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REVIEW ARTICLE

Impact of Sitka spruce on biodiversity in NW Europe with a special focus on Norway – evidence, perceptions and regulations

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ABSTRACT

The impact of historical and present drivers on biodiversity, particularly species richness and abundance, in afforestation areas concerning non-native tree species is still poorly understood. A better understanding is important to ensure appropriate forest management in the face of climate change and increasing demand for wood products. Here, we have reviewed 75 biodiversity studies in Sitka spruce plantations in NW Europe, forest management recommendations for maintaining biodiversity, timber production and carbon sequestration in Sitka spruce forests in coastal Norway compared to NW Europe. Due to more focus on non-market landscape benefits and protection sites in coastal areas, transformation of spruce plantations is common. Premature cutting of stands and shelterbelts and clearing away saplings has become the dominant management practice in Norway. Based on the extent of use in Norway, and results from biodiversity studies in Sitka spruce plantations in NW Europe, the quality of evidence for the prevailing practice and recommendations in coastal Norway is highly questioned. To reduce conflicts, we propose a more knowledge-based management, a broader perspective underpinning the range of afforestation goals, also including the use of alternative silvicultural methods to increase structural variation in Sitka spruce stands.

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Sitka spruce; non-native; Norway; biodiversity; effects

Introduction

Cost and benefits of growing different tree species, including native versus non-native, have been debated over hundreds of years and are still debated worldwide (Zobel et al. 1987; Richardson 1998; Felton et al. 2013; Krumm and Vítková 2016; Pötzelsberger et al. 2018). In general, the most attractive commercial forest species to grow are those yielding great timber volumes of high value in relatively short rotations and with little damage from wind, snow and pathogens. In Europe the area of non-native tree species is c. 85 million hectares or c. 5.2% of the total forest area. The two most common non-native conifer trees in NW Europe are the Douglas-fir (*Pseudotsuga menziesii*) and Sitka spruce (*Picea sitchensis*), both from the Pacific North West. In addition to timber production, non-native tree species contribute to other ecosystem services like carbon sequestration, providing shelter, soil stabilisation, habitats, recreational purposes (Hasenauer et al. 2017; Burton et al. 2018).

Sitka spruce in North-west America

Sitka spruce, the largest of the world's spruces, is one of the most prominent forest trees in stands along the Pacific North-west coast (Harris 1978, 1990). In its original range the species is mainly confined to coastal forests between Alaska and northern California. The temperate rainforest of the Pacific North West (PNW) has few tree species, but rather complex horizontal and vertical structures and a large amount of dead wood (Alaback and Herman 1988; Franklin and Dyrness 1973; Van Pelt 2007; Deal 2014). Biomass production, carbon pools and productivity in the Western hemlock– Sitka spruce forests are relatively high, with biomass accumulations far exceeding those of forests in other north temperate regions (Peterson et al. 1997; Krankinaet al. 2014). The coastal temperate rainforest of North America shows high species richness and supports c. 350 species of birds and mammals, c. 50 species of amphibians and reptiles, hundreds of species of fungi and lichens and thousands of species of insects, mites, spiders and other soil organisms (cf. Pojar and MacKinnon 1994; Peterson et al. 1997; Swanson et al. 2014). Basically, two stand types have been identified in the Western hemlock-Sitka spruce forest types in PNW: (1) even-aged stands following catastrophic blowdown; and (2) multi-aged stands resulting from gradual fine-scale natural disturbances such as wind throw, landslides and pathogens (Van Pelt 2007; Deal et al. 2017). Pure stands of Sitka spruce usually occur in early successional stages and as tidewater stands; Sitka spruce is often the dominant conifer in riparian forests near rivers and streams. The species richness and species composition varies greatly with successional stage. Generally, the early herb/shrub establishment and mature to old-growth transitioning to shifting mosaic stages contain the greatest number of species (OECD 2002). This pattern is common for many groups of organisms, including vascular plants, birds and many invertebrates. Over the last decades there has been a general concern that many of these old-growth characteristics are lacking in even-aged young-growth

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forests resulting from forest management (Deal 2014). However, several management options exist which can be utilised to improve the managed forests biodiversity value (Deal et al. 2017).

Sitka spruce in Europe

Sitka spruce has become the most important timber tree in NW Europe over the last 60 years (Joyce and O'Carroll 2002; Lee et al. 2012; Houston Durrant 2016). This species is favoured in parts of Europe with an oceanic climate because of a relatively safe production, its fast growth and ability to produce high-quality timber, which is suitable for a variety of uses; structural timber, pallets, fencing and panel products, pulp and energy wood (Moore 2011). The use of Sitka spruce is also recognised as an effective tool to sequester carbon and facilitate adaptation of forests to global climate change (Mason and Perks 2011; Øyen and Nygaard 2008).

In Europe, Sitka spruce plantation area presently covers approx. 1.26 million hectares (Table 1).

Forest statistics, regarding annual harvesting of Sitka spruce in NW Europe, reports a present level of 12–13 million m^3. Indisputably, the timber resources of Sitka spruce are presently playing a crucial role for the wood-based industry in the region and will do so in the foreseeable future (Moore 2011; Houston Durrant 2016).

Sitka spruce seed was first imported from the Pacific NW by David Douglas to Europe in 1827 and the first seedlings were planted in Scotland in 1831 (Anderson 1967). The first major imports of seed into Britain were in 1852 (Anderson 1967), and the rapid early growth led to the establishment of trial plantations in Scotland, Wales, North England and Ireland from the 1880s onwards. In Scandinavia, Sitka spruce was first introduced to Denmark in 1855 (Oppermann 1922; Skovsgaard 1997), and in Germany the first trials of Sitka spruce were established in the 1880s (Schober 1962).

There is a great portfolio of long-term trials in NW Europe where Sitka spruce is represented, a search (Oct. 2019) in the Northern European Database of Long-Term Forest Experiments (NOLTFOX, http://noltfox.metla.fi/) displayed 469 trials. Several operational trials have been established to explore the feasibility of Sitka spruce; however, none of these includes biodiversity studies.

Table 1. Area of Sitka spruce in NW Europe (kha = 1000 ha). Sources: Forestry Statistics UK, Forestry Statistics Ireland, Lee et al. (2012), Tomter (2018), Mason and Perks (2011), Pötzelsberger et al. (2018).

Country	Plantations with Sitka spruce (kha)
Scotland	567
Ireland	358
England and N. Ireland	80
Wales	77
France	50
Norway	48
Denmark	37
Germany	20
Sweden	7
Iceland	7
Netherland	2
Sitka spruce in Europe	1255

Sitka spruce in Norway

The pioneer plantings

The first Sitka spruce seeds in Norway were sown in Sandnes forest nursery in 1869, and seedlings were planted in 1872 (Schübeler 1885; Øyen 2005a, 2005b). Scattered planting took place up to World War 1, often with little success due to the use of provenances that were too far south (Hagem 1916, 1931; Magnesen 1992, 2001). Anton E. Smitt, later chief forest researcher established seed-contacts in British Colombia and Alaska in 1916 (Smitt 1950; Hagem 1931). The first forest plantations of some hectares were established in West- and North-Norway in the 1920s based on seed import from British Colombia and southeast Alaska (Hagem 1931). The total Sitka spruce plantation area in Norway before the 1950s was restricted to 3400 hectares (Table 2).

However, cultivation and Sitka spruce planting increased rapidly after the 1950s when the national afforestation plans for West- and North-Norway were launched (Skogdirektøren 1954; Øyen 2008). In the 1950s, the Forest Authorities recommended Sitka spruce to be the number one afforestation tree in the outermost, coastal districts of western Norway (Skogdirektøren 1954; Boertnes 1971).

Early research and use

Cultivation trials in West Norway showed that Sitka spruce was heavily damaged in sites with high risks for summer frost (Magnesen 1992). In addition, locations, where annual precipitation was lower than 1000 mm, i.e. inner fjord sites and continental inland sites, were unsuitable (Hagem 1931; Robak 1966; Bergan 1994). In the northernmost counties of Norway, Sitka spruce was sensitive to autumn frost, and the hybrid Lutz spruce (*P. sitchensis* x *P. glauca* = *P.* x *lutzii* Henry) has proved to be a better choice (Kaasen et al. 1993; Skaret 2005; Øyen 2008). Lutz spruce covers c. 5000 hectares. Seed supply of northern materials of Sitka spruce and Lutz spruce from Pacific NW, especially Alaska, was a challenge up to the mid-1950s (Stener 2015).

The pre-thicket growth of Sitka spruce was early described as very promising (Smitt 1950; Bauger and Smitt 1960; Bauger 1961; Robak 1966). However, in certain *Calluna*-dominated heathlands growth inhibition, commonly referred to as "check" (cf. Taylor and Tabbush 1990), was identified as a serious problem (Hagem 1931). Cultivation methods like scarification and phosphate-fertilisation became a more common feature in the 1960s and 1970s, and the check problem was solved (Nilsen 2001). However, the interest in afforestation on wetland and heathland gradually diminished. Although there are some reports of frost damages (Hagem 1931; Robak 1966; Magnesen 1992; Bergan 1994), *Elatobium*-attacks (Bakke et al. 1998; Orlund and Austaraa 1996), and root rot (Øyen and Øen 2003), Sitka spruce has been the most vital and stable tree species in numerous trials along the Norwegian west coast (Bauger 1978; Øyen and Tveite 1998; Magnesen 2001; Øyen 2008; Nygaard & Øyen 2017).

Table 2. Plantation area (ha) per decade of Sitka spruce in Norway. Source: Annual reports, Skogdirektøren 1875–2018. Per cent denotes proportion in 10-year classes of the total area of 48 000 hectares.

Decade	−1920s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
Area	400	1400	1200	200	4300	11900	16800	7400	3900	600	100
Age-class	+100	95	85	75	65	55	45	35	25	15	5
Per cent	0.8	2.9	2.5	0.4	8.9	24.7	34.9	15.3	8.1	1.2	0.2

Table 3. Norwegian studies on biodiversity in Sitka spruce compared to neighbouring stands or landscapes. S denotes species richness; A are abundance or density; S + A both.

Taxonomic group	Author(s), published in year	Scale of study	Effect of SS
Birds	Nygaard and Stabbetorp (2006)	1 stand	Negative (S)
Collembola spp.	Fjellberg et al. (2007)	1 stand	Neutral (S + A)
Cryptogams	Hilmo et al. (2014)	18 stands	Slightly negative (S + A)
Epiphytic lichens	Øyen and Skye (1999)	1 stand	Slightly negative (S)
Epiphytic lichens	Wannebo-Nilsen et al. (2010)	6 stands	Negative (S)
Ground flora	Nygaard and Stabbetorp (2006)	1 stand	Negative (S)
Ground flora	Saure et al. (2013a, 2013b)	38 saplings	Slightly negative (S + A)

Sitka spruce is the most commonly planted non-native tree species in Norway, presently occupying 48,200 hectares or 0.4% of the national forest covered area. However, locally, Sitka spruce is the only commercial tree species of interest, like in the outer coastal districts of West-Norway and parts of Nordland County where it locally dominates forested parts of the landscape. The distribution of age structure is rather narrow, three quarter of the plantations being established between 1961 and 1980 (Table 3).

Planting of Sitka spruce was also prioritised in windbreaks and shelterbelts on islands and outer and mid-fjord sites up to latitude 69°N due to the ability to withstand a harsh coastal climate with sea salt (Aamlid and Horntvedt 2002; Øyen 2008). We estimate that 5000 hectares of the Sitka spruce area is windbreak plantings, shelterbelts and planting along property borders in islands and archipelagos. Almost all plantation area in Norway has been located on private land on c. 10,000 rather small properties along the coast. The soil conditions suitable for Sitka spruce vary from very fertile mineral soils to impoverished peaty and podzolic conditions. Most of the planting sites are intermediate mineral soils; heathland, pastures and abandoned farmland (Øyen 2005a, 2005b; Nygaard and Øyen 2017). In the 1970s some afforestation of Sitka spruce on drained marshland and cultivated bog was performed (Arnøy 1986; Brække 1984), most with favourable results regarding growth and development (Nyeggen and Øyen 2014). Sitka spruce applied in coastal Norway shows certain similarities to other plantation sites in NW Europe. However, due to small property sizes the plantations are rarely more than a few hectares visible as distinct dark polygons interspersed with Scots pine and Downy birch (Gjerde 1993; Øyen 2008). Plantations in sparsely populated areas are often surrounded by sea, barren hills, grazing land, mires or abandoned pastures, i.e. regrowth areas with prethickets of Downy birch and Aspen (Nygaard and Stabbetorp 2006; Ørka and Hauglin 2016).

The use of Sitka spruce over the last 30 years

After the 1980s the planting of Sitka spruce declined in most parts of coastal Norway (Øyen 2008). From 2002 onwards, the annual cultivation area of Sitka spruce decreased to less than 25 hectares per year (Landbruksdirektoratet 2018). In the same period the annual cutting has gradually increased to a level corresponding to c. 300 ha per year (Miljødirektoratet 2019).

Despite inconsistent results from observational studies, in 2012 the Norwegian Biodiversity Information Centre blacklisted Sitka spruce according to a risk evaluation for biodiversity in Norway. Sitka spruce was classified as having severe impact mainly due to the precautionary principle, and emphasising possible negative ecological effects, and particularly its potential threats to heathland revert (Norwegian Biodiversity Information Centre 2012; Kjær et al. 2014). A similar conclusion was drawn in 2018 (Norwegian Biodiversity Information Centre 2018). The strict regulations and certification schemes have now led to premature harvesting and very little replanting of Sitka spruce. General negative and critical recommendations supported by environmental organisations (WWF 2014; Naturvernforbundet 2018; Sabima 2018) have been the driver for this development the last decade.

Annual roundwood cut area of Sitka spruce in Norway is expected to raise to a level of 800–1000 ha. Most of the raw-wood for sawtimber is exported for sawmilling in neighbouring countries, while the pulpwood and energy-wood are applied for domestic forest industries. Sitka spruce has been, and will continue to be, the dominant timber species in outer coastal sites in Norway and consequently will account for most of the harvesting output during the next decades. However, the estimated future cut is highly influenced by the prevailing management practice. Over the last 30 years the political focus has been on heathland restoration. Heathland has been value rated and defined as a prioritised landscape type, and the main goal in management plans for such areas involves clearing of forest, especially non-native tree species even if they play a minor role (e.g. Vesterbukt 2018; Johansen et al. 2017). Blacklisting and associated legislative obstacles for the forest owner's silviculture practice mixed with more extensive landscape management has led to a political scepticism of further planting (Miljødirektoratet 2019).The rationale for forest management decisions about clearing Sitka spruce stands is often dubious, sometimes related to possible ecological effects and future risk for spread to areas of special interest.

The main aim of this review is to examine the impact of Sitka spruce in afforestation on biodiversity in coastal Norway compared to NW Europe. We also discuss the differences in research findings between Norway an NW Europe and its implication for perception, recommendations and management.

Methods

An extensive literature search was carried out using the web-based search engines: Agris, Open Access Journal Search Engine and Google Scholar. Generally, these were designed to cover peer-reviewed scientific publications from the fields of forestry and conservation ecology.

Search terms were chosen based on the main tree species of interest: Sitka spruce (*Picea sitchensis)*, the type of outcomes of interest (changes, effects, impact), the habitat context (afforestation, forest, forested habitats) and a subject context (biodiversity, species richness). The searches for biodiversity studies were partly restricted by taxa; we have not included studies on pests and damages, since these have recently been reviewed (Tuffen and Grogan 2018). Neither have we included studies covering algae, bacteria, viruses or taxonomic groups with their habitat in streams, rivers and lakes.

A separate search was done for various terms of interest. We recognise that searches using online search engines have a bias towards more recent publications, especially those published after the mid-1990s. To attempt to counter this bias, further articles cited in relevant Sitka spruce reviews and publications: Harris (1970), IUFRO (1978), Staines et al. (1985,1987), were also explored during the data collection stage. Finally, we included "gray literature from Norway" applying anniversary catalogues, preliminary papers, internal reports and booklets from the Norwegian Forest Research Institute.

We recognise that the impact of non-native species falls into four main categories: directionality, classification and measurement, ecological changes and scale. Many of the questions asked in biodiversity studies include the term change, reflecting that the impacts of non-native species are due to the changes caused by them (Jeschke et al. 2014).

For each study we have sorted and listed the main taxonomic/functional group by using the following variables and the following classes (marked with underscore):

Taxonomic group (vascular plants, mosses, epiphytic lichens, molluscs, arthropods, insects, fungi, mammals, birds, annelids)

Country (United Kingdom, Ireland, Norway, Iceland)

Name of author(s)

Study published in year

Title

Name of journal

Type of journal

First or second rotation

Development stage (sapling stage, pre-thicket stage, thinning stage, mature forests, degradation-stage, chronology)

Reference landscape or forest-type (grassland, heathland, broadleaved-forests, conifer-forests)

Scale of study (tree, stand, landscape)

Main effect (negative, slightly negative, none, slightly positive, positive) – all in comparison with reference type. Whether studies report effects on species richness (S), abundance/densities (A) or combinations (S + A) as specific indices (for instance Shannon–Wiener index or others), is indicated.

In this review, we have included and listed 75 biodiversity studies covering afforestation with Sitka spruce in NW Europe and published from 1945 up to 2018.

Results

We identified a total of 75 biodiversity studies in Sitka spruce in NW Europe, studies that included either a comparison with a reference stand or comparisons with other types of landscapes and forests. Geographically, 65 of the studies originated from the British Isles and 10 from Nordic countries. About one-fourth of the studies we identified were published before 1997 and three quarters were published between 1997 and 2018. Many papers followed the British Isles programmes BioForest and Planforbio (Ireland) and Biodiversity Assessment project (UK). Most studies looked into effects on birds, ground flora and insects (Figure 1).

We identified seven studies or inventories regarding biodiversity effects of Sitka spruce stands from Norway (Table 3). Only five taxonomic groups are included in the Norwegian surveys; lichens, vascular plants, bryophytes, arthropods and birds. The Norwegian papers regarding birds in afforestation areas (Gjerde & Sætersdal 1997, 2005; Hausner et al. 2002) are mainly about the effects of *Picea* sp. forest. However, Sitka spruce occupies a negligible proportion of the spruce forest in their study areas, and therefore none of those papers have been included here.

All the Sitka spruce studies from Norway are on a tree level or they cover a limited number of stands. The reported effects are exclusively negative for the registered species groups except for *Collembola* where the recorded species number and densities in soil samples are about the same in a Sitka spruce stand compared to a neighbouring Downy birch stand, but where species composition changed (Fjellberg et al. 2007).

From NW Europe we compiled and listed 75 scientific papers on Sitka spruce and biodiversity including a far larger number of species groups (Appendix). When evaluating the magnitude and direction of effects in the papers; 26 showed a positive effect, 24 are reported negative effects and 25 showed no directional significant effect (Figure 2, appendix).

Although the studies are varying in reference landscape, in scale and duration; positive effects are mainly reported for soil fauna, Mollusca, fungi, bryophytes, seed-feeding birds and mammals, while negative effects are mostly reported for vascular plants, epiphytic lichens and wetland birds.

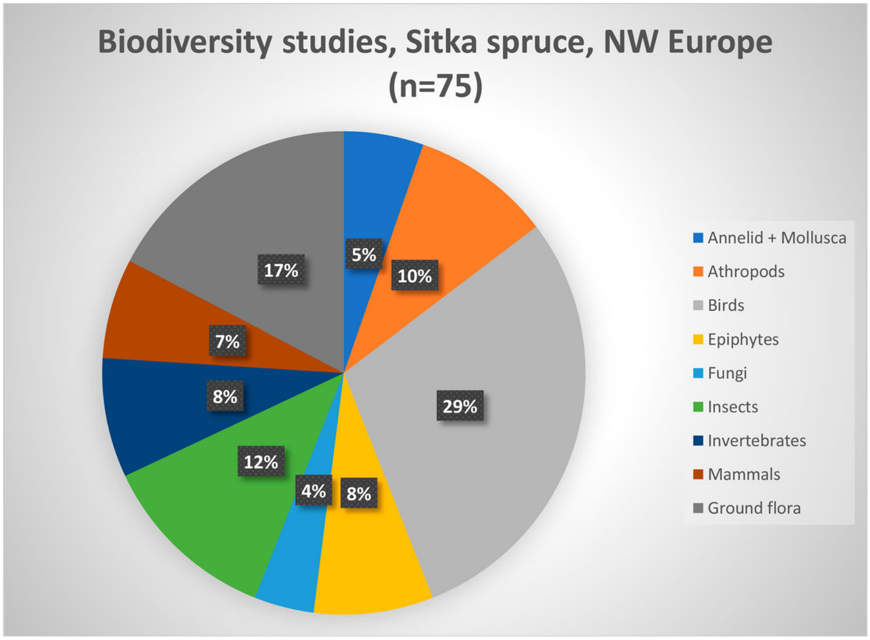

Figure 1. Proportion of taxonomic groups, Sitka spruce biodiversity studies, NW Europe.

Discussion

Biodiversity and afforestation

In spite of steeper Norwegian ecological gradients in elevation and latitude, we think that a shared history, quite similar habitats and oceanic climatic conditions suitable for Sitka spruce make results from other areas in NW Europe comparable to those from Norway. Similarities in previous land use and differences in scaling of plantations and silvicultural practice can provide the basis for further improving forest management strategies with respect to biodiversity.

The Norwegian studies report exclusively negative effects of Sitka spruce planting on biodiversity for a narrow window of time, for vascular plants and epiphytic lichens. This is in broad agreement with the European results and seems to be well documented (Hill 1979; Halldorson et al. 2008; Pedley et al. 2014; Irwin et al. 2014). The few Norwegian small-scale surveys are mostly conducted in dense, canopy closured, unthinned stands or even under crown projections on small trees (Saure et al. 2013a, 2013b). In such conditions light is the limiting factor, leading to out shading and lower species richness in vascular plants. However, this is not a Sitka spruce specific trait, dense stands of other native tree species such as Norway spruce and European beech also shade out most vascular plants and understorey vegetation layers. Changes in the composition of vascular plants during a rotation period are the rule rather than the exception. The species turnover during a rotation period for Sitka spruce is well described (Hill 1979; Wallace and Good 1995). As long as plantation areas are marginal compared to surrounding landscapes, local negative effects on vascular plants, mosses, lichens and birds have not been regarded as a problem on a regional scale due to the species-area relationship (Gjerde and Sætersdal 1997; Nygaard and Stabbetorp 2006).

The discrepancy between the mainly negative findings of Norwegian studies and the more balanced findings of positive and negative results from the British Isles is likely a result of the low number of species groups included in the few Norwegian studies. Further research, including a broad range of species groups, is very likely to change the estimates of positive and negative effects. One reason for lack of Norwegian investigations is that there is little tradition for biodiversity studies in afforestation stands (Rolstad et al. 2012). None of the Norwegian studies have examined biodiversity of mature Sitka spruce plantation forests and assessed their conservation value in relation to unmanaged coastal woodlands or heathlands. In addition, the perspective of the Norwegian Environmental Agency in only emphasising the negative impacts in risk analyses may have influenced the results from observational studies, but also recommendations, guidelines and public perception (Norwegian Biodiversity Information Centre 2018). This means that neutral and positive effects from Sitka spruce on diversity have been overlooked and underestimated. Overall, the lack of positive findings from Norway compared to NW Europe seems to be a result of a low number of surveys combined with observational bias due to a negative predisposition towards non-native tree species.

By contrast, many European studies have also reported neutral and positive effects of afforestation of Sitka spruce on several groups of species, e.g. wood-mice (Fernandez et al. 1994), spiders (Smith et al. 2008; Irwin et al. 2014), bats (Kirckpatric et al. 2017), seed-eating birds (Wilson et al. 2006; McKenzie et al. 2007; Sweeney et al. 2010a, 2010b, 2010c), pioneer-grasses (Buscardoet al. 2008), fungi (Humphrey et al. 2003; O'Hanlon & Harrinton 2012) and ants (Procter et al. 2015). Several of the British Isles studies are large scaled and include all phases over the entire rotation period from establishment to harvesting across first and

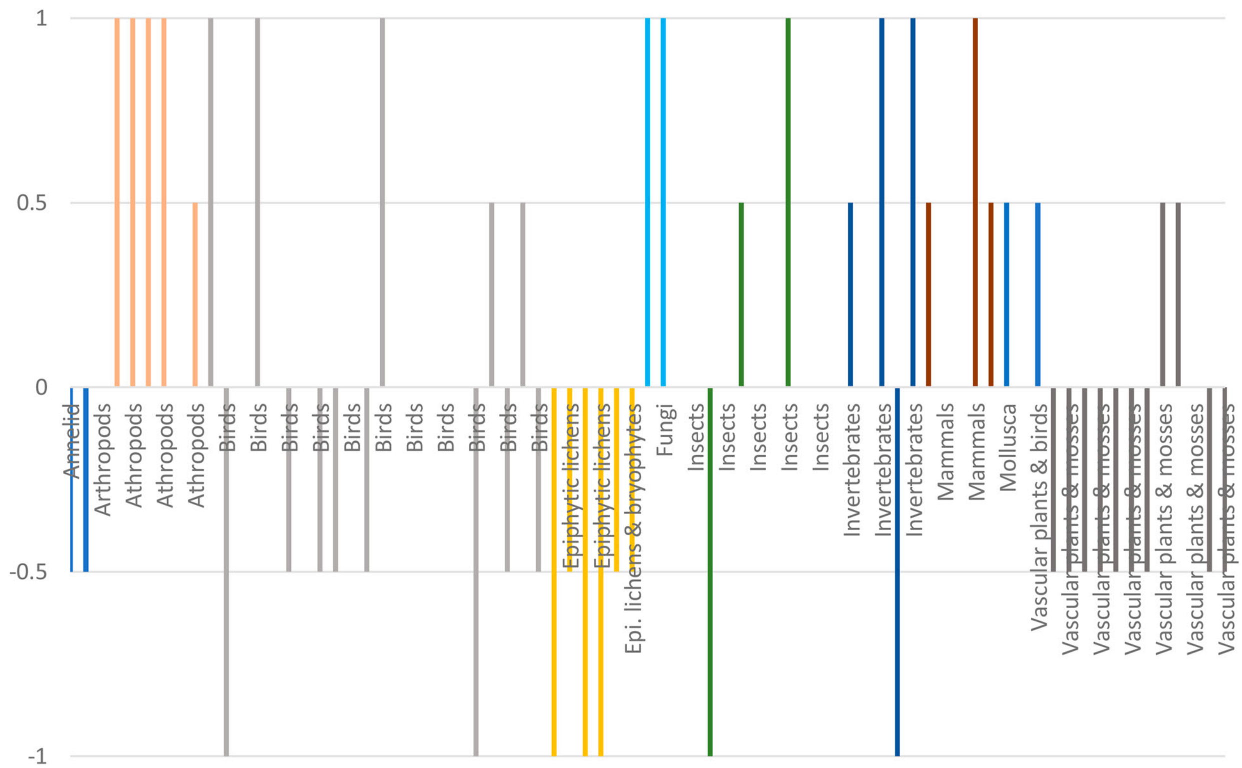

Figure 2. Direction of effects of Sitka spruce on various taxonomic groups with respect to species richness or abundance when compared to reference site for studies in NW Europe (*n* = 75). Positive effects = 1, slightly positive = 0,5, none = 0, slightly negative = −0,5 and negative = −1.

second rotations. Positive effects on vascular plant and bryophytes have been observed during early and late phases of the rotation period (Hill 1979; Wallace and Good 1995).

Additionally, positive impacts reported from the British Isles could be explained by differences in silvicultural measures (Savill 1991; Malcolm 1997; Mason 2007), differences in prior land use and initial conditions for reference sites (Smith et al. 2006), and also differences in disturbances (Quine et al. 1999; Díaz-Yáñez et al. 2016). Afforestation typically results in the reduced prevalence of open habitat species (Anderson 2003), while benefitting forest bird species, i.e. predators and seed eaters, which have high conservation values (Staines et al. 1987; Bibby et al. 1989; Sweeney et al. 2010a, 2010b, 2010c; Burton et al. 2018). Several studies have shown that structural heterogeneity increases the diversity of several groups of species (e.g. Ferris et al. 2000; O'Halloran et al. 2011). Therefore, forest management strategies can be used as a tool to increase selected diversity (Staines et al. 1987; Humphrey et al. 2003; Sweeney et al. 2010a, 2010b, 2010c; Deal 2014).

The reviews of biodiversity conclude that for certain taxa, plantation forests are less diverse than neighbouring habitats (cf. Iremonger et al. 2006; Halldorson et al. 2008; O'Halloran et al. 2011; Irwin et al. 2014; Burton et al. 2018; Castro-Díez et al. 2019). The biodiversity value of Sitka spruce plantation forests is highly variable and depends on the prior and alternative land use and prevailing forest management (Ferris and Humphrey 1999; Iremonger et al. 2007). There was a clear bias in the types of biodiversity studied, with the majority of studies concentrating on birds, ground flora and insects and less on fungi, invertebrates and others.

We can improve our knowledge of Sitka spruce and biodiversity by thorough reviewing of the literature, but new data from field experiments and observational studies are urgently needed. We also recognise that there can be large differences between the short- and long-term impacts of non-native species on species groups due to the variation during first or subsequent rotation periods.

Even-aged Sitka spruce-dominated woodland is often seen as unfavourable for biodiversity since it can shade out the understorey and ground flora. However, other studies have revealed that all types of British Isles woodlands supported biodiversity, with different tree species being favourable for different groups (Humphrey et al. 2003; Quine and Humphrey 2010). Various management practices can enhance woodland biodiversity (Brockerhoff et al. 2008; Humphrey et al. 2003, Deal 2014), i.e. by including a range of tree species in mixed stands to support a greater range of species.

Plantation forests are also shown to enhance landscape level biodiversity where natural or semi-natural forests are rare (Carnus et al. 2006; Brockerhoff et al. 2008). Sitka spruce plantations have proved to provide suitable habitats for a wide range of forest species, including species of conservation concern (red-listed species), and also common wildlife like birds and mammals (Ratcliffe and Petty 1986; Staines et al. 1987; Picozziet al. 1992; Weir et al. 1996; Humphrey et al. 2000; Quine and Humphrey 2010; Irwin et al. 2014). Different taxa differ in their response to afforestation, and while species richness in forest plantations can be as high as in semi-natural woodlands, the two forest types may support different assemblages of species in different forest stages, and a turnover of species is frequently reported

(Moss et al. 1977; Butterfield 1999; Fjellberg et al. 2007; Palfner et al. 2005; Fuller et al. 2008; Arroyo and Bolger 2007; Arroyo et al. 2010; Irwin et al. 2013; Burton et al. 2018).

Generally, the traditional management of Sitka spruce in coastal Norway up to the 1990s could be described as close spacing (planting 2500–4000 seedlings per ha), mostly no or low thinning and harvesting after 60–80 years. The practices are resulting in rather homogenous small-scaled stands, where the main purpose has been high timber yield and high-quality timber production. Various thinning measures, continuous cover forestry (CCF) and mixed stand silviculture have rarely been practised outside research trials, although suggested (Øyen 2001); Øyen 2005a, 2005b). Increased thinning intensity has been shown to increase vascular plant species richness; however, thinning operations have also caused a decline in the bryophytes and epiphytic lichens (Iremonger et al. 2006), and heavier thinning in coastal Norway may prove difficult, due to increased risk of wind throw (Øyen 2001). In Irish spruce stands large input of dead wood from thinning operations has been beneficial for the diversity of invertebrates (Nadeau et al. 2015). Successful CCF management (Mason 2015) requires a transformation period, long-term planning, and is complicated to implement in a landscape dominated by small stands located on many small forest properties. Further challenges include forest road-access for thinning operations due to steep terrain, and wind-stability challenges regarding the size and shape of the plantations. However, for larger stands, such management should be considered also in coastal Norway. The felling in broadleaved forests and Scots pine stands is presently very limited, and due to reduced grazing, there is a substantial regrowth in heathlands and abandoned grasslands (Tomter 2018). Improvements of within stand habitat provision by increasing the proportion of broadleaves above 10% (Skogdirektøren 2006) are expected. Suggestions to increase the rotation length of Sitka spruce stands up to 80 years or more seem favourable regarding yield, biomass production and structural heterogeneity, despite increasing the risk for windthrow and economic loss. Additional impacts from grazing due to animal husbandry (cf. Humphrey and Patterson 2000) and browsing and fraying of deer should be clarified (Latham 2000).

A management searching for mimicking natural processes involves mixing with broadleaves and conifers, more vertical and horizontal structural complexity and more deadwood creation from natural disturbances and from cuttings (Deal 2014). All these measures would likely increase stand complexity and enhance biodiversity (Staines et al. 1987; Bibby et al. 1989; Butterfield 1999; Humphrey et al. 2003; Humphrey 2005; Coote et al. 2008; Quine et al. 2013; Burton et al. 2018). Whether an area-effective (and cost-effective) concentrated wood production in many small Sitka spruce assets is better or worse than larger assets with regard to biodiversity still remains to be thoroughly investigated. We consider that the prevailing management practice of Sitka spruce in several small stands leads to less species diversity within stands and increased variation on landscape level due to a substantial edge effect (Odum 1983).

The results and in particular the interpretation of the results from Sitka spruce biodiversity studies have obviously influenced the societal and political perception in Norway, Denmark and the British Isles.

Some studies have discussed plantation forests and the appliance of the term "biological desert" (cf. Stephens and Wagner 2007; Hartmann et al. 2010; Bremer and Farley 2010; Brockerhoff et al. 2013). This viewpoint has also been frequently adopted and applied by Norwegian environmental organisations and also the Norwegian Environment Agency. This has now led to expensive environmental management practices in parts of coastal Norway where the eradication of Sitka spruce saplings and premature felling of Sitka spruce stands are carried out. This practice relies on low quality of evidence and high degree of values and beliefs.

This opinion has also influenced the regulations on non-native tree species in NW Europe. In Norway, which already has strict regulations on non-native trees, a proposal of a prohibition of Sitka spruce and other non-native tree species was discussed recently by the Norwegian Environment Agency and the Norwegian Agriculture Agency on a request from the Ministry of Climate and Environment and the Ministry of Agriculture and Food (Miljødirektoratet 2019). The proposal was highly influenced by environmentalists and "expert opinions" presented as evidence. However, in 2019 when ecosystem services i.e. carbon sequestration, adaptive management to climate change and industrial values were included, the Agencies rejected a ban of non-native trees and recommended controlled use of non-natives for forestry (Miljødirektoratet 2019).

In coastal Norway the negative perception and strong regulations have also been directed towards the invasion potential of Sitka spruce. Particularly, the spread into areas of special interest like reserves and national parks, might threaten biodiversity. However, so far the spread of Sitka spruce is limited in quantity and distance in coastal Norway (Nygaard and Øyen 2017; Vikane 2019). On disturbed seedbeds, short distance spread is locally abundant, but unwanted spread can be effectively controlled by management.

Conclusion

Coastal Norway has benefited from the production of high-quality Sitka spruce for several decades. In recent years, the use of Sitka spruce has been criticised because of possible negative effects on biodiversity and the risk of spread outside of targeted planting areas. One-sided emphasis on negative effects on biodiversity has affected the perception and also the regulation of Sitka spruce in Norway and thereby management. However, knowledge is fragmentary and superficial leading to low quality of evidence, but still strong recommendations. In order to provide more evidence-based recommendations and management we argue that further research in Norway should be done more holistically by also including positive effects on biodiversity. We also recommend the inclusion of further taxonomic groups and the intensification of the research on biodiversity in plantations, particularly in early and late development stages. The controversy between the forestry sector and the nature conservation sector relies on low quality of evidence. In addition, studies on other aspects of biodiversity like habitats, landscapes and genetics are needed to strengthen the level of knowledge. We consider that the debate will benefit from a more knowledge-based approach where Sitka spruce is judged in a rational way based on both negative and positive effects. The present body of knowledge suggests a future management modification of Sitka spruce in Norway, and forest managers should consider more stand-wise mixtures of tree species, increase the proportion of early and late growth stages compared to the thicket stage but also avoid plantations on high risk "take off landscapes with respect to spread" to restrict future spread into conservation areas.

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Appendix. Biodiversity studies regarding Sitka spruce in NW Europe (latest update may 2019).

1 Taxon. group	2 Country	3 Author(s)	4 Published	5 Title of paper	6 Journal	7 Type	8 Rotation	9 Stage	10 Prior land	11 Scale	12 Effect	13 BioDiv	Value
Annelid	UK	Muys, B., *et al.*	1992	Effects of grassland afforestation with different tree species on earthworm communities	Soil Biol. Biochem. 24	Peer-review-article	1	TS	Heathland	Stand	Slightly negative	S	-0.5
Annelid	IC	Gudleifsson, B.E.	2007	Affornord. Earthworms in Icelandic forest soils.	Proceedings. TemaNord 508	Booklet	1	Chron	Broadleaf forest	Stand	Slightly negative	S	-0.5
Arthropods	UK	Butterfield, J.	1999	Changes in decomposition rates and Collembola densities during the forestry cycle in conifer plantations	Journal of Applied Ecology 36, 92-100	Peer-review-article	1	Chron	Heathland	Stand	None	A	0
Athropods	UK	Murphy, P.W	1953	Soil faunal investigation	Report For. Res 1952	National report	1	TS	Heathland	Stand	Positive	S+A	1
Athropods	UK	Gifford, W. J.	1959	Soil fauna research	Report For. Res. 1958	National report	1	TS	Heathland	Stand	Positive	S+A	1
Athropods	UK	Gifford, W. J.	1964	Studies on soil microarthropod populations in Scottish forests	Report For. Res. 1963	National report	1	TS	Heathland	Stand	Positive	S+A	1
Athropods	UK	Heyes, A.J.	1965	Studies on the distribution of some acarid mites (Acari: Oribatidae) in a coniferous forest soil	Pedobiologia	Peer-review-article	1	TS	Heathland	Stand	Positive	S+A	1
Athropods	NO	Fjellberg, A., *et al.*	2007	Affornord. Structural changes in Collembola populations following replanting of birch forest with spruce species in North Norway.	Proceedings, TemaNord 508	Booklet	1	TS	Heathland	Stand	None	S+A	0
Athropods	IR	Arroya, J. *et al.*	2010	The Mesostigmatid mite (Acari, Mesostigmata) community in canopies of Sitka spruce in Ireland and a comparison with ground moss habitats	Graellsia 66(1)	Peer-review-article	1	TS	Forest	Stand	Slightly positive	S+A	0.5
Birds	UK	MacKenzie, J.	1945	The preference shown by birds for different species of trees in plantations.	Forestry 19	Peer-review-article	1	TS	Heathland	Stand	Positive	A	1
Birds	UK	Marquiss, M., *et al.*	1978	The decline of raven (Corvus corax) in relation to afforestation in southern Scotland and northern England.	Journal of Applied Ecology 16	Peer-review-article	1	TS	Heathland	Landscape	Negative	A	-1
Birds	UK	Moss, D.	1978	Song bird populations in forestry plantations	Quarterly Journal of Forestry	Peer-review-article	1	Chron	Heathland	Landscape	None	S+A	0
Birds	UK	Moss, D.	1978	Breeding of sparrowhawks (Acipiter nisus) in different environments.	Journal of Animal Ecology	Peer-review-article	1	Chron	Heathland	Landscape	Positive	A	1
Birds	UK	Moss, D.	1979	Even-aged plantations as a habitat for birds	IUFRO proceedings	Peer-review-article	1	Chron	Heathland	Landscape	None	S	0
Birds	UK	Avery, M.I.	1989	Effects of upland afforestation on some birds of the adjacent moorland	Journal of Applied Ecology 26, 957-966.	Peer-review-article	1	TS	Heathland	Landscape	Slightly negative	A	-0.5
Birds	IR	Brennan, M. & Whealan, J.	2000	A comparative study of bird communities in coniferous and broadleved woodland at various stages in the growth cycle	Irish Forestry 58, 11-19	Peer-review-article	1	Chron	Broadleaf forest	Stand	None	S+A	0
Birds	UK	Whitfield, D. *et al.*	2001	The effects of forestry on golden eagles on the Island of Mull, western Scotland	Journal of Applied Ecology 38	Peer-review-article	1	TS	Heathland	Landscape	Slightly negative	A	-0.5
Birds	UK	Fuller, R. *et al.*	2005		British Birds, 98		1 and 2	Chron	Heathland	Landscape		A	-0.5

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1 Taxon. group	2 Country	3 Author(s)	4 Published	5 Title of paper	6 Journal	7 Type	8 Rotation	9 Stage	10 Prior land	11 Scale	12 Effect	13 BioDiv	Value
				Recent declines in populations of woodland birds in Britain: a review of possible causes.		Peer-review-article					Slightly negative		
Birds	IR	Wilson, M.W *et al.*	2009	Effects on growth stage and tree species composition on breeding bird assemblages of plantation forests	Bird Study, 53	Peer-review-article	1	Chron	Heathland	Landscape	None	S+A	0
Birds	UK	Pearce-Higgins *et al.*	2007	The role of forest maturation in causing the decline of Black Grouse Tetrao tetrix	Ibis 149 (1), 143-155	Peer-review-article	1	Chron	Heathland	Landscape	Slightly negative	A	-0.5
Birds	UK	Wilson, M.W *et al.*	2009	The importance of pre thicket conifer plantations for nesting Circus cyaneus in Ireland	Royal Irish Academy, Proceedings 112	Peer-review-article	1	TS	Heathland	Stand	Positive	A	1
Birds	UK	Calladine, J. *et al.*	2009	Effects on bird abundance and species richness of edge restructuring to include shrubs at the interface between conifer plantations and moorland	Bird Study 60, 345-360.	Peer-review-article	1	TS	Heathland	Landscape	None	S+A	0
Birds	IR	Sweeney,O. et al.	2010	Are bird density, species richness and community structure similar between native woodlands and non-native plantations in an area with a generalist bird fauna?	Biol. Conserv., 19	Peer-review-article	1	Chron	Heathland	Landscape	None	S+A	0
Birds	IR	Sweeney,O. *et al.*	2010	Breeding bird communities of second-rotation plantations at different stages of the forest cycle.	Bird Study 57, 301–314.	Peer-review-article	2	Chron	Grassland	Landscape	None	S+A	0
Birds	IR	Sweeney,O. *et al.*	2010	The influence of a native tree species mix component on bird communities in non-native coniferous plantations in Ireland.	Bird Study 57, 483–494.	Peer-review-article	1 and 2	Chron	Grassland	Landscape	None	S+A	0
Birds	IR	O'Connell, S. *et al.*	2012	How can forest management benefit bird communities? Evidence from eight years of research in Ireland	Irish Forestry 69, 44-57.	Peer-review-article	1 and 2	Chron	Grassland	Landscape	None	S+A	0
Birds	UK	Douglas *et al.*	2013	Upland land use predicts population decline in a globally near threatened wader	Journal of Applied Ecology, 51	Peer-review-article	1 and 2	TS	Heathland	Landscape	Negative	S+A	-1
Birds	IR	Graham, C. *et al.*	2013	Tracking the impact of afforestation on bird communities	Irish Forestry 70	Peer-review-article	1	Chron	Grassland	Landscape	Slightly positive	S+A	0.5
Birds	UK	White, P.J. et al.	2013	Forest expansion in Scotland and its potential effects on black grouse *Tetrao tetrix* conservation	For. Ecol. Manage. 308	Peer-review-article	1	TS	Heathland	Landscape	Slightly negative	A	-0.5
Birds	UK	Burgess, M.D. *et al.*	2015	The impact of changing habitat availability on population trends of woodland birds assosiated with early successional woodland	Bird Study 62, 39-55	Peer-review-article	1	TS	Heathland	Landscape	Slightly potitive	S+A	0.5
Birds	IR	Graham, C. *et al.*	2015	Implications of afforestation for bird communities: the importance of preceding land-use type	Biodiversity and Conservation	Peer-review-article	1	Chron	Grassland	Landscape	Slightly negative	S+A	-0.5
Epifytic lichens	IR	Coote, L. *et al.*	2008	Epiphytes of Sitka spruce (Picea sitchensis) plantations in Ireland and the effects of open spaces.	Biodiversity and Conservation 17	Peer-review-article	1	Chron	Heathland	Landscape	Negative	S+A	-1
Epiphytic lichens	UK	Orange, A.	1998	Lichens in upland spruce plantations	Forestry Commission Technical Paper	National report	1	Chron	Conifer forest	Landscape	Slightly negative	S	-0.5
Epiphytic lichens	NO	Øyen, B.-H. & Skye, E.	1999	Coastal forests– new habitats for epifypic lichens. A case study from Finnkona, Nordland county [In Norwegian]		Chapter, booklet	1	TS	Heathland	Stand	Negative	S	-1
	NO		2013				1	TS		Stand	Negative	S+A	-1

Epiphytic lichens		Wannebo-Nilsen *et al.*		Epiphytic macrolichens in spruce plantations and native birch forests along a coast-inland gradient in North Norway	Boreal Environment Research 15	Peer-review-article			Broadleaf forest				
Epi. lichens & bryophytes	UK	Humphrey, J. W. *et al.*	2002	Lichens and bryophyte communities of planted and semi-natural forests in Britain: the influence of site type, stand structure and deadwood.	Biological Conservervation 107	Peer-review-article	1	Chron	Conifer forest	Landscape	Slightly negative	S+A	-0.5
Epi. lichens & bryophytes	NO	Hilmo, O. *et al.*	2014	Biodiversity in plantations of Norway spruce (Picea abies) and Sitka spruce (Picea sitchensis). A comparison. [English summary]	Report NINA 1031	National report	1	TS	Conifer forest	Stand	Slightly negative	S+A	-0.5
Fungi	UK	Humphrey, J. W. *et al.*	2000	The importance of conifer plantations in northern Britain as a habitat for native fungi.	Biological Conservation 96	Peer-review-article	1	Chron	Broadleaf forest	Landscape	Positive	S+A	1
Fungi	IR	O'Hanlon, R. & Harrington, T. J.	2011	The macrofungal component of biodiversity in Irish Sitka spruce forests	Irish Forestry	Peer-review-article	1	Chron	Heathland	Landscape	Positive	S	1
Fungi	IR	O'Hanlon, R. & Harrington, T.J.	2012	Similar taxonomic richness but different communities of ectomycorrhizas in native and non-native tree species forests	Mycorrhiza 22, 371-382.	Peer-review-article	1	Chron	Heathland	Stand	None	S+A	0
Insects	UK	Day, K.R. & Carthy, J.	1988	Changes in carabid beetle communities accompanying a rotation of Sitka spruce	Agr. Ecosystem and Environment 24, 407-415	Peer-review-article	1	Chron	Heathland	Stand	None	S+A	0
Insects	UK	Buse, A & Good, J.E.G.	1993	The effects of conifer forest design and management on abundance and diversity of rove beetles (Coleoptera: Staphylinidae): implications for conservation	Biological Conservation 64, 67-76	Peer-review-article	1	Chron	Heathland	Stand	Negative	S+A	-1
Insects	UK	Humphrey, J. W. *et al.*	1999	Relationships between insect diversity and habitat characteristics in plantation forests.	For. Ecol. Manage. 113, 81-95	Peer-review-article	1	Chron	Broadleaf forest	Landscape	None	S+A	0
Insects	UK	Jukes, M. *et al.*	2001	Carabid beetle communities associated with coniferous plantations in Britain: the influence of site type, ground vegetation and stand structure.	For. Ecol. Manage. 148	Peer-review-article	1	Chron	Conifer forest	Stand	Slightly positive	S+A	0.5
Insects	IR	Gittings, T. *et al.*	2006	The contribution of open spaces to the maintainance of hoverfly in Irish plantation forests	For. Ecol. Manage 237	Peer-review-article	1 and 2	Chron	Conifer forest	Stand	None	S+A	0
Insects	IR	Coll, M.T. & Bolger, T.	2007	Biodiversity and species composition of carabidae in Irish coniferous forests: additional insight from the use of paired sites in comparisons of open habitats	Proc. Royal Irish Acad. 107B, 1-11	Peer-review-article	1	TS	Grassland	Stand	None	S+A	0
Insects	UK	Lin, Y. e t al.	2007	Conservation of heathland ground beetles (Coleoptera, Carabidae): the value of lowland coniferous plantations	Biodiversity and Conservation. 16(5), 1337-1358	Peer-review-article	1	Chron	Heathland	Stand	Positive	S+A	1
Insects	UK	Mullen K. *et al.*	2008	Distribution and composition of carabid beetle (Coleptera, Carabidae) communities accross the plantation forest cycle - implications for management	For. Ecol. Manage. 256	Peer-review-article	1 and 2	Chron	Grassland	Landscape	None	S+A	0
Insects	UK	Straw, N. *et al.*	2017	Influence of forest management on the abundance and diversity of hoverflies in commercial plantations of Sitka spruce: The importance of sampling in the canopy	For. Ecol. Manage. 406	Peer-review-article	1 and 2	Chron	Heathland	Stand	None	S+A	0
Invertebrates	IR	Oxbrough,A. *et al.*	2006	The influence of open space on ground dwelling spider assemblages within conifer plantations.	For. Ecol. Manage. 237, 404-417.	Peer-review-article	1 and 2	Chron	Forest	Stand	None	S+A	0

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1 Taxon. group	2 Country	3 Author(s)	4 Published	5 Title of paper	6 Journal	7 Type	8 Rotation	9 Stage	10 Prior land	11 Scale	12 Effect	13 BioDiv	Value
Invertebrates	IC	Olafsson, E. & Ingimarsdottir, M.	2007	Affornord. Changes in communities of ground living invertebrates following afforestation.	Proceedings. TemaNord 2007: 508	Booklet	1	Chron	Broadleaf forest	Stand	Slightly positive	S+A	0.5
Invertebrates	IR	Oxbrough,A. *et al.*	2010	Ground dwelling invertebrats in reforested conifer plantations.	For. Ecol. Manage. 259, 2111-2121.	Peer-review-article	1	Chron	Heathland	Landscape	None	S+A	0
Invertebrates	IR	Fuller, L. *et al.*	2013	The importance of young plantation forest habitat and forest road-verges for ground dwellling spider diversity	Royal Irish Academy, Proceedings 113	Peer-review-article	2	TS	Conifer forest	Stand	Positive	S+A	1
Invertebrates	IR	Pedley, S.M. *et al.*	2014	Commercial spruce plantations support a limited canopy fauna: Evidence from a multi taxa comparison of native and plantation forests	For. Ecol. Manage 314	Peer-review-article	1 and 2	TS	Broadleaf forest	Tree	Negative	S+A	-1
Invertebrates	UK	Procter, D.S. et al.	2015	Do non-native conifer plantations provide benefits for a native forest spesialist, the wood ant Fomica lugubris	For. Ecol. Manage. 357	Peer-review-article	1 and 2	Chron	Heathland	Landscape	Positive	A	1
Mammals	UK	Fernandez *et al.*	1994	Local variation in rodent communities of Sitka spruce plantations: the interplay of successional stage and site-specific habitat parameters.	Ecography, **17**, 305-313	Peer-review-article	1	Chron	Heathland	Landscape	Slightly positive	A	0.5
Mammals	UK	Petty, S. *et al.*	2000	Spatial synchrony in field vole abundance in a coniferous forest in northern England	Journal of Applied Ecology. 37	Peer-review-article	1	Chron	Heathland	Landscape	None	A	0
Mammals	UK	Bryce, J. *et al.*	2005	Habitat use by red and grey squirrels.	Forestry Commission, Info note	National report	1	Chron	Heathland	Landscape	None	A	0
Mammals	UK	Kirkpatric, L. *et al.*	2016	Bat Exploitation of Sitka Spruce Plantations: Impacts of Management on Bats and Nocturnal Invertebrates		PhD-dissertation	1 and 2	Chron	Heathland	Landscape	Positive	S+A	1
Mammals	UK	Kirkpatric, L. *et al.*	2017	Responses of bats to clear fell harvesting in Sitka Spruce plantations, and implications for wind turbine installation.	For. Ecol. Manage. 395	Peer-review-article	1 and 2	Chron	Heathland	Landscape	Slightly positive	S+A	0.5
Mollusca	UK	Paul, C.R.C.	1978	The ecology of Mollusca in ancient woodlands	Journal of Conchology 29, 281-294	Peer-review-article	1	TS	Heathland	Stand	Slightly positive	S+A	0.5
Mollusca	UK	Alexander, K. & Dubbeldam, A.	2013	A survey of ancient woodland indicator molluscs in selected sites on the Isle of Man	Journal of Conchology 41, 407-417	Peer-review-article	1	TS	Broadleaf forest	Stand	None	S+A	0
Vascular plants & birds	UK	Sykes, J.M. *et al.*	1989	Some effects of afforestation on the flora and fauna of an upland shepwalk during 12 years after planting	Journal of Applied Ecology 26(1), 299-320.	Peer-review-article	1	TS	Heathland	Landscape	Slightly positive	S+A	0.5
Vascular plants & insects	IR	Fahy, O. & Gormally, M.	1998	A comparison of plant and carabid beetle communities in an Irish oak woodland with a nearby conifer plantation and clearfelled site	For. Ecol. Manage. 110, 263-273.	Peer-review-article	1	Chron	Broadleaf forest	Stand	Slightly negative	S+A	-0.5
Vascular plants & mosses	UK	Hill, M.O. & Jones, E.W.	1978	Vegetation changes resulting from afforestation of rough grazings in Caeo Forest, South Wales	Journal of Ecology	Peer-review-article	1	TS	Grassland	Landscape	Slightly negative	S+A	-0.5
Vascular plants & mosses	UK	Hill, M.O.	1979	Development of flora in even-aged plantations	IUFRO proceedings	Peer-review-article	1	Chron	Grassland	Landscape	Slightly negative	S+A	-0.5
Vascular plants & mosses	UK	Wallace, H. *et al.*	1992	The effects of afforestation on upland plant communities: an application on the British National Vegetation Classification	Journal of Applied Ecology 29	Peer-review-article	1	Chron	Heathland	Landscape	Slightly negative	S+A	-0.5
Vascular plants & mosses	UK	Wallace, H. & Good,J.	1995	Effects of afforestation on upland plant communities and implications for vegetation management	For. Ecol. Manage. 79	Peer-review-article	1	Chron	Heathland	Landscape	Slightly negative	S+A	-0.5

Vascular plants & mosses	UK	Ferris, R. *et al.*	1999	Relationships between vegetation, site type and stand structure in coniferous plantations in Britain	For. Ecol. Manage. 136	Peer-review-article	1	Chron	Heathland	Landscape	Slightly negative	S+A	-0.5
Vascular plants & mosses	IC	Elmarsdottir, A. & Magnusson, B.	2007	Affornord. Changes in ground vegetation following afforestation.	Proceedings. TemaNord 2007: 508	Booklet	1	Chron	Broadleaf forest	Stand	Slightly negative	S+A	-0.5
Vascular plants & mosses	IR	Buscardo, E. *et al.*	2008	The early effects of afforestation on biodiversity of grasslands in Ireland	Biodiversity and Conservation 17	Peer-review-article	2	Sapling	Grassland	Landscape	Slightly positive	S+A	0.5
Vascular plants & mosses	IR	French, L. *et al.*	2008	Ground flora communities in temperate oceanic plantation forests and their influence of silvicultural, geographic and edaphic factors	For. Ecol. Manage 255	Peer-review-article	1	Chron	Grassland	Landscape	Slightly positive	S+A	0.5
Vascular plants & mosses	IR	More, K.M.	2012	Manipulation of vegetation sucsession in forestry and applications for sustainable forest management		PhD-dissertation	2	Chron	Conifer forest	Stand	None	S+A	0
Vascular plants & mosses	NO	Saure, H. *et al.*	2013	Do vascular plants and bryophytes respond differently to coniferous invasion of coastal heathlands?	Biological Invasions	Peer-review-article	1	Sapling	Heathland	Tree	Slightly negative	S+A	-0.5
Vascular plants & mosses	NO	Saure, H. *et al.*	2013	Effects of invasion by introduced versus native conifers on coastal heathland vegetation.	Journal of Vegetation Science 24	Peer-review-article	1	Sapling	Heathland	Tree	Slightly negative	S+A	-0.5