

Forest Sustainability: A Force to Recon with in the Phase of Global Environmental Challenges

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Abstract: We live in a moment where so many unimaginable things are happening simultaneously. The most natural formation in our climatic and geological zone today is the forests. They are vital component of ecological stability, continuity of life, landscape, and balance of impurities, subsequently checking ecological dilapidation. Forests, as a type of land use, permit biological production with a market worth and assist with shaping the quality of human life and existence. Poland's timber assets have been consistently expanding, their volume remains at 2.5 billion m³ of gross merchantable lumber. Toward the finish of 2010, Poland's woodland cover estimated by the global appraisal standard added up to 30.4% and was below the European normal (32.2%, except the Russian Organization). Over the years, forests covered practically the entire area of Poland. Due to socio-economic development, however, the forest cover remained at 40% toward the end of the 18th century but dropped to 20.8% by 1945. This cycle was switched during 1945-1970 when nearly a million hectares of land was afforested, which expanded the forest cover to 27.0%. The figure has since then been fluctuating, at the end of 2014 forest area covered 30.7% and today, it 31%. This review evaluates the state of Polish forests in the past, present and suggests a strategy for the way forward through diverse means of sustainable management.

Keywords: Forest Cover, Management, Polish Forest, Plantation, Structure

1. Introduction

Forest plantations over the decades has been reported to provide an array of benefits, these includes; the provision of carbon sequestration [1], carbon storage [2], ecosystem functionality [3], counterweighing continuing deforestation and degradation [4], promoting efficient nutrient cycling, increasing plant species diversity and community structure, and preventing soil erosion [5]. Forested regions manage streamflow and alter the overflow [6], and increase soil water retention [7]. The advantages of establishing forests and maintaining reforestation after timber harvesting are extremely important to meet the increasing demands for timber as it reduces deforestation and strengthens local ecosystem functions. Production of tree seedlings and establishment of new forests (afforestation) are common restoration strategies often successful in fast-tracking forest recovery either through the natural or artificial renewal of a

diversity of forest tree species.

In this period of continuous global change, a central issue confronting ecologists is to decide the degree to which the modification of ecological circumstances will influence the structure and dynamics of the plant community [8-10]. Varieties in temperature, rainfall patterns, biogeochemical cycles and land use have previously been recorded overall and are anticipated to escalate in future [11]. These progressions involve the concurrent change in the normal levels and spatio-transient fluctuation of the essential resource for plant recovery, principally light, water and nutrients. Forests are significant for such countless reasons, they give living space to wildlife, and their seeds are a significant source of food for wildlife species. Since they can grow to old age, forests give lasting protection to soil against from erosion. Many tree species like pine (*Pinus* spp.) or larch (*Larix* spp.) can serve as a caretaker crop for more youthful seedlings of intolerant tree species, for example, beech, fir, but also, to some extent, spruce, oak, ash, and

maple, which fill well temporarily in their shade, consequently accommodating the continuation of forest cover as the upper layer of the forest die or be harvested.

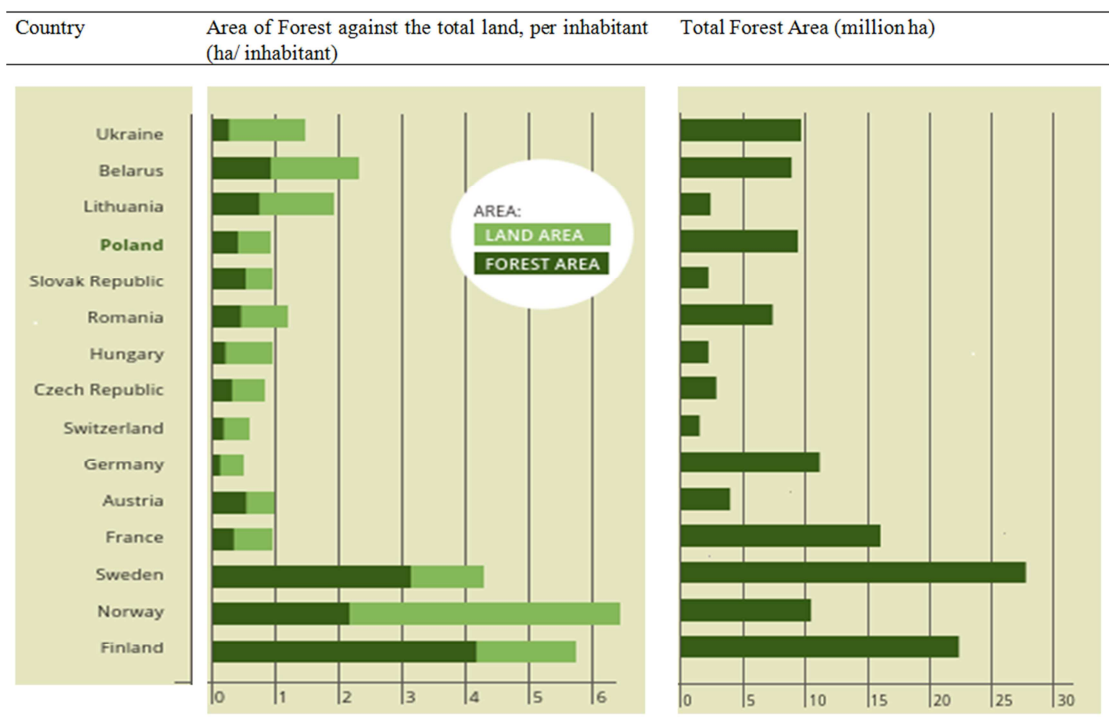
Lastly, since forest attracts wildlife, it beautiful in all seasons and represents life support in gas exchange and carbon fixation, forest therefore appeal to global ecological balance and it is therefore paramount and ideal to have them. Like other Nations of the world especially in Europe, Poland stands a major role in increasing more of it land area to be under forest cover. Although, a lot has been done over the years to achieve 31%, yet a lot more is to be done. Therefore this review evaluated the past, present and better prospects of the Polish forest through the adoption of sustainable forest management.

2. Forest Area in Poland

In Europe like other continents of the world, Forests are the most un-distorted natural establishment. They are an important component of ecological balance and simultaneously, a type of land use which guarantees biological production with market

esteem. Forest is of significant benefit to everyone as it upgrades the nature of human existence. The total area of forests in Poland is 9197.9 thousand hectares, which puts forest cover at 29.4% in 2004. Poland is among the nations with the largest forest area in central Europe, after France, Germany and Ukraine (Figure 1).

Toward the end of the year 2010, Poland's forest cover estimated by the worldwide evaluation standard added up to 30.4% and was below the European average 32.2% (excluding of the Russian Federation). A similar but reduced figure was determined toward the end of the year 2014 when it was 30.7%. A relation of forest area per capita in Europe with a general land area plainly shows that these values are higher in nations with more modest populations. The forest area per capita in Poland (0.24 ha) is one of the least in the region. In the past, forests covered practically the entire area of Poland. Because of socio-economic development, the forest covers, remained at 40% toward the end of the 18th century and dropped to 20.8% by 1945. This cycle was switched during 1945-1970 when nearly a million hectares of land were afforested, which expanded the forest cover to 27.0%.



Source [12]

Figure 1. Nations with largest forest area in central Europe.

2.1. State of Polish Forest

The forest area in Poland in 2020 was 94,830 km² addressing 30.97%. Forest area of Poland expanded from 90,860 km² in 2001 (29.66%) to 94,830 km² in 2020 (30.97%) [13]. In 2014 the area of post-agricultural land and wasteland afforested under the "National Program for the Augmentation of Forest Cover", which as at then, accepts the expansion in forest cover to 30% by 2020 and 33% by 2050, diminished

again in relation with the earlier years. The all-out area of afforestation was 3.8 thousand hectares (4.1 thousand hectares in 2013 and 4.9 thousand hectares in 2012). 37 662 thousand m³ of net merchantable timber was harvested in Poland in 2014, of which 35 686 thousand m³ came from the State Forests (102.8% of the volume of estimated yearly endorsed cut). The forest area where clear-cuts were used was restricted to 26.6 thousand hectares and wood harvested from clear-cut to 6515 thousand m³ of merchantable timber

(18.3% of the complete harvest). Harvesting of timber resources in the State Forests remained at 53% of the volume increment in 2014. The health of forests in Poland, evaluated base on defoliation of tree crowns, stayed at the level reported in 2013. The portion of damaged trees with overabundance defoliation of 25% and defoliation classes 2-4 remained at 18.9% in 2013. However, the portion of sound trees reduced from 13.7% in 2013 to 11.6% in 2014. This looks simple, but exceptionally critical and should as a matter of urgency be tackled. The primary obligation regarding modifying forest lands and keeping up with them healthy and proper design falls on the State Forests. In 2014 renewal of forest stands was completed on an area of 7.7 thousand hectares, cleaning on 135.7 thousand hectares and thinning

on 311.0 thousand hectares. Also, the quality of stands was supported by the introduction of the understory [12].

Biologically, the acts of the most damaging essential insect pest significantly lessened in 2014 by 71%. This set of pest arose in 122.1 thousand hectares of the State forests region and the control treatment covered an area of 38.8 thousand hectares. The danger to forests from secondary insect pest expanded by 27% in correlation with the earlier year. The region impacted by infectious fungal diseases diminished by almost 27% in 2014 and added up to 208.3 thousand hectares. Harm to forests was additionally brought about by herbivore warm blooded animals, basically red deer, roe deer and elk, and locally by rodents significantly beavers and mice [14].

Table 1. Summary of the state of forest and forest product in Poland 1990-2020.

SN	Values	Year						Unit
		1990	2000	2005	2010	2015	2020	
1a	Ownership of forest (Public)	7406	7535	7610	7661	7606.1	7609.5	Forest [1000 ha]
1b	Ownership of forest (Private)	1475	1524	1590	1658	1698.0	1785.7	Forest [1000 ha]
2	Change in extent of forest	8881	9059	9200	9319	9420	9464	Area [1000 ha]
3	Change in forest area available for timber supply	8323	8342	8417	8532	9214	9260	Area [1000 ha]
4	Felling on forest available for timber supply	24814	31389	38316	40693	40247	39674	Felling (1000 m ³)
5	Carbon stock on forest (Biomass)	467	546	648	767	826	886	million tonnes
6a	Area of damage to forests (Insects & disease)	197.0	194.0	167.0	384.0	172.5	192.72	1000 ha
6b	Area of damage to forests (Wildlife & grazing)	-	-	61.0	620.6	686.3	513.9	1000 ha
6c	Area of damage to forests (Storm, wind, snow)	-	-	248.0	568.6	510.7	604.9	1000 ha
6d	Area of damage to forests (Fires)	5587.0	7994.0	11038.0	2126.0	5510.0	8417.0	1000 ha
7a	Quantity and value of total roundwood removals	22601	27483	33506	35281	35.500	41.400	Volume [1000 m ³]
7b	Quantity and value of total roundwood removals	448	833	1046	1291	2709	3588	Value [million €]
8	Forest area subjected to protection	-	-	11	13	54	86	1000 ha
9	Natural regeneration and natural expansion	370	414	433	448	-	-	Forest area [1000 ha]
10	Afforestation and regeneration by coppice	8511	8645	8767	8871	54660	64180	Forest area [1000 ha]
11	Area managed for in situ gene conservation	-	4737	-	6071	-	-	[ha]
12	Area managed for ex situ gene conservation	13331	16028	-	16516	-	-	[ha]
13	Area of forest protected, according	30	51	54	55	86	54	Forest area [1000 ha]
15	Import of forest products (volume)	0.8	7.9	14.8	17.9 (5.6)	-	8 599.8	Million m ³ RWE, (%ARC)
16	Exports of forest products (volume)	0.8	7.9 (13.4)	14.8	17.9 (5.6)	26.6	4602 (3.21)	Million m ³ RWE (% ARC)
17	Contribution of forest sector to GVA	-	648 (0.4)	676 (0.3)	994 (0.3)	5240	-	million Euro/ECU (% of total GVA)
18	Consumption of forest products	410	634 (5.6)	924 (7.8)	1064 (4.1)	-	-	m ³ RWE/1000 inhabitants (ARC [%])

Source: [12, 15].

NAI: Net Annual Increment, GVA: Gross Value Added, ARC: Annual Rate of Change, RWE roundwood equivalent

2.2. Contribution of Forest and Forest Products to Poland Economy

Poland's forestry and raw material resources are significant not only in national but also on an international scale. Its enormous area of forest was rated 7th among EU nations, its rich raw material base was ranked 4th and a huge volume of wood production ranked 5th in the EU. These and more put Poland among the significant makers of the European, additionally the world wood market. When it comes to furniture production (Figure 2), Poland is one of the world's leaders (6th position in the world and 3rd in Europe) and wood-based panel production (7th largest global producer and 2nd European). The production capability of the forestry-wood sector likewise permits compelling extension on the global market sectors. Poland's furniture export represents 6% of the

world's furniture export (4th on the World and 3rd in the EU). In Europe, Poland is a significant exporter of fiberboard with over 730, 000 m² in 2018, primarily wet-process porous board (Figure 5). The wood sector, (wood processing-based industries), is also a significant component of the Polish economy with a 2% portion of the Gross domestic product, 3.3% of the international production of Poland, and 2.2% of gross added value. Frequently called a driver of Poland's economic development addresses 35% of business creation, 49% of work, and 41% of the business unit. The wood sector represents over 62,000 business, fundamentally little and very few wood companies (92% - particularly in the sawmilling and furniture industry), produces 9% of the worth of commercial production and create 12% of the job in the forest industry [16]. The production of particle boards, fibre boards and also paper and paper board has extensively contributed (in thousand per

tons) to the Polish economy as shown in Figure 3. According to the report of GUS [15] in no little measure has non wood

forest products, particle and fibre boards, pulp and paper products has also contribute to Poland GDP (Figures 3 and 5).

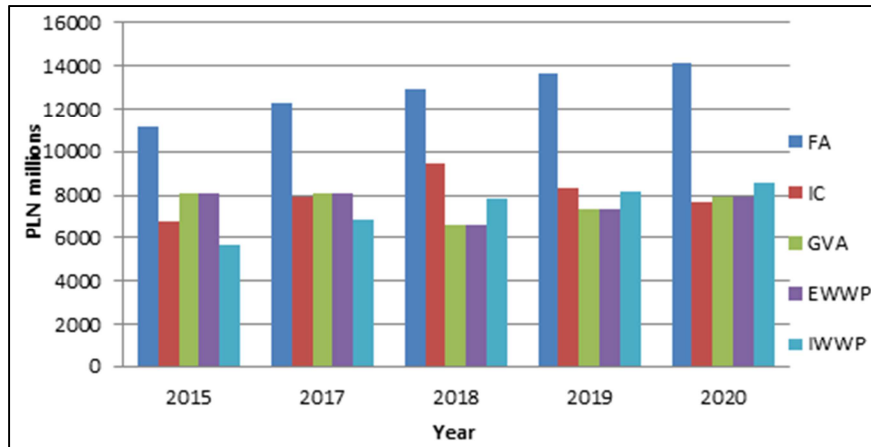
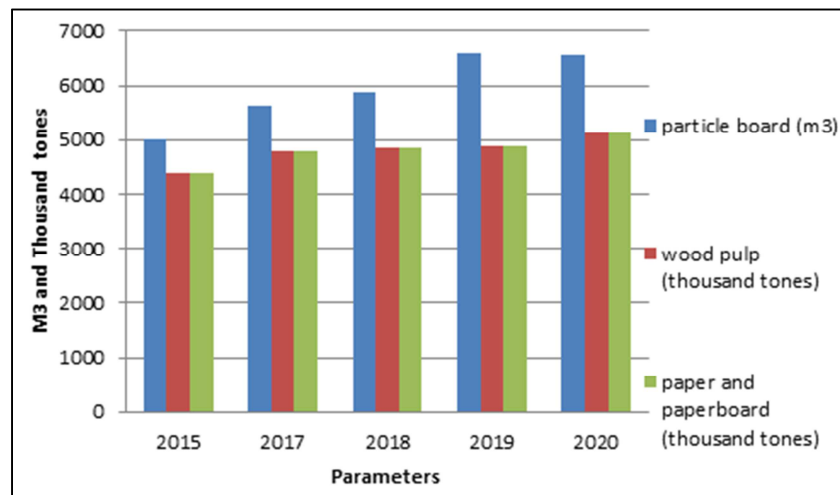


Figure 2. Consumption and exports.

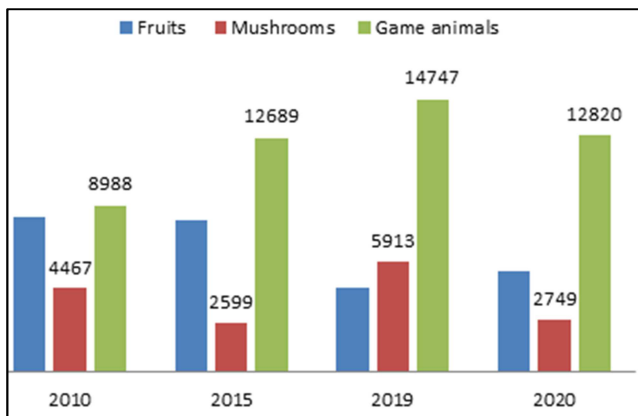
Note: AWP= average wood prices per (1 m³ in PLN), FA= Fixed assets, IC= Intermediate consumption, GVA= Gross value added, EWWP= Exports of wood and Wood products, IWWP= Import of wood and wood products

Source: [15]



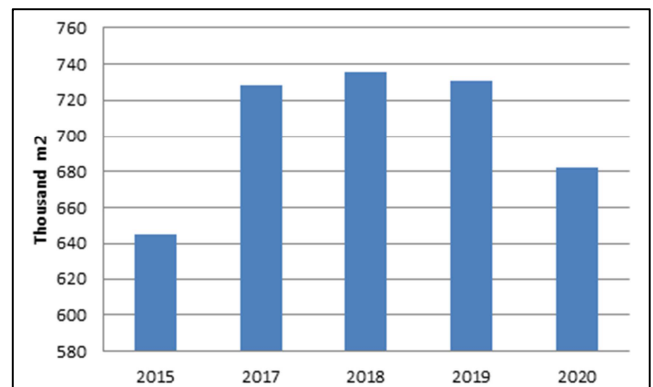
Source: [15]

Figure 3. Wood waste and paper products.



Source: [15]

Figure 4. Non Timber Forest Products (tones).



Source: [15]

Figure 5. Fiberboards (thousand m²).

3. Threats and Disturbances of Forests in Poland

There is no doubt that changes in forest disturbances over the years have had strong impacts on forests in Poland. Polish forests are progressively more defenseless against the impacts of abiotic factors, which frequently cause serious calamities. This, in addition to acquaintance with insect pests, fungi pathogens and wild animals, threatens the sustainability of the Polish forests. The recently documented changes in climate that result in dynamic (or possibly catastrophic), climate phenomena (droughts seasons, floods, storms) meaningfully affect the health and condition of forest stands, as well as populations of destructive pests. Over the years, the forester's triers to expand the sustainability of forest has predominantly experienced the revamping of stands to coordinate them with the environmental conditions in a manner that doesn't necessarily forestall harm, particularly when confronted with erratic weather patterns.

A study carried out by Szmyt and Dobrowolska [14] on spatial diversity of forest regeneration in Szast protected forest of ages 43-104 years after catastrophic wind, reported the occurrence of irregular organization of young growth. Despite the fact that bunches of recovery were seen less significantly in all portion of the forest, nonetheless, species variety was reported to be moderate and was the highest in the marginally or seriously disturb stands. In their study, scots pine formed homogenous collection of recovery and oaks were mixed among other tree species.

The plots of the experiment was divided into; Slightly disturbed (less than 10% of the trees showed visible damage), Moderately disturbed (11-50% of the trees in stands showed visible damage) Severely disturbed - removed wood (Sr) (over 90% of the trees were damaged and logged) and Severely disturbed - left wood (Sl) (stands with timber left on the ground). It was reported that the seedlings of scots pine (*Pinus sylvestris* L.) which grows through natural regeneration dominated in the moderately disturbed stands (Mo). The most reduced level of pine seedlings was seen in the seriously disturbed stands (Sl). The seedlings of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* L. Karst) were reported to be tracked found in the slightly disturbed stand (Se). Young developing silver birch (*Betula pendula* Roth) was missing in the seriously disturbed stand. Oak (*Quercus robur* L.) seedlings were the main in the slightly and severely disturbed stands unlogged wood. In the evaluation of the sapling growth stage, Scots pine was again reported to be the dominant tree species in the moderately disturbed stands. Additionally, the percentage of pine saplings was high in the severely disturbed stands having unlogged wood. Birch overwhelmed in the severely disturbed stands with logged wood. The level of oak was highest in the severely disturbed stands without reclaimed logging. Saplings of spruce were discovered in the entirety of their examined stands with the highest rate in the slightly disturbed forests [14].

3.1. Trend of Forest Change in Poland

According to the land records, forest area in Poland has increased by 504 thousand hectares since 1991. In 2014, Poland's forest area increased by 21 thousand hectares, which was far greater than in earlier years with earlier years. The reason for all afforestation in Poland is the "National Program for the Augmentation of Forest Cover", prepared by the Forest Research Institute and suggested for execution by the Council of Ministers in 1995 (the program was modified in 2002). Starting around 2014, it was estimated that by 2020, forest cover in Poland will be 30% and 33% by 2050 to guarantee an ideal spatial and progressive distribution of afforestation. Forest area from that point forward started to increase at a typical yearly pace of 0.23% (Figure 6). As at 2020, the forest area for Poland was 94,830 km² (30.97%). Forest area expanded from 90,860 km² in 2001 (29.66%) to 94,830 km² in 2020 (30.97%) [13]. This practical action of afforestation program by the Forestry Research has in the last 3 decades, keep a perpetual increase in the area covered by forest in Poland this area ranges from 29.0km² in the year 1990 to 29.58km² in 2000. The increase trend continued to 30.46 km² in 2010 and 30.97km² in 2020 (Figure 6).

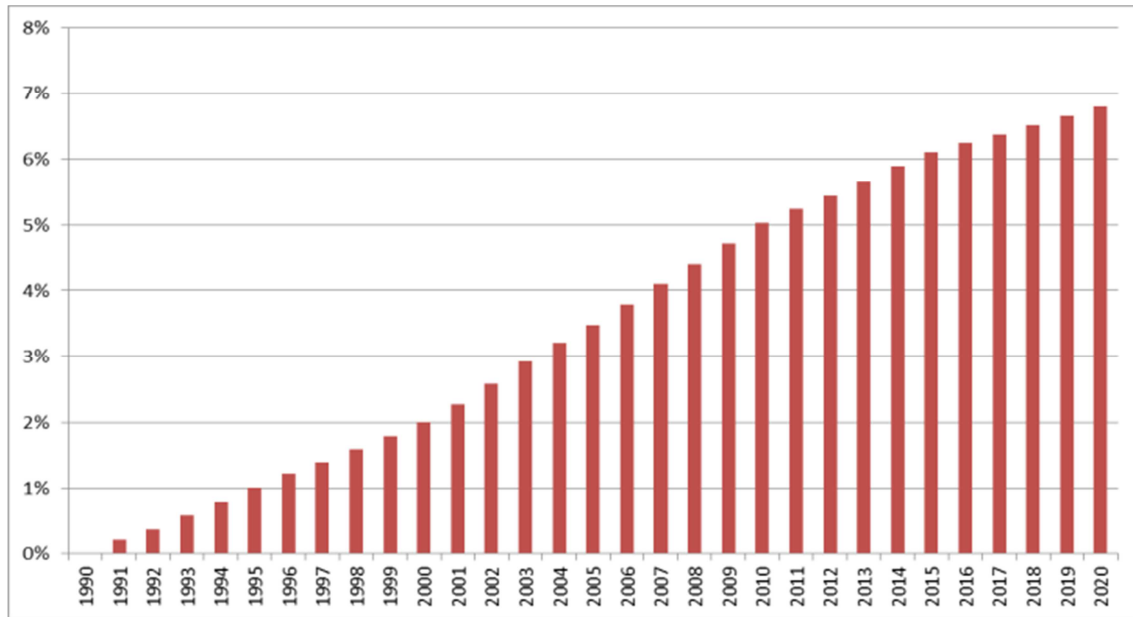
3.2. Structural Determination and Habitation of Forests in Poland

Forests in Poland essentially occur in regions with the poorest soils, which determine the structure and habitat and type of the forest environment. Between 1945-2014 the species structure of Poland's forests changed significantly, which is obvious in the expanded portion of stands with a commonness of broadleaved tree species. In the State Forests, where these progressions are checked every year, the increment of broadleaved species share changed from 13% to 23.4%. The wood stand mature from 60 to 100 years has happened most often in Poland, and the typical rotation of forest stands is 80-100 years. Generally, in terms of forest area, coniferous forest habitats predominate, accounting for 51% of the total forest area, while broadleaved habitats account for 49%. In state forests, in any case, coniferous species dominate, representing 68.7% of the total forest area. In the lowland and upland regions, the most common species is pine. It accounts for 64.3% of the forest area in the State Forests Holding and 57.7% in private and community-owned forests. In the mountains, it is spruce that dominates (western part) while both spruce and beech are more common in the eastern part of the region. The present domination of pine specie in the Polish forest is the consequence of past forest management practices and the occurrence of coniferous forest habitats as shown on Figure 7 [13].

The portion of other tree species, most of which are broadleaved, develops steadily. Reports has shown that foresters are not engaged in monoculture establishment any longer in all forest habitats, rather they change the species composition of stands to that growing naturally in a specific region and habitat. Hence the area of broadleaved species remains in the State Forests expanded from 13% to over

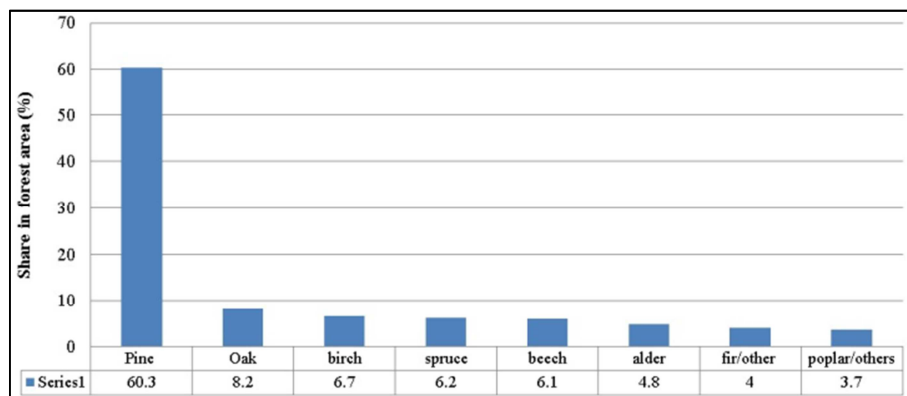
28.2% in the period 1945-2014. The more abundant tree species are oak, birch, beech, alder, maple, sycamore, elm (Figure 8) yet additionally poplar, hornbeam, aspen, linden

and willow. Fir and other conifers cover 4% while poplar and other broadleaved species cover 3.7% as shown in (Figure 9) [13].



Source: [13]

Figure 6. Percentage trend of forest area increase in Poland from 1990-2020.



Source: [13]

Figure 7. Dominant tree species in the Polish forests.

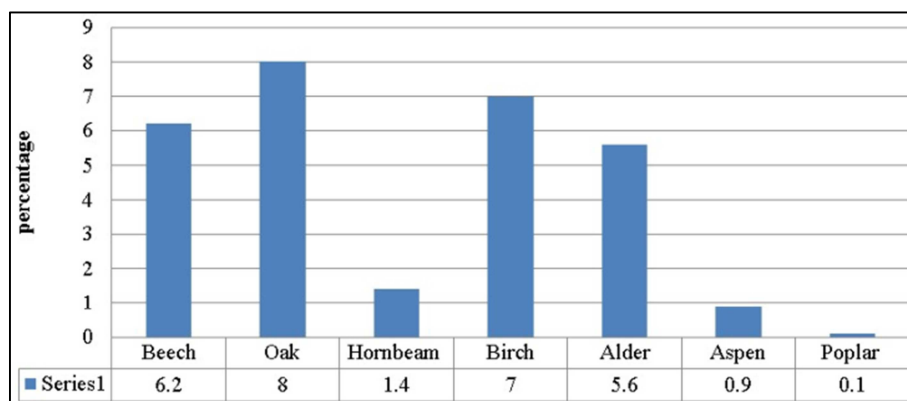


Figure 8. Species structure of tree stands in the Polish forests (broadleaves covers 31.7%).

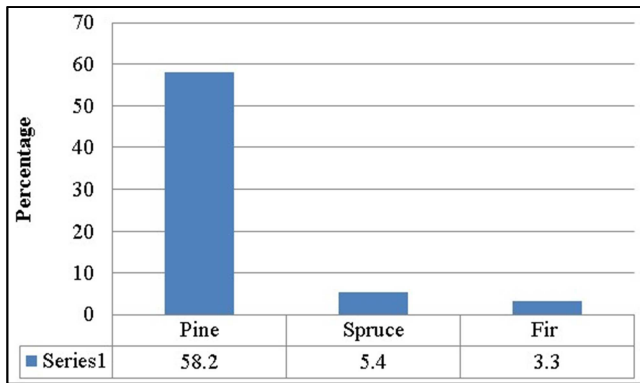


Figure 9. Species structure of tree stands in the Polish forests (Conifers covers 68.3). Source: [13]

4. Prospect Amidst All Odds

After identifying different forest disturbances and challenges that have led to a drastic reduction in forest area, the most important question is how to reduce the calamity risk and accelerate forest restoration despite the increasingly high demand for forest and forest products in the 21st century. The demand is so high that timber has been identified as the main material for structural works of the century. Obviously, the demand for consumption cannot be denied, yet, consumption should not lead to desolation. What then can we do moving forward?

4.1. Sustainable Forest Management: A Strategy for Way-Forward

Over the years, there have been different definitions by deferent persons and group on SFM. In respects, the real concept of SFM is that the approach is dynamic and progressive that maintains the Production, Protection and Recreation functions of every forests in a manner that satisfy the now generation without jeopardizing the same perfect functions to the future generation. The fact still remains that when the forests and trees are managed in a sustainable manner, fundamental support are render not only to man but the planet at large, To manage the forest in a sustainable manner is to maximize the advantages to meet societal need in a manner that maintains and conserve our treasured ecological system.

Generally, the silvicultural measures after natural disturbances include retrieving, logging and replanting the cleared forest area. In the high mountain zone, replanting is considered as a crucial measure for forest regeneration since such process in open areas can be delayed because of the rough environmental circumstances and the viable suppression by the thick vegetation cover [17, 18, 19, 20, 21, 22]. Unfavourable environmental factors, for example, extreme climatic condition, drought and suppression by grass or bush vegetation can have adverse consequences likewise on the endurance of established trees [23, 19, 24, 25]. Different studies showed, however, that natural regeneration could play a key role in the recovery of wind-disturbed

spruce forests [17, 26, 20, 27). A precondition for bountiful spruce plantation establishment is the accessibility of adequate regeneration, as well as the presence of suitable recovery substrates, for example rotted deadwood and uncovered mineral soil when seed sources are available [28, 21, 29, 30]. In addition, natural regeneration is considered as a more sustainable and economically profitable choice for forest restoration in contrast to artificial plantations [25].

4.2. The Need for Species Regeneration

Most of the forest stands in Poland are regenerated artificially. Recently, particular attention has been given to increasing natural regeneration, which is a crucial part of the implementation of the concept of sustainable improvement as a major pillar of the close-to-nature silviculture [31]. Between 1976 and 1980, the contribution of natural regeneration in Poland was 3.4% of the total area dedicated to regeneration, this significantly increased to 10.4% in 2001 and 2010 [32]. As of 2020, it stands at 15.4% [33]. This increasing trend is highly commendable and if this continues, surely the 2050 target of attaining 33% will be met.

The future stocking and forest density (trees per ha) are reliant upon the number of tree seedlings planted with a conscious focus on the future management goals to obtain quality wood. Spacing between planted seedlings, for instance, apart from the habitat conditions, is a function of definite stocking objectives and distribution of established forest regeneration. For millennia oaks have been one of the predominant trees specie in Europe. In Poland, this important species is presently a fundamental part of ecology (food for wildlife; shaping the environment and biodiversity), economy, and social legacy. For quite some time, there has been a rising worry that oaks are not recovering a predominant canopy position following the regeneration of harvested stands [34].

However, Andrzejczyk and Godowski [35] reported that oaks growing in a group plantation show a greater average height with other desirable characteristics than in a traditional plantation as a result of edge effect and this makes internal oaks in a group differed in growth, habit and quality. The competitive effects on oaks was said to also depend on planting distance. It was further reported that spruce planted in close proximity of 1.5 m was strongly competitive where inhibition of growth and increasing slenderness of edge oak trees. Linden tree planted at a distance of 3 m was reported to positively impact the quality of oaks without causing inhibition of their growth. Numerous ongoing forest management strategies including clearcutting, shelterwood methods, and the single tree and group selection systems in most cases favour the dominant species base on site conditions [36]. On this note therefore if forest directors and managers will pick a particular species like oaks as a huge part of the up-and-coming age forests and ecological system, it will become so important to find different management and regeneration techniques to increase quality seedling production for plantation establishment and wood quality.

5. Conclusions

There is no doubt that forest stands enhance species structure, including mixed-species forests, vertical and horizontal stratified stand structures, and fine-grained mixing of tree species among others. Hitherto, pines have succeeded as the dominant tree species in Poland. However, beech has been identified as the healthiest tree species in Polish forests and should be incorporated. If forest managers will maintain oaks as a significant component of the next generation of forests and ecological systems, it is crucial to discover different management and regeneration strategies in order to increase quality seedling production for plantation establishment and wood quality. It is of paramount importance to adopt sustainable principles in the management of the Polish forest. These principles should involve deliberate actions to maintain a balance between three main pillars of environmental sustainability (ecological, economical and socio-cultural) in a manner that would allow for a balance to be found between ethical forestry and maintaining biodiversity. Deliberate focus should be made to maintaining natural patterns of disturbance and forest regeneration. Finally, successfully achieving sustainable forest management will definitely provide integrated benefits to all, ranging from safeguarding local livelihoods, reducing rural poverty, and mitigating the effects of climate change to protecting biodiversity and ecological systems services.

References

- [1] Kongsager R, Napier J and Mertz, O., 2013. The carbon sequestration potential of tree crop plantations. *Mitigation and Adaptation Strategies for Global Change*, 18: pp. 1197-1213.
- [2] Chen, H., Gurmesa, G. A., Liu, L., Zhang, T., Fu, S., 2014. Effects of litter manipulation on litter decomposition in successional gradients of tropical forests in southern China. *PLoS One* 9 (6), e99018. <https://doi.org/10.1371/journal.pone.0099018>.
- [3] Hector A, Bagchi R (2007) Biodiversity and ecosystem multi functionality. *Nature* 448: 188–190.
- [4] FAO., 2010. Forests and climate change in the Asia-Pacific region. Forest and Climate Change Working Paper 7, Food and Agriculture Organization of the United Nations, Rome, Italy, p 126.
- [5] Lawson S. S, Michler C. H 2014. Afforestation, restoration and regeneration not all trees are created equal. *J For Res* 25 (1): 3–20.
- [6] Buendia, C., Bussi, G., Tuset, J., Vericat, D. Sabater, S. Palau, A. Batalla, R. J. 2015. Effects of afforestation on runoff and sediment load in an upland Mediterranean catchment. *Sci Total Environ* 540 (1): 144–157.
- [7] Kahle P, Baum C, and Boelcke B., 2005. Effect of afforestation on soil properties and mycorrhizal formation. *Pedosphere* 15 (6): 754–760.
- [8] Vitousek P. M., 1994. Beyond global warming: ecology and global change. *Ecology* 75: 1861–1876.
- [9] Chapin III F. S., Osvaldo E. S., Huber-Sannwald E., and Leemans R., 2001. Global biodiversity in a changing environment. (eds) Springer.
- [10] Peñuelas J, Sabaté S, Filella I, and Gracia C., 2004. Effects of the climatic climate on the terrestrial ecosystems: observation, experimentation and simulation. In: Valladares, F. (ed.), (In French) *Ecología del Bosque Mediterráneo en un Mundo Cambiante. Naturaleza y Parques Nacionales*. Ministerio de Medio Ambiente, pp. 425–460.
- [11] Canadell J. G., Patak D. E., and Pitelka., L. F.. (2006) *Terrestrial ecosystems in a changing world*. (eds) Springer.
- [12] SoEF/FOREST EUROPE, UNECE and FAO 2011: State of Europe's Forests (2011). Status and Trends in Sustainable Forest Management in Europe © Ministerial Conference on the Protection of Forests in Europe, ISBN 978-82-92980-05-7.
- [13] FAO, 2020.: Food and Agriculture Organization, electronic files and web site. Poland Forest area. indexmundi.com/facts/poland/indicator/AG.LND.FRST.ZS
- [14] Szmyt, J., Dobrowolska, D. 2016. Spatial diversity of forest regeneration after catastrophic wind in northeastern Poland. *Forest* (early view). DOI: 10.3832/for1699-008.
- [15] GUS., 2021. Główny Urząd Statystyczny /Statistical Yearbook of Forestry. Warsaw 2021.
- [16] NSG 2016. The forest-based sector in Poland <https://www.forestplatform.org>
- [17] Dimitrov M., 1999. Successional changes of the vegetation in a windthrow area in the association *Piceeto Abietum luzulosum*. *Forestry ideas* 18 (1): 13–27 (in Bulgarian).
- [18] Pavlov D., Tashev A., Kitin P., Dimitrov M., 1996. Secondary succession of the vegetation after a windthrow of the forest stand in the association *Piceetum calamagrostoso myrtillosum*. *Forestry ideas* 6 (1): 3–17 (in Bulgarian).
- [19] Milev M., Iliev N. 2000. Artificial regeneration of high mountain spruce forests in DL “Beglika”. Anniversary collection of scientific reports, University of Forestry Sofia: 272–281.
- [20] Wohlgemuth T., Kull P., Wüthrich H., 2002. Disturbance of microsites and early tree regeneration after windthrow in Swiss mountain forests due to the winter storm Vivian 1990. *Vivian 1990. Forest, Snow and Landscape Research* 77 (1–2): 17–47.
- [21] Brang P, Schönenberger W, Frehner M, Schwitter R, Thormann JJ, Wasser B (2006). Management of protection forests in the European Alps: an overview. *Forest Snow and Landscape Research* 80: 23–44.
- [22] Rotowa O. J., and Adeagbo A. A., 2019. Provenances Trial of *Gmelina aborea* (Roxb.) in Middle-Belt Zone of Nigeria. *Research Journal of Agriculture and Forestry Sciences* Vol. 7 (3), 1-8, ISSN 2320 – 6063 July (2019).
- [23] Jonsson B., 1999. Stand establishment and early growth of planted *Pinus sylvestris* and *Picea abies* related to microsite conditions. *Scandinavian Journal of Forest Research* 14: 425–440.
- [24] Frehner M., 2002. Untersuchungen über den Einfluss unterschiedlicher Kleinstandorte und der Pflanztechnik auf Fichtenpflanzungen in subalpinen Lawenschutzwäldern. PhD thesis, ETH Zurich, *Schweizerische Zeitschrift für Forstwesen, Beiheft* No 92: 279 p.

- [25] Schönenberger W. 2002. Post windthrow stand regeneration in Swiss mountain forests: The first ten years after the 1990 storm Vivian. *Forest, Snow and Landscape Research* 77: 61–80.
- [26] Jehl H., 2001. Forest development after windthrow in the high areas of the Bavarian Forest National Park. In: *Forest development in mountain forests after windthrow and bark beetle infestation*. Published Bavarian Forest National Park, scientific series 14: 49–98 (in German).
- [27] Jonášová M., Vávrová E., Cudlin P., 2010. Western Carpathian mountain spruce forest after a windthrow: Natural regeneration in cleared and uncleared areas. *Forest Ecology and Management* 259: 1127–1134.
- [28] Kuuluvainen T., Kalmari R., 2003. Regeneration microsites of *Picea abies* seedlings in a windthrow area of a boreal old growth forest in southern Finland. *Annales Botanici Fennici* 40: 401–413.
- [29] Zielonka T., 2006. When does dead wood turn into a substrate for spruce replacement? *Journal of Vegetation Science* 17: 739–746.
- [30] Holeksa J., Zielonka T., Żywiec M. 2012. Norway spruce *Picea abies* regeneration and canopy disturbance in a Carpathian subalpine forest. In: Nowak K. I., Strybell H. F. (Eds.) *Spruce: Ecology, Management and Conservation*. New York, USA: 1–40.
- [31] Hafemann, E. 2004. Naturverjüngung der Kiefer – Erfahrungen, Probleme, Perspektiven. *AFZ Wald*, 59 (5), 226–228.
- [32] Koziół, C., Matras, J. 2011. Raport krajowy o leśnych zasobach genowych. (In Polish).
- [33] Masternak, K., Głębocka, K., Surowaniec, K. & Kowalczyk, K. 2020. Growth traits of natural regeneration of Scots pine (*Pinus sylvestris* L.) in south-eastern Poland. *Folia Forestalia Polonica*, 62 (3) 220–226. <https://doi.org/10.2478/ffp-2020-0021>
- [34] Morrissey, R. C., Seifert, J. R., King, N., & Selig, M. F., 2007. Enrichment Planting of Oaks FNR-225. Resources, Purdue University. FNR-260. 12p.
- [35] Andrzejczyk, T., and Godowski Z., 2010. Effect of admixture species on the growth of pedunculated oak (*Quercus robur* L.) in a plantation established using the Szymanski Method. *Forest Research Papers*, 2010, Vol. 71 (4): 321–330. DOI: 10.2478/v10111-010-0027-9 (In Polish).
- [36] Seifert, J. R., Selig, M. F., Jacobs, D. F., and Morrissey R. C., 2005. Natural oak regeneration following clearcutting on the Hoosier National Forest. Department of Forestry and Natural.