential of most regulating services is considered to be higher in transitional reed wetlands than in homogeneous reeds (Table 1). Our views did not differ significantly and standard deviation was low.

The potential for the regulation of baseline flows and extreme events (e.g., erosion control) is regarded as high in transitional reed, while in homogeneous wetlands, it is only considerable to medium (Table 1). This is supported by the scientific literature

that emphasizes the capability of coastal wetlands to reduce impact forces at the sea and land side (Möller et al., 2011; Duarte et al., 2013; Karstens et al., 2015a,b). Reed stems are flexible, and their “bending stiffness” (Ostendorp, 1995) enables the plant to cause high drag forces and attenuate waves (Möller et al., 2011). How the plants impact erosion regulation depends strongly on the location within the wetland: Dense *Phragmites* stands in the interior zone effectively suppress particle transport even during heavy winter storms. Wind attenuation profiles in coastal reed beds showed that wind speed at the sediment surface was <10% of that measured at 2-m height (Karstens et al., 2015b). In the fringe zone bordering the sea, waves and water flow are the dominant impact forces. Möller et al. (2011) compared wave height attenuation in a sheltered reed site at the southern Baltic Sea (attenuation of 2.6% at the transition from open water to reed vegetation) with an exposed site (attenuation of 11.8%) and showed that reed plant morphology and stem density are important. Vegetation density and stem width were also responsible for the reduction of turbulent kinetic energy from the sea toward the inner part of reed wetlands (Karstens et al., 2015a). Also, the large reed rhizome network supports shoreline stabilization (Ostendorp, 1993), but the ability to trap and accumulate sediment and thereby to

TABLE 2 | Results of the authors' ecosystem service assessment for provisioning services in transitional and homogeneous reed wetlands.

Section Class	Potential MEAN (potential compared to possible maximum)		Use MEAN (% of potential)	
	Transitional reed (%)	Homogeneous reed (%)	Transitional reed (%)	Homogeneous reed (%)
P Animals reared for nutritional purposes	1–20	21–40	1–20	1–20
P Fibers and other materials from reared animals for direct use or processing	21–40	1–20	1–20	0
P Wild plants used for nutrition	1–20	21–40	0	0
P Fibers and other materials from wild plants for direct use or processing	41–60	61–80	21–40	21–40
P Wild plants used as a source of energy	21–40	41–60	0	1–20
P Wild animals used for nutritional purposes	41–60	41–60	21–40	21–40
P Fibers and other materials from wild animals for direct use or processing	21–40	21–40	0	0

change the bathymetry is of higher importance for shoreline protection (Duarte et al., 2013).

Also, the potential for the mediation of wastes or toxic substances and the regulation of soil quality is assumed to be higher in transitional reed areas than in homogeneous areas (Table 1). Processes such as filtration, sequestration, storage, accumulation, decomposition, and fixing by plants and microorganisms in transitional reed wetlands are important ESs. Nutrient uptake in *Phragmites* is larger than in many other wetland plants due to the high biomass (Wanner, 2009; Berthold et al., 2018). During growth in spring and early summer, large amounts of nutrients are incorporated in the aboveground biomass (Schieferstein, 1999; Berthold et al., 2018). In autumn, the majority of nutrients is transported back into the rhizomes and stored belowground during winter (Ostendorp, 1993). Peat formation is an important contribution to nitrogen and phosphorus deposition, and for the coastal *Phragmites* peatland Karrendorfer Wiesen in Mecklenburg-Vorpommern, a nitrogen deposition of 80 kg N ha⁻¹ year⁻¹ at a predicted peat growth of 1.5 mm year⁻¹ was calculated (Lampe and Wohlrab, 1996; Wanner, 2009). Also, carbon burial in peat is an important contribution to the reduction of atmospheric CO₂ (Succow and Joosten, 2001; Chmura et al., 2003; Choi and Wang, 2004; Andrews et al., 2006). Buczko et al. (under review) measured carbon stocks down to 1-m depth in two coastal *Phragmites* wetlands at the southern Baltic Sea, and values ranged from 10 to almost 60 kg C m⁻², with lowest carbon contents in the fringe zones due to lower biomass production. Averaged over all wetland zones, carbon stocks were 16 and 39 kg C m⁻² at the two wetland sites and comparable to the worldwide average for salt marshes of 25 kg C m⁻² (Pendleton et al., 2012). Lampe and Wohlrab (1996) calculated a carbon fixation of 5.1 t CO₂ ha⁻¹ year⁻¹ for the de-embanked coastal peatland Karrendorfer Wiesen in Mecklenburg-Vorpommern, which is dominated by *Phragmites*. However, the authors did not include the possible emission of CH₄ in their net carbon sequestration estimations, which can occur under anaerobic conditions in waterlogged soils (Succow and Joosten, 2001; Wanner, 2009). While in many terrestrial wetlands, carbon sequestration is partially offset by methane emission from plant decomposition, methanogenesis can be inhibited by sulfates in coastal wetlands, thus reducing greenhouse gas emissions (Howe et al., 2009).

In our view, the potential to maintain habitats and nursery populations is high in transitional reed belts, whereas it is only considerable in homogeneous inland reed areas (Table 1). In homogeneous wetlands around shallow inland waters, reed tends to form near monocultures with only few accompanying species. In transitional systems, habitat gradients are more pronounced and *Phragmites* might be accompanied by *Calystegia*, *Urticaceae*, *T. fragiferum*, or *C. monogyna* in the interior zone or by submerged macrophytes such as *S. pectinata*, *Potamogeton* spp., and *Chara* sp. in the fringe zone. However, the zone in between is also often characterized by dense reed monocultures (Paulson and Raskin, 1998; Berthold et al., 2018). Coastal *Phragmites* wetlands are important (breeding) habitats and refuges for birds such as bittern (*Botaurinae*), red-necked grebe (*Podiceps*), reed warbler (*Acrocephalus scirpaceus*), or water rail (*Rallus aquaticus*); for insects such as the Flame Wainscot (*Senta flammea*), large copper (*Lycaena dispar*), or dragonflies (*Aeshna isosceles*); and for mammals such as water shrew (*Neomys fodiens*), otter (*Lutrinae*), raccoon dogs (*Caninae*), deer (*Dama dama*), or wild boars (*Sus scrofa*) [LUNG (Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern), 2003].

The actual use of the potential of the abovementioned regulating services was seen as mostly high in the homogeneous reed wetlands, with some even very high (Table 1). This shows that although reed wetlands offer a high potential for regulating services, the demand can exceed a sustainable supply.

Provisioning Services

The highest potential has the utilization of reed stems for direct use or processing (e.g., roof thatching, insulation material) in homogeneous reed wetlands. Also, the potential to use reed as an energy source (e.g., combustion, biofuel, biogas) is considered higher in homogeneous than in transitional reed wetlands (Table 2). In homogeneous areas, harvest with heavy machinery is easier than in transitional systems with stronger gradients regarding water level as well as species composition.

A medium potential exists for the use of wild animals for nutritional purposes (Table 2). Currently, mainly wild boars are hunted in reed wetlands along the Baltic Sea. Wild boars are omnivores and find plenty of food there, e.g., young reeds,

insects, or small animals. During summertime, they benefit from the shading and cooling effects inside the dense reed stands. Hunters report that they often find the nests for the young boars, indicating that reed areas are also a popular place for birth (Task force “sustainable stock reduction wild boars Greifswald-Vorpommern”, personal communication). In some regions, wild boars have become a nuisance, causing major destructions to agriculture and infrastructure. As a response, nature conservation authorities have revised the permit procedure and now allow the cutting of “hunting aisles” into reed wetlands to facilitate the hunt on wild boars (Merkblatt Schussschneisen StALU Vorpommern).

All provisioning services are currently only slightly or considerably used, some even not at all (Table 2). This was different in the past, where harvest of reed stems or grazing of cattle in wetlands was very common (Köbbing et al., 2013). Reed-thatched houses are still popular, but the majority of the reed for roof thatching is currently imported [LUNG (Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern), 2017]. The underutilization of the potential can be explained by the strict nature protection status of reed wetlands in Germany and also in other countries along the Baltic Sea. They are legally protected biotopes. Reed harvest, grazing activities, or other interventions in the ecosystem have to take into account biodiversity concerns and require specific approvals from the responsible federal nature conservation authority [LUNG (Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern), 2003].

Cultural Services

The potential of cultural services is considered to be higher in transitional than in homogeneous reed wetlands (Table 3). Reed has a great cultural importance in the Baltic Sea region and its utilization has a long tradition, explaining that the authors valued the importance for heritage as high (Table 3). Roofs thatched with reed are characteristic in the coastal regions. Locals appreciate the use of reed as construction material, and it forms part of their regional identity (Stoll-Kleemann, 2015).

However, not only the utilization of reed as a resource has a cultural value, but also the landscape itself. The recreation potential through passive or observational activities is regarded as high in transitional systems while only a medium potential exists in homogeneous reed wetlands (Table 3). Bird-watching and active interactions such as fishing and canoeing along coastal *Phragmites* wetland are popular recreational activities. However, reed wetlands are considered less aesthetic than salt meadows (Stoll-Kleemann, 2015). Semistructured interviews and group discussions in 2012/2013 with people living at the Darss-Zingst Bodden Chain showed that reed areas were only considered as “beautiful” when growing in moderation. If they expand and become dominant, e.g., due to mowing and grazing prohibitions, people start to perceive only the negative aspects such as hindering the view to the bay, reducing biodiversity, and increasing the abundance of wild boars (Stoll-Kleemann, 2015). However, perceiving something as aesthetically pleasant is very subjective and individualistic. This is also reflected in our assessment, where one author regards the aesthetic potential

as very high, whereas the other two authors viewed it as only moderately aesthetically pleasant.

Expert-Based Ecosystem Service Assessment of Different Management Scenarios

In transitional reed wetlands along coastlines, the potential for regulating and cultural services is regarded as moderate to high while the potential for provisioning services remains between slight to medium. According to Burkhard et al. (2014) the provision of crops, bioenergy, or fibers is not relevant in marshes. The potential is low, as well as the current use, which is based on the fact that nature conservation agencies heavily restrict the utilization of coastal reed. For harvest or grazing activities, specific approvals are needed. This was different in the past when not only summer and winter harvest but also grazing by cattle was very common in Baltic wetlands (Wanner, 2009).

Scenario 1: Winter Harvest

For the winter harvest scenario in reed wetlands, experts expected the highest increases for biomass utilization (e.g., reed as construction material, insulation material, pulp, or paper), for bioenergy, and for culture and heritage (Table 4). Assessments in the section “regulation and maintenance” reflected the very contrasting views of different experts (ranging from -2 to $+3$) but were less negative than for the summer harvest scenario (Annex I). During the discussion, the experts pointed out that for the assessment of regulating services, it is important to have more detailed information about the winter harvest scenario, e.g., the exact time of harvest or the machinery used. Harvest in November before the winter storm season could lead to a decrease in erosion control and mass stabilization, while harvest in February would not impact service provision in their eyes.

Winter harvest has a long tradition along the Baltic Sea (Köbbing et al., 2013). The amount of harvested reed during winter time ranges between 3.6 and 15 t dry mass h year⁻¹ (Rodewald-Rudescu, 1974; Knoll, 1986; Timmermann, 2009; Dahms et al., 2015). Most commonly, winter reed is used for roof thatching. First references for the use of reed for roof thatching along the coast of the North and Baltic Sea date back to the last ice age (Schaatke, 1992). Along the coast, reed and straw were often the only materials available for roofing until the late 1800s (Iital et al., 2012). With the yield from 1 ha reed wetland, approximately up to 100 m² of roof can be thatched (Schaatke, 1992; Haslam, 2009). Today, the annual reed demand for thatching often exceeds the supply (Köbbing et al., 2013) and 80% of the reed for roof thatching is currently imported [LUNG (Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern), 2017]. Reed can be used as an industrial material, such as for the construction of garden fences and indoor furnishings (such as blinds, floor, and wall coverings), as an insulation material, and for bio-based plastics or the cellulose for pulp and paper production (Köbbing et al., 2013). Some utilizations of harvested reed have become almost forgotten and less popular today, e.g., the manufacture of schnapps, coffee, and boats (Holzmann and Wangelin, 2009; Köbbing et al., 2013).

TABLE 3 | Results of the authors' ecosystem service assessment for cultural services in transitional and homogeneous reed wetlands.

Section Class	Potential MEAN (potential compared to possible maximum)		Use MEAN (% of potential)	
	Transitional reed (%)	Homogeneous reed (%)	Transitional reed (%)	Homogeneous reed (%)
C Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	41–60	21–40	21–40	1–20
C Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	61–80	41–60	61–80	61–80
C Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	61–80	41–60	41–60	41–60
C Characteristics of living systems that enable education and training	41–60	41–60	21–40	21–40
C Characteristics of living systems that are resonant in terms of culture or heritage	61–80	41–60	1–20	1–20
C Characteristics of living systems that enable aesthetic experiences	41–60	41–60	61–80	61–80
C Characteristics or features of living systems that have an existence value	41–60	41–60	61–80	61–80

Harvest during winter compared to summer harvest reduces conflicts with nature protection (e.g., bird breeding), and harvest costs are lower when the wetland soils are frozen (Köbbing et al., 2013). Winter cutting can increase culm density and overall aboveground biomass production of *Phragmites* in the following vegetation period (Ostendorp, 1999). Also, Hansson and Graneli (1984) and Huhta (2009) noted an increase in reed vitality after winter harvest. According to Günther et al. (2015), reed harvest has no negative effect on greenhouse gas balances on a timescale of a few years; however, the long-term effects are still under investigation, and once results are available, they should be incorporated into the sustainable harvest concept for coastal wetlands. Reed harvest diminishes insect and fungus populations and decreases oxygen consumption by decomposer organisms due to the biomass removal (Hansson and Graneli, 1984; Brix, 1988; Schäfer and Wichtmann, 1999; Hansson and Fredriksson, 2004; Kask et al., 2007; Köbbing et al., 2013). However, nutrient removal efficiency is minimal during winter harvest with phosphorus concentrations in the aboveground plant material with 1,100 mg P m⁻² in November down to 100 mg P m⁻² in March (Berthold et al., 2018). This is reflected in the experts' results, which show a higher increase regarding nutrient accumulation for the summer harvest scenario than for the winter harvest scenario (Table 4 vs. Table 5). Reed harvest impacts cultural, social, and economic aspects. In particular, Lithuanian experts expect a high increase (+3) for culture and heritage (Table 4). Roofs thatched with reed are characteristic along the Baltic coast. Many of those houses are even under historic preservation underlining their cultural importance (FAZ, 2016).

Scenario 2: Summer Harvest

Reed harvested during summer has a higher nutrient content than winter biomass, and it is usually utilized as fodder or fertilizer or for biogas production with the advantage that the land of coastal reed wetlands seldom competes with food production (Köbbing et al., 2013). Productivity surveys showed that 6.5–23.8 t dry mass ha⁻¹ year⁻¹ of reed could be harvested during summertime (Steffenhagen et al., 2008; Schulz et al., 2011). It is thus not surprising that the questioned experts of this study saw the highest provision increases for the following services: agriculture (e.g., harvested amount of reed as fodder, straw for stables, fertilizer, or compost) and filtration, sequestration, accumulation, and storage of nutrients (Table 5). The assessment of changes in the section “regulation and maintenance” was again very heterogeneous, ranging from -3 to +3 for services such as erosion control, maintaining nursery populations and habitats or local climate regulation (Annex I). On average, a low decrease of mass stabilization and local climate regulation is predicted by the experts. Regarding cultural services, on average, no or only low changes were expected for the summer harvest scenario. Experts with only a moderate knowledge on reed wetland functioning saw a higher increase of agricultural services for the summer harvest scenario compared to the assessment of experts with excellent or good knowledge on reed wetlands (Table 5).

During the discussion, the experts pointed out that a shift in vegetation patterns and thus ecosystem structure and functions can be introduced by continuous summer harvest over several years. In some areas along the Baltic coast, summer harvest is applied as a nature conservation measure, for example, for the promotion of ground-nesting birds (Köbbing et al., 2013). The

TABLE 4 | Mean values and standard deviation (SD) of expert assessments of the changes in ecosystem service provision for management scenario 1: Winter harvest.

Ecosystem Service	Indicator	Mean (all experts)	SD (all experts)	Mean (experts with excellent/good knowledge)	Mean (experts with moderate knowledge)	Mean (German experts)	Mean (Lithuanian experts)	Mean (Polish experts)
Livestock	e.g., number of animals (e.g., cattles of water buffalos, herd of sheep)	0	1	0	0	0	0	1
Agriculture	e.g., harvested amount of reed as fodder, straw for stables, fertilizer, or compost	1	1	0	1	1	0	1
Biomass utilization: Fibers and other material for direct use or processing	e.g., harvested amount of reed as construction material, insulation material, pulp, or paper	2	1	2	2	2	3	2
Bioenergy	e.g., harvested amount of reed as energy source (combustion, biogas, biofuel)	2	1	2	2	2	3	2
Wild animals and their output	e.g., number of hunted animals (e.g., wild boar, deer)	0	1	0	0	0	0	0
Filtration/sequestration/storage/accumulation	e.g., nutrient removal efficiency or carbon storage	1	1	1	1	2	1	2
Mass stabilization and control of erosion rates	e.g., sediment accumulation rate and buffer for wind and water energy	0	2	1	0	0	0	1
Maintaining nursery populations and habitats	e.g., biodiversity (Wild plant and animal species richness)	0	1	1	0	0	1	0
Regulation of soil quality	e.g., decomposition rates	0	1	0	0	0	0	0
Local climate regulation	e.g., impacts on temperature and humidity, including ventilation, and transpiration	0	1	0	0	0	0	0
Health, recuperation or enjoyment	e.g., number of visitors looking for enjoyment provided by ecosystems (e.g., view, wildlife, activities)	0	1	0	0	0	0	0
Scientific and educational	e.g., scientific and educational publications, documentaries, exhibitions, nature trails	1	1	1	1	1	0	1
Culture and heritage	e.g., number of reed thatched houses	2	1	2	2	2	3	2
Existence and bequest	Non-use value, preservation for future generations, protected areas	0	1	0	0	0	0	0

Results were further divided for different groups based on the experts' background knowledge on reed wetland functioning and nationality. Negative numbers represent a decrease in services provision, positive numbers represent an increase, and the number "0" represents no changes. For the individual results of the expert assessment, see Annex 1.

TABLE 5 | Mean values and standard deviation (SD) of expert assessments of the changes in ecosystem service provision for management scenario 2: Summer harvest.

Ecosystem Service	Indicator	Mean (all experts)	SD (all experts)	Mean (experts with excellent/good knowledge)	Mean (experts with moderate knowledge)	Mean (German experts)	Mean (Lithuanian experts)	Mean (Polish experts)
Livestock	e.g., number of animals (e.g., cattles of water buffalos, herd of sheep)	0	1	1	0	0	0	0
Agriculture	e.g., harvested amount of reed as fodder, straw for stables, fertilizer, or compost	2	1	1	2	2	2	2
Biomass utilization: Fibers and other material for direct use or processing	e.g., harvested amount of reed as construction material, insulation material, pulp, or paper	1	1	0	1	1	1	1
Bienergy	e.g., harvested amount of reed as energy source (combustion, biogas, biofuel)	1	1	1	2	2	1	1
Wild animals and their output	e.g., number of hunted animals (e.g., wild boar, deer)	-1	1	0	-1	-1	-1	0
Filtration/sequstration/storage/accumulation	e.g., nutrient removal efficiency or carbon storage	2	1	2	2	2	1	2
Mass stabilization and control of erosion rates	e.g., sediment accumulation rate and buffer for wind and water energy	-1	2	0	-1	-1	0	-1
Maintaining nursery populations and habitats	e.g., biodiversity (Wild plant and animal species richness)	0	2	2	-1	0	0	1
Regulation of soil quality	e.g., decomposition rates	0	1	0	0	-1	0	0
Local climate regulation	e.g., impacts on temperature and humidity, including ventilation, and transpiration	-1	2	-1	-1	-1	-1	0
Health, recuperation or enjoyment	e.g., number of visitors looking for enjoyment provided by ecosystems (e.g., view, wildlife, activities)	0	1	1	0	1	2	0
Scientific and educational	e.g., scientific and educational publications, documentaries, exhibitions, nature trails	1	1	1	1	1	1	2
Culture and heritage	e.g., number of reed thatched houses	0	1	0	0	0	0	0
Existence and bequest	Non-use value, preservation for future generations, protected areas	0	1	0	0	0	0	0

Results were further divided for different groups based on the experts' background knowledge on reed wetland functioning and nationality. Negative numbers represent a decrease in services provision, positive numbers represent an increase, and the number "0" represents no changes. For the individual results of the expert assessment, see Annex 1.

TABLE 6 | Mean values and standard deviation (SD) of expert assessments of the changes in ecosystem service provision for management scenario 3: Grazing.

Ecosystem Service	Indicator	Mean (all experts)	SD (all experts)	Mean (experts with excellent/good knowledge)	Mean (experts with moderate knowledge)	Mean (German experts)	Mean (Lithuanian experts)	Mean (Polish experts)
Livestock	e.g., number of animals (e.g., cattles of water buffalos, herd of sheep)	2	1	2	3	3	2	3
Agriculture	e.g., harvested amount of reed as fodder, straw for stables, fertilizer, or compost	0	1	1	0	1	-1	0
Biomass utilization: Fibers and other material for direct use or processing	e.g., harvested amount of reed as construction material, insulation material, pulp, or paper	-1	1	-1	-1	0	-2	0
Bienergy	e.g., harvested amount of reed as energy source (combustion, biogas, biofuel)	-1	1	0	-1	0	-2	0
Wild animals and their output	e.g., number of hunted animals (e.g., wild boar, deer)	0	1	0	0	0	-1	1
Filtration/sequstration/storage/accumulation	e.g., nutrient removal efficiency or carbon storage	0	2	0	1	1	1	0
Mass stabilization and control of erosion rates	e.g., sediment accumulation rate and buffer for wind and water energy	-1	1	-1	-1	-1	-2	0
Maintaining nursery populations and habitats	e.g., biodiversity (Wild plant and animal species richness)	1	2	2	0	1	0	1
Regulation of soil quality	e.g., decomposition rates	0	1	0	0	-1	0	1
Local climate regulation	e.g., impacts on temperature and humidity, including ventilation, and transpiration	-1	1	0	-1	-1	0	0
Health, recuperation or enjoyment	e.g., number of visitors looking for enjoyment provided by ecosystems (e.g., view, wildlife, activities)	1	1	1	1	1	2	2
Scientific and educational	e.g., scientific and educational publications, documentaries, exhibitions, nature trails	1	1	2	1	1	2	2
Culture and heritage	e.g., number of reed thatched houses	-1	1	-1	0	0	-2	-1
Existence and bequest	Non-use value, preservation for future generations, protected areas	0	1	0	0	0	-1	0

Results were further divided for different groups based on the experts' background knowledge on reed wetland functioning and nationality. Negative numbers represent a decrease in services provision, positive numbers represent an increase, and the number "0" represents no changes. For the individual results of the expert assessment, see Annex 1.

possible shift in ecosystem structure made it difficult for the experts to assess the expected increases or decreases in service provision. This is especially true with regard to maintaining nursery populations and habitats as it really depends on target species. Thus, expert ratings were ambiguous regarding habitats and biodiversity (**Annex I**).

Scenario 3: Grazing

For the grazing scenario, an increase in livestock and maintenance of nursery populations and habitats was expected by the experts, as well as an increase in health, recuperation, or enjoyment and in scientific and educational services (**Table 6**).

Grazing has a long tradition in the Baltic Sea region, and until the 1940s, coastal wetlands were usually used for livestock (Wanner, 2009). Continuous grazing in coastal reed wetlands can lead to a shift in vegetation pattern toward short salt marsh grassland, which is preferred by ground-nesting birds (Jeschke, 1987; Esselink et al., 2000; Jutila, 2001; Bernhardt and Koch, 2003; Rannap et al., 2004; Burnside et al., 2007; Wanner, 2009). Once grazing activities stop, reed will quickly re-dominate the area, which often results in a loss of biodiversity and habitats (Esselink et al., 2000; Rannap et al., 2004; Burnside et al., 2007; Wanner, 2009). However, the use of common cattle for reducing spread and growth of reed is only successful, when grazing pressure is kept high (Vulink et al., 2000). This contradicts the nature conservation goal to keep cattle stocking densities low. Further, high grazing intensities might also threaten the nesting success of waders (Müller et al., 2007). A moderate grazing pressure with mosaics of intensively and moderately grazed patches often provides the highest biodiversity benefit (Doody, 2008).

Regarding regulating services, the experts' views were again very contrasting; for example, for the service "maintaining nursery populations and habitats," the individual assessments ranged from -3 to $+3$ (**Annex I**). This is comparable to the results for the summer harvest scenario. The experts pointed out that more details about temporal and spatial scales are important to evaluate whether the provision of regulating services increases or decreases. Information about grazing pressure (length of grazing season, livestock unit per hectare) and the type of livestock (cattle, sheep, horses, water buffaloes) impact the reed wetland structure (Scherfose, 1993; Kiehl et al., 1996; Kiehl, 1997; Kleyer et al., 2003; Rannap et al., 2004; Doody, 2008; Wanner, 2009). In scientific literature, water buffaloes with their wetland-adopted hooves and grazing behaviors are described as most suitable for conservation purposes (Georgoudis et al., 1999; Wiegleb and Krawczynski, 2010; Wichtmann, 2011; Sweers et al., 2013). A grazing study in brackish coastal reed wetlands by Sweers et al. (2013) showed that grazing by water buffaloes successfully reduced the reed dominance and led to a shift toward salt marsh grassland with higher species diversity. Water buffaloes carry out this transformation process already at lower livestock densities than common cattle (Sweers et al., 2013). This supports the observations by Georgoudis et al. (1999), Wiegleb and Krawczynski (2010), and Wichtmann (2011) that water buffaloes have a greater preference for wetland plants. Therefore, they are suitable animals for wetland management

especially when it aims at shifting reed monocultures into diverse salt marsh grassland.

Similar to maintaining habitats and nursery populations, the expert assessment was very heterogeneous for the service "filtration/sequestration/storage/accumulation," ranging from -3 to $+3$ (**Annex I**). Also, the scientific literature offers no clear results whether nutrient retention and peat growth are enhanced or reduced by different grazing regimes (Wanner, 2009). On one hand, reed contributes to peat formation and nutrient accumulation (Schieferstein, 1997; Mitsch and Gosselink, 2000; Succow and Joosten, 2001; Meuleman et al., 2002). A shift from reed wetlands toward salt grasslands could potentially release accumulated nutrients (Huhta, 2007). Also, sedimentation rates are usually lower in intensively grazed salt marshes with shorter vegetation, and thus nutrient deposition would be lower in salt marshes than in reed wetlands (Andresen et al., 1990; Bakker et al., 1997; Kiehl, 1997; Stock et al., 1997; Esselink et al., 1998; Neuhaus et al., 1999). On the other hand, biomass and thus organic matter are directly removed by livestock, and some authors argue that grazing has the potential to increase carbon and nutrient sequestration (Jones and Donnelly, 2004). Furthermore, soil compaction as a result of grazing pressure may lead to more waterlogged soils, resulting in higher denitrification rates of grazed salt marshes (Jensen et al., 1990).

SYNTHESIS AND CONCLUSIONS

Coastal reed belts are transitional systems with pronounced gradients from land to sea. The resulting higher heterogeneity of abiotic factors, such as vegetation structure, salinity, or topography, and a higher spatial biodiversity lead to an increased provision of regulating and cultural ESs, compared to reed wetlands surrounding inland waters. This study deals with the impacts of three different habitat management scenarios on ES provision in coastal reed wetlands: (1) winter harvest, (2) summer harvest, and (3) grazing. If reed utilization—and thus an increase in provisioning services—conflicts with nature protection depends strongly on (a) spatial and temporal scales as well as on (b) the pre-defined set of nature protection goals. For the latter, Natura 2000 management plans with its prefixed target species and habitats are a good example, e.g., designated areas in the Curonian Spit National Park (Lithuania) as well as in the Western Pomerania Lagoon Area National Park (Germany) are supposed to serve as habitats for ground-nesting birds (see **Figure 1**). To restrict the reed dominance in these areas, management intervention that leads to a shift in vegetation toward salt marsh grasslands is necessary. This can be achieved by grazing or by summer harvest of reed. However, the temporal scale determines the success of the intervention: Only if grazing or harvest is carried out continuously every summer for several years can reed be restrained.

Our study contributes to an enhanced knowledge with respect to reed wetland ecosystem functioning. Further, the assessments allow the identification of trade-offs between ESs. These trade-offs serve as a basis to explore the impact of

multiple management options. For example, grazing with livestock leads to a reduction of reed area. As a consequence, the provision of regulating services like erosion control and cultural services like heritage (e.g., loss of reed for roof thatching) would decrease. This is just one example of a trade-off that was identified by the ES assessments. The identification of trade-offs is considered as beneficial for decision-making processes (e.g., Seppelt et al., 2013; Howe et al., 2014; Bennett et al., 2015; King et al., 2015). Further, the communication of anticipated trade-offs resulting from different management options is an important prerequisite for successful ecological governance. An example is the Natura 2000 site management: Based on a social network analysis, Manolache et al. (2018) show that productive collaboration between various actors (e.g., law enforcement agencies, NGOs, enterprises) is still low, regardless by whom the protected areas are governed. Simply delegating administration of protected areas to NGOs in order to increase collaborations proved to be insufficient (Manolache et al., 2018). Our evaluation of ES provision under different management regimes can increase the information flow between different actors and thereby improve their cooperation. The inclusion of stakeholder views at an early state can help to identify conflicts and thus contributes to a better acceptance of the taken decisions (Hauck et al., 2013; Ruiz-Frau et al., 2018). Our assessment approach can be easily transferred to other situations, ranging from specific local management demands to conceptual management consideration within an international policy implementation context. An assessment not necessarily results in consensus on management decisions, but the tool highlights topics that are controversial and allows more focused discussions between stakeholders. An example is the need to reduce nutrient loads into coastal waters according to the European Water Framework Directive. Compared to winter harvest, our experts expect a higher nutrient removal efficiency for the summer harvest scenario, due to the higher nutrient concentration in reed biomass. However, if harvest is carried out in summer instead of winter, the experts also assume a decrease with respect to mass stabilization and erosion control. Stronger erosion could lead to a sediment transport into the coastal water and counteract nutrient removal. As our methodological framework relies on a tier-1 ES (qualitative) approach, the results reflect the expert views. For a more comprehensive understanding, specific analysis of regional patterns and processes would be beneficial. This would require the use of more sophisticated tier-2 or tier-3 ES (quantitative) approaches.

Cultural and regulating services are regarded as more important in coastal reed belts than provisioning services. This does not mean *per se* that reed utilization has to be in conflict with nature protection or diminish the other services. For the winter harvest scenario, experts expect no changes or even slight increases for regulating and cultural services. Roofs thatched with reed have a long tradition along the Baltic Sea and are part of the regional identity and heritage. However, most of the reed used for roof thatching has to be imported nowadays.

The regional supply of winter reed for roof construction could enhance the regional bond and offer an income opportunity in economically weak regions. Winter harvest can be in line with nature protection goals and can be carried out in a sustainable way: A rotating system should be applied, where each year another area is harvested. A “greenbelt” between the terrestrial hinterland and the coastal wetland without harvest should always remain to maintain the erosion control also immediately after cutting in wintertime. Sensitive areas (e.g., steep topography and vulnerable to erosion) should remain untouched. Timing of harvest should take into account the regional climate (e.g., in February after winter storms). A transferability of this recommendation to other areas outside the Baltic Sea is difficult because reed-thatched houses are part of the regional identity and markets for harvested reed biomass might not exist in other regions. However, the tool itself—the assessment of ESs under changing management scenarios—is transferable and universally applicable.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and the **Supplementary Material**.

AUTHOR CONTRIBUTIONS

SK developed the article concept, took care of the data analyses, and did most of the article writing. MI provided the assessment tool, took part in the assessment, supported the analysis, and commented on the paper. GS supported the article concept development, the writing, and the analysis and took part in the assessment.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2019.00063/full#supplementary-material>

Annex I | Overview of the single expert assessments for all three scenarios as well as mean values and standard deviation (SD).

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