ALTERFOR

Deliverable 1.1 – FMM descriptions (in report form)

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I. Forest Management Models (FMMs) description

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3. Ireland

3.1. Background and forest history

Following periods of heavy reforestation and deforestation from the 1600s to 1900s, forest cover in Ireland was about 1% in the early 1900s. To develop a forest industry in Ireland, the government started a large afforestation project mainly using the fast-growing exotic softwoods Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and lodgepole pine (*Pinus contorta* Douglas). The main purpose of these forests was to produce timber for domestic use. Since the early 1980s, government afforestation has declined and focus has shifted to encourage private landowners to afforest their agricultural land in exchange for economic incentives.

The total area of the Republic of Ireland is 6 975 000 ha. In 2012, about 10.5% (732 000 ha) of this was covered with forests and the goal is to bring the forest cover to 17% by 2030. The average standing volume is 140m^3ha^{-1} and the yield capacity (Sitka spruce) 20.4 $m^3ha^{-1}yr^{-1}$.

Introduced tree species dominate forestry in Ireland. The most important economically is Sitka spruce with more than 50% of the standing volume. Second is lodgepole pine, at 10% of Ireland's forest cover. There are also other tree species in Ireland. These species and their proportions are presented in Table 11.

Today, ecological and social benefits of forests are recognised in certification and legislation. This is reflected in more awareness about sensitive species habitats, increased environmental consideration during forest operations and species diversification towards more native and broadleaf forest. Since much of Irish forest area comprise fast growing softwoods, managed for a timber oriented forestry sector, spruce and pine clearcutting remain the dominant forest management models in Ireland. The long tradition of agricultural production and revenue generation through land-use management means that the exotic softwood's good production capability is a good fit for Ireland's heritage and is unlikely to change.

3.1.1. Ownership

The biggest owner of forest land in Ireland is Coillte. It is a semi-state company. Coillte own 53% of the forest area in Ireland while the remaining 47% is privately owned.

3.1.2. Nature Conservation and Biodiversity Protection non-forested land

Nature conservation and biodiversity protection in Irish forestry often incorporates areas that are not forested, this is due to Ireland historically being heavily deforested and only gaining a significant forest area in recent years. Most historically forested areas have been converted into agricultural land and much of the current forested area was historically blanket peat. Thus, a wider nature conservation approach is often taken in Irish forestry to include non-forested adjacent land that has high biodiversity values (e.g. open bog habitat, rivers and lakes).

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3.2. The case study area

The CSA is 12 511 ha forest. The forest is dominated by wet sites with a productivity between 8-14 m^3 ha^{-1} yr^{-1}. The CSA, like much of western Ireland, is dominated by blanket peat which limits the productivity of species and potential for many FMMs that could be implemented in the CSA. The eastern side of the country is more fertile and hence has more productive forests, in many cases with similar species choice. There is more interest in restoring bogs today than there was in the past and to date, some bog restoration has taken place in western Ireland.

Table 9. The forest land in the CSA expressed as forest area proportion (%) within productivity and moisture classes.

Productivity/ moisture	Productivity, yield class ($m^3ha^{-1}y^{-1}$)	Dry %	Mesic %	Moist %	Wet %
High	>14	1.3	1.8	0.2	11.0
Medium	8-14	3.0	3.3	0.1	71.8
Low	<8	0.3	0.5	0.1	6.6

Using data from the INTEGRAL project and reading Coillte forest management plans, an estimate is that ca 1,700 ha, (13.3 %) of the total 12,735 ha forest is made up of nature conservation and bio-diversity protection non-forested land. Since this area is non-forested it was not included when calculating the coverage of the actual FMM, thus the 100% Coverage of CSA forestland in question 4 is calculated from the 86.7% of the "forest estate" that is actually forested.

There are some differences in dominant soil type in the CSA compared to the rest of Ireland. CSA Connacht, like much of western Ireland, is dominated by blanket peat which could potentially limit the productivity of species and FMMs that could be implemented in the CSA. The eastern side of the country is more fertile and hence has more productive forests, in many cases with similar species choice. There is more interest in restoring bogs today than there was in the past and to date, some bog restoration has taken place in Western Ireland, see below for FMM description. Thus there could be fewer conifer clearcutting stands in the future if it is more favourable to let them develop into biodiversity habitats after clearcutting rather than planting exotic conifers again.

3.2.1. Land area and forest cover

The forest cover of the CSA is similar to Ireland, around 10%. Also in standing volume and owner-ship structure the CSA is similar to Ireland, Table 10.

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Table 10. Total land area, forest area, standing volumes, productivity and ownership in the CSA (Barony of Moycullen), County Galway and Ireland. Source: Forest Service (2013). National Forest Inventory – Republic of Ireland.

	Barony of Moycullen	**County Galway**	**Republic of Ireland**
Total Area (ha)	**77 528**	**612 430**	**6 976 110**
Forest Area (ha)[1]	12 511	59 410	731 650
Forest cover (%)[1]	16.1	9.7	10.5
Average Volume ($m3ha^{-1}$)[1]	*No information exists at present, likely similar to County Galway*	135	140
Average Yield Class (m3ha-1yr-1)1	12	16.3	20.4
Forest Ownership (%)[1] Public (Coillte) Private (Grant aided) Private Other	 81.1 14.2 4.7	 65.1 26.2 8.7	 53.2 34 12.8

3.2.2. Tree species

Introduced tree species dominate forestry in Ireland and in the CSA. Most important is Sitka spruce which makes up more than 50% of the standing volume. Second is lodgepole pine making up 10% of forest cover in Ireland and 21 % in the CSA. There are also a number of other tree species and are presented in Table 11.

Table 11. Tree species, proportion of total forest area. Forest Service (2013). National Forest Inventory – Republic of Ireland – Results.

	Barony of Moycullen	**County Galway**	**Republic of Ireland**
Species (Latin name)	Proportion (% total area)	Proportion (% total area)	Proportion (% total area)
Sitka spruce (*Picea sitchensis*)	50.1	55.5	52.5
Pines, mainly lodgepole pine (*Pinus contorta*), excl. Scots pine (*Pinus sylvestris* L.)	37.4	20.9	9.7
Short lived broadleaves: Birch, Alder, Salix and poplar, (*Betula spp, Alnus spp, Salix spp, Populus spp* etc.)	6.1	15.7	15.5
Long lived broadleaves Oak Beech, Ash, Maple species (*Quercus* spp, *Fagus sylvatica* L., *Fraxinus excelsior* L., *Acer* spp etc.)	1.1	6.1	10.3
Norway spruce (*Picea abies*)	0.5	2.9	4.1
Larch, (*Larix* spp.)	2.7	2.2	4.4
Scots pine (*Pinus sylvestris* L.)	0.3	1.5	1.3

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Other conifers: Oregon pine (*Pseudotsuga menziesii*), English yew (*Taxus baccata*), Fir (*Abies spp) and more*	1.8	0.1	2.2

3.3. FMMs in Ireland and in the Irish CSA

Irish forestry dominates by silvicultural systems or models characterized by clear-felling. Approximately 85% of forest land is managed with CF systems. For nature conservation and biodiversity protection other management systems are used. This "FMM" won't be described below because it is not forested, but it is important to meet nature conservation and biodiversity goals in Irish forestry.

When much of Ireland's current forest area was afforested since the year 1900, the main goal was to produce timber and there was little consideration of how different species would perform on different sites and how species selection would influence non-timber benefits, i.e. biodiversity, water quality, recreation, tourism, etc.

Central and eastern Ireland has the soil to accommodate a more diverse forest, but in the CSA, the majority of all soil is blanket peat which has limitations for tree species selection. With forest knowledge increasing and policies emerging that aim to protect and enhance biodiversity features, the way forward is to establish native woodland sites, plant lodgepole pine on sites where fertilisation is restricted (Tony Clarke, pers. comm.) and restore some afforested sites back into their previous peatland habitat.

Recent changes in forest policy has resulted in a different value extraction from Irish forestry and thus timber production is no longer the only goal.

Increased emphasis on environmental and ecological factors mean that some sites are no longer considered suitable for certain species. Some of the above-mentioned sites will allow for establishment if fertiliser is applied, but new policies limit the use of fertiliser especially near freshwater pearl mussel (FPM) watersheds. In the future, it may be beneficial to establish some other forest management types on these sites, e.g. low stocking of lodgepole pine or other land-use types e.g. bog restoration.

Afforestation was initially done by the state, who bought marginal land (mainly blanket peat) for afforestation. Since the 1980s, government afforestation has declined and virtually ceased while private land owners (mainly farmers) are incentivised for afforestation grants. Much of private afforestation is carried out on marginal agricultural land which are often more productive than blanket peat.

Three FMMs are used in larger scale in the Irish CSA; 1) Clearfelling Sitka spruce and other conifers (but not lodgepole pine), 2) Clear-felling lodgepole pine 3) Nature conservation and biodiversity protection management (Table 12).

The two clear cutting models are similar. The difference is the tree species and depending on the species they are used on slightly different sites and while it is a choice to thin for other conifers, thinning is not an option for lodgepole pine.

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Table 12. The three major forest management models (FMMs) used in the Irish CSA, and in Ireland.

Forest management models (FMM) Domestic name in English	"General characteristic"	Coverage CSA (% forestland)	Coverage Ireland (% forestland)
Clearcutting system – Sitka spruce (mainly) and other conifers	Clearcutting system	55-60	63-66
Clearcutting System – lodgepole pine	Clearcutting system	25-30	20-25
Nature Conservation and Biodiversity Protection	No intervention	10-15	15
Nature Conservation and Biodiversity Protection non-forested land	No intervention	N/A	N/A

3.4. Ecosystem services

There is a large difference in the services provided with the three FMMs. Sitka spruce and lodgepole pine are used for timber or pulpwood production while areas managed with models for nature conservation and biodiversity protection are expected to result in a number of other services, see

Table 13.

Table 13. Ecosystem services connected to the four FMMs in the Irish CSA. Ranking of important ESs within each FMM. No ranking between FMM.

Forest manage model (FMM)	Clear-cutting system Sitka spruce and other coniferous	Clear-cutting system lodgepole pine	Nature conservation and Biodiversity protection
Timber production	**1**		
Timber and fibre production		**1**	
Habitat protection for invertebrates, fungi deer red squirrel, birds, plants etc.			**1**
Water quality for salmonids, freshwater pearl mussel and other aquatic species			**2**
Carbon sequestration			**3**
Recreation and tourism			**4**
Landscape amenity			**5**

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3.5. Alternative FMMs

In the CSA, three models for managing forests are dominating. But there are also other models used in Ireland, clearcutting models with broadleaves, models characterised by continuous forest cover and models for restoration of bogs. These models are described here briefly.

Continuous cover forestry. The goal is to create high forest native woodlands that can facilitate a combination of high quality wood production, biodiversity enhancement and reduce the adverse visual impact of clear-cuts in the landscape. Very few sites in the CSA have the soil to facilitate proper implementation of CCF and the current CCF area is very low. Regeneration by planting suitable conifer, broadleaves or a mix of species, full or partial natural regeneration is also acceptable.

Bog restoration. Forest land on blanket peat sites that has the potential to develop into good quality bog habitat is not replanted after harvesting. In addition, drains are blocked to facilitate the growth of Sphagnum. Between 2003 and 2020, it is expected that about 3% of the forest in the CSA will be converted into bog and most of this transformation has already occurred. Bog restoration programmes are often renewed and extended so it is possible that more forest will be converted back into bog.

Clearcutting system – Broadleaves. Similar to the two FMMs with conifer – that will be described in below - but with broadleaf tree species like oak, European beech, maple, lime and birch. Major differences to conifer clearcutting systems is generally later first thinning and longer rotation age (rarely clearcutting before the stand is 60 years of age). Since much of the CSA is blanket peat, this FMM is unsuitable as a reforestation option for most of the present day forest. Thus this FMM is more suitable for afforestation and reforestation on private land, which generally has more favourable soils for broadleaf plantations.

3.6. The two Clearcutting systems used in the Irish CSA

Today the two clear-cutting models are used on 75-85% of the forest area in the CSA, 30% of the forest area is lodgepole pine dominated stands. In the future, the total area Sitka spruce may be reduced as less fertilizer is now permitted for successful establishment, lodgepole pine will most likely be planted instead. In addition, some areas are likely to be managed as biodiversity conservation areas meaning that the total area managed under the two clear-cutting systems is likely to be reduced in the future.

Edaphic conditions

The clearcutting models can be used on more or less all sites. At present Sitka spruce is used in the CSA on all these combinations except on dry sites with low production. In the future, many suitable highly productive sites should be regenerated with native woodland species in order to reach national forest policy goals that aim to increase the area forested with native woodland species rather than exotic conifers.

Sitka spruce will produce a higher economic revenue on suitable sites (=high production sites), lodgepole pine should be used on medium and low production sites. Clearcutting (lodgepole pine) today also is used on Moist and Wet sites with higher production.

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Tree species

The main tree species managed with the two clearfelling FMMs are Sitka spruce and lodgepole pine but there are a number of other species such as larch and Scots Pine, for more details see Table 11.

The average site should be planted with either Sitka spruce, but Norway spruce, Scots pine, Douglas fir are also options.

Low productive forest sites should be regenerated with lodgepole pine or bog restored and thus no longer be included as forest land.

The stands can be described as monocultures as 90% of the volume should be the principal tree species and 10% in broadleaves (or native conifers if the site isn't suitable for broadleaves).

New planting rules require a mixture of 10-15% broadleaf or conifers other than Sitka spruce and lodgepole pine in both afforestation and reforestation stands. These rules did not exist when most of the forest stands in the CSA were established.

Tree species composition

The clearcutting systems aimed at and result in more or less pure stands (100%) of conifers including lodgepole pine. It is estimated that 80% of the stands in the CSA are monocultures, 15% have an admixture of 5-25% and the remaining 5% of the stands have an admixture of 25-50%. Afforestation and reforestation plantation rules in 2016 require that a minimum of 10% broadleaves are planted in the stand, depending on site suitability native conifers could make up these 10%. Most of the already established forest stands are homogenous as this was not a requirement previously. Most stands will therefore in the future have 5-25% admixture of other species, mainly broadleaves, DAFM (2015).

As lodgepole pine is a low nutrient demander, some Sitka spruce stands in areas where fertiliser use is restricted will be regenerated with lodgepole pine.

Rotation periods

There is no regulation of the rotation period in Ireland. Generally final felling occurs when the most profitable timber assortments can be harvested from the forest (Forest Service 2000).

Optimal rotation periods are around 35-65 years on a financial rotation, which produces the most valuable distribution of timber assortments. Other conifers have slightly longer rotation ages than Sitka spruce on the same site, Coillte (2003).

Sometimes, operational management issues change the optimal financial rotation length, this can mean longer or shorter rotations. This could be for reasons such as access, adjacent forest's suitability for harvesting, wind risk, etc.

Especially for private forest landowners, rotation ages are shorter than the optimal financial rotation as these owners prefer to see the financial values of their forests being realised earlier than the optimal financial rotation.

In addition, forests are sometimes not thinned for various reasons (e.g. wind risk, not economically viable, not informed of its benefits, etc.) which means that rotation lengths are typically shorter.

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Size of clearcuts

Harvested area is regulated in the PEFC Irish Forestry Certification Standards. No clearfell coup size larger than 25 ha and woodland clear felling area must not exceed 25% in 5-year period (Forest Service 2008a, PEFC (Ireland) 2014). The 25 ha limit also applies to all harvest operations (i.e. non-certified forests) that are 6km upstream of FPM populations.

Forest regeneration

Restocking takes place with planted stock typically. Natural regeneration is not typical for the Irish condition.

Some form of site preparation is used on 100% of the regeneration areas. Rather than using the technical definition of soil scarification where mineral soil is disturbed we refer to a wider definition called ground cultivation to include site preparation of deep blanket peat. The practical application is the same – to improve the growing site for seedlings. Mound and mound-and-drain are the most commonly used ground cultivation methods in the CSA. This number (100%) also includes regeneration sites that utilise still functioning ground cultivation method from the previous stand rotation. Replanting direct into clearfelling soil has been dried and resulted in large scale crop failure. (pers. Comm. Tony Clark).

Ground cultivation in Ireland can be divided into three systems:

Soil scarification (with mineral soil disturbance). This method is suitable only for free draining soils in eastern and southern Ireland, is done to a small extent in Ireland and not done at all in the CSA.

Mound-and-drain is the preferred ground cultivation method on wet mineral soils with a peat layer. Drains are dug in 12 m intervals to drain the peatland soils of Western Ireland. The spoils from the drain are laid out in small mounds at 2 m intervals and used as a planting medium for the seedlings.

Mounding only is done as described above but without adding drains. Mounding only is done on thick blanket peat where the old plough ribbon is no longer usable (see below).

Ploughing was the preferred ground cultivation method in the past, especially on sites with thick blanket peat, which is the dominating soil type of the CSA. The plough furrow acted as the drain and the plough ribbon as a planting medium. During reforestation, the plough ribbon from the first rotation is in many cases still present and reused as a planting medium. The impact of the first rotation crop causes the peat to be more friable and more mobile in water; since the risk of water runoff is increased, there is usually no new drainage carried out for reforestation.

Timber producing lodgepole pine is planted at 2500 seedlings/ha and the 1800 seedlings/ha stocking is used for fiber production on sites with a low yield class (Sitka spruce yield class =<12) Source: Coillte (2003). Sitka spruce is planted at a 2500 seedlings/ha stocking.

Browsing and fencing

There is little browsing threat from game and livestock on Sitka spruce in the CSA. Douglas fir and larches are the most susceptible conifers to browsing, but they only comprise up to 2% of the total forest area, so the annual regeneration area that is in need of fencing is very small.

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Introduced species

Introduced (exotic species) are used to a large extent in Ireland, approx. 85% of the seedlings. Sitka spruce, origin North America, is traditionally the most commonly used species in Irish forestry, NFI (2013). Norway spruce, is used up to 5% of the seedlings. Lodgepole pine, origin North America, is traditionally the second most used species in Irish forestry, NFI (2013).

Genetically improved or modified seedlings

Many seeds are sourced from stands all over Ireland which have been identified as having superior genetics for providing the objectives of Irish forestry, i.e. good quality timber. For this reason, it is difficult to know the extent to which non-local seed sources are used. All (100%) pf seeds/seedlings used are genetically improved (Coford, 2012). Tree breeding still has a lot of potential in increasing favourable tree features and the forest sector hasn't developed to this stage as of yet.

No genetically modified seeds/seedlings are used.

Hybrids are used very rarely in Irish forestry. A small amount of hybrid larch *(Larix x eurolepis*) is used in Ireland but not in the CSA.

Herbicides and chemicals used

Herbicides are used where vegetation competition is high; a treated plantation receives 2-3 applications in a rotation age.

Seedlings are coated in insecticides prior to planting and sometimes sprayed in the field to protect against large pine weevil (*Hylobius abietis*).

Trials are being done where a solution with entomopathogenic nematodes are been sprayed on stumps to reduce the number of emerging large pine weevil.

Fungicides are rarely used in Irish forestry, but stumps are painted with urea to prevent future dam-age from *Heterobasidium annosum* (Fr.) Bref.

A general trend in Irish forestry is that the number of available chemicals and the quantity at which they are used are being reduced. Source: Dillon & Griffin (2008).

Fertilisation

The majority of the public afforestation that took place on blanket peat is in need of fertilisation to successfully establish plantations of coniferous including lodgepole pine. One application at establishment is usually sufficient to get the stand started, but a second application might be necessary in some cases. Private afforestation is generally done on more productive sites and is not as dependent on fertilization as the public blanket peat forestry.

Nature protection/consideration

All afforestation plantations must contain a minimum 10% of broadleaves as Areas of Biodiversity Enhancement (ABE).

When an area is proposed for afforestation, it is necessary to give special regard to nature protection by identifying ABEs and rank them according to environmental sensitivity. ABE must

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comprise 15% of the afforested stand (may be reduced to 10% if the stand is smaller than 10 ha). ABEs consist of both open habitat (5-10% of the stand) and retained habitat (5-10% of the stand). Open habitats are setbacks for water (aquatic buffer zone), setbacks around roads and archaeological setbacks. Retained habitats are existing habitats like areas of scrub, non-high forest species, individual high forest species and hedgerows.

Identifying ABEs are crucial to ensuring that proper buffer zones are established around certain environmental features when afforested. However, ABEs can consist of anything from native woodland species acting as an aquatic buffer zone around a FPM watercourse to some birches and alders planted in a spruce stand, far away from any sensitive environmental feature. To some degree, ABEs can thus very similar to the Swedish FMM "Nature conservation with management" since active management is necessary to establish them and to some degree maintain them. This would justify describing them as their own FMM but it is a fairly new concept and a very broad definition.

There is a requirement to have minimum 10% broadleaves or suitable conifers (not Sitka spruce or lodgepole pine) in conifer and 10% suitable conifers (see above) in broadleaf plantations for reforestation. Special reforestation objectives exist to ensure the establishment of native woodland species in aquatic buffers for biodiversity protection, these areas are described as a different FMM.

Additionally, large parts of the CSA's forests are within or adjacent to proposed Natural Heritage Area (pNHA), Special Areas of Conservation (SAC) or a FPM watershed which restrict possible forestry prescriptions.

3.7. Clearcutting system conifers: Sitka spruce

Today the FMM clearfelling conifers/Sitka is used on 50-55% of the area but could be used on 55-60%.

Tree species

The main tree species managed with the clearfelling model conifers are: Sitka spruce, Norway spruce (*Picea abies* (L.) H. Karst.), Douglas fir, (*Pseudotsuga menziesii* (Mirb.) Franco.), Japanese larch (*Larix Kaempferi* (Lamb.) Carr.), and Scots Pine, (*Pinus sylvestris* L.)

Sitka spruce is used on approximately 90% of all stands in this model and the principal tree species account for approximately 95-100% of the stand volume. The tree species mentioned above are also used but to a lesser extent.

Stand management

Pre-commercial thinning

Pre-commercial thinning, PCT, is not used or used only in up to 5% of the established stands in this FMM. Sitka spruce has fast diameter growth in its juvenile stage and opening up the stand too early would promote the growth of undesirable juvenile wood. Due to naturally slow self-pruning it is beneficial to grow young Sitka spruce at a tight spacing.

Productivity in Ireland is generally so high that the first commercial thinning occurs before the stand starts experiencing stunted growth or heavy competition from undesired species. Due to Ire-

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lands forest estate recently being established there is little natural regeneration of broadleaf species in most conifer stands that would justify pre-commercial thinning.

Commercial thinning

Thinning is rather uncommon in this FMM, 25-35% of the stands are thinned one or more times during a rotation. Thinning should be done where appropriate, taking risk and demand factors into account. Forests dominated by blanket peat become unstable after commercial thinning which increases the risk of windthrow and there is no recommendation to increase or decrease the proportion of thinning.

Pruning

Pruning is not done, and it is not recommended.

Harvest and logging residues

Harvesting and wood extraction in this FMM is fully mechanized.

Logging residues, e.g. branches >5cm are removed only removed from fertile sites, Yield class >=18. It is financially neutral to carry out this process. The benefits of carrying it out are that there is more biomass supply and replanting is easier (where logging residue isn't extracted, it is windrowed to make planting easier) and the disadvantages are that nutrients are carried off-site and increased risk of rutting and soil compaction.

3.8. Clearcutting system: lodgepole pine

This FMM is in many aspects similar to clearcutting system (conifers). But it has been recognized as an own FMM.

Tree species

Lodgepole pine is now growing on 25-30% of the area in the CSA and all managed with the clear-felling system.

In the future the proportion of lodgepole pine will decrease to 20-25%. Recent changes in forest policy has resulted in a different value extraction from Irish forestry and thus timber production is no longer the only goal.

Despite biodiversity concerns, lodgepole pine is a suitable species on nutrient poor sites and will produce timber and pulpwood even if established with low stocking where clearcutting and reforestation of other more site demanding conifers are not an option because restricted use of fertilisers (Pers. Comm. Tony Clarke, Forest Service (2008b) Forest Service (2015).

Stand management

Pre-commercial thinning

Pre-commercial thinning is not done in FMM/lodgepole pine. Productivity in Ireland is generally so high that the first commercial thinning occurs before the stand starts experiencing stunted growth or heavy competition from undesired species. Due to Ireland's forest estate recently being

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established, there is little natural regeneration of broadleaf species in most lodgepole pine stands that would justify pre-commercial thinning.

Thinning and pruning

Thinning or pruning are not done in lodgepole pine in the CSA.

Harvest

Harvest is 100% mechanized. Logging residues, e.g. branches >5cm, are in some stands extracted. It is financially neutral to carry out this process. The benefits of carrying it out are that there is more biomass supply and replanting is easier (where logging residue isn't extracted, it is windrowed to make planting easier) and the disadvantages are that nutrients are carried off-site and increased risk of rutting and soil compaction. For this reason, logging residues are only removed from productive sites, i.e. YC(Yield Class) >= 18.

3.9. FMM for Nature conservation and biodiversity protection

This FMM don't include any active management. Today approx. 10-15% of the area in the CSA is left for no management for nature conservation and biodiversity protection. The ambition is to leave around 15% of the area. This number is an estimate based on forested area and does not include large open spaces with biodiversity protection, however small open spaces that are integrated in the stand as retained Area for Biodiversity Enhancement (ABE) are included in the number. This 15% area includes water setbacks (aquatic buffers), woody habitat, scrub forest, Native Woodland Site (NWS) Conservation and other forests with biodiversity and conservation designation.

The number is difficult to estimate properly and is based on a national goal for establishing ABEs as a way to diversify the Irish forest industry to accommodate biodiversity and social values along with timber production (which was the main reason for the national afforestation project that started in the 1920s and continues to this day). The forested portion of ABEs and other protected forest areas should comprise 15% of the total forested area in the CSA.

It is important to understand that nature conservation and biodiversity protection in Irish forestry often incorporates areas that are not forested, this is due to Ireland historically being heavily deforested and only gaining a significant forest area in recent years. Most historically forested areas have been converted into agricultural land and much of the current forested area was historically blanket peat. Thus, a wider nature conservation approach is often taken in Irish forestry to include non-forested adjacent land that has high biodiversity values (e.g. open bog habitat and lakes). Policy zones such as Special Areas of Conservation (SAC, designated according to the EU Habitats Directive), Special Protected Areas (SPA, designated according to The EU Birds Directive), National Heritage Areas (NHA, basic Irish statutory designation for wildlife habitat protection) and Proposed National Heritage Area (NHA, non-statutory designation for wildlife habitat protection) are often designated to protect non-forest land. Thus, forests that fall inside a SPA, SAC, NHA or pNHA are often subjected to regulated operation in consultation with a Forest Service official, but timber production can still be the main objective. For example: according to a management plan, large areas of the forest might be in a SAC, but if the SAC is meant to protect an adjacent bog it might only regulate forest operations adjacent to the SAC rather than restrict all forest operations

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inside the policy zone. Such a forest would not be included in this FMM but would be described in the conifer FMMs, with regulation of operations done on a case by case basis. Additionally, areas such as open peat land, unplantable land, waterbodies and swamps may be included in a forest management plan as land with a biodiversity or conservation objective, but we try not to include those areas when referring to this FMM. (Forest Service (2015a) Forest Service (2015b) Forest Service (2015c) Forest Service (2016)).

The difference between ambitions of 15 % of the area and todays 10-15% depends is mainly due to nature protection policies that were not in place when the current forest was established. When an area is proposed for afforestation, it is necessary to give special regard to nature protection by identifying ABEs and rank them according to environmental sensitivity. ABE must comprise 15% of the afforested area (may be reduced to 10% if the site is smaller than 10 ha). ABEs consist of both open habitat (5-10% of the site) and retained habitat (5-10% of the site). Open habitats are setbacks for water (aquatic buffer zone), setbacks around roads, open areas for biodiversity and landscape amenity, and archaeological setbacks. Retained habitats are existing habitats like areas of scrub, non-high forest species, individual high forest species and hedgerows. Identifying ABEs are crucial to ensuring that proper buffer zones are established around certain environmental features when afforestation occurs. However, ABEs can consist of anything from native woodland species (native broadleaves and Scots pine (*Pinus sylvestris* L.)) acting as an aquatic buffer zone around a FPM watercourse to some birches and alders planted in a spruce stand, far away from any sensitive environmental feature. To some degree, ABEs can be very similar to the Swedish FMM “Nature conservation with management” since active management is necessary to establish them and to some degree maintain them. This could justify describing them as their own FMM but it is a fairly new concept and a very broad definition.

When reforestation happens, there is a requirement to have a minimum 10% broadleaf area or diverse conifers (i.e. not Sitka spruce) or lodgepole pine in conifer plantations and 10% suitable conifers (see above) in broadleaf plantations. Special reforestation objectives exist to ensure the establishment of native woodland species in aquatic buffers for biodiversity protection.

Source: Forest Service (2015a) Forest Service (2015b) Forest Service (2015c) Forest Service (2016).

Tree species

Any species could technically be used, but other species than Sitka spruce and lodgepole pine are encouraged.

Acceptable species for NWS establishment are listed below, suitable species for the site depend on the soil type.

Alnus glutinosa (L.) Gaertn., *Betula pendula* Roth., *Betula pubescens* Ehrh., *Querqus petraea* L., *Quercus robur* L., *Pinus sylvestris* L., *Populus tremula* L., *Prunus avium* L., *Salix cinerea* L., *Sorbus aucuparia* L., *Taxus baccata* L. and many, bushy small-trees. *Fraxinus excelsior* L. is a NWS species, but the planting of European ash is currently not allowed on new afforestation sites in Ireland due to risk from the ash dieback fungus (*Hymenoscyphus fraxineus*). Forest Service (2015b) Forest Service (2015d).

Ecosystem services

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Wood production is not important for this FMM, see also Table 13 above. The ecosystem services are ranked;

1. Habitats protection for invertebrates, fungi, deer, red squirrel, birds, plants etc.

2. Water quality for salmonids, freshwater pearl mussel and other aquatic species

3. Carbon sequestration

4. Recreation and tourism

5. Landscape amenity

Management

There is normally no or very sparse interventions in this FMM. Planting is often necessary in order to establish the desired native species on site when New Native Woodlands Sites (NWS) are established. Subsequent management may be necessary in order to maintain the desired species composition (e.g. removing shade tolerant conifers from broadleaf plantation). On some sites, small amounts of environmentally sensitive timber extraction is allowed which would make the FMM most similar to D. Selection system.

As described above, nature protection has broad definitions that do not always focus on the protection of the forest but of the surrounding land-uses; also ABEs can vary in their make up so it is difficult to separate groups, hence this is a combined nature conservation and biodiversity protection FMM.

3.10. References

LCC Dr. Edwin Corrigan (UCD)

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District Manager Tony Clarke (Coillte)

COFORD, National Consultative Committee on Forest Genetic Resources, 2012. Forest Genetic Resources in Ireland. COFORD, Arena House, Sandyford, Dublin 18, Ireland

Coillte, 2003. Special Feature – Cloosh Valley Forest Management Plan. Coillte Head Office, Newtownmountkennedy, Co. Wicklow, Ireland.

Coillte, 2009. Forest Management Plan - Cloosh Forest 2011-2015 v.2. Coillte Head Office, Newtownmountkennedy, Co. Wicklow, Ireland

Dillon, A. & Griffin, C., 2008. Controlling the large pine weevil, Hylobius abietis, using natural enemies. Silviculture Management No. 15. COFORD, Arena House, Sandyford, Dublin 18, Ireland.

Forest Service, 2000. Code of Best Forest Practice – Ireland. Department of the Marine and Natural Resources, Dublin 2, Ireland.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Forest Service, 2008a. Forestry and Freshwater Pearl Mussel Requirements – Site Assessments and Mitigation Measures. Department of Agriculture, Fisheries and Food, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service, 2008b. Irish Forests – A Brief History. Department of Agriculture, Fisheries and Food, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service (2013). National Forest Inventory – Republic of Ireland – Results. Johnstown Castle Estate, Wexford, Ireland, Forest Service.

Forest Service, 2015a. Afforestation Grant and premium Scheme 2014-2020. Forest Service, Department of Agriculture, Food & the Marine, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service, 2015b. Forestry Standards Manual. Forest Service, Department of Agriculture, Food & the Marine, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service, 2015c. Native Woodland Conservation Scheme. Forest Service, Department of Agriculture, Food & the Marine, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service, 2015d. Native Woodland Establishment GPC9 & GPC10 – Silvicultural Standards. Forest Service, Department of Agriculture, Food & the Marine, Johnstown Castle Estate, Co. Wex-ford, Ireland.

Forest Service, working document reviewed 27Jan 2016. Reforestation objective Table. Forest Service, Johnstown Castle Estate, Co. Wexford, Ireland.

Forest Service, Unpublished draft, revised 05 February 2016. Environmental Requirements for Afforestation – Water, biodiversity, archaeology and landscape. Johnstown Castle Estate, Co. Wex-ford, Ireland.

Forest Service, Unpublished draft, revised 05 February 2016. Environmental Requirements for Afforestation – Water, biodiversity, archaeology and landscape. Forest Service, Department of Agriculture, Food & the Marine, Johnstown Castle Estate, Co. Wexford, Ireland.

PEFC (Ireland) Ltd., Unpublished draft, revised January 2014. PEFC Irish Forest Certification Standard. PEFC (Ireland) Ltd, Cork, Ireland.

Renou, F. and Farrell, E. P., 2005. Reclaiming peatlands for forestry: the Irish experience. In Stanturf, J. A. (Ed) Restoration of Boreal and Temperate Forests (pp. 541-557). Boca Raton, Florida, USA. CRC Press.

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ALTERFOR

II. Ranking of Ecosystem Services (ES)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

2.2. Ireland

2.2.1. Contrasting the relative biological diversity of Ireland's stand level FMMs

Clearcutting FMMs

A clearfell FMM is a rotation-based system which involves 4 growth stages. Each clearfell FMM roughly follow these stages and the difference between them will be described more distinctly in the remainder of the document.

- **Establishment stage** is where light reaches the ground, providing food and habitat for bird species (Wilson et al., 2009) *inter alia.* In larger forest blocks that are present in the CSA, these areas mixed in between maturing stands helping to form a structural mosaic pattern on the landscape (O'Callaghan et al., 2016), i.e. useful for biodiversity;
- **Thicket stage** is when the forest canopy has closed, no mortality has taken place yet and no thinning has been carried out. The forest floor is restricted from sun light and although providing cover for some species (O'Halloran et al., 2011; Smith et al., 2005), the biodiversity value is quite low;
- The **Commercially maturing** stage is where thinning has been carried out/or mortality has set in. The forest canopy is more uneven and there are gaps in places allowing sun light to reach the ground. Some natural regeneration may occur from this point on;
- **Commercially mature**. Here stands have reached financial maturity and may have undergone several thinnings. In either case, there are at least some openings in the forest canopy making the canopy structure diverse. When a stand is clearfelled, broadleaf trees (which may have regenerated naturally throughout the latter stages of the rotation) are retained and some harvesting residue is left on site.

Ireland has relatively short-term rotations 30 – 60 years. This means that disturbance events are relatively frequent as are changes between the four changes in structure described above. The retention of naturally regenerated broadleaves within a stand during clearfell is now common practice. This will mean that more mature trees will benefit biodiversity into subsequent rotations. But it is not expected to reach the biodiversity levels of some other FMMs. For example, native woodland sites, watercourse bufferzones.

Clearcutting conifer – Spruce monoculture

Sitka spruce is an exotic and conifer species. This sub-FMM is the most dominant in the CSA and it has little species diversity. This FMM is not permitted for establishment into the future as there must be some form of species diversity measures from now on at establishment stage (alternative FMMs are described). The stand is even-aged and the production focus means that commercial thinnings are carried out where financially feasible meaning that there is little mortality for natural deadwood. At the end of a rotation (age can vary depending on a site's productivity and spatial location), residue may be removed from site (on fertile mineral sites mainly) or windrowed (on exposed sites), both practices will benefit plants at re-establishment stage. Considering this FMM to be the predominant one in the landscape, it will be considered as the baseline for the Irish FMM assessment Table 7 below.

Clearcutting conifer – Spruce with 10% diverse conifer mix

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This is the first sub-FMM commonly used as an alternative to the spruce monoculture sub-FMM. It comprises an intimate mix of Sitka spruce and/or lodgepole pine together with a suitable diverse conifer. The diverse conifer content must be at least 10% of the total number of trees planted. This diverse species can be intimately mixed through the forest or planted in groups through the forest, or a combination of both where silviculturally compatible with the main species (Forest Service, 2015). The additional conifer species adds some species diversity to this FMM. In some cases, there is an option to establish Scots pine (*Pinus sylvestris*) as the diverse conifer meaning that this FMM can contain some native species.

Clearcutting conifer – Spruce with 10% broadleaf mix

This is the second sub-FMM commonly used as an alternative to the spruce monoculture FMM. It comprises an intimate mix of Sitka spruce and/or lodgepole pine together with a suitable broadleaf species. The broadleaf can be established intimately if growth rates are comparable or in groups (Forest Service, 2015). The broadleaf species are chosen from an approved list containing mostly native species, e.g. Cherry (*Prunus avium*), common alder (*Alnus glutniosa*), sycamore (*Acer pseudoplatanus*) birch (*Betula spp.*). The addition of broadleaves increase stand level species diversity, structural diversity and also native trees.

Clearcutting conifer – Diverse conifer

This sub-FMM comprises an acceptable diverse conifer species at establishment e.g. Scots pine, Douglas fir (*Pseudotsuga menziesii*), Western red cedar (*Thuja plicata*). Considering the Sitka spruce and lodgepole pine dominated landscape, this FMM is considered to create more tree species diversity in the CSA. If Scots pine is chosen, this would also increase the area of native tree species.

Clearcutting lodgepole pine

This FMM is monoculture lodgepole pine. This species is not thinned as it responds by producing large side branching which means that thinning will not increase the economic viability of the crop. This means that there is typically more natural deadwood at the commercially maturing and commercially stages due to mortality. Considering the monoculture nature of this FMM it's biodiversity is relatively low. Like the spruce monoculture, this FMM must also be reforested with either of the 10% mixes described above, however the main species is lodgepole pine and no thinning takes place.

Nature conservation and biodiversity protection – Open space

These are areas, sometimes within stands and sometimes separated. They are scrub like in appearance and very often provide suitable areas for foraging while also allowing for cover in nearby stands. There may be woody shrubs present. If these areas are within another forest stands, attempts will be made to re-establish them, meaning that they have a similar level of permanence to the clearcut FMMs however, considering the diversity, the biodiversity value of these areas is considered to be relatively high.

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Table 7 Summary of ranking Biodiversity values Ireland. 1 Lowest value, 7 highest.

FMM	FMM subcategory	Tree species composition (native trees, broadleaves, tree species diversity)	Forest structures (older/larger trees coarse woody debris)	Disturbance regime (emulate natural disturbance regimes spatially and temporally	Rank out of 7
Clear cutting conifer	Spruce monoculture	2	2	2	2
	Spruce with 10% diverse conifer mix	3	3	2	2.67
	Spruce with 10% broadleaf mix	4	4	2	3.33
	Diverse conifer	3	3	2	2.67
Clear cutting lodgepole pine	Unthinned. 10% diverse mix required for reforestation	1	3	2	2
Nature conservation and biodiversity protection	Open space	2-5	1-5	2	2.17
	Watercourse bufferzone	2-5	3-7	7	4.5
	Bog habitat	0	0-2	7	2.67

Nature conservation and biodiversity protection – Watercourse bufferzone

These areas are riparian buffers. They contain small proportions of native broadleaves and the remainder of the area is scrub. The intention is to buffer the effect of nearby forest stands and management operations carried out on them. However, the areas themselves provide wildlife corridors which are beneficial for *inter alia* foraging animals etc. and the biodiversity value of these areas is relatively high. However, once established, it will not be disturbed as is the case with the clearcut FMMs. It is possible that the trees will eventually mature, naturally regenerate and form a diverse structure.

Nature conservation and biodiversity protection – Bog habitat

Some areas in the CSA have been restored from an afforested forest site to the area's most-likely previous peatland habitat. Approximately 11% of the CSA has a bog land-use and hence from a diversity perspective, more of this sub-FMM is not expected to add much. However, once established, it will not be disturbed as is the case with the clearcut FMMs. Where bog habitat was restored on very young sites, whole trees are left on site meaning that deadwood content is high.

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2.2.2. Contrasting the relative carbon of Ireland's stand level FMMs

Clearcutting FMMs

A difference between the carbon ES and others is that carbon can both be stored in living pools during a clearcutting FMM's rotation and also in pools of harvested material and deadwood. The living carbon pools quantified for ALTERFOR are described below and are grouped into one 'living carbon' pool for this analysis:

- **Aboveground carbon** – The carbon stored in living trees that is above the ground, it includes carbon stored in stem, bark, branch and leaf;
- **Belowground carbon** – The carbon stored in living trees that is below the ground, i.e. roots.

The non-living carbon pools are listed below. A certain proportion of each of these pools is considered to decay annually:

- **Natural deadwood** – The deadwood that typically happens from mortality in Ireland's plantation-based FMMs, it includes both above ground and below ground natural deadwood;
- **Harvest residue** – The material that is left on site post harvesting events, also includes below ground deadwood from harvesting;
- **Harvested wood products** – The carbon that is stored in processed products. The products are divided into paper and pulp, wood-based panels and sawlog products but are totalled and presented as one pool in this analysis.

A measure of the relative quantities of carbon emissions replaced from cement and steel and fossil fuels is also provided.

Clearcutting conifer – Spruce monoculture

A monoculture of Sitka spruce with a productivity of 16 m^3 ha^{-1} yr^{-1} is used for this analysis. There are 4 commercial thinnings carried out with a clearfell at the age of 42 years (Figure 1).

Until clearfell, the total living carbon increases as the stand matures. There is a slight increase in the non-living pools from commercial thinnings throughout the rotation. There is stand mortality throughout the rotation increasing the natural deadwood carbon pool. Decay factors on these non-living pools accounts for a decrease in their carbon content over time. The clearfell event at age 42 means that the living carbon pool is completely removed and some of this carbon moves into the non-living carbon pools.

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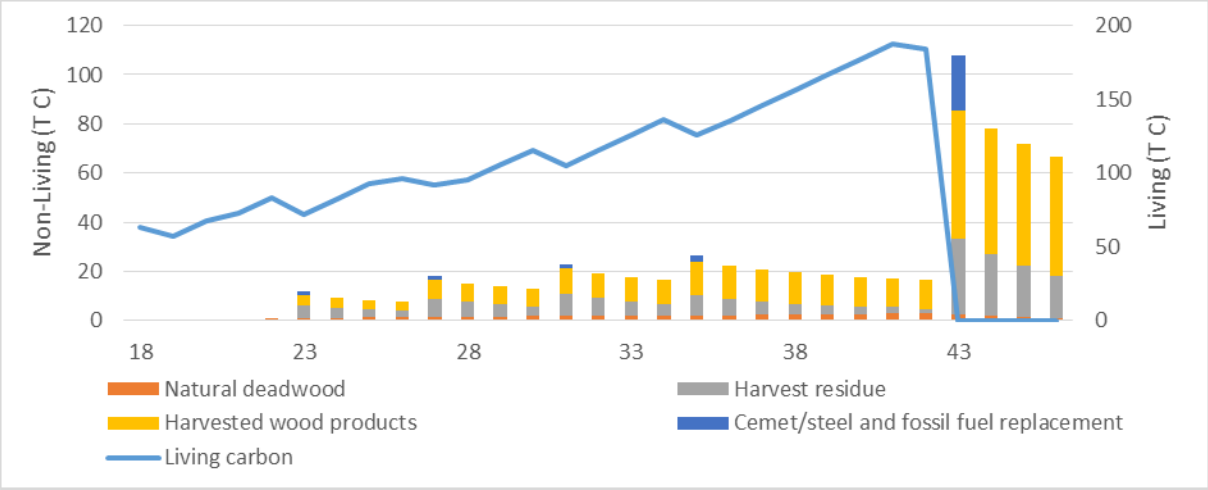

Figure 1 A per-age (x-axis) carbon assessment (T C ha^{-1}) for the clearcutting conifer - spruce monoculture sub-FMM

Clearcutting conifer – Spruce with 10% diverse conifer mix

A monoculture of Sitka spruce with a productivity of 16 m^3 ha^{-1} yr^{-1} and 10% Douglas fir with a productivity of 14 m^3 ha^{-1} yr^{-1} is used for this analysis. There are 4 commercial thinnings carried out with a clearfell at the age of 42 years).

Typically Sitka spruce will have the highest yield class for any site in Irish forest management. For this reason, the slightly less productive diverse conifer (used in this analysis) means that the carbon storage potential is slightly lower than the spruce monoculture sub-FMM.

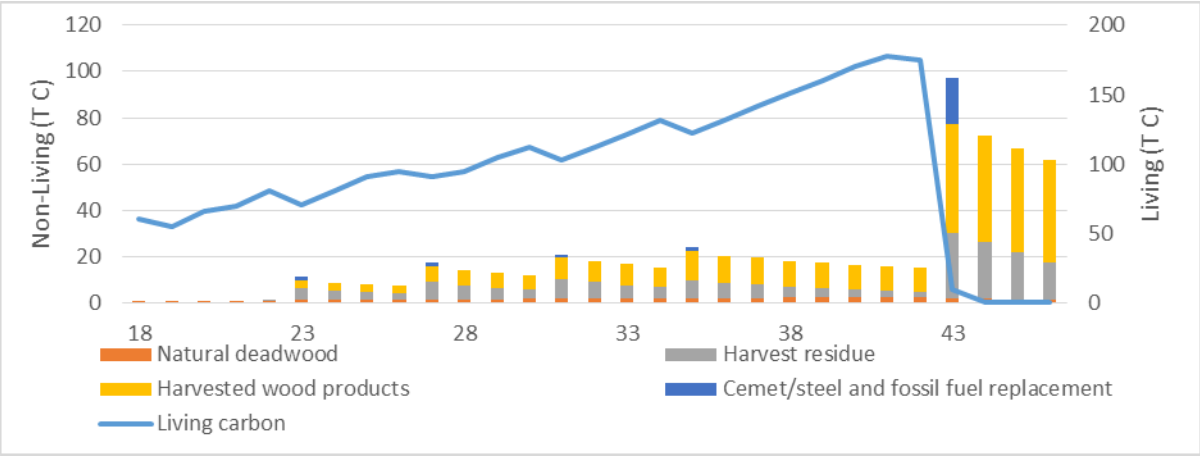

Figure 2 A per-age (x-axis) carbon assessment (T C ha-1) for the clearcutting conifer – spruce with 10% diverse conifer mix sub-FMM

Clearcutting conifer – Spruce with 10% broadleaf mix

A mixture of 90% Sitka spruce with a productivity of 16 m^3 ha^{-1} yr^{-1} and 10% birch with a productivity of 6 m^3 ha^{-1} yr^{-1} is used for this analysis. There are 4 commercial thinnings carried out with a clearfell at the age of 42 years (Figure 3).

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Over the course of a 42 year rotation, Sitka spruce will grow much quicker than the 10% broadleaf mix in this sub-FMM and hence, living carbon is lower than the monoculture or diverse mixture sub-FMMs. When harvested, birch material is used for firewood which is not considered to be a harvested wood product nor replace cememt/steel or fossil fuels for this analysis.

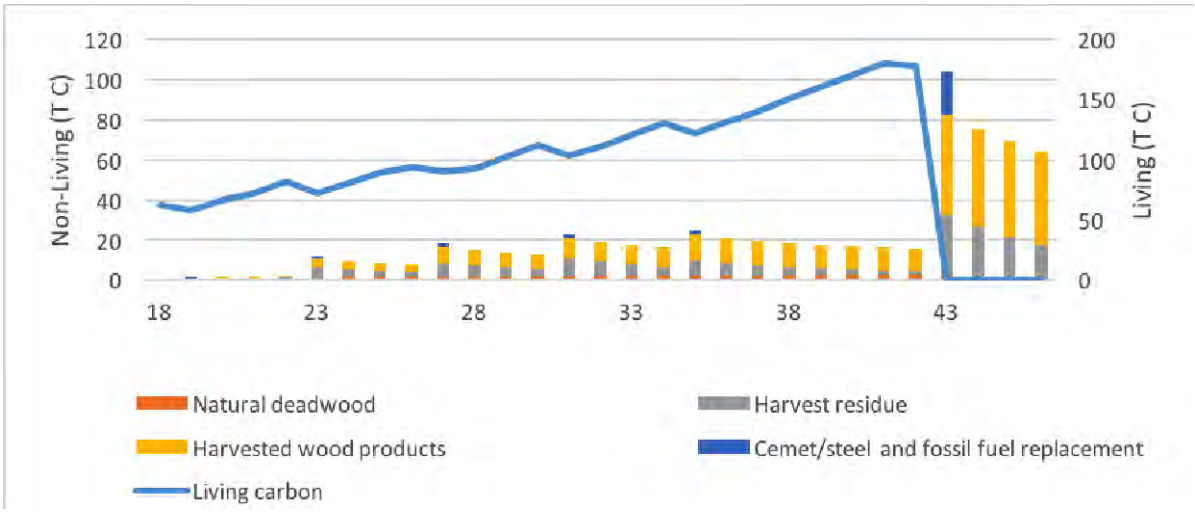

Figure 3. A per-age (x-axis) carbon assessment for the clearcutting conifer - spruce with 10% broadleaf mix sub-FMM

Clearcutting conifer – Diverse conifer

A monoculture of Douglas fir with a productivity of 14 m^3 ha^{-1} yr^{-1} is used for this analysis. There are 4 commercial thinnings carried out with a clearfell at the age of 42 years (Figure 4). The diverse conifer is not as productive as Sitka sprue meaning that there is less carbon stored.

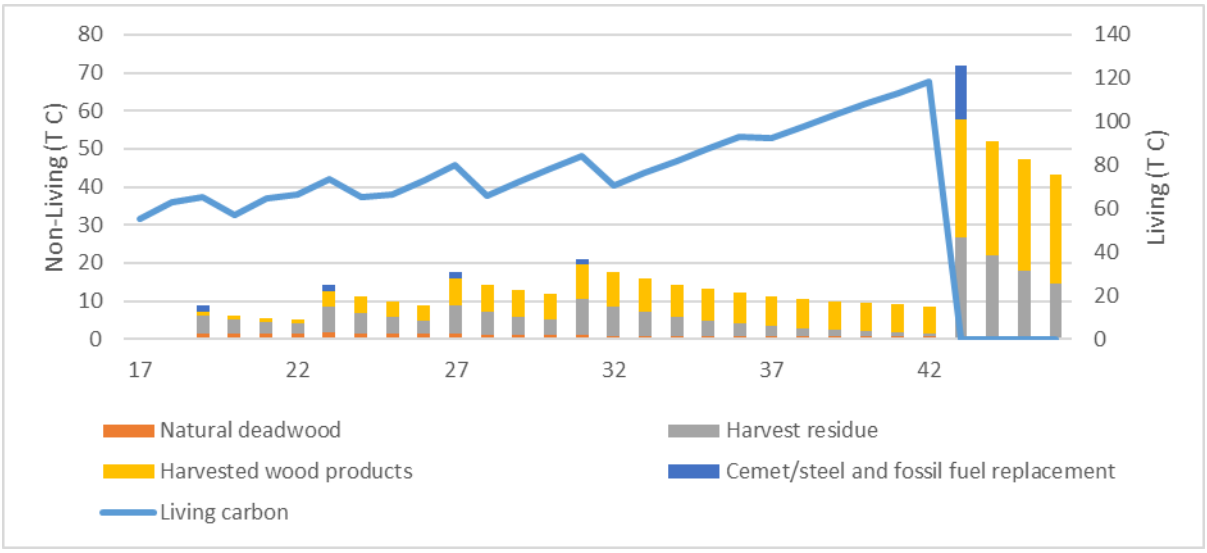

Figure 4. A per period carbon assessment for the clearcutting conifer - Diverse conifer sub-FMM

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Clearcutting lodgepole pine

A monoculture of Lodgepole pine with a productivity of 10 m^3 ha^{-1} yr^{-1} is used for this analysis. No thinning takes place for this FMM and there is a clearfell at the age of 45 years (Figure 5).

Lodgepole pine is less site sensitive to Sitka spruce and it is chosen for sites that are not suitable for Sitka spruce. However, it will not reach the same productive capacity or meet the same timber quality indicators required for sawlog products. Instead, 90% harvested is used for panel products while 10% is used for biofuel (Clarke, 2017, Business Area Unit 2 Team Leader, Coillte Forest *Pers. Comm.* to Lundholm, A.) which is included in this analysis.

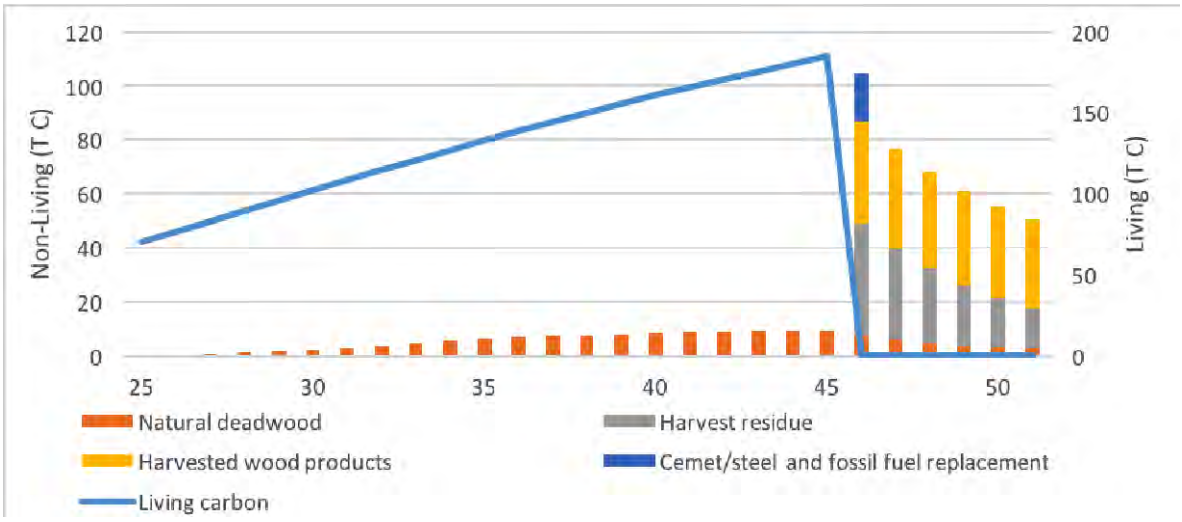

Figure 5 A per-age (x-axis) carbon assessment for the clearcutting lodgepole pine FMM

Nature conservation and biodiversity protection FMMS

Carbon from non-forest sources is not calculated for Ireland's analysis. This means that the open space and bog FMMs are assumed not to have any carbon fluctuations. The watercourse buffer zone used within 6 km hydrological distance of a freshwater pearl mussel breeding site is established with 20% broadleaf species. These trees will never be harvested which means that only living carbon and natural deadwood is accounted for in this assessment (Figure 6).

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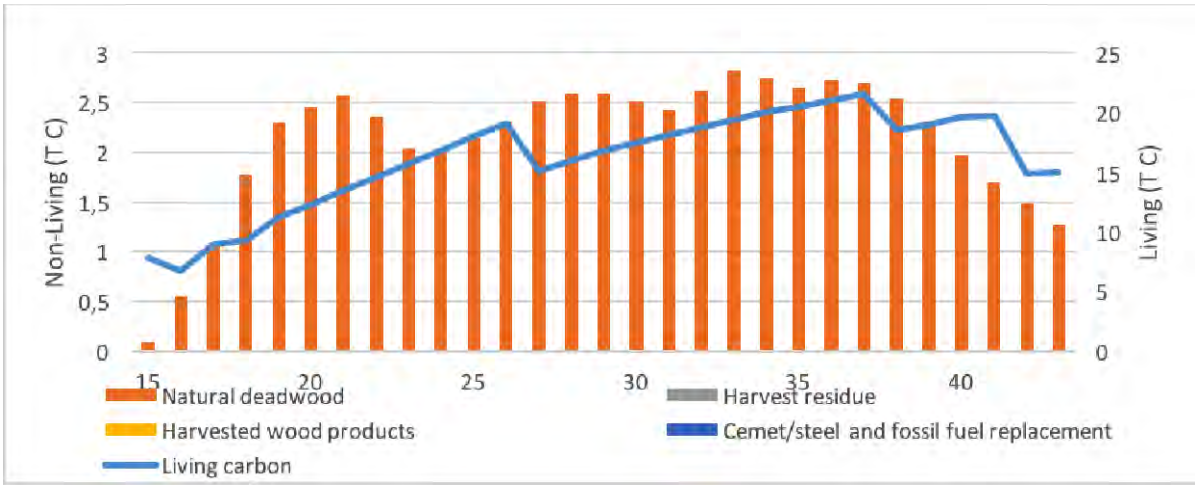

Figure 6 A per-age (x-axis) carbon assessment for the Nature conservation and biodiversity protection – buffer zone sub-FMM

Ranking FMMs

Each sub-FMM has been ranked according to the guidelines set out by the carbon ES expert

Table 8 Ecolocigal service - Carbon, Ranking of FMMs

FMM	FMM subcategory	Rank
Clear cutting conifer	Spruce monoculture	2.56
	Spruce with 10% diverse conifer mix	3.09
	Spruce with 10% broadleaf mix	3.04
	Diverse conifer	2.89
Clear cutting lodgepole pine	Unthinned	2.17
Nature conservation and biodiversity protection	Open space	N/A
	Watercourse bufferzone	0.56
	Bog habitat	N/A

These numbers were produced using the model provided by ALTERFOR's Carbon ES expert Dr. Kevin Black.

The growth and yield curves used to produce the carbon storage were developed by Coillte using Grofor (Irish stand level dynamic yield models) for their modelling process and provided to UCD for ALTERFOR.

2.2.3. Cultural Values

Outcome of ranking of cultural values are showed in Figure 7. The result is difficult to evaluate and the figure shoiw the complexity of "cultural values".

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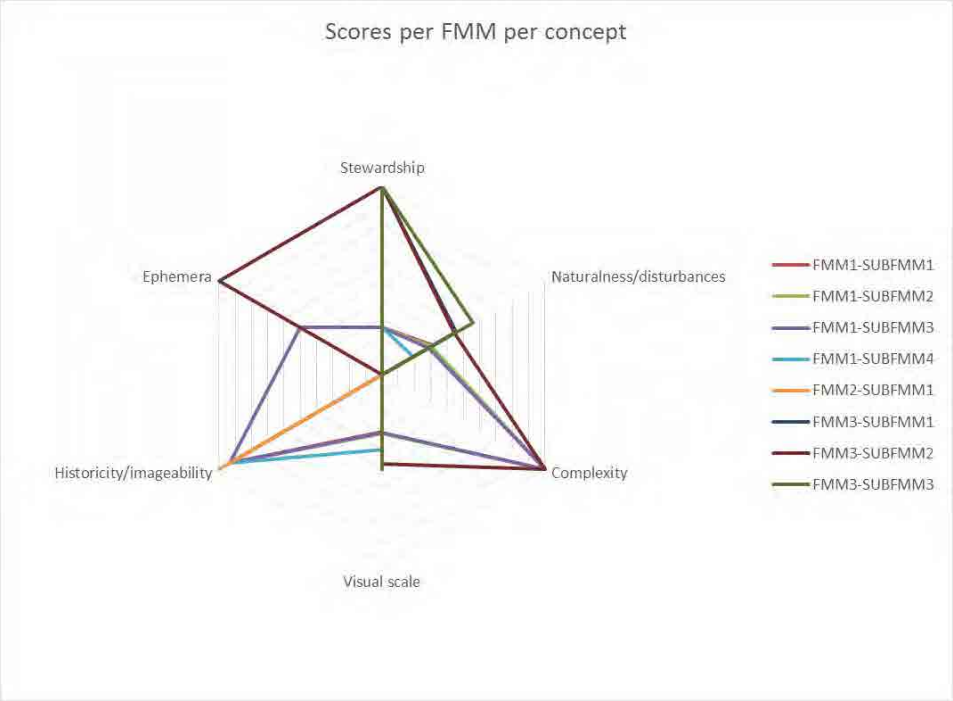

Figure 7 Cultural values for FMM and subFMM.

2.2.4. Contrasting the relative regulatory services of Ireland's stand level FMMs

Wind risk

Site characteristics

Certain site characteristics can alter the windthrow risk. The windthrow probability model used in this ecosystem service (ES) assessment was developed by Ní Dhubháin et al. (2009) and includes coefficients for soil type, elevation and wind risk zone (Miller, 1986). The predominant soil type in the CSA is blanket peat an even though there are coefficients for a wider range of soils, only this soil type is used for this assessment. Elevations of 50 m and 200 m were used to show the effect of this parameter. Similarly, the wind risk zones B and D/C were assessed as they were the only one present in the CSA. The more extreme wind risk zone, B, having higher wind risk probability.

Clearcutting FMMs

A clearfell FMM is a rotation-based system which involves 4 growth stages. Each clearfell FMM roughly follow these stages and the difference between them will be described more distinctly in the remainder of the document.

- **Establishment stage** and **Thicket stage -** Although at very young ages plants can be affected by wind causing basal sweep (Forest Service, 2002).
- The **Commercially maturing** stage is where thinning has been carried out/or mortality has set in. To represent this stage in Table 9 below, the age at with first thinning takes place according to our growth and yield models (BFC, 1973 to 1980) was used;

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- **Commercially mature**. Here stands have reached financial maturity which is typically the age of maximum mean annual increment – 20% of age (years) and may/may not have been thinned. In either case, there are at least some openings in the forest canopy and combining this with tall trees increases the probability of stand windthrow.

Clearcutting conifer

The species in this FMM (i.e. Norway spruce, Douglas fir, etc.) produce relatively straight knot-free timber than the lodgepole pine FMM even when thinned which makes this FMM more susceptible for windthrow. In addition, the yield class of this species is typically higher meaning that trees reach greater height which increases their windthrow probability.

Clearcutting lodgepole pine (always unthinned)

This FMM is monoculture lodgepole pine. This species is not thinned as it responds by producing large side branching which means that thinning will not increase the economic viability of the crop. The decision not to thin this FMM means that windthrow probability is typically lower than the clearcutting conifer FMM. This species typically has a lower yield class than the clearcutting conifer FMM also which further reduces the wind risk in comparison.

Table 9 The probability of windthrow occurring with a variety of factors that are typical characteristics for stands located in the CSA.

FMM	Thinned	Windzone	Elevation	Age	Windthrow Probability***
Clear cutting conifer: Sitka spruce Yield class 16 Blanket peat/gley soil type*	Y	B	50	21	0.16
	Y	B	50	42	0.93
	Y	B	200	21	0.45
	Y	B	200	42	0.98
	Y	D/C	50	21	0.05
	Y	D/C	50	42	0.80
	Y	D/C	200	21	0.18
	Y	D/C	200	42	0.94
	N	B	50	21	0.05
	N	B	50	42	0.78
	N	B	200	21	0.17
	N	B	200	42	0.94
	N	D/C	50	21	0.01
	N	D/C	50	42	0.50
	N	D/C	200	21	0.05
	N	D/C	200	42	0.81
Clear cutting lodgepole pine**: Yield class 10	N	B	50	25	0.06
	N	B	50	45	0.64
	N	B	200	25	0.21
	N	B	200	45	0.88
	N	D/C	50	25	0.02

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FMM	Thinned	Windzone	Elevation	Age	Windthrow Probability***
Blanket peat/gley soil type*	N	D/C	50	45	0.34
	N	D/C	200	25	0.07
	N	D/C	200	45	0.68
Nature conservation and biodiversity protection	Open space				N/A
	Watercourse Bufferzone				N/A
	Bog habitat				N/A

*The predominant soil type category in Irelands CSA;

**The windthrow probability model was developed using Sitka spruce only. The ages used for this FMM are the typical first thin (although not thinned for this FMM) and clearfell ages for this species and yield class;

***The probability of significant windblow occurrence. For example a probability of 0.50 means that 50 stands out of 100 with these attributes will suffer windblow.

Fire risk

Background and site characteristics

The upland and/or bog areas with grassland and commonage land of low fertility have been historically used for sheep farming in Ireland. Heather is traditionally burned in spring to increase the palatability for grazing sheep (Tubridy, 2013). This time coincides with the most vulnerable time of year for wildfire as land-cover is at its driest. Until the 1950's, much of these upland landscapes in Ireland did not contain forest (Neeson, 1991). This means there was little risk burning affecting forest land. More recently, sheep farming in these areas has become less economically viable. This is, in part, from lack of burning practices permitted under current legislation (Irish Uplands Forum, 2015), and hence land-owners are choosing not to farm their land. This means higher fuel loads than there have been in the past. The effect of this change is that when fires happen they are typically more severe than they have been historically.

Clearcutting FMMs

A clearfell FMM is a rotation-based system which involves 4 growth stages. Each clearfell FMM roughly follow these stages and the difference between them will be described more distinctly in the remainder of the document.

- Whether at an afforestation or reforestation **Establishment stage,** fuel loads build up before canopy closure. This makes this stage the most vulnerable and damage can be quite severe (Forest Service, 2002);
- **Thicket stage** is where trees have closed canopy and the living crowns of trees are also close to the ground. This means that it is relatively easy for ground fires to spread into the canopy and also from adjacent land-uses and damage can be quite severe (Menning and Stephens, 2007)*;
- The **Commercially maturing** and **Commercially mature** stages are where thinning has been carried out/or mortality has set in. There is a well-established canopy which is further away from the ground than thicket stage meaning a reduced risk from ground fire. A risk for

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these stages is the possibility of fires spreading from adjacent land-uses and laddering from ground to canopy using side-branches of edge trees (Menning and Stephens, 2007)*

*The risk of fire spreading from adjacent land-uses greatly decreases if adequate fire breaks (length of fire breaks should be proportional to potential flame length) and pruning of edge trees is carried out

Clearcutting conifer

The species in this FMM (i.e. Sitka spruce, Norway spruce, Douglas fir, etc.) produce relatively straight knot-free timber than the lodgepole pine FMM even when thinned. In addition, the yield class of this species is typically higher meaning that trees reach greater height which increases their windthrow probability.

Clearcutting lodgepole pine (always unthinned)

Lodgepole pine has evolved thinner bark and uses fire as a mechanism to release seeds from cones (Lotan et al., 1985). Its thinner bark means that fires are far more damaging than other conifers such as Scots pine (Zackrisson, 1977).

Nature conservation and biodiversity protection – Open space

These are the areas that may contain high fuel loads, they can catch fire easily and are the predominant land-use that is ignited for the burning of vegetation (Forest Service, 2002).

Nature conservation and biodiversity protection – Watercourse bufferzone

These areas contain small groups of broadleaf trees and can have high fuel loadings. The spatial location of these areas and their proximity to forests mean that they can act as a fire corridor helping to distribute fires throughout a landscape. However, these areas are managed as forest land and hence it is not common for fires to be ignited within this land-use type.

Nature conservation and biodiversity protection – Bog habitat

Bog contains seasonal grasses. In spring, the previous years growth dries out and will ignite, similar to open space.

Table 10 Fire risk for FMMs and subcategories.

FMM	FMM subcategory	Fire risk (0 – 5)*
Clear cutting conifer	Establishment / thicket stage	4
	Commercially maturing / commercially mature	0
Clear cutting lodgepole pine	Establishment / thicket stage	5
	Commercially maturing / commercially mature	2
Nature conservation and biodiversity protection	Open space	5
	Watercourse bufferzone	3
	Bog habitat	4

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*At this stage (deliverable 1.1 due for May 31st 2017) the exact vulnerability classes used for fire risk in Ireland's DSS are undergoing a refinement phase with experts in this area. Hence, the fire risk classes in this table should be treated tentatively.

2.2.5. Water

2.2.6. Contrasting the relative biological diversity of Ireland's stand level FMMs

Water sedimentation risk

There are 4 factors used to determine water sedimentation risk in Ireland's DSS: soil type, upslope contributing area, distance to watercourse and land-use based on Sivertun and Prange (2003). Soil type, upslope contributing area and distance to watercourse are inherent to a site, they will influence water sedimentation risk although they will not change over the modelled planning horizon. The land-use factor is most relevant for ALTERFOR as it is applied dynamically in the model depending on land management actions. This factor will be described and the water sedimentation risk factors for a combination of land-use and inherent factors are presented in Table 11.

Land-use

Both the clearcutting conifer and clearcutting lodgepole pine FMMs have two land-use factors for water sedimentation risk within their rotation. The only distinction in terms of water sedimentation risk between these two FMMs is rotation length, i.e. the longer the rotation (i.e. the less clearfelled forest area there is), the lower the water sedimentation a risk a stand will have over the planning horizon.

- **Clearfelled forest**. Here stands are clearfelled (or disturbed from site-preparation for afforestation). This stage continues for 4 years post clearfell (or post afforestation) and is the highest risk land-use for water sedimentation (Risk Factor = 0.4);
- **Undisturbed forest** is where forest is growing and soil is not disturbed, it has a much lower risk than clearfelled forest (Risk Factor = 0.005).

There are also land-use factors for non-forest land which relate to the minor FMMs.

- **Bufferzone and bog**. Bufferzones are designed to buffer watercourses from human land-use management interventions (Forest Service, 2000). They reduce water sedimentation risk from land-use management practices and hence these are the lowest land-use factor for water sedimentation risk. The bog land-uses are also a permanent undisturbed vegetation layer and hence have similar characteristics to Bufferzones (Risk Factor = 0.004);
- **Agricultural land and scrub**. These land-uses may (some scrubland is not grazed) have annual land-use management practices and hence have a higher risk than undisturbed forest but much less than clearfelled forest (Risk Factor = 0.01).

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Table 11 Water sedimentation risk for a range of factors typcial to the CSA

Land-use	Soil type (K)	Distance to water course (0 is over 1 km, while 1 is adjacent to watercourse)	Slope length (S, dimensionless unit)	Water sedimentation risk factor (P)*
Undisturbed forest	Till	0	50	0.10
Undisturbed forest	Till	400	50	0.03
Undisturbed forest	Till	900	50	0.00
Undisturbed forest	Clay	0	50	0.11
Undisturbed forest	Clay	400	50	0.04
Undisturbed forest	Clay	900	50	0.00
Undisturbed forest	Organic	0	50	0.08
Undisturbed forest	Organic	400	50	0.02
Undisturbed forest	Organic	900	50	0.00
Cleared forest	Till	0	50	0.76
Cleared forest	Till	400	50	0.25
Cleared forest	Till	900	50	0.00
Cleared forest	Clay	0	50	**0.90****
Cleared forest	Clay	400	50	0.30
Cleared forest	Clay	900	50	0.00
Cleared forest	Organic	0	50	0.60
Cleared forest	Organic	400	50	0.20
Cleared forest	Organic	900	50	0.00
Bufferzone	Till	0	50	0.08
Bufferzone	Till	400	50	0.03
Bufferzone	Till	900	50	0.00
Bufferzone	Clay	0	50	0.09
Bufferzone	Clay	400	50	0.03
Bufferzone	Clay	900	50	0.00
Bufferzone	Organic	0	50	0.06
Bufferzone	Organic	400	50	0.02
Bufferzone	Organic	900	50	0.00
Agricultural	Till	0	50	0.19
Agricultural	Till	400	50	0.06
Agricultural	Till	900	50	0.00
Agricultural	Clay	0	50	0.23
Agricultural	Clay	400	50	0.07
Agricultural	Clay	900	50	0.00
Agricultural	Organic	0	50	0.15
Agricultural	Organic	400	50	0.05
Agricultural	Organic	900	50	0.00

**P the sediment loss risk, K the soil type, S the slope length factor, W the proximity to watercourse and U the land-use.*
*** Highlights the maximum water sedimentation risk in the table*

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2.2.7. References

BFC, 1973 to 1980. Yield Models for Forest Management. Forestry Commission, Alice Holt Lodge, United Kingdom.

Clarke, T., 2017, Business Area Unit 2 Team Leader, Coillte Forest *Pers. Comm.* to Lundholm, A.

Forest Service, 2000. Forestry and Water Guidelines. Forest Service, Johnstown Castle Estate, Wexford, Ireland.

Forest Service, 2002. Forest Protection Guidelines. Forest Service, Johnstown Castle Estate, Wexford, Ireland

Forest Service, 2015. Afforestation Grant and Premium Scheme 2014-2020, 2nd ed. Department of Agriculture, Food and the Marine, Wexford, Ireland.

Irish Uplands Forum, 2015. Review of the Legislative Controls set out in Section 40 of the Windlife Actos 1976 to 2012 Governing the Control of Burning and Hedge Cutting: Submission from Irish Uplands Forum. NPWS.

Lotan, J.E., Brown, J.K., Neuenschwander, L.F., 1985. Role of fire in lodgepole pine forests.

Menning, K.M., Stephens, S.L., 2007. Fire climbing in the forest: a semiqualitative, semiquantitative approach to assessing ladder fuel hazards. Western Journal of Applied Forestry 22, 88-93.

Miller, K.F., 1986. Windthrow Hazard in Conifer Plantations. Irish Forestry 43.

Neeson, E., 1991. A History of Irish Forestry. Liliput Press, Dublin, Ireland.

Ní Dhubháin, Á., Bulfin, M., Keane, M., Mills, P., Walshe, J., 2009. The Development and Validation of a Windthrow Probability Model for Sitka Spruce in Ireland. Irish Forestry 66, 74-84.

O'Halloran, J., Irwin, S., Kelly, D., Kelly, T., Mitchell, F., Coote, L., Oxbrough, A., Wilson, M., Martin, R., Moore, K., Sweeney, O., Dietzsch, A., Walsh, A., Keady, S., French, V., Fox, H., Kopke, K., Butler, F., Neville, P., 2011. Management of Biodiversity in a Range of Irish Forest Types. Report Prepared for the Department of Agriculture, Fisheries and Food.

O'Callaghan, C.J., Irwin, S., Byrne, K.A., O'Halloran, J., 2016. The role of planted forests in the provision of habitat: an Irish perspective. Biodivers Conserv, 1-22.

Tubridy, M., 2013. A Study to Identify Best Management of Upland Habitats in County Wicklow. Wicklow Uplands Council, Roundwood, Wicklow.

Zackrisson, O., 1977. Influence of Forest Fires on the North Swedish Boreal Forest. Oikos 29, 22-32

Sivertun, Å., Prange, L., 2003. Non-point Source Critical Area Analysis in the Gisselö Watershed Using GIS. Environmental Modelling & Software 18, 887-898.

Smith, G., O'Donoghue, S., Iremonger, S., Gittings, T., Pithon, J., O'Halloran, J., Wilson, M., O'Donnell, V., Kelly, D., French, L., McKee, A.-M., Mitchell, F., Oxbrough, A., Giller, P., Kelly, T., 2005. Assessment of Biodiversity at Different Stages of the Forest Cycle. Report to the National Council for Forest Research and Development and the Environmental Protection Agency.

Wilson, M.W., Irwin, S., Norriss, D.W., Newton, S.F., Collins, K., Kelly, T.C., O'HALLORAN, J., 2009. The importance of pre-thicket conifer plantations for nesting Hen Harriers Circus cyaneus in Ireland. Ibis 151, 332-343.

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