Climate Change Adaptation and Mitigation strategies in Poland

- A study of the Forest Carbon Farms project's (Leśne Gospodarstwa Węglowe) implications for biodiversity

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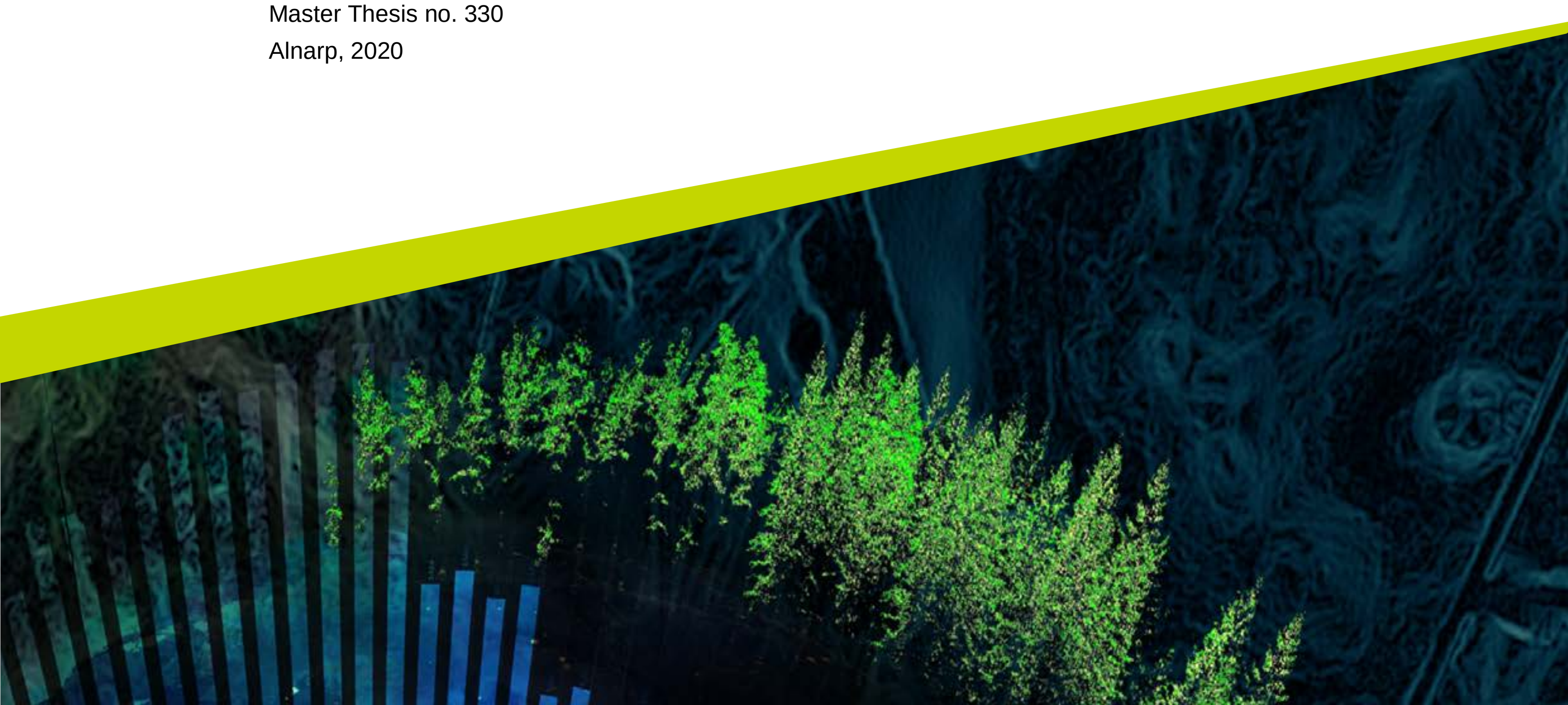

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Abstract

Climate change is affecting forests in Europe. In response, Polish State Forests developed the Forest Carbon Farms project (FCF) which involves a range of climate change adaptation and mitigation strategies (CCAMS) for adoption. Those strategies are meant to change the current forest management in Poland. However, there is no research done on how these changes might affect key habitat determinants of biodiversity Polish forests. In this work I evaluate which of these strategies are likely to positively or negatively influence habitat availability in the current forest state. To do so I summarized the most important biodiversity goals for forests in Poland, which are mentioned in the legislation and sustainable forest management standard, in relation to the possible outcomes of each CCAMS for these goals, which I sourced from the recent scientific literature.

My results showed that some of the CCAMS already adopted in FCF are not consistent with Poland's biodiversity goals. Further use of strategies like Energy Wood Yards or fast-growing tree species might threaten biodiversity in Polish forests, which has been actively conserved and enhanced over recent years. In contrast, some of the strategies suggested by the FCF are likely to have a positive impact on habitat availability relative to current forest management. For example, shelterwood systems managed in direction of natural spread of tree species, might be a good strategy to enhance the biodiversity in Polish forests. Other way of implementing the CCAMS together with habitat protection would be to diversify the strategies on the landscape scale.

There is still a place for more evaluation of the FCF project, which could be more accurately implemented if such assessment has been done prior launch of the project.

Keywords: Climate change adaptation and mitigation, Biological conservation, *Pinus sylvestris*, Sustainable forest management, Forest Carbon Farms, Leśne Gospodarstwa Węglowe

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Abbreviations

CC	Climate Change
CCAMS	Climate Change Adaptation and Mitigation Strategies
FA	Forest Act
FCF	Forest Carbon Farms
FSC	Forest Stewardship Council
GUS	Główny Urząd Statystyczny (Central Statistical Office)
GHG	Greenhouse Gas
NPA	Nature Protection Act
PGL LP	Państwowe Gospodarstwo Leśne Lasy Państwowe (Polish State Forest, National Forest Holding)
PEFC	Programme for Endorsement of Forest Certification
Dec. 11	The 11th Decree of General Director of State Forests
IFP	The Instruction of Forest Protection
RS	The Rules of Sylviculture

1. Introduction

1.1. Climate Change

The climate around the world is changing. The current weight of scientific evidence is that these changes are man-made, result from an increase in greenhouse gases in the atmosphere, and will cause numerous climate-related risks, such as droughts or intensive precipitation (Smith *et al.* 2014). Uncertainties and risks will increase if we do not reduce these emissions (IPPC 2014). As a result of climate change there are rapid changes in the environment, which are beyond those experienced during human history (Millar *et al.* 2007; Lenton *et al.* 2019). In the view of such great changes, many efforts have been made to model the effects of climate change (CC) around the globe, as scientists try to figure out how and to what extent the climate will change in different regions. Models for global and regional levels can project broad patterns of climate change with some confidence, but the predictions for subnational and especially local levels are less accurate (Food and Agriculture Organization of the United Nations 2013). Modelling the implications of climate change is still not accurate enough to make confident projections, even though the knowledge about sensitivities and the areas of climate risks and opportunities is increasing (Lindner *et al.* 2010). In this regard it is easier to project the response of ecosystems to gradual changes that are more consistent with past conditions. In contrast, human induced climate variability will result in much more rapid and extreme changes to the climate that are far more difficult to model (Lindner *et al.* 2010).

In the central temperate zone of Europe projections suggest that by 2100 the average temperature will rise by 3-8°C relative to 2007 (Lindner *et al.* 2010). Depending on different RCP (Representative Concentration Pathways) scenarios the rise might be higher or lower (Smith *et al.* 2014). In the springtime it is predicted that the average temperature will be up to 3℃ higher, and up to 4℃ in other seasons. However, perhaps of greatest concern is that the minimal temperature for the winter time in this climate zone might rise as much as 8-15℃ (Zajączkowski *et al.* 2013). This difference in temperatures is expected to occur within only a 100-year timespan.

This time period corresponds with the average rotation period of a managed forest stand in Poland and will thus have a large influence on forest processes and their management. Thus, we need to prepare for and understand the implications of climate change for forest systems and adapt to ensure that the ecosystem services provided by forests to future generations are sustained.

1.2. Biodiversity

As production forests cover more than half of the forest area in Europe, the issue of biodiversity conservation in production forests is very important for overall forest biodiversity protection. Defined by the Convention on Biological Diversity in 1992 (United Nations 1992): biological diversity is*:*

> "the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, among species, and of ecosystems".

According to Secretariat of the Convention on Biological Diversity (Thompson *et al.* 2009) most of the processes and the resilience of ecosystems depend on biological diversity at different scales. Some species are more important to maintain the resilience of the forest ecosystems than others (Walker 1995; Dıaz *et al.* 2003). The resistance and resilience of the forest ecosystems might be crucial in the choice of forest management strategies implemented to mitigate or adapt to climate change. After Holling (1973) resilience is:

> "the capacity of an ecosystem to return to the pre-condition state following a perturbation, including maintaining its essential characteristics taxonomic composition, structures, ecosystem functions, and process rates" and resistance is "the capacity of the ecosystem to absorb disturbances and remain largely unchanged".

In Poland the conservation of biodiversity is determined in legislative acts and some normative documents, such as The Instructions for Forest Protection (Haze 2012a), FSC and PEFC Standards (PEFC Polska 2012; FSC Polska, 2013), etc. In those documents most of the important parts of forest biodiversity protection are mentioned, such as: maintenance of dead wood, promotion of mixed species stands, increasing the area of naturally regenerated forests, decreasing the area and amount of clear-cuts, using native tree species for regeneration, etc. According to the Instruction for Forest Protection (Haze 2012a):

> "biodiversity protection should be respected in the forest management to ensure the resilience and resistance of the forest. Biodiversity should be protected on different scale: genetic diversity, species diversity, landscape and ecosystem diversity."

In this work I will evaluate how the official Climate Change Adaptation and Mitigation Strategies (CCAMS) implemented in Polish State Forests might affect the biodiversity goals described in the official Polish documents and normative acts. Specifically I evaluate strategies included in Forest Carbon Farms (FCF) project, which has been implemented in Polish State Forests in 2017 (Tomaszewski 2017). Each of the CCAMS impacts on biodiversity are identified in one of three categories: tree species composition, forest structures, spatial/temporal patterns. To assess the CCAMS I contrast the most common production forest type, with each strategy of the FCF project in regard to these three categories relevant to habitat provision, and look for the references in the literature which explain the possible biodiversity impacts of each strategy. My results should be useful for determining which of the CCAMS in the FCF project are in line with the Polish legislative requirements for biodiversity protection. Moreover, if the CCAMS are further studied, it might help with decision if some of the FCF strategies should continue, be improved, or stopped.

1.3. Forests in Poland

Poland is a country located in the centre of Europe, in the temperate – continental zone. In the north of Poland there is the Baltic sea, which causes a slight maritime climatic influence on its ecosystems. In the south there are mountainous areas reaching up to 2499 meters above the sea level. Most of Poland is covered by lowlands. The total area of Poland is 32 257 500 hectares (Kondracki 1994), and forests cover 9 242 000 hectares, equating with 29,5% of the terrestrial area (GUS Departament Rolnictwa 2017).

Scots pine (*Pinus sylvestris*) is the dominate tree species in the country, covering 58.2% of the total forest area. It is chosen by foresters for planting because of suitable climate and site conditions, and because of its reasonably fast growth. Norway spruce (*Picea abies*) covers approximately 6% of total forest area and around 4% consists of other conifer tree species. The most common deciduous species are Oak (*Quercus spp*.) (around 8%), Birch (*Betula spp.*) (more than 7%) and European beech (*Fagus sylvatica*) (around 7%). Production stands of 40 – 80 years of age are prevalent, covering around 44% of the forest cover of the country. Stands older than 100 years cover less than 8% of total forest area in Poland. Total timber volume in the country is around 2,550 mil m^3, which equates to approximately 280 m^3 per hectare. (PGL Lasy Państwowe 2017). Most forests are used for production, as their primary goal, whereas only 2% of the forest area belongs to national parks, and less than 1% as forest reserves (GUS Departament Rolnictwa 2017). Around 77% of the forest cover is managed by Polish State

Forests, and over 45% of these forests have production as their dominant function. The remaining forest areas consist of e.g. watershed protection forests, city forests, and additional minor categories. Notably, in all these categories forestry operations are allowed. Unfortunately specific information regarding the types of management conducted in private forests (up to 20% of country forest area) is not known (PGL Lasy Państwowe 2017). Overall, 47% of the total forest area is managed using even-aged clear-cut management. According to most recent data 87% of regenerated area is done by planting, only 13% is regenerated naturally, and in last years the amount of naturally regenerated stands has reduced (GUS Departament Rolnictwa 2017).

2. Materials and methods

2.1. Choice of the Strategy – Forest Carbon Farms

Climate Change Adaptation and Mitigation Strategies are methods used to change the management of productive forests to mitigate or adapt to climate change effects on the forest, such as pest outbreaks, abiotic damages (wind throws, fires, etc.) or stresses caused by difference in water availability or temperature change (Felton *et al.* 2016). In Poland there is no official program for the adaptation of forests to climate change, and relatedly, there are no specific CCAMS intended for the country. However, there is a recently implemented pilot project run by the Polish State Forests - Forest Carbon Farms (in Polish: Leśne Gospodarstwa Węglowe). In the decree of General Director of Polish State Forests, a general overview of the project is provided, for which the stated main aim is to evaluate the potential to increase the CO^2 sequestration capacity of the forests by implementing different management strategies in areas located all over the country (Tomaszewski 2017).

As Poland is also a member of the European Union, EU directives will also shape the future of Polish forest management. The European Commission recently came out with proposals for land use and forestry regulation for the years 2021-2030, which aims to fulfil the requirements of the Paris Climate Change Agreement. Namely this involves a 40% reduction of greenhouse gases (GHG) emissions by 2030 in comparison to 1990 levels. The idea is to incorporate the land use and forestry sector into EU efforts to reduce greenhouse gases emissions. The basic principle is to ensure that all CO^2 going to the atmosphere from the land use, land use change and forestry (LULUCF) sector would be compensated by CO^2 removal provided by the same sector – known in this regulation as the “no debit” rule. The Polish Forest Carbon Farms (FCF) project fits very well into this EU regulation, and for this reason I also evaluate some of its potential implications.

2.2. Forest Carbon Farms in a nutshell

The project of Forest Carbon Farms was created for implementation in the Polish State Forests as an experiment in the years 2017-2020. The project is implementing research activities regarding the accumulation of CO^2 in the forests and practical activities in the forests, further mentioned as “Additional activities”. The main research target of the project is to calculate the amount of CO^2 stored in the forests, so payments could be implemented for carbon credits in Polish State Forests (Krzewina 2017). One idea is to “reduce” the influence of some heavy industry on the CO^2 emissions, by giving them the opportunity to buy carbon credits produced in the FCF. Recently the State Forests has been broadly promoting the Forest Carbon Farms as a way to produce carbon credits, which are being sold to Polish companies with high emissions, e.g. LOT – Polish airlines, LOTOS group –Polish petroleum group (PGL Lasy Państwowe 2019).

Here I do not evaluate the effectiveness of the CO^2 sequestration aspects of the FCF project, but instead focus on the proposed additional activities that are of relevance to habitat provision and biodiversity goals. Below I explain which of these FCF sub-projects I evaluate and why.

2.2.1. Additional activities in the forests

The central aim of the FCF project is to increase the accumulation of carbon in existing forests. Authors of the project (FCF) described several of the options available to achieve this, and have chosen specific areas in Poland for their implementation (Krzewina 2017):

1. Underplanting of stands using shade tolerant deciduous tree species such as beech, hornbeam;
2. ‘Sobański’ method of forest regeneration – a method of regeneration in which the traditional planting is replaced by sewing several different tree species at once. It is already used in many forests as a method for increasing tree species diversity and allowing more natural development of young forest stand (Kannenberg & Szramka 2008; Wesoły & Niemiec 2008);
3. Natural regeneration – a method already used in many forests stands in Poland on clear-cuts;
4. Afforestation of non-forested lands administrated by the State Forests;

5. Use of fast-growing tree species, which are faster at accumulating CO^2 from the atmosphere;
6. Shelterwood systems – which most common one is underplanting;
7. Pioneer crop – planting fast growing tree species for shortened rotation before planting the designated species on the afforested area

The methods described fall into the scope of increasing the GHG sinks and more specifically as a means of maintaining forest area, increasing forest area and maintaining carbon stocks in the forest (Food and Agriculture Organization of the United Nations 2013). Moreover, some of them, e.g. natural regeneration or underplanting, are not only acting as CC mitigation options, but are also expected to improve the forests adaptive capacity to climate change (Bolte *et al.* 2009; Kolström *et al.* 2011; Smith *et al.* 2014). This underlines that we cannot think of CC mitigation and adaptation strategies as single actions narrowly directed, but as a broad "package" of strategies often implemented together (Millar *et al.* 2007; Hallegatte 2009).

2.2.2. Energy wood yards – logging residue removal

Another idea of the project was to designate areas all over Poland on which energy wood could be stored for a long time. Logged residues from the forest are meant to be stored on specially designated areas instead of left to decompose inside the forest – thus I recognize the outcomes of Energy wood yards as equal to the ones of logging residue removal. In other words, my focus is not on where the wood is stored, but the fact that the wood is to be extracted from the forest rather than left there. The theory behind it is that the timber which could not be used by industry (by definition, or because of its shape or other properties), would be stored in such places to accumulate the carbon dioxide and not release it to the atmosphere. After a period of a time, the idea would be to actually use it as energy wood for power plants. The main objectives of wood yards, accordingly to the project, would be to accumulate organic carbon, store the energy wood for longer time and to act as research places, where the actual carbon dioxide released by the timber could be evaluated. (Krzewina 2017; Tomaszewski 2017)

2.3. Biodiversity goals for Poland

To evaluate each CCAMS impact on biodiversity (via habitat provision) in Poland I had to find out which goals are stated in the country's legislation and the most important normative acts regarding forestry and nature protection and define the biodiversity goals in those documents.

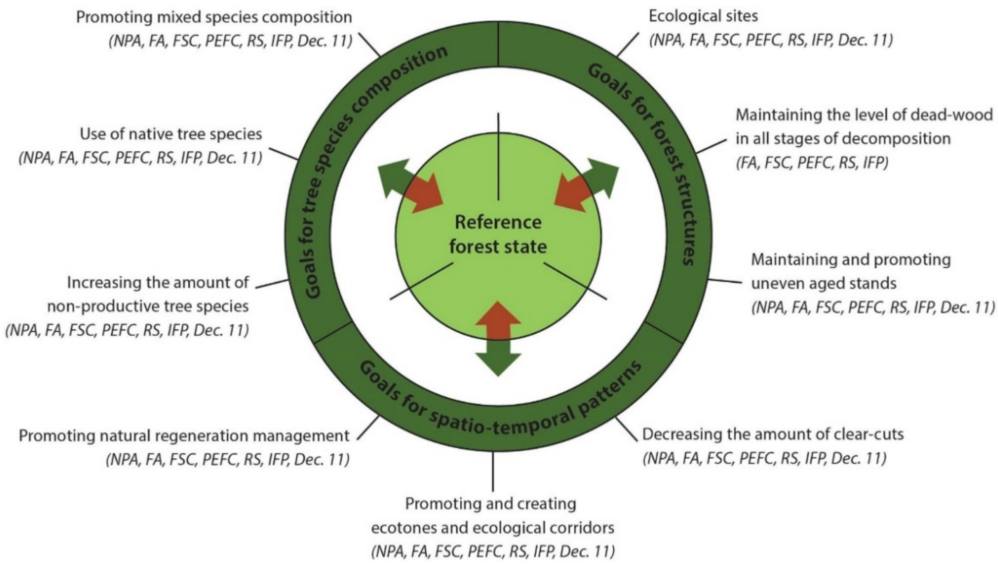

Figure 1. Biodiversity goals

For each management strategy from the FCF project we illustrate the relationship between: Polish normative acts regarding biodiversity, reference forest state (lowland scots pine monoculture, with clear-cut management type) and each FCF management strategy's potential to reduce or increase the difference between the reference state and the goals from the biodiversity relevant legislation and certification requirements (Felton et al., 2016). In the brackets the normative document in which the approach appears is stated: Nature Protection Act (NPA), Forest Act (FA), FSC Forest Management Standard (FSC), PEFC Standard (PEFC), The Rules of Sylviculture (RS), The Instruction of Forest Protection (IFP), The 11th Decree of General Director of State Forests (Dec. 11) The classification of biodiversity goals that I used is taken from the article by Felton et al. (2016). The space between the rings stands for the difference between biodiversity objective and reference forest state. The arrows are showing the direction in which the CCAMS would influence the forest - Green – improvement for biodiversity goals, brown – deterioration. Hollow arrow means low impact. Both arrows mean some indication of improvement, but also negative impact mentioned in the literature. No arrow – no change

There are two main acts which are relevant to biodiversity protection in Poland: The Forest Act (*Ustawa o Lasach* 1991) and The Nature Protection Act (*Ustawa o Ochronie Przyrody* 2004). These two documents broadly shape the biodiversity protection goals for Poland in general, and for Polish forests in particular. These documents were created or updated in response to the Convention on Biological Diversity of United Nations from 1992. Moreover for forest management the relevant official documents are: The Rules of Sylviculture (Haze 2012b), The Instructions for Forest Protection (Haze 2012a), and the 11th Decree of General Director of Polish State Forests (Dawidziuk 1995). These are core documents issued by the State Forests Directorate on how to manage the Polish forests and how to maintain their protection. However, they also refer to non-state-owned forests and non-productive forests. As 77% of Polish forests are managed by the state, and 90% of the state owned forests are certified, by either FSC or PEFC, these standards are also relevant to biodiversity protection (PEFC Polska 2012; FSC Polska, 2013).

In each of the biodiversity relevant regulations or the standards there are a limited number of ways by which biodiversity protection takes place in forestry. I decided to focus on the ones which are appearing in the majority or all of these documents. Figure 1 shows three groups of biodiversity protection goals and the approaches used within them.

The choice of a baseline reference condition for Poland had to be done prior to analysing the influence of each management strategy in the light of normative acts. I decided to use for a reference the standard silvicultural approach for productive forest lands**- lowland Scots pine monoculture with clear-cut management type and artificial regeneration -** as it is the most common productive forest type in the country.

The approaches which are defined as the "goals for forest structures" are the ones that will have an impact on biodiversity by changing the structure of stands, such as:

1. maintaining and promoting uneven aged stands,
2. retaining dead wood in all stages of decomposition,
3. creating and protecting Ecological Sites.
   Ecological Site (Użytki Ekologiczne) is a term introduced by the Nature Protection Act to refer to small places with unique ecological values, such as: natural water bodies, ponds, small bushy area, swamp, peatlands, etc.

Goals for spatio-temporal patterns are those which aim to protect biodiversity by managing larger areas than forest stands. The patterns in the forest could be affected by acting at the landscape scale, such as:

1. creating and protecting ecotone area – as it is a border area i.e. between forest and grassland it can be an environment for both forest and grassland species, but also for the ones which are not occurring in either of them separately.(Murat 2005)
2. promoting natural regeneration – it is mentioned as a way of enhancing positive effects for biodiversity. (Lust *et al.* 2001)
3. decreasing the amount of clear cuts, which by changing the forest microclimate can exclude populations of rare and sensitive forest species. (Stefańska-Krzaczek 2012)

The goals for tree species composition are those aiming to:

1. increase the amount of tree species at the stand level – promoting mixed species composition.
2. Increase the use of native tree species. This is correspondingly associated with a decreased usage of introduced species, especially invasive ones.
3. Enhance the growth and use of non-production tree species - the ones that are not broadly used in the timber industry but can be of a great biological value. The non-production tree species are meant to be promoted in the national legislation as they provide fruits, nectar and nesting places for many organisms (Haze 2012a)

2.4. FCF vs. Biodiversity goals – literature review

I decided to evaluate each strategy, by researching the literature looking for its potential impacts on biodiversity.

I have focused on the sylvicultural methods in FCF that might be used in the reference forest state chosen for assessment (i.e. Scots pine monocultures). As wetland protection cannot be adopted in the typical lowland Scots Pine monoculture, this option has not been evaluated. From the group of additional activities in the forest I decided to not evaluate strategies which address the creation of a new stand: afforestation (4) and pioneer crop (7). As ‘Sobański’ method (2), natural regeneration (3) and shelterwood system (6) could be used for the regeneration of the existing stands, I decided to keep them for the evaluation. Use of fast-growing species (8) and underplanting (1) was also evaluated. The Energy Wood Yards (EWY) has been also chosen for the evaluation as the idea is based on the logging residue removal from the forests.

To review the literature regarding how each of the evaluated FCF project ideas might impact on biodiversity goals, I started by systematically searching the literature.

I began with searching online (Google Scholar) for the literature in English for each of the strategies. The search was made in April and March of 2019, by connecting the keywords for each strategy with "biodiversity". The pattern I used for search terms has been the same for each method: *temperate OR Europe OR Poland "*name of the sylvicultural method*" AND biodiversity*. For each method I used different keywords as **name of the sylvicultural method**:

1. Shelterwood and Underplanting as both practices are similar – "*underplanting*", and "*shelterwood", and "continuous cover"*
2. 'Sobański' method – "*sobanski*": (no results in English papers has been found), I searched for any research regarding 'Sobański' method in Sylvan and then in the abstract searched for references regarding biodiversity or ecological influences. However Kint et al. (2006), found when searching for natural regeneration literature, has been also defining the results of methods similar to 'Sobański' method
3. Natural regeneration – "*natural regeneration*", *"natural regeneration on clear-cuts"*
4. Fast growing tree species: "*fast growing tree species*", *"short rotation", "bioenergy stands"* and *"hybrid aspen",* as this is most commonly used fast growing tree species in Europe and the best alternative for the Scots pine.
5. Logging residue removal - "Energy Wood Yards": "*logging residue removal*" and "*energy wood extraction*", as the EWY idea is based on removal of logging residues – shoots, tops and roots, which would normally decompose in the forest and storing them in the specifically designated areas.

For issues specific to Poland - as 'Sobański' method - I searched for relevant literature mostly in Sylvan magazine, which is the most common magazine to publish scientific papers among Polish Forest Scientists. This search was conducted in Polish. To focus my efforts on the most recent scientific evidence, I've limited the review to studies published after 2000. In some cases when the method (such as underplanting or shelterwood) is more commonly applied in forestry (the impacts has been studied broadly before 2000), I have used some earlier scientific literature (Bernadzki & Andrzejczyk 1983; Matthews 1991).

The research showed many results most of them were not relevant to the subject, e.g. for natural regeneration it resulted in 16 600 positions. Some of them treating about American sylviculture, some of them relevant to oak stands, etc. That is why I decided that there is a need to filter the literature, so it would be more relevant to the subject (Figure 2). Resulting in looking up for references in each article/book title/abstract to the biodiversity impacts of the method, especially on Pine stands, as it is the dominating tree species in Poland. If I haven't been able to find any relevant information regarding the biodiversity outcomes for any of the strategies in Poland, I broadened the scope to papers to those addressing impacts in temperate Europe, then further to include the whole Europe. Moreover, by some type of snowball sampling I found relevant literature in the reference lists of articles already used or even in some of the articles which were not relevant to the subject.
As an example: When looking for literature addressing the 'Sobański' method, I searched for the articles only in the Sylvan magazine and on the website of the Polish State Forests, as the method has been developed and is used in Poland (Kannenberg & Szramka 2008). Whereas for articles regarding the "Energy Wood Yards" (EWY), I searched on the google scholar website for references on "logging residue removal" – as core to the EWY idea is the removal of logging residues. Then I narrowed the search to articles which address issues related to the effects on biodiversity as a whole, or specifically on some specific taxa, i.e. ground active beetles (Gunnarsson *et al.* 2004; Jonsell 2007).

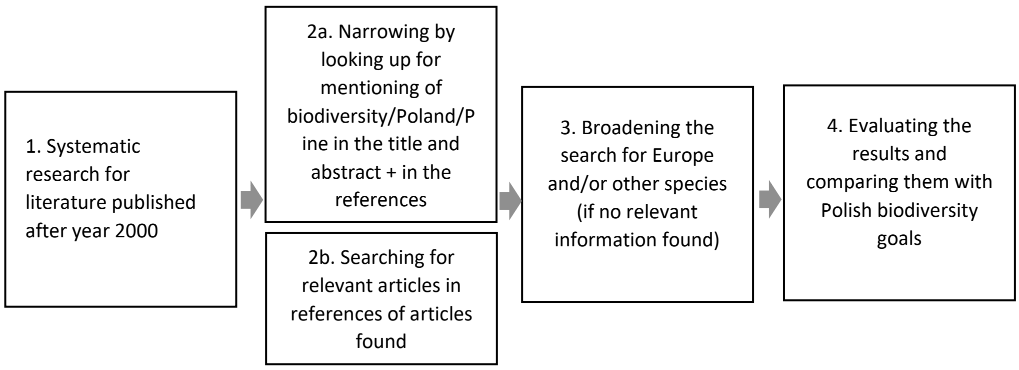

Figure 2. General scheme of literature review.

I tried to narrow the search for papers treating only biodiversity outcomes in *Pinus sylvestris* stands, but in other cases the analysis has been done for other coniferous species, such as *Picea abies*. In such cases, and depending on the context, the outcomes may be of a similar nature. The biological diversity of pine and spruce stands differs (Felton *et al.* 2019), but the sylvicultural management in Poland of those stands is very similar – clear-cut with monocultures, artificially regenerated, with comparable rotation time (Haze 2012b).

As some methods are likely to have similar outcomes to others, I collated the results and consider them as part of one CCAMS strategy. For this reason, shelterwood was evaluated together with underplanting, as the majority of literature reviewed considered that their biodiversity impacts are comparable. Moreover, in Polish literature those two terms are often used in exchange. Most of the naturally regenerated pine stands in Poland are done on clear-cuts, so natural regeneration was evaluated separately.

In the next chapter I evaluated the chosen management strategies mentioned in the FCF project in regard to the biodiversity goals set up in the official acts. For the evaluation I used the conceptual framework of Felton et al. (2016), which shows the relationship between potential result of each management strategy, relative to the reference forest state and in this case, Polish biodiversity goals.

3. Results

3.1. Shelterwood and Underplanting

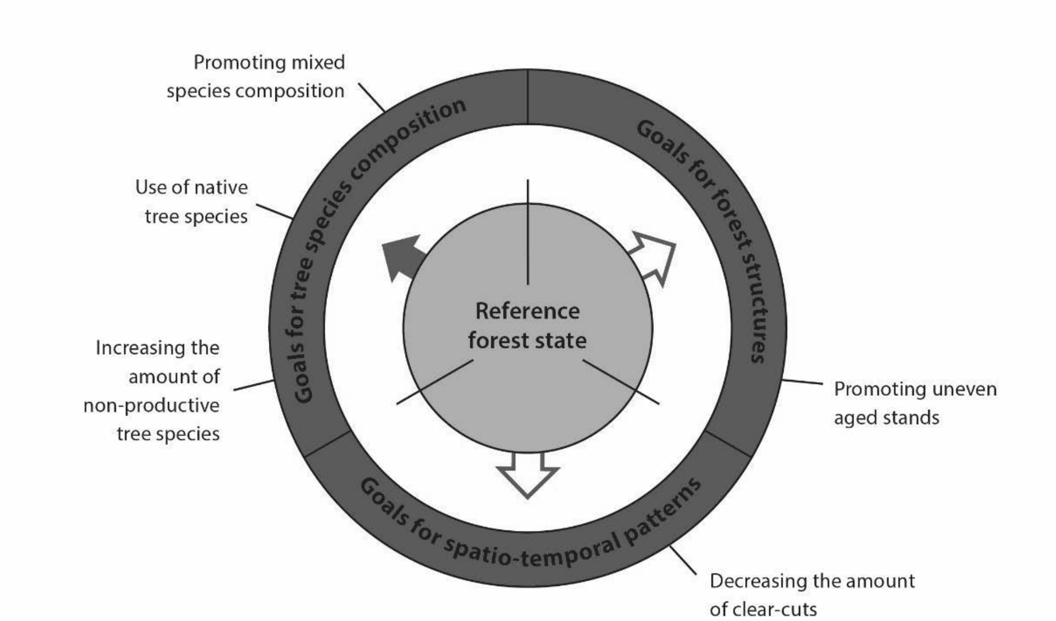

Figure 3. Shelterwood and underplanting

The literature reviewed shows the use of Shelterwood and underplanting has an improvement in tree species composition by promoting mixed species (Ferris 2000, Lust 2001) and increasing the amount of non-productive tree species (IFP, 2012). It also positively modify forest structures by promoting uneven aged stands (Carey 2003). The amount of clear-cuts could be also decreased by those methods (Stefańska-Krzaczek 2012, Carey 2003), thus goals for spatio-temporal patterns are also reached.

Shelterwood method of regeneration is a way to establish the new crop underneath or on the side of the old stand. Then in different variation of the methods the old stand is removed, either at once or in few steps. The establishment of the new generation is mostly done artificially in Poland (as in Underplanting or 'Sobański' method). In some cases the natural regeneration of pine is done under a shelter

(Andrzejczyk & Żybura 2012). The existence of the old stand gives seedlings some protection against frosts and keeps the microclimate in a condition that supports the survival of the new stand, especially in the early stages. As the stand is mostly naturally regenerated the species composition at the place is mostly similar to the one in the old stand, however it helps to illustrates in a more accurate way the local site variation. (Matthews 1991)

Underplanting can be regarded as a method similar to that of shelterwood systems, due to the use of artificial regeneration or planting of the understorey in a stand which is not yet harvested. The underplanting in Scots pine stands would be most likely done with species such as beech or oak, to increase the productivity of the stand and to enrich the stand diversity. By underplanting the deciduous trees underneath a faster growing pine, a stand can be readily stabilized by improving its structure. Moreover, this practice enriches the species mixture of the stand. In Poland underplanting of beech and oak has often been studied (Bernadzki & Andrzejczyk 1983). Planting beech underneath the pine should be done in the early stages of Scots pine stand development, before the first thinning in the existing stand. It is said that this type of underplanting is very good for productivity when done on rich soils, where beech can grow in good conditions (Bernadzki & Andrzejczyk 1983). In the case of underplanting using oak, this should be done on less rich soils, when the pine is around 60 years old and there is enough light in the understory (Aleksandrowicz-Trzcińska *et al.* 2018).

In the reviewed literature most authors suggest that clear-cut management is bad for many elements of biodiversity, especially for species associated with mature and structurally complex forest conditions (Ferris & Pritchard 2001; Carey 2003; Stefańska-Krzaczek 2012). The heterogeneity of forest is reduced when the whole stand is harvested (Carey 2003). In Poland there is however a regulation that enforces the forest manager to leave at least 5% of the old stand (Haze 2012b). Clear-cutting changes the site conditions suddenly, so non-forest species are promoted (Stefańska-Krzaczek 2012) and many forest species, such as e.g. ground beetles, are lost from such stands (Ferris & Pritchard 2001). Impacts are not, of course, restricted to forest beetles. Clear-cut management also promotes ruderal plants. The amount of non-forest and ruderal species increases overall species number and may improve biodiversity numerically, however this change from typical forest conditions does not mean the improvement of forest ecosystem overall, as changes to community composition may involve population declines for many later-successional species (Stefańska-Krzaczek 2012).

Underplanting with deciduous species in pine monocultures will create a mix of species in the forest. As it is known mixed forest stands often have higher levels of biodiversity, which in this case may be driven by the occurrence of those species that are associated with both the occurrence of oak/beech and Scots pine (Lust *et al.* 2001). In this regard, increasing the share of mixed forests is emphasized in most of the biodiversity related acts and regulations. The 11th Decree of General Director of State Forests (Dawidziuk 1995) states that the preferred method of increasing the resistance of forest stands is to use a larger diversity of native tree species. Moreover the complex, mixed species structure of the forest has to be favoured by the foresters (Dawidziuk 1995; PEFC Polska 2012; FSC Polska, 2013). The underplanting of young trees underneath the older stand will also change the age and structural diversity of the stand, which is also consistent with goals for forest structures (*Ustawa o Lasach* 1991; Dawidziuk 1995; PEFC Polska 2012; FSC Polska, 2013). Stands managed in this way will not be clear-cut, which is likewise consistent with goals to decrease clear-cut area throughout Poland (*Ustawa o Lasach* 1991; Dawidziuk 1995; PEFC Polska 2012; FSC Polska, 2013). Underplanting also leads to increased stand structural and age diversity. Heterogeneous forests are likewise associated with more diverse biological communities and provide a higher diversity of habitats compared to even aged monocultures (O'Hara 1998; Ferris & Pritchard 2001; Carey 2003).

As the most common method of regenerating pine stands in Poland is clear-cutting and artificially planting, underplanting and shelterwood methods can be regarded as altering the sylviculture and reducing the environmental impact (Figure 3), by not removing the forest cover and not changing the microclimate.

3.2. 'Sobański' method

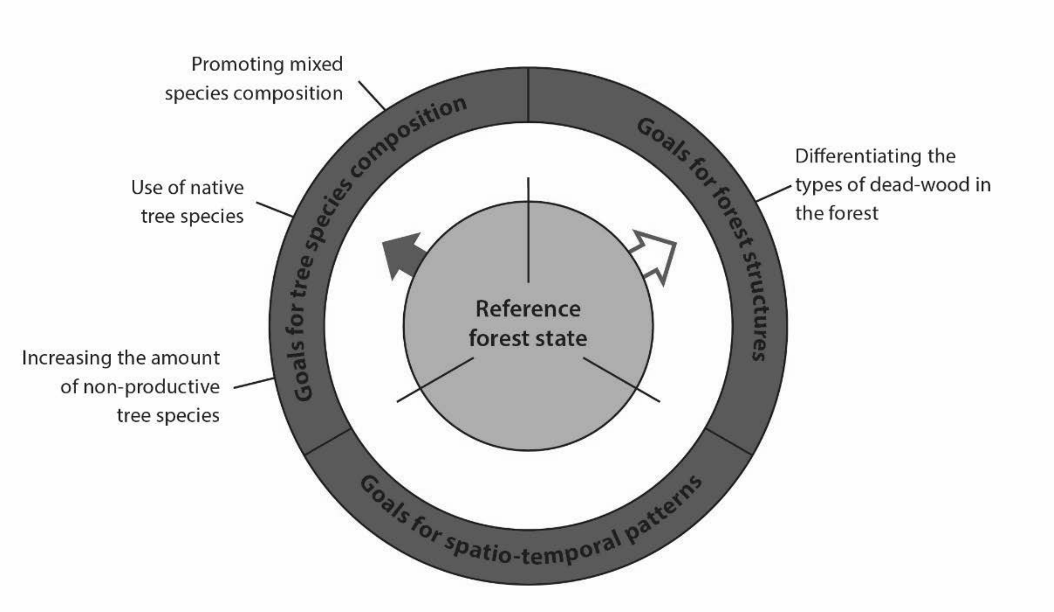

Figure 4. 'Sobański' method

This method is a way to reach the biodiversity goals only from the tree species composition group. However it meets all three of them. In the method it is described to use native broadleaf tree species(Wesoly & Niemiec 2008, Wojciechowski 2014), so the stand which is created should have mixed species composition. Moreover in the method there is mentioned the use of non-productive species to enhance biodiversity (Haze 2012a, Wesoly & Niemiec 2008).

This method was created by the forester Stanisław Sobański in western Poland in the end of twentieth century, to increase biodiversity in the monocultures of pine that were planted after World War II (Kannenberg & Szramka 2008).

On low productivity soils other methods of introducing additional tree species failed, so the method is aimed at seeding the same place using a few different species, and after that planting Pine. Most often it is Scots Pine and hardwood deciduous species, like Oak or Beech. The area is fenced until the trees are from 5 to 6 years old. By planting more trees at the same time and grouping them with a few different tree species, the newly planted stand is more resistant to browsing damages. As the success or failure of the deciduous hardwoods to regenerate reveals local small-scale changes in stand fertility, the method acts as an easy way to increase the stand structural differentiation (Wesoły & Niemiec 2008; Wojciechowski 2014), resulting in more diverse spatio-temporal patterns in the forest.

As a mixed species method of regenerating, The Sobański method favours the achievement of biodiversity goals specifically related to more complex tree species composition (Figure 4). As the normative acts (*Ustawa o Lasach* 1991; Dawidziuk 1995) state, the use of different native species at the stand level is desired. Kint et. al (2006) likewise states that converting Scots pine stands enrichens the ecosystem and acts in favour of biodiversity. According to his paper the self-conversion of pine stands to beech or oak can be expected to happen over longer time scales, and the artificial acceleration of this change acts to speed up the achievement of associated biodiversity benefits. Moreover, this method has been specially created to diversify species mixtures in pine monocultures. Furthermore, as one of the recommended measures to enhance biodiversity is to introduce broadleaves into coniferous monocultures (Lust *et al.* 2001), the 'Sobański' method has the advantage of enabling such biodiversity benefits even on the poor soils of Scots pine stands. If in the mixture of species used in this method we would introduce some non-production tree species (such as cherry, plum and other species which are not broadly used in the industry, but have high biological value) also, then all of three goals in the group are fulfilled. The non-production tree species are meant to be promoted in the national legislation as they provide fruits, nectar and nesting places for many organisms (Wesoły & Niemiec 2008; Haze 2012a). Moreover the differentiation of tree species is affecting the composition of dead-wood in the stand – causing more complex structure of dead-wood (Samuelsson *et al.* 1994; Ciach 2011).

3.3. Natural regeneration

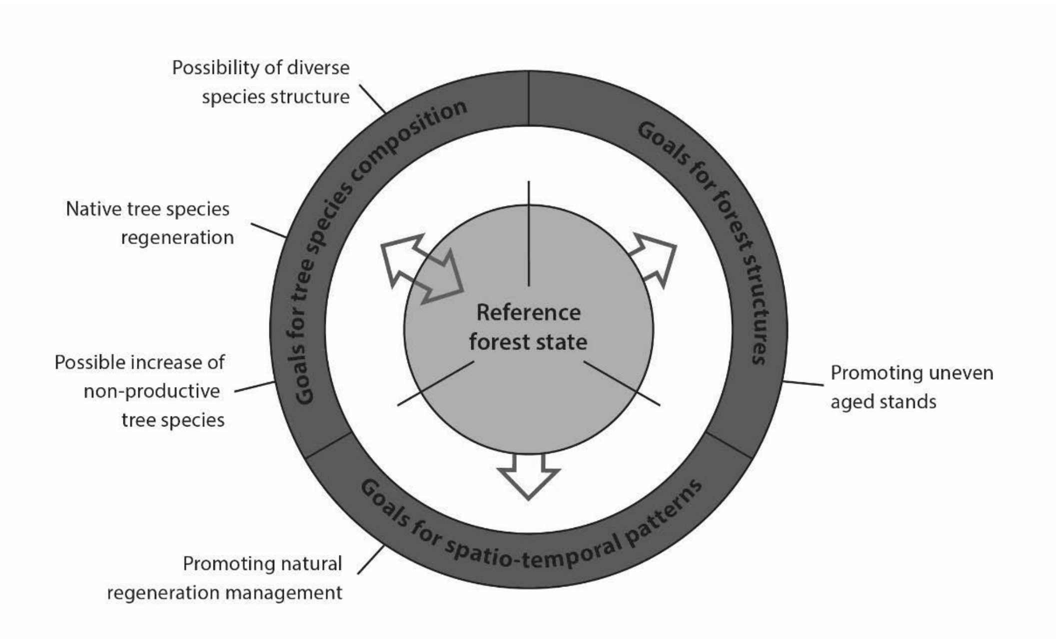

Figure 5. Natural regeneration

Naturally regenerated stands are more likely to have increased amount of non-productive tree species (Lust 2001) and more diverse species structure when the stands are managed in the right way (e.g. The non-native species spreading is blocked). Natural regeneration can be a way of promoting uneven aged stands (O'Hara 1998; Ferris 2000; Lust 2001) – reaching forest structure goal. However, in Poland the natural regeneration management is done on clear-cuts with intensive soil preparation (Andrzejczyk & Żybura 2012), which means the goals are not met in most cases.

Natural regeneration most likely means of shifting from traditional artificially regenerated, clear-cutting method of Pine stands management towards less intensive sylviculture with thinning regime to increase openness of the forest floor and provide light for seedlings. However in Poland the most common use of natural regeneration of pine stands is to clear-cut the area neighbouring the old pine stand, prepare the soil and wait for the seed dispersal (Andrzejczyk & Żybura 2012). This type of approach is not much different in terms of reaching biodiversity goal than the reference forest state management (Figure 5).

As it is mentioned, forest management practices have the potential to have a negative influence on the diversity of species, often via the exclusion from stands of habitat specialists (Stefańska-Krzaczek 2012). Even though the species richness is higher in the managed Pine stands – compared to natural ones– it mostly bases on the common species, whereas the rare ones are not favoured as they are in the more natural stands (Lust *et al.* 2001).

There are many drawbacks for the forest biodiversity mentioned also in connection to soil preparation. Natural regeneration in Poland is also connected with soil preparation and the most intensive preparation is done in clear-cut management and has negative influence on the abundance of typical forest floor invertebrates (Hartley 2002). It also reduces the availability of coarse woody debris, which is essential habitat for many dead-wood dependent species (Stokland *et al.* 2012). As Hartley (2002) mentions minimization of site preparation would serve the biodiversity in many ways, even by saving the residues of native vegetation.

There is a broad expectation to move towards more complex forest management and resign from simple clear-cutting sylviculture type (Dawidziuk 1995; Mason & Alía 2000; Haze 2012b; a). While natural regeneration is mentioned as a guideline for a positive impact on forest biodiversity and mentioned in guidelines for forestry managers in Poland (PEFC Polska 2012; FSC Polska, 2013) the share of naturally regenerated stands in Poland has lowered in recent years (Figure 6).

There is limited evidence that planting and artificial regeneration results in a lowering genetic diversity of forest trees compared to natural regeneration (Lust *et al.* 2001). Moreover in Spain it has been found that the 50-60 years old artificially seeded Pine forests were not different in the floristic composition than the same age naturally regenerated ones (Cañellas *et al.* 2000). This might suggest that by regenerating artificially we have the same potential to move towards species differentiation as in the case of natural regeneration of the same monotypic forest.

Artificial regeneration on clear-cuts can shorten the time period of non-forest microclimate conditions in the stand, compared with naturally regenerated clear-cuts (which are often happening in Poland). Potentially the artificial regeneration might create a better environment for understorey plants regeneration (Stefańska-Krzaczek 2012).

With these thoughts in mind we might rather change from artificial regeneration on clear-cuts to natural regeneration in shelterwood systems without intensive soil preparation and uneven age management (not to clear-cuts with natural regeneration of pine monoculture) to even better conserve the forest microclimate during the regeneration period – i.e. the forest floor would stay under canopy.

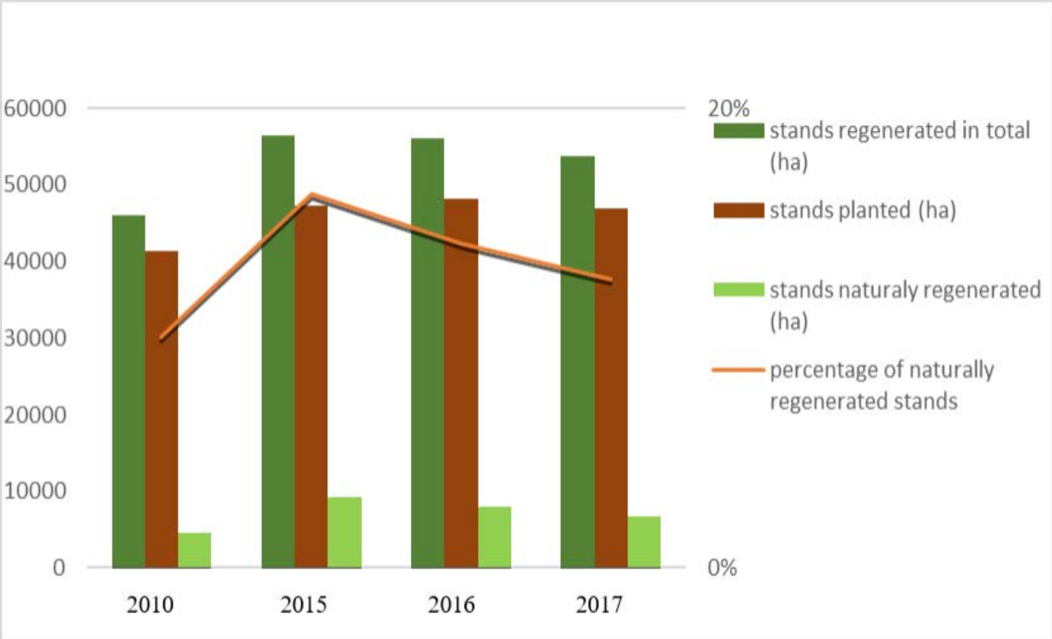

Figure 6: Natural regeneration vs. planting in Poland

Natural regeneration is already being used in Poland, but the FCF project addressing the additional activities in the forest aims at increasing the share of naturally regenerated forests. In the last years the share of naturally regenerated stands has been going down, however it is still higher than in 2010. Still more than 80% of stands are being artificially regenerated. (GUS Departament Rolnictwa 2017)

However, allowing for natural regeneration in the Pine stands might lead to biodiversity enhancement through conversion towards more complex structure and regeneration of other tree species. Seed dispersal of birch can be induced by wind even at very long distances and the heavy seeds from oak and beech are widely spread by birds and rodents. This mixed stands with complex structure occur as an effect of slow, gradual changes and are more naturally distributed in relation to the soil type (Kint *et al.* 2006). As broadleaved forests are associated with more diverse communities of vascular plants in their understory (Barbier *et al.* 2008), this approach would enable a shift towards a higher share of such forest types. Moreover, natural regeneration readily provides for multi-aged stands with a complex structure, which if not overridden by subsequent thinning regimes, can be used to favour biodiversity. The structural type of diversity is encouraged by the naturalness of regeneration. (O'Hara 1998; Ferris & Pritchard 2001; Lust *et al.* 2001)

3.4. Fast-growing tree species

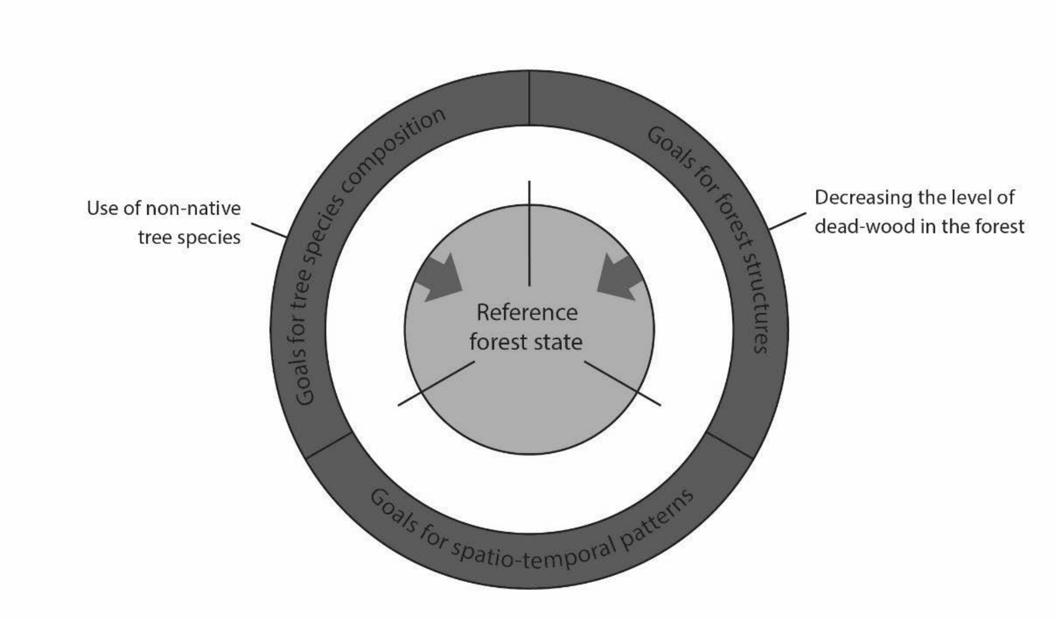

Figure 7. Fast growing tree species

Conversion to Fast Growing Trees has a negative impact on dead wood amounts and is a way of creating single-aged monocultures (Ferranti 2014) – the difference is that the existing monocultures have longer rotation period which allows for more dead wood to be left in the forest. The management is done by clear-cuts and artificial regeneration (the same way as reference forests), so there is no improvement for spatio-temporal patterns goals. As one of tree species composition goals is the use of native tree species – with the use of short rotation hybrid broadleaves the impact would be negative, comparing with the reference forest state (Tullus 2012) and not allowing for non-productive species dispersal (Carnus 2006).

An additional alternative being considered is to use fast growing tree species instead of Pine (for the reference state forest). In practice this would primarily involve using hybrid broadleaves. Hybrid broadleaf species are well studied and are already used in Poland, but not in forestry. In the official recommendations for State Forests, the use of short rotation species is not recommended (Haze 2012b). Instead these species are used as alternatives for typical agriculture. With rotations shorter than 10 years the farmers are getting large amounts of biomass from these stands, and even some pulpwood. For example the GreenWood Resources Company together with International Paper have invested in hybrid aspen plantations in Poland since 2004 (Jabłoński, 2012).

As the use of short rotation hybrid broadleaves is primarily on post-agricultural lands, there is a gap in knowledge about replacing forests with this type of plantations (Lindbladh *et al.* 2014). However, in the literature I have been researching there is much more information about negative correlation between short rotation plantations and biodiversity.

First of all the conversion of the forest stand to such plantations is not allowed by the FSC, as it is considered to result in a degradation of forest habitat (Brockerhoff *et al.* 2008; FSC Polska, 2013). It might be however the "lesser evil", comparing to deforestation, but we will not focus on that in this work.

The most common problem connected to fast growing tree species forestry is reduction of site-level species richness. As the diversity of tree species has a positive influence on the diversity and number of insects (Lindbladh *et al.* 2014), plantations of short rotation trees (mostly monocultures) might not be favourable for these organisms, so the impact in field of tree species composition is neutral. It might be however that at the landscape scale, tree species diversity is favoured. In spite of this, as Brockerhoff et al. (2008) wrote, plants and animals which are typical for old forest may not have the opportunity to settle up in the plantations with comparatively short rotations. Colonization of these habitats might be difficult for poorly dispersed, native plants. Moreover distinct understorey development may be limited in plantations of fast growing tree species, which can lead to poor suitability for wildlife species (Carnus *et al.* 2006). Long term biodiversity can also decline due to a reduction of forest species populations connected to short rotation systems (Tullus *et al.* 2012). Generalist species are not so badly influenced, as are forest specialists. Moreover, Dauber et al. (2010) found out that in most cases the short rotation stands are reported to be colonized by farmland bird communities, rather than forest typical ones. Carnus (2006) also mentions the negative influence of short rotation plantations on the amount of dead wood, which leads to declines of saproxylic beetles.

Impacts on species diversity in the plantations is not only from direct causes. Plantations often consist of non-native tree species that may spread and invade neighbouring stands (Brockerhoff *et al.* 2008), which can cause problems with regeneration of some native species, thus lead to decline in the natural biodiversity. As the gene flow coming from the plantations might be a risk for the native gene diversity (Tullus *et al.* 2012), the use of hybrid tree species might be of risk for the genetic diversity of native tree species. In summary, short rotation plantations should be done with a great care. Hybrid broadleaves are not only clones of native species. For example, hybrid aspen is commonly used in Poland and is a cross between European aspen and the American aspen (Tullus *et al.* 2012). During longer rotations than 8-10 years it can start to pollinate, which makes it highly possible to crossbreed with our native poplar species (Tullus 2012). As in short rotation forestry the hybrid aspen is harvested between 20-30 years after planting, the pollination can occur many times, thus crossbreed with wild populations of European aspen (Tullus *et al.* 2012; Felton *et al.* 2013).

Fast growing tree species are mostly managed with high intensity sylvicultural approaches. Meaning that to establish such a plantation the stand needs to be clear-cut followed by intensive soil preparation. As mentioned before (see chapter 3.3) this can have a negative impact on the abundance of forest floor related invertebrates, eliminate natural ground vegetation, etc. (Hartley 2002). The understorey plants are also highly influenced by clear-cutting, as there is a dramatic change from a forest microclimate to one closer to open spaces (Carnus *et al*. 2006).

3.5. Logging residue removal - “Energy wood yards” (EWY)

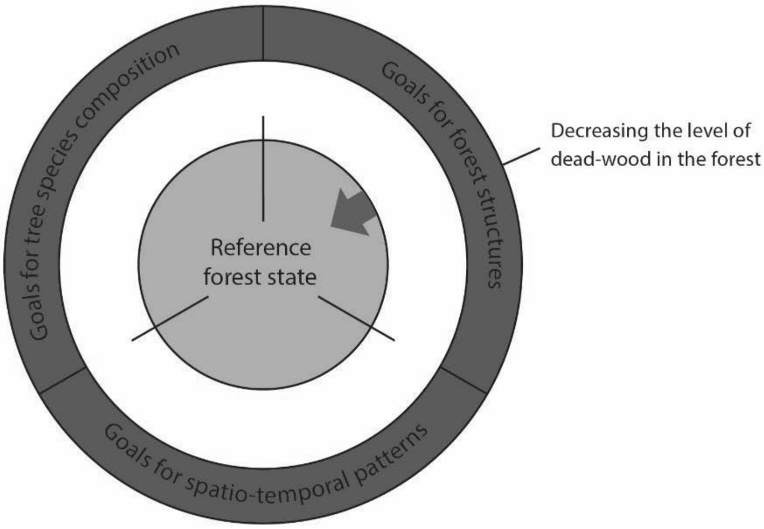

Figure 8. Logging residue removal

“Energy Wood Yards” idea will have a negative impact on the forest structures, as the maintenance of the level of dead wood in all stages of decomposition is not considered. Rest of the goals would be met at the same level as in the baseline forest, as the EWY strategy is not mentioning any changes in sylviculture, species composition, etc.

One of the central ideas of the FCF project which does not alter sylvicultural practices *per se*, is to remove logging residues and fuelwood from the forest and store it in the specially designated areas (Energy Wood Yards). As the storage of material might not have any specific influence on the forest, I evaluated the outcomes of reducing the amount of decomposing wood in the forest, such as snags, branches, etc., which would be removed from the forest stands if EWY is introduced.

Logging residue removal such as stumps snags and branches is broadly discussed in the literature. Many forest species are highly dependent on the amount of deadwood in the forest (Pedroli *et al.* 2013). For example in UK almost 25% of forest species relies on the deadwood (Walmsley & Godbold 2010). This means that the habitat creation potential of logging residues cannot be forgotten. Moreover the EU 2020 3b target for biodiversity protection points out keeping the deadwood in the forest as a measure to protect biological diversity (Ferranti 2014). Polish legislation and normative acts also emphasize the importance of maintaining the substantial amounts of dead wood in the forest (*Ustawa o Lasach* 1991; Haze 2012a; b; PEFC Polska 2012; FSC Polska, 2013). The most common aim of logging residue removal is to extract wood for energy purposes. Trade-offs between biomass extraction and biodiversity thereby exist (Ferranti 2014). European Parliament acknowledges this trade-off by its resolution in which they point out the potential conflict between biomass utilization and biodiversity (European Parliament 2012).

There is significant scientific evidence of a potential negative impact of logging residue removal, though these impacts may not always extend to threatened species (de Jong & Dahlberg 2017).This practice will result in the loss of deadwood and habitat for those species dependent on these structures, such as saproxylic beetles, soil fauna and some plant species and even birds (Ferris & Pritchard 2001; Jonsell 2007; Walmsley & Godbold 2010; Pedroli *et al.* 2013; de Jong & Dahlberg 2017; Ranius *et al.* 2018). It is important to leave substantial amount of large pieces of deadwood and stumps as they are creating the most significant habitat on the harvested sites as large wood is decomposing slower and providing habitat for longer periods of time (Walmsley & Godbold 2010). Importantly, it is not only the large pieces of deadwood that might play a significant role in habitat provision for biodiversity. Piles of branches might act as physical shelter for many ground living organisms or rodents or even a protection from extreme dry and hot microclimate occurring on clear-cut areas. (Jonsell 2007). Moreover the decaying piles of wood can provide valuable nutrition to the ground and support ground living invertebrates and vegetation (Jonsell 2007; Walmsley & Godbold 2010; Ranius *et al.* 2018). Due to loss of nutrients from the slash removal the biomass production itself can also be threatened (Ranius *et al.* 2018). Overall, the removal of logging residues might favour generalist species, not dependent on the deadwood, while some specialist deadwood dependent species might decline. With an increased extraction of deadwood, simulations showed that the decline of rare species accelerates more than the common ones. Extraction of large amounts of logging residues might lead to creation of new red listed species. (de Jong & Dahlberg 2017)

However, the additional impact on biodiversity of logging residue removal compared to the clear-cuts may not be considered high. Most of the species declines already occur because of clear-felling, with few additional loses due specifically to slash harvesting (de Jong & Dahlberg 2017). That said, these two approaches can be used in combination, with logging residue removal increasing the biodiversity impacts associated with clear-cutting.

4. Discussion

The CCAMS which were evaluated in this paper are the official strategies to mitigate carbon dioxide emissions as considered by the Forest Carbon Farms program. Some of the strategies were not affecting the sylvicultural practices, and therefore I have selected 6 of them which involve changes to forest management.

In my review of the literature I found similarities between two groups of CCAMS. There is no direct pathway in the literature, which strategies are biodiversity positive and which are not favouring the biodiversity goals. Resulting in no straightforward CC mitigation or adaptation guideline for the forest managers in Poland. One way of defining such a guideline is to compare the possible result of each strategy with the defined goals for biodiversity protection, using standard sylvicultural practice as a baseline to contrast with.

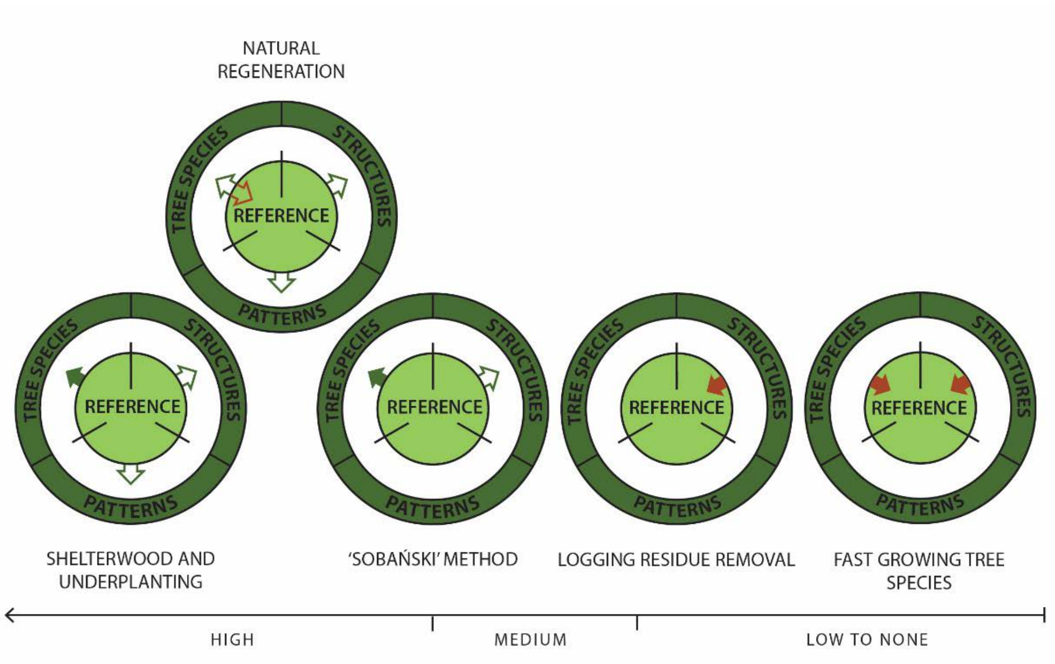

Figure 9. Consistency with biodiversity goals

The CCAMS are classified by their consistency with biodiversity goals - from left to right (with a decrease). Scheme of the classification is based on the paper by Felton et al. (2016)

Comparing the results of the literature review I classified the CCAMS from the Forest Carbon Farms Project. The most likely to be biodiversity positive are those which comply on almost all points with the biodiversity goals defined in the national legislation and in the standards (Figure 9). I found that shelterwood systems and underplanting are the ones most consistent with these goals, if managed correctly, i.e. allowing for spread of non-production trees and other plant species. The use of mixed species is of high importance in biodiversity goals, mentioned in all of the Polish legislative documents and standards (*Ustawa o Lasach* 1991; *Ustawa o Ochronie Przyrody* 2004; Dawidziuk 1995; Haze 2012b; a; PEFC Polska 2012; FSC Polska, 2013). Shelterwood systems minimized the impact from clear-cuts and in many cases from soil preparation (Stefańska-Krzaczek 2012), which puts them in line with the biodiversity goals for forest structures. Both of these two CCAMS increase the mixture of tree species and result in more diverse forest stands, both from the perspective of species composition, as well as age structure (Lust *et al.* 2001; Kint *et al.* 2006).

In the middle there is a group of CCAMS that I conclude are likely to positively affect biodiversity goals. Natural regeneration, which is commonly applied in Poland, involving clear-cut management with soil preparation (Andrzejczyk & Żybura 2012), is not very different with respect to reaching biodiversity goals than typical forest management. Notably, natural regeneration appears to be a central aim for the Polish State Forest, as it is mentioned through all the documents and standards. I found it surprising that natural regeneration is itself not the most consistent with biodiversity goals for Poland of the CCAMS assessed. 'Sobański' method favours mixed species composition and increased the use of non-production tree species (Ferris & Pritchard 2001; Carey 2003). This technique has some positive influence on forest patterns and structures, as it promotes uneven-aged stands (Ferris & Pritchard 2001; Carey 2003; Spathelf & Ammer 2015). For the places where shelterwood systems are not an option, the 'Sobański' method may be a beneficial alternative.

"Energy Wood Yards" did not result in a large change from standard forest management, but nevertheless remains contrary to some biodiversity goals (Figure 8). The main strategy in scope of this CCAMS is to take out the logging residues from the forest stands (Krzewina 2017; Tomaszewski 2017). Meaning that the actual type of the forest would not be influenced – no impact on the forest patterns and tree species composition. However the amount of deadwood left in the forest for decomposition will be lowered and the organisms associated with decaying wood can be expected to decrease (Carey 2003; Pedroli *et al.* 2013; Ferranti 2014).

The least positive in scope of the biodiversity goals is the introduction of fast-growing tree species (Figure 7). This practice had no discernible positive outcome in relation to forest spatio-temporal patterns, as it is most likely managed in the same way as the reference forest. The management of fast-growing tree species is also based on clear-cuts and artificial regeneration, resulting in a monoculture. However it can have direct negative impacts on the tree species composition, as usually the trees used are non-native hybrids (Brockerhoff *et al.* 2008). It is also not positive for the mixed species composition, as the short-rotation management is too intensive to allow for the establishment of tree species other than those planted.

Bearing in mind all these results, it could be suggested that the best way to adapt and mitigate to climate change in scope of the FCF Project would be to focus on shelterwood system with minimized site preparation. However, the forest manager should take into consideration other risks, such as browsing damages production loss, increased harvesting cots, etc. With the inclusion of those risks, not all forest stands might be suitable to implement shelterwood management regimes. Fortunately, State Forests managers might have the possibility to implement CCAMS consistent with biodiversity goals, in at least at some parts of the production forest area, as the economic and browsing risks can be spread more than in the case of the private forest owner. In most cases the forest manager is obliged by legislation and standards to shift towards more biodiversity positive management. This means that CCAMS which negatively affecting forest biodiversity are not the only alternatives on offer, especially when implementing new projects, such as Forest Carbon Farms.

4.1. Caveats

Ideally, my evaluation, or something akin to it, should have been made prior to implementing management strategies in the Forest Carbon Farms project. When I have looked for papers to write the thesis, I found no scientific research, nor any article which was written on request of State Forests to justify for inclusion all of the CCAMS proposed by FCF. By evaluating such projects before their implementation, we could be more precise with channelling the funds and resources for better biodiversity protection or climate change mitigation and adaptation. My work is not fully analysing every aspect of the FCF strategies, however it might be a good point to start discussion about the expected outcomes of this particular project promoted by Polish State Forests.

The limited availability of polish literature evaluating CCAMS has also made it harder to adequately address this topic. I often had to use literature from boreal or

Mediterranean regions and assume that the results would be similar in the case of pine forests within Polish biogeographical regions. Moreover, the impacts on biodiversity from different sylvicultural methods are often not the primary focus of the articles or books that are available. To find out if the literature is relevant for my study, I had to go through many papers that were of limited relevance to my focus.

5. Conclusions

Climate change adaptation and mitigation is an important concern in current forest management. However, some of the CCAMS evaluated in this work seems to reduce the chance for Poland to meet its biodiversity goals, as stated in legislation and other standards. As my results indicate, the implementation of some of these strategies is likely to cause negative impacts on the availability of suitable habitat for forest in Poland. While adopting the CCAMS mentioned in FCF project into the forest management plans we should consider:

1. The use of those CCAMS which are consistent with the majority of key facets of biodiversity goals, e.g. shelterwood systems
2. Reducing the negative impact on biodiversity goals of the CCAMS we use, e.g. promote natural regeneration under shelter and with less intensive site preparation
3. Diversify CCAMS at the landscape scale, to provide habitats for the species which might be negatively influenced by the use of some individual CCAMS

I think that there is a large need to further investigate the impact of management practises on biodiversity, as during literature review, I found very few articles and books addressing the subject. The biodiversity issue is raised in many legislative documents and standards but is only a small part of the management strategies implemented in the State Forests. In my opinion the forest managers should have clear information on how to promote biodiversity and habitat for rare species while managing productive forests or implementing CCAMS included in the FCF project. However other impacts of CCAMS should be also taken into consideration. The proposed use of strategies is only relevant if all of them are at the same level reaching the main targets of the FCF project, which is increased CO^2 sequestration in Polish forests. Moreover, some of the strategies might be better for reducing browsing damages or pests' outbreaks, etc., while being less consistent with biodiversity goals. Thus, we cannot determine that the CCAMS which are best for biodiversity goals as shelterwood systems are indisputably the best for the forest manager to be used.

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