SYLWAN 166 (7): 415-430, July 2022
https://doi.org/10.26202/sylwan.2022044
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

Forest-stand survival in different age classes

Radosław Kanabus✉, Stanisław Miścicki

Department of Forest Management Planning, Dendrometry and Forest Economics, Institute of Forest Sciences, Warsaw University of Life Sciences, 159 Nowoursynowska Street, 02-776 Warsaw, Poland

ABSTRACT

As forests are affected by many different biotic, abiotic and anthropogenic factors, not all stands (or parts thereof) survive the period of development for which a forest management plan is elaborated. On the other hand, due to the historical background, a part of the stands that should be cut are spared, to go on to exceed the fixed cutting age. This situation prompts questions as to how many stands are being cut (or destroyed by bio- or abiotic factors) and under what influences, as well as in regard to the level of exploitation of mature and over-mature stands that takes place? Responding to such questions, the work forming the basis of the present study has sought to estimate the probability of survival of stands in ten-year age classes, as against the probability that shelterwood cutting will be commenced within them. The data used to do this were collected by the Forest Management and Geodesy Bureau in line with Forest Management Instructions (2003, 2012), in respect of 64 Polish forest districts located within 14 regional directorates of the State Forests, and with a view to forest management plans being developed and made available by the State Forests General Directorate. Specifically, data from forest management plans elaborated in 2009 and 2010 were used, as were in essence repeat data (from Plans elaborated for the same Districts 10 years later – in 2019 and 2020). The empirical survival of stands in ten-year age classes was estimated by overlapping the vector map of stands of Forest Districts with a 100×100 m grid of sample plots. The probability estimate was then achieved using logistic regression in line with silvicultural method and the presence or absence of shelterwood cutting, and clear-cutting), as well as in respect of the six main tree species in Polish forestry. In total, data were collected from 615,516 individual sample points, of which dominant species in stands were *Pinus sylvestris* in 65.8% of cases, as compared with figures of 4.6% for *Picea abies*, 5.7% for *Alnus glutinosa*, 5% for *Fagus sylvatica*, 11.4% for *Quercus robur* and *Quercus petraea* and 7.6% for *Betula pendula*. Survival probabilities were found to differ between Forest Management Units (FMUs) of different species, cutting age and silvicultural method. Thus, for pine stands with a projected cutting age of 110 years, the probability of that the first age class would transition into the second was only 96.4%, increasing slightly thereafter. Spruce stands associated with the clearcut method had a relatively high probability of early mortality at 30-50 years of age (of about 5%), with this decreased in pre-mature stands. Among beech stands, there was a clear decrease in the probability of survival in age classes 2 and 3 (11-20 and 21-30 years old respectively). In the stands associated with the clear-cutting silvicultural method, the probability of that taking place was found to be even in each age class in mature and over-mature

---

✉e-mail: radoslaw_kanabus@sggw.edu.pl

Received: 26 July 2022; Revised: 30 September 2022; Accepted: 5 October 2022; Available online: 5 November 2022

stands. It was also shown that, in each case in which the cutting age had been exceeded after some time, the probability of survival was greater with age, with the probability of a cut not being below 25% in any age class.

KEY WORDS

clear-cutting, dieback, forest management, mortality, shelterwood, silviculture methods, stand, temperate forests

Introduction

Forestry differs from other types of rural economic method, with this difference of course seen to lie in the long production period often over 100 years, the need for external criteria to being taken account of in determining the moment of maturity of stands (or trees) in respect of their being felled, the (consequent) ambiguity when it comes to the determination of yields, and the large areas of land that have to be devoted to production (Klocek and Rutkowski, 1986). In the course of the lengthy production referred to, cycle stands are exposed repeatedly to disturbances or damage reflecting the action of biotic and abiotic factors (Orzechowski and Wójcik, 2014).

Equally, both Polish and international legislation provide that forests should be managed in a sustainable way (Act, 1991; Helsinki, 1993; Rykowski, 1994; Borecki and Stępień, 2017). Thus, if forest management is to be both effective and sustainable, there will be a need for appropriate planning (Bachman *et al.*, 2002; Siry *et al.*, 2005; MacDicken *et al.*, 2015). And if that is also to be denote responsible, then there will need to be access to data informing usefully to the extent that ‘right’ decisions may arise (Miller and Mork, 2013).

The idea of forest sustainability was in fact established more than 300 years ago, with Hans von Carlovitz’s publication of his *Silvacultura Oeconomica*. This event had a direct impact on the ways and methods deployed in describing forest development, with the result being fuller perception of information regarding forest as such, as well as the means of regulation and management that might be applied to it (Klocek and Oesten, 1993; Lusawa, 2009). Indeed, the history of both science and forestry indicates that the state of forests and the manner in which they functions came to be learned about in relation to deterministic-mechanistic, deterministic-random, and/or probabilistic concepts (Poznański, 2003).

The first of these concepts can be related to the ‘normal forest’ model created by Hundeshagen (1826; by Zabielski, 1976; Knoke *et al.*, 2010). Indeed, this model was long the one underpinning forecasts of the development of wood resources and used in determining final yields in forestry. However, unrealistic assumptions such as constant yield, a lack of influence of external factors on stands, constant economic conditions, and a constant structure *vis-à-vis* wood resources all served to trigger criticism of the ‘normal forest’ model (Möhring, 1986); with the effect that a ‘conceptual forest’ model was established (Sekot, 2012), as sometimes also called the ‘intentional forest’ model.

In essence, it proved possible to notice that over the aforesaid long production period a forest is affected by various factors independent of foresters’ decisions, such as gales (Everham and Brokaw, 1996; Bruchwald and Dmyterko, 2012; Cannon *et al.*, 2017), disturbances in water conditions (Szwagrzyk, 2000; Bréda *et al.*, 2006; Brodrick *et al.*, 2019), wildfires (Kolström and Kellomäki, 1993; Macias Fauria and Johnson, 2008; Szczygieł *et al.*, 2009) or mass outbreaks of insect pests or infectious fungal diseases (Liebhold, 2012; Flower and Gonzalez-Meler, 2015; van Lierop *et al.*, 2015).

Poznański (2003) was thus able to list 10 situations in which a stand ended up being cut before reaching maturity. These factors may relate to forest management, or be completely independent of it, as when a road is constructed, for example.

This all means that not all stands forming a given 10-year age class will actually transfer through to the next (older) class during a 10-year period (the use of ten-year age classes proves convenient when a Forest Management Plan covers a ten-year cycle). Following the afforestation of a clear-cut or damaged stand part of the area of a given age class of stands transfers into the first age class.

In the 'conceptual forest' model, as related to the deterministic-random concept of learning about reality, a narrow interpretation of the probability of survival and mortality of forest stands is then used (Poznański, 2000). This probability is described using an exponential function (Lucas and Andres, 1978 a, b) or using Markov Chains (Kouba, 1973, 1977; Klocek and Oesten, 1993; Logofet and Lesnaya, 2000). The forecasting of forest development, performed with the use of the special conceptual forest model, then has a deductive character (Poznański, 1982; Wysocka-Fijorek and Zajączkowski, 2020).

Another approach, based on the use of knowledge and empirical data, is the 'real forest' model (Rutkowski, 1971), and related to that is an inductive type of forecasting based on stand survival that is determined empirically and subject to variation. This survival rate can be defined by reference to that part of the forested area that exceeds a certain age in a given place and period (Staupendahl and Möhring, 2011), as well as to dynamics of a forest (forest unit) that can be presented using a probability matrix for transitions between age classes (Poznański, 1973).

Thus far, data on survival rates for individual age classes have been little known (Kouba, 1973, 2002; Gadow, 2000; Poznański, 2003; Holécy, 2009) and concerned mainly with pine stands.

It was therefore the aim of the work underpinning the present study to present the probability of transitioning from a given ten-year age class of stands to the next age class during 10 years, in the face of the clear-cutting and shelterwood silvicultural methods, as well as (in the case of shelterwood) the probability that shelterwood cuts will be commenced with in a given age class.

Materials and methods

The data used were collected by the Forest Management and Geodesy Bureau by reference to the Forest Management Instruction (IUL, 2003, 2012), and in respect of 64 Polish forest districts (Fig. 1), as in 14 of the country's SF regional directorates. This was done with a view to forest management plans being developed and made available by the SF General Directorate. Use was made of data from the forest management plans drawn up in 2009 and 2010, as these could be set against repeat data (from plans elaborated after 10 years – in 2019 and 2020) relating to the same forest districts. These data related to locations of given stands, as well as sizes and shapes (vector information), as well as the most important attributes in regard to dominant tree species, stand age, cutting age (CA) and silvicultural method.

The empirical survival rate of stands in ten-year age classes was determined using the QGIS ver. 3.18.2 Zurich program, with a vector map of stands in forest districts in 2009 and 2010 overlain by a 100×100 m grid of sample points (these then corresponding with the minimum stand area under the 2012 Forest Management Instruction). Each point in the grid was assigned the attributes of the stand in which it was located, i.e. dominant tree species, age of dominant species, silvicultural method, and cutting age. A vector layer with the contours of stands from 2019 and 2020 was superimposed on the grid of sample points, with the aim then being to checked whether, at a given point after 10 years:

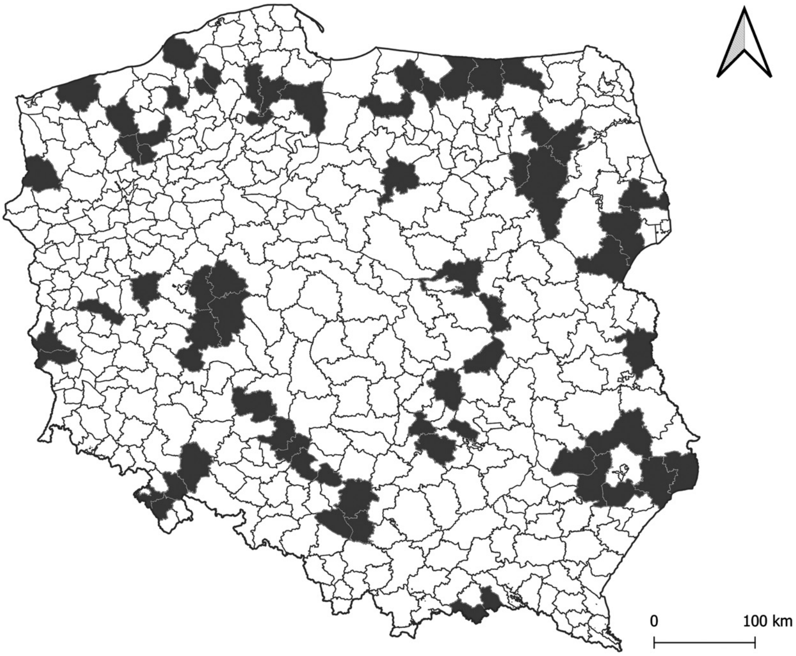

Fig. 1.
Forest districts on which the research was carried out

- stand felling has taken place (transition to age class 1 (1-10 years old), taking into account unregenerated areas),
- whether the forest stand has transformed to the regeneration class (regeneration class means that in a given stand shelterwood cuts have been started, and seedlings and/or saplings have appeared – in line with the 2012 Polish Forest Management Instruction).

It was determined that analyses should be carried out separately for Forest Management Units (FMUs), where these are understood to be units in which stands are grouped under similar habitat conditions, in relation to the same production goals and cutting ages), with management then reflecting either shelterwood or clear-cutting silvicultural methods, and with this involving the six most-important and dominant tree species present in Poland, as well as the cutting age applied most frequently in regard to that species (Table 1). In total, data were collected from 615,516 points, of which the stands had Scots pine *Pinus sylvestris* L. as dominant in 65.8% of cases, while the comparable figures for other species were 4.6% for spruce *Picea abies* (L.) H.Karst., 5.7% for black alder *Alnus glutinosa* (L.) Gaertn., 5% for beech *Fagus sylvatica* L., 11.4% for oaks *Quercus robur* L. and *Q. petraea* (Matt.) Liebl. and 7.6% for silver birch *Betula pendula* Roth.

The probability of a stand being subject to cutting (i_u), or else to the commencement of regeneration (i_{ko}), within a 10-year period in a given age class was then calculated for each species and each cutting age, in line with the relevant age of the dominant species in the stand. Logistic regression was applied, according to the formula:

$$i = 1 / (1 + \exp(b_0 + b_1 \cdot (\ln(w))^1 + \ldots + b_n \cdot (\ln(w)^n)) \quad [1]$$

where:

$b_0, b_1, \ldots, b_n$ are coefficients of the equation,

w is the age of the dominant species in the stand.

Table 1.
Tree species, silvicultural methods and cutting ages applied in the research

Dominant tree species in the Forest Management Unit	Clear-cutting method	Shelterwood method
	studied cutting age [years]	
Scots pine	100, 110, 120	100, 110, 120
Norway spruce	90	80, 90
Black alder	80	80
European beech		100, 110, 120
Oaks (pedunculate or sessile)		140, 160
Silver birch	80	80

Due to the expected large difference in values for cutting rates between mature stands (which could reach this within a 20-year period, when the cutting age is 80 or more, or 10 years when the cutting age is 70 or less); over-mature stands (in which the cutting age has already been passed), as well as pre-mature stands (in which the minimum age of maturity is reached within 20 years when cutting age is 100 or more, or 10 years when cutting age is 90 or less); and younger stands, a segmental regression form (consisting of two parts) was applied. To determine the joining point for these two segments of the regression a moving average for each species and cutting age was then used to depict changes in survival (Fig. 2). The probability of survival in a given age class was calculated using the formula:

$$p = 1 - i_u \qquad [2]$$

The coefficients of the equation [1] were calculated by performing progressive stepwise multivariate regression. Sequential logistic regression with two steps was performed in the case of the shelterwood silvicultural method. In the first step, the probability of stand-cutting was calculated – regardless of whether it was clear-cutting or shelterwood-cutting was to be involved. In the second step, data on stands cut at a given age were used to calculate the probability of shelterwood cutting (*i.e.*, transition to the regeneration class), by reference to:

$$k = (1 - p) \cdot i_{ko} \qquad [3]$$

where:

k is the probability of the shelterwood cut, while p is as in formula [2].

The STATISTICA 13 (TIBCO, 2017) program was used to perform calculations.

Results

The survival rate of forest stands in FMUs subject to clear-cutting differed in relation to age class and dominant species in the stand. In the first age class, not all pine stands passed on to the next age class (Fig. 3). The probability of survival was 96.4% in the case of CA of 110 years, while it increased slightly after that. A similar situation concerned FMUs with stands of black alder and silver birch. In FMUs with a dominant pine stand and a CA of 100 years, the survival probability decreased from the first age class (with a 98% value in the first class). The probability of survival of spruce stands of the first age class in FMUs assigned to ultimate clear-cutting was higher, amounting to 99%. The probability of survival of spruce stands in middle age classes (4-5) on FMUs with a CA of 90 years was lower and amounted to approx. 95%. This means that in these age classes the probability of survival was lower than in pre-mature stands. The probability of sur-

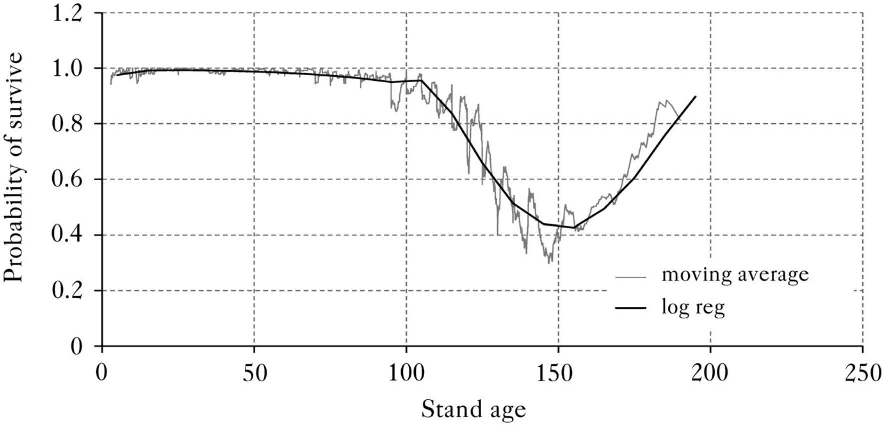

Fig. 2.
Survival probability (logistic regression) of oak's stands and survival moving average

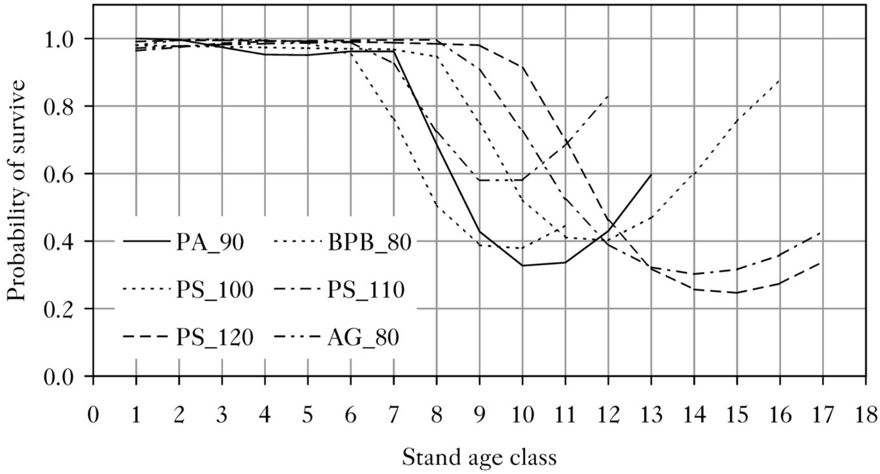

Fig. 3.
Survival probability of forests stands in different age classes depending on the dominant species and the cutting age in clear-cutting system
PA_90-Norway spruce-cutting age = 90; BPB_80-silver birch-cutting age = 80; PS_100/110/120-Scots pine-cutting age = 100/110/120; AG_80-black alder-cutting age = 80

vival of the latter where other dominant species were present was lower, and reached 90% in the case of pine stands of CA of 110 years. In all cases, the probability of the cut was not less than 25%. In the case of stands of each of the analysed species, the probability of survival began to increase following the attainment of a minimum value where the age of stands was about 20 years greater than the cutting age. A good example of this phenomenon could be found in Scots pine FMUs with a CA of 100 years, as well as in FMUs involving black alder.

In the case of the shelterwood FMUs involving young age classes (1-4), certain stands also passed through into the first class on account of premature cutting. Such a situation also applied to some pre-mature, mature, and over-mature stands in FMUs of this type. In FMUs with beech, the probability of survival in age classes 1 and 2 was reduced in the case of cutting ages of 100 and

110 years (Fig. 4). However, in relation to the CA of 110 years, the share affected by clear-cutting was small in all age classes, in contrast to the CA of 100 years, where it amounted to even 11% in certain age classes of over-mature stand. The probability of a stand transitioning to the regeneration class was already present in pre-mature stands, and reached its peak in age class 13, and CA values of 100 and 110 years, as well as in age class 14 at CA of 120 years. The probability of transition to the regeneration class in over-mature stands decreased with greater age, regardless of the cutting age determined.

In the shelterwood FMUs with spruce stands, a probability of shelterwood cutting commencing was already present in the middle age classes, in the case of CA of 80 years in age class 5. The probability of a clear cut was also of 2-5% in this age class (Fig. 5a, b). The highest probability of stands transitioning into the regeneration class was present in over-mature stands, but decreased with age, as did the probability of transition to age class 1. FMUs with birch stands were characterised by a relatively low probability of transition into the regeneration class (the highest value being the 12.5% noted for age class 9) (Fig. 5c); and this probability was lower than that of a clear-cut in mature and over-mature stands. In FMUs with oak stands, the probability of transition to the regeneration class, or of clear-cuts being performed, was highest in over-mature stands, reaching a peak value in age classes 15 and 16 at CA of 140 years, as well as in age classes 17 and 18 at CA of 160 years. Beyond that, there was a decrease with further age (Fig. 6a, b), though in stands with CA of 160 years the probability of clear cut was over 10% in the oldest age classes, even as with CA of 140 years it did not exceed 3.5%.

Where shelterwood was concerned, FMUs with stands featuring black alder had a probability of going on to be cut not exceeding 50%. This was true whether it was clear-cutting or shelterwood-cutting likely to be involved (Fig. 6c). In the young (1-5) age classes, the figure was low, but – after attaining its highest value in connection with age class 10 – it declined beyond that. In the shelterwood FMUs with pine stands, the greatest probability of transition to the regeneration class was in stands of age classes that exceeded the cutting age by 10-20 years. Subsequently, the trend was for lower values – in fact to a level below 10% in the case of the

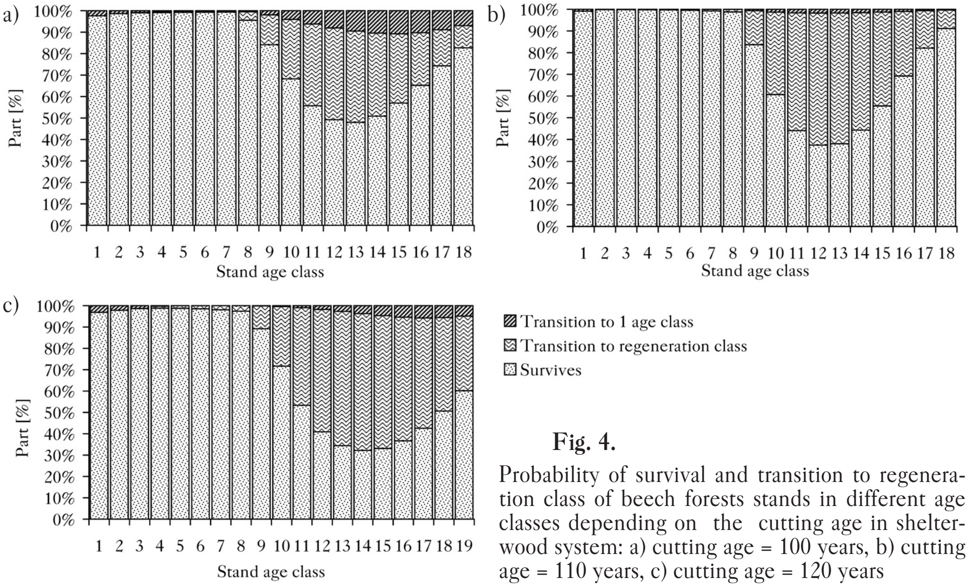

Fig. 4.

Probability of survival and transition to regeneration class of beech forests stands in different age classes depending on the cutting age in shelterwood system: a) cutting age = 100 years, b) cutting age = 110 years, c) cutting age = 120 years

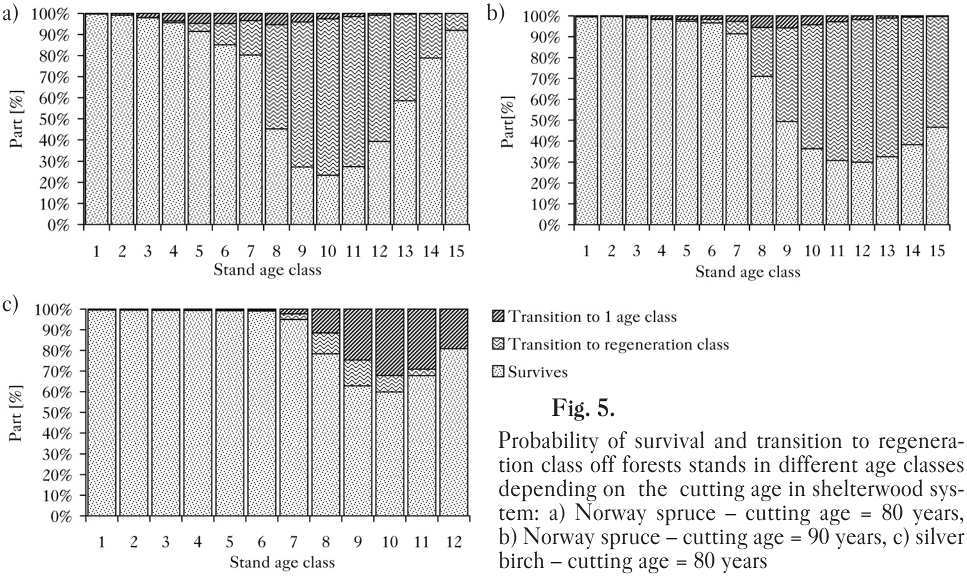

Fig. 5.

Probability of survival and transition to regeneration class off forests stands in different age classes depending on the cutting age in shelterwood system: a) Norway spruce – cutting age = 80 years, b) Norway spruce – cutting age = 90 years, c) silver birch – cutting age = 80 years

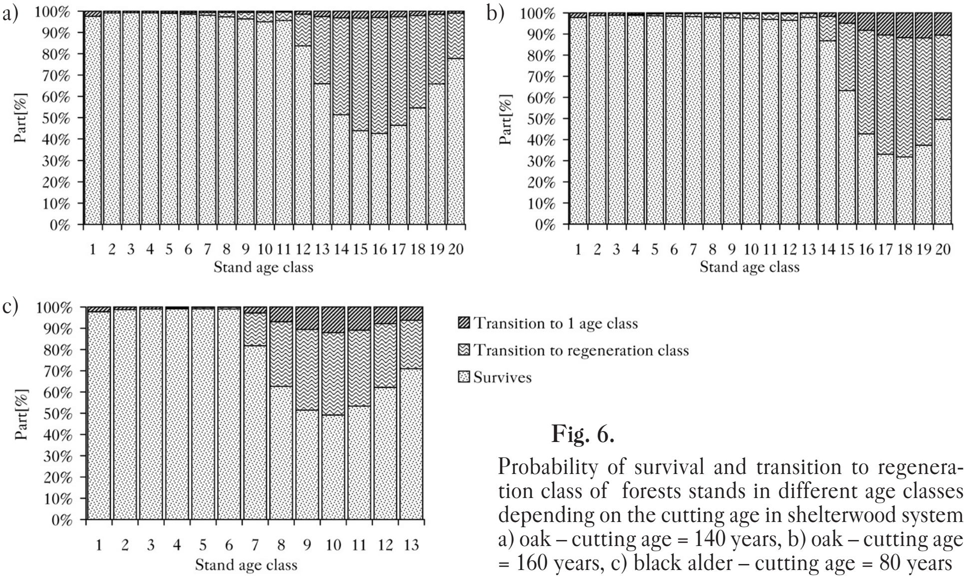

Fig. 6.

Probability of survival and transition to regeneration class of forests stands in different age classes depending on the cutting age in shelterwood system a) oak – cutting age = 140 years, b) oak – cutting age = 160 years, c) black alder – cutting age = 80 years

oldest age classes where CA was equal to 100 years (Fig. 7). The probability of transition to age class 1 was especially high in age class 2 and over-mature stands, when CA was 110 years. The probability relating to stands being cut also differed between pine stands of different cutting ages. In the case of CA of 120 years, the probability of clear-cutting going ahead did not exceed the value of 1% in any age class, while with CA of 110 years in the second class the figure was about 5%. The trend with advancing age was then for decrease, as followed by re-increase up to a point of culmination 30-40 years beyond the cutting age. The probability of transition to the regeneration class was the highest in over-mature stands, but as in the cases of other species, this was progressively lower where greater and great ages were concerned.

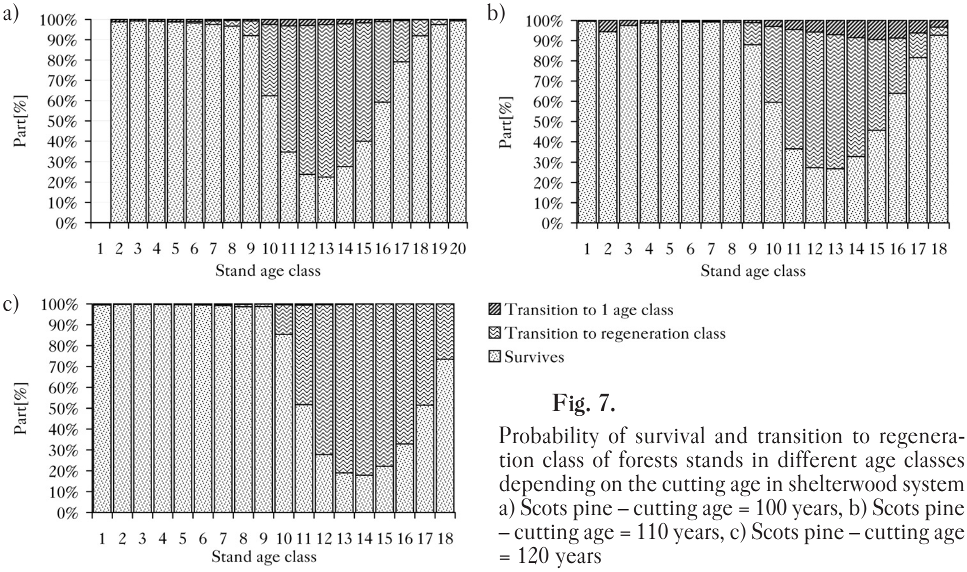

Fig. 7.

Probability of survival and transition to regeneration class of forests stands in different age classes depending on the cutting age in shelterwood system a) Scots pine – cutting age = 100 years, b) Scots pine – cutting age = 110 years, c) Scots pine – cutting age = 120 years

Discussion

The survival of forest stands is determined by various factors relating to the stand itself, such as mechanical stability (Peltola *et al.*, 1997; Wilson and Oliver, 2000), species diversity, concordance between species composition of the stand and habitat (Stępień *et al.*, 2019), or the vicinity of stands, the combined effect of which affects the possibility of destructive external phenomena arising, due to biotic, abiotic or human-determined factors. The most important among these are gales (Bruchwald and Dmyterko, 2010), droughts (Gruber *et al.*, 2010; Steinkamp and Hickler, 2015), frosts, snow, wildfires (Szczygieł *et al.*, 2009), insects, pathogenic fungi (Sierota *et al.*, 2019), the action of game animals, and industrial pollution (Akkerman, 1987; Greszta, 1987). In the current realities of forestry, there is an increase in levels of threat and risk arising out of climate change (Zajączkowski *et al.*, 2013; Jarzyna, 2021), the increasing levels of damage being sustained by forests (Hanewinkel *et al.*, 2013) (as well as in the forest environment), and increased 'rivalry' between different forestry tasks, especially where those involving production are set against the requirements of nature conservation and protection of the landscape (Minsch, 1992; Stępień *et al.*, 2019).

The presented models for stand survival in different age classes offer a synthetic encapsulation of the possibility of further development of stands, or of their being cut, in relation to environmental factors biotic or abiotic, as well as in direct or indirect connection with forest management, or in total isolation from it.

Through until now, such information has only been known to a limited extent, being related to the unplanned cutting of stands, with no connection being established with shelterwood FMUs. Only Poznański (2003) attempted such a synthetic assessment, albeit solely for the clear-cut system in stands of Scots pine. Data on stand mortality were also made known by the work of Kouba (2002) – who argued that the risk of a stand being cut in its entirety or in part was greater with increasing age; and by that of Holécy and Hanewinkel (2006), who proposed applications of the risk of damage to stands for insurance purposes. However, the latter work focused mainly on spruce stands, and was based on the analysis of only certain age classes, and across a limited area. Möhring *et al.* (2010) presented the survival rates of stands according to the Weibull function depending on the indicator related to what initial part of the stand area has survived to an age of hundred years (as therefore very closely related to the idea of the conceptual forest and OPAL model), as well as the á parameter, which characterises the distribution of risk across age classes.

A similar approach was also followed by Staupendahl and Möhring (2011), who determined the survival function with age, albeit for a constant probability at an age of 100 years set at a level of 0.6. Staupendahl and Zucchini (2011) estimated the risk of stands dying as a result of random factors in relation to 5 species groups of different ages. In that work too, the highest risk was noted for spruce stands, amounting to about 30% at an age of 100 years. Holécy (2009) presented the probability of destruction of stands of Norway spruce, silver fir, larch, Scots pine, and oak (including beech), where these belonged to individual age classes and were distributed across Slovakia. He found that the probability of dying was highest in the young age classes, then decreasing and not usually exceeding 5% at any stage. These results therefore pointed to a phenomenon different from the one observed in this study.

Our obtained results indicate that middle-aged forest stands and those in young age classes are at risk of being cut prematurely, regardless of either the species of tree that prevails or the silvicultural method. However, some species (such as spruce) are more vulnerable to being cut or damaged in middle age, probably given the more-limited resistance to destructive factors (Bruchwald and Dmyterko, 2010; Pretzsch *et al.*, 2014; Orphan *et al.*, 2019). Ultimately, the probabilities of survival estimated for spruce stands are similar to with the results obtained by Höller (2009). On the other hand, oak and beech stands were characterised by a relatively low probability of survival in the youngest age classes, perhaps as a result of the impacts of wet snow (Nicolescu *et al.*, 2004), insects feeding on roots, or increased pressure imposed by ungulates.

In each case, irrespective of the dominant tree species, cutting age, or the silvicultural method, there is a probability that over-mature stands will arise. Furthermore, the probability of a stand surviving after the minimum value has been reached is seen to increase at greater stand age. This may reflect the way in which decisions not to cut over-mature stands are made frequently on an arbitrary basis at forest district level – in line with the presence of valuable natural features, for example (Kašpar *et al.*, 2015). After all, once a certain age has been exceeded, stands become more complex as regards species composition and variability in terms of age, with the effect that, should individual trees die, these are replaced by others from younger tree-layers. According to Kłapeć *et al.* (2009), the share of over-mature stands in Poland had exceeded 5% by 2008, with it not being possible to reduce the area covered by this group of stands to any great degree, given the very complex reasons accounting for their creation in the first place.

Numbers should be controlled, however, despite the difficulty in line with the tendency for cutting age to decrease. The creation of such stands, apart from the obvious advantages of increasing biodiversity in older forests, ensures the possibility of wood raw-material decay (Poznański, 2012; Klimek *et al.*, 2018), which is not optimal from the point of view of stand cutting-ages being adjusted in line with the need for carbon dioxide from the atmosphere to be sequestered (Wysocka-Fijorek and Zając, 2016), or from the economic perspective (Parzych *et al.*, 2018). According to the authors cited, the optimal cutting age for pine in the first site class would be 56 years. However, old-growth stands with dead trees may store a lot of carbon (Jacob *et al.*, 2013). Although the cutting age of a given stand may differ from the average cutting age, depending on the species composition or technical quality, a failure to heed cutting age does represent a non-heeding of goals in line with which for cutting age is determined in the first place, notably the adopted production-related goal. Equally, exact heeding of a cutting age set will never prove possible, as a forest is a biological system open to the influence of natural and human-induced environmental factors (Poznański, 2005).

The results estimated for birch stands in the context of the clear-cutting silvicultural method are surprising, because, irrespective of the method, in mature and over-mature stands there is a greater probability of the first age class being transitioned into than the regeneration class. In each case, the probability of the latter happening is greatest in over-mature stands, with this therefore offering an indication that cuts have usually been embarked upon too late, in terms of cutting age.

Equally, it is important to stress that cutting age should not be the final criterion that qualifies a specific stand for felling, but only an element helpful in planning the final yield for an entire area. The results obtained may in some way tend to confirm this thesis (Smykała, 1993).

Such data on the survival of stands as are dealt with here could be used to estimate the risk of premature cutting (or dieback) of stands, or to predict the accumulation of over-mature stands. They can also serve as a basis upon which to forecast the development of wood resources (Poznański, 1982, 1983; Głaz, 1997). The application of such data to calculation of final yield is an unused advantage when it comes to the probability of survival of stands. Such data will gain in importance shortly, due to the growing need for unplanned yield to be forecast (in relation to biotic and abiotic factors).

On the other hand, the subject matter is definitely a 'hot topic' as Poland's forestry circles must regularly fend off accusations from both at home and abroad, to the effect that there is excessive cutting of the country's old forests. The presented analyses go some way to contradicting that suggestion, as a rather large part of the old forests in Poland are probably left for natural development, even when it comes to stands whose leading function is production-related. The situation in which the cutting rate in any age class, in any species and under any type of silvicultural management, is not 100%, and is often within the 50-60% range, also points to cutting not proving possible in reality, in connection with a disturbed spatial order among stands.

Conclusions

- Irrespective of tree species, stand age class, cutting age, and silvicultural method, not all stand areas go on to transit into older age classes. This means that factors affecting forest stand mortality are important in every year of the life of a forest. This point of view should be developed when it comes to forecasting a final yield in line with increasing unplanned yield.
- In line with the shelterwood silvicultural method, certain stands in each age class (and even therefore those that are mature or over-mature) gain utilisation by way of clear-cutting. This shows that, notwithstanding the silvicultural method whose application is intended, it is not always possible for shelterwood cutting to be engaged in.
- The probability of an over-mature stand being felled usually decreases with age, with the effect that there is accumulation, with this potentially leading to less carbon being sequestered, and a loss of full-value timber being incurred. This situation arises where the spatial ordering of stands is wrong, or else where other factors dependent on human decisions are present.
- The level of utilisation of stands in any age class never achieves 100%. This result shows how it is not possible for every part of a forest management plan to be pursued, with this also proving forecastable in some parts.
- The probability of survival demonstrated in this study might gain application as final yields for forest management plans developed in Poland are determined. This might help with the forecasting of unplanned cuts arising through the increased impact of biotic or abiotic factors.

Authors' contributions

R.K. – conceptualization, methodology, formal analysis, material collection, statistical analyses, investigation, writing – original draft preparation; S.M. – conceptualization, methodology, investigation, manuscript review and editing.

Conflict of interest

The authors declare the absence of potential conflicts of interest.

Funding source

The research was financed from the authors' own funds.

References

Act, 1991. Ustawa o lasach. (Forest Act). Dz.U. 1991 nr 101 poz. 444.

Akkerman, R., 1987. Zur Situation der Baum und Waldschäden in Nordwestdeustchland. Teil I. Wardenburg: BSH, 293 pp.

Bachmann, P., Amman, S., Kunz, B., 2005. Moderne forstbetriebliche Planung. *Schweizerische Zeitschrift fur Forstwesen*, 5: 184-185. DOI: https://doi.org/10.3188/szf.2002.0184.

Borecki, T., Stępień, E., 2017. Evolution of the role and current tasks of forest management planning. *Sylwan*, 161 (3): 179-188. DOI: https://doi.org/10.26202/sylwan.2016105.

Bréda, N., Huc, R., Granier, A., Dreyer, E., 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes, and long-term consequences. *Annals of Forest Science*, 63 (6): 625-644. DOI: https://doi.org/10.1051/forest:2006042.

Brodrick, P.G., Anderegg, L.D.L., Asner, G.P., 2019. Forest drought resistance at large geographic scales. *Geophysical Research Letters*, 46 (5): 2752-2760. DOI: https://doi.org/10.1029/2018GL081108.

Bruchwald, A., Dmyterko, E., 2010. Metoda określania ryzyka uszkodzenia drzewostanu przez wiatr. (The method of determining risk of wind damage to tree stands). *Leśne Prace Badawcze*, 71 (2): 165-173. DOI: https://doi.org/10.2478/v10111-010-0012-3.

Everham, E.M., Brokaw, N.V., 1996. Forest damage and recovery from the catastrophic wind. *The Botanical Review*, 62 (2): 113-185. DOI: https://doi.org/10.1007/BF02857920.

Flower, C.E., Gonzalez-Meler, M.A., 2015. Responses of temperate forest productivity to insect and pathogen disturbances. *Annual Review of Plant Biology*, 66: 547-569. DOI: https://10.1146/annurev-arplant-043014-115540.

Gadow, V.K., 2000. Evaluating risk in forest planning models. *Silva Fennica*, 34 (2): 181-191. DOI: https://doi.org/10.14214/sf.639.

Głaz, J., 1997. Metodyka prognozy rozwoju zasobów drzewnych. (Methodology of forecasting the development of wood resources). *Prace Instytutu Badawczego Leśnictwa*, 831: 46-69.

Greszta, J., 1987. Wpływ przemysłowego zanieczyszczenia powietrza na lasy. Warszawa: Wydawnictwo SGGW-AR, 176 pp.

Gruber, A., Strobl, S., Veit, B., Oberhuber, W., 2010. Impact of drought on the temporal dynamics of wood formation in *Pinus sylvestris*. *Tree Physiology*, 30 (4): 490-501. DOI: https://doi.org/10.1093/treephys/tpq003.

Hanewinkel, M., Cullmann, D.A., Schelhaas, M.J., Nabuurs, G.J., Zimmermann, N.E., 2013. Climate change may cause severe loss in the economic value of European forest land. *Nature Climate Change*, 3 (3): 203-207. DOI: https://doi.org/10.1038/nclimate1687.

Holécy, J., 2009. The paradigm of risk and measuring the vulnerability of forest by natural hazards. In: K. Střelcová, C. Mátyás, A. Kleidon, M. Lapin, F. Matejka, M. Blaženec, J. Škvarenina, J. Holécy, eds., *Bioclimatology and Natural Hazards*. Dordrecht: Springer, pp. 231-247. DOI: https://doi.org/10.1007/978-1-4020-8876-6_20.

Holécy, J., Hanewinkel, M., 2006. A forest management risk insurance model and its application to coniferous stands in southwest Germany. *Forest Policy and Economics*, 8 (2): 161-174. DOI: https://doi.org/10.1016/j.forpol.2004.05.009.

Höllerl, S., 2009. Consideration of financial aspects in silvicultural decisions – a case study on pure spruce stands in the montane mixed forest zone. *Forstarchiv*, 80 (1): 4-14. DOI: https://doi.org/10.237603004112-80-4.

IUL, 2003. Instrukcja Urządzania Lasu. (Forest Management Instruction). Warszawa: Państwowe Gospodarstwo Leśne Lasy Państwowe.

IUL, 2012. Instrukcja Urządzania Lasu. (Forest Management Instruction). Warszawa: Państwowe Gospodarstwo Leśne Lasy Państwowe.

Jacob, M., Bade, C., Calvete, H., 2013. Significance of over-mature and decaying trees for carbon stocks in a Central European natural spruce forest. *Ecosystems*, 16 (2): 336-346. DOI: https://doi.org/10.1007/s10021-012-9617-0.

Jarzyna, K., 2021. Climatic hazards for native tree species in Poland with special regards to silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.). *Theorethical and Applied Climatology*, 144 (1): 581-591. DOI: https://doi.org/10.1007/s00704-021-03550-y.

Kašpar, J., Maruscaronk, R., Hlavatý, R., 2015. A forest planning approach with respect to the creation of overmature reserved areas in managed forests. *Forests*, 6 (2): 328-343. DOI: https://doi.org/10.3390/f6020328.

Klimek, K., Jelonek, T., Tomczak, A., 2018. Wpływ procesów starzenia się drzew na wybrane właściwości fizyczne tkanki drzewnej sosny zwyczajnej (*Pinus sylvestris* L.). (The influence of tree aging processes on selected physical properties of Scots pine (*Pinus sylvestris*) wood tissue). *Acta Scientiarum Polonorum. Silvarum Colendarum Ratio et Industria Lignaria*, 17 (4): 353-360. DOI: http://dx.doi.org/10.17306/J.AFW.2018.4.33.

Klocek, A., Rutkowski, B., 1986. Optymalizacja regulacji użytkowania rębnego drzewostanów. Warszawa: PWRiL, 321 pp.

Klocek, A., Oesten, G., 1993. Optymalizacja wieku rębności w lesie normalnym oraz celowym. (Optimization of cutting age in normal and conceptual forest). *Prace Instytutu Badawczego Leśnictwa*, 747-751: 3-31.

Kłapeć, B., Miścicki, S., Stępień, E., 2009. Drzewostany przeszłorębne w Lasach Państwowych. (Overmatured stands in the State Forests National Forest Holding). *Sylwan*, 153 (9): 594-606. DOI: https://doi.org/10.26202/sylwan.2009015.

Knoke, T., Hahn, A., Schneider, T., 2010. Linking inventory and forest optimisation: information and decision-making in forest management. *European Journal of Forest Research*, 129 (5): 771-775. DOI: https://doi.org/10.1007/s10342-010-0398-8.

Kolström, T., Kellomäki, S., 1993. Tree survival in wildfires. *Silva Fennica*, 27 (4): 277-281.

Kouba, J., 1973. Cepi Markova i opredelenje normalnego lesa. Dokłady TSChA, 194.

Kouba, J., 1977. Markov chains and modelling the long-term development of the age structure and production of forests – proposal of a new theory of the normal forest. *Scientia Agriculturae Bohemoslovaca*, 9 (3): 179-193.

Kouba, J., 2002. Das Leben des Waldes und seine Lebensunsicherheit (Forest life and its temporal uncertainty). *Forstwissenschaftliches Centralblatt*, 121 (4): 211-228. DOI: https://doi.org/10.1046/j.1439-0337.2002.02026.x.

Liebhold, A.M., 2012. Forest pest management in a changing world. *International Journal of Pest Management*, 58 (3): 289-295. DOI: https://doi.org/10.1080/09670874.2012.678405.

Logofet, D.O., Lesnaya, E.V., 2000. The mathematics of Markov models: what Markov chains can really predict in forest successions. *Ecological Modelling*, 126 (2-3): 285-298. DOI: https://doi.org/10.1016/S0304-3800(00)00269-6.

Lucas, H., Anders, B., 1978. Mathematische Grundlagen zur Anwendung von Übergangswahrscheinlichkeieten bei der Strukturregelung im Walde. Tech. Univ. Dresden. Sektion Forstwirtschaft Tharandt und Sektion Mathematik Tharandt.

Lucas, H., Anders, B., 1978. Zur Problematik der Anwendung von Übergangswahrscheinlichkeieten auf Modellbetriebsklassen. Tech. Univ. Dresden. Sektion Forstwirtschaft Tharandt und Sektion Mathematik Tharandt.

Lusawa, R., 2009. Hans Carl von Carlowitz – the author of the concept 'Sustainable Development'. *Rocznik Naukowy Wydziału Zarządzania w Ciechanowie*, (1-2): 5-16.

Macias Fauria, M., Johnson, E.A., 2008. Climate and wildfires in the North American boreal forest. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363 (1501): 2315-2327. DOI: https://doi.org/10.1098/rstb.2007.2202.

MacDicken, K.G., Sola, P., Hall, J.E., Sabogal, C., Tadoum, M., de Wasseige, C., 2015. Global progress toward sustainable forest management. *Forest Ecology and Management*, 352 (7): 47-56. DOI: https://doi.org/10.1016/j.foreco.2015.02.005.

Miller, H.G., Mork, P., 2013. From data to decisions: a value chain for big data. *It Professional*, 15 (1): 57-59. DOI: https://doi.org/10.1109/MITP.2013.11.

Minsch, J., 1992. Gesamtheitliche Betrachtungen zu tatsächlichen und vermeintlichen Nutzungskonflikten im Wald. BUWAL, Schriftenreihe Umwelt. *Holz*, 175: 67-89.

Möhring, B., 1986. Dynamische Betriebsklassensimulation – ein Hilfsmittel für die Waldschadensbewertung und Entscheidungsfindung im Forstbetrieb. *Berichte des Forschungszentrums Waldökosysteme/Waldsterben*, 20: 268.

Möhring, B., Staupendahl, K., Leefken, G., 2010. Modellierung und Bewertung naturaler forstlicher Risiken mit Hilfe von Überlebensfunktionen. *Forst und Holz*, 65 (4): 26-30.

Orzechowski, M., Wójcik, R., 2014. Regionalne zróżnicowanie ryzyka wystąpienia uszkodzeń drzewostanów w Polsce. Regional differentiation of the risk of forests damages in Poland. *Studia i Materiały Centrum Edukacji Przyrodniczo--Leśnej*, 16, 39 (2A): 44-54.

Parzych, S., Mandziuk, A., Wysocka-Fijorek, E., 2018. Wpływ zasobności drzewostanów sosnowych na ustalanie ekonomicznego wieku dojrzałości rębnej. (Impact of Scots pine stand growing stock on determining the optimal economic rotation age). *Sylwan*, 162 (8): 671-678. DOI: https://doi.org/10.26202/sylwan.2018070.

Poznański, R., 1973. Las jako układ i macierz prawdopodobieństwa przejść. (Forest as a system and matrix of transition probability). *Sylwan*, 117 (5): 29-38.

Poznański, R., 1982. Formy rozumowania logicznego a typy prognoz w gospodarstwie leśnym. (Forms of logical thinking and types of forecasts in forest management). *Sylwan*, 126 (5), 11-17.

Poznański, R., 1983. Metodologiczne podstawy prognozowania w urządzaniu lasu. (Methodological bases of forecasting in forest management). *Sylwan*, 127 (5): 1-12.

Poznański, R., 2000. Idea lasu celowego a idea lasu rzeczywistego. (The idea of a target forest and the idea of a real forest). *Sylwan*, 144 (2): 57-62.

Poznański, R., 2003. Wpływ czynników otoczenia na przeżywanie i ubywanie drzewostanów w klasach wieku. Kraków: Katedra Urządzania Lasu Akademii Rolniczej, 156 pp.

Poznański, R., 2005. Wieki rębności i wieloaspektowa ocena ich stosowania. (Rotation ages and multi-aspect evaluation of their application). *Sylwan*, 149 (3): 24-33. DOI: https://doi.org/10.26202/sylwan.9200418.

Poznański, R., 2012. Analiza i ocena wyników gospodarowania w Lasach Państwowych w minionym dwudziestoleciu. (Analysis and evaluation of forest management in the State Forests National Forest Holding in the last two decades). *Sylwan*, 156 (7): 542-547. DOI: https://doi.org/10.26202/sylwan.2010059.

Pretzsch, H., Rötzer, T., Matyssek, R., Grams, T.E.E., Häberle, K.H., Pritsch, K., Munch, J.C. 2014. Mixed Norway spruce (*Picea abies* [L.] Karst) and European beech (*Fagus sylvatica* [L.]) stands under drought: from reaction pattern to mechanism. *Trees*, 28 (5): 1305-1321. DOI: https://doi.org/10.1007/s00468-014-1035-9.

Rutkowski, B., 1971. Problem regulacji w gospodarstwie leśnym. (Problem of regulation in forest management). *Sylwan*, 115 (3): 1-11.

Sekot, W., 2012. Zielstrukturen und Zielvorrate für die Ertragsregelung. *Forstzeitung*, 11: 4-6.

Sierota, Z., Grodzki, W., Szczepkowski, A., 2019. Abiotic and biotic disturbances affecting forest health in Poland over the past 30 years: impacts of climate and forest management. *Forests*, 10 (1): 75. DOI: https://doi.org/10.3390/f10010075.

Siry, J.P., Cubbage, F.W., Ahmed, M.R., 2005. Sustainable forest management: global trends and opportunities. *Forest Policy and Economics*, 7 (4): 551-561. DOI: https://doi.org/10.1016/j.forpol.2003.09.003.

Smykała, J., 1993. Wiek rębności (kolej rębu) jako instrument polityki leśnej. (Rotation age as an instrument of forest policy). *Sylwan*, 137 (5): 5-11.

Staupendahl, K., Möhring, B., 2011. Integrating natural risks into silvicultural decision models: a survival function approach. *Forest Policy and Economics*, 13 (6): 496-502. DOI: https://doi.org/10.1016/j.forpol.2011.05.007.

Staupendahl, K., Zucchini, W., 2011. Schätzung von Überlebensfunktionen der Hauptbaumarten auf der Basis von Zeitreihendaten der Rheinland-Pfälzischen Waldzustandserhebung. *Allgemeine Forst-und Jagdzeitung*, 182 (7/8): 129-145.

Steinkamp, J., Hickler, T., 2015. Is drought induced forest dieback globally increasing? *Journal of Ecology*, 103 (1): 31-43. DOI: https://doi.org/10.1111/1365-2745.12335.

Stępień, E., Kędziora, W., Orzechowski, M., Wójcik, R., Borecki, T., 2019. Regionalne zróżnicowanie potrzeb i pilności przebudowy drzewostanów. (Regional diversity of the need and the urgency of stands conversion). *Sylwan*, 163 (4): 267-278. DOI: https://doi.org/10.26202/sylwan.2018108.

Szczygieł, R., Ubysz, B., Kwiatkowski, M., Piwnicki, J., 2009. Klasyfikacja zagrożenia pożarowego lasów Polski. (Forest fire hazard classification in Poland). *Leśne Prace Badawcze*, 70 (2): 131-141. DOI: https://doi.org/10.2478/v10111-009-0013-2.

Szwagrzyk, J., 2000. Rozległe naturalne zaburzenia w ekosystemach leśnych: ich zasięg, charakter i znaczenie dla dynamiki lasu. *Wiadomości Ekologiczne*, 46 (1): 3-19.

TIBCO, 2017. TIBCO Software Inc., Statistica (data analysis software system), version 13. http://statistica.io.

Van Lierop, P., Lindquist, E., Sathyapala, S., Franceschini, G., 2015. Global forest area disturbance from fire, insect pests, diseases, and severe weather events. *Forest Ecology and Management*, 352: 78-88. DOI: https://doi.org/10.1016/j.foreco.2015.06.010.

Wysocka-Fijorek, E., Zając, S. 2016. Metody optymalizacji wieku dojrzałości rębnej drzewostanów z punktu widzenia wiązania węgla. (Optimization methods of the rotation age from the point of view of carbon sequestration). *Sylwan*, 160 (9): 720-729. DOI: https://doi.org/10.26202/sylwan.2016064.

Wysocka-Fijorek, E., Zajączkowski, S., 2020. Indukcyjna metodyka prognozy rozwoju zasobów drzewnych. (Inductive methodology of the forecast of wood resources development). *Sylwan*, 164 (4), 267-279. DOI: https://doi.org/10.26202/sylwan.2019110.

Zabielski, B., 1976. Urządzanie lasu. Warszawa: PWRiL, 347 pp.

STRESZCZENIE

Przeżywalność drzewostanów w klasach wieku

Na lasy wpływa wiele różnych czynników biotycznych, abiotycznych i antropogenicznych. Nie wszystkie drzewostany (lub ich części) dożywają do końca okresu, dla którego opracowywany jest plan urządzenia lasu. Z drugiej strony, ze względu na uwarunkowania historyczne, niektóre drzewostany, które powinny być użytkowane rębnie, są pozostawiane na pniu i przekraczają ustalony wiek rębności. Sytuacja ta skłania do postawienia pytania: ile drzewostanów jest użytkowanych planowo (lub niszczonych przez czynniki biotyczne i abiotyczne) w danym okresie (na ogół przyjmuje się 10 lat) i co na to wpływa, a także jaki jest poziom użytkowania drzewostanów rębnych i przeszłorębnych? W niniejszej pracy oszacowano prawdopodobieństwo przeżycia drzewostanów w dziesięcioletnich klasach wieku i – jako dopełnienie tej wartości – prawdopodobieństwo wykonania cięcia zupełnego lub rozpoczęcia cięć złożonych. Wykorzystano dane zebrane przez Biuro Urządzania Lasu i Geodezji Leśnej dla 64 nadleśnictw (ryc. 1) na potrzeby sporządzenia planów urządzenia lasów, udostępnione przez Dyrekcję Generalną Lasów Państwowych. Użyto danych zawartych w planach urządzenia lasów z lat 2009 i 2010 oraz z późniejszych o 10 lat planów dla tych samych nadleśnictw z lat 2019 i 2020. Dane te zawierały informację wektorową o położeniu danego drzewostanu, jego wielkości i kształcie, a także najważniejsze informacje taksacyjne. Empiryczną przeżywalność drzewostanów w dziesięcioletnich klasach wieku określono, wykorzystując program QGIS ver. 3.18.2 Zurich, nakładając na mapę wektorową drzewostanów nadleśnictw z lat 2009 i 2010 siatkę punktów próbnych w więźbie 100×100 m. Każdemu punktowi przypisano atrybuty drzewostanu, w którym się znajdował. Na siatkę punktów próbnych nałożono warstwę wektorową z konturami drzewostanów z lat 2019 i 2020, a następnie sprawdzono, czy w danym punkcie po 10 latach wystąpiło wycięcie drzewostanu (przejście do 1 klasy wieku lub do kategorii powierzchni nieodnowionych) lub zainicjowanie cięcia złożonego (i przejście drzewostanu do klasy odnowienia). Postanowiono, że analizy zostaną przeprowadzone oddzielnie dla gospodarstw zrębowych (GZ) i przerębowo-zrębowych (GPZ) dla 6 najważniejszych gatunków lasotwórczych Polski przy najczęściej stosowanych wiekach rębności (WR) (tab. 1). Łącznie zebrano dane z 615 516 punktów, z czego na drzewostany z danym gatunkiem dominującym przypadło: 65,8% na sosnę, 4,6% na świerk, 5,7% na olszę czarną, 5% na buk, 11,4% na dąb i 7,6% na brzozę. Prawdopodobieństwo wycięcia drzewostanu lub rozpoczęcia cięć złożonych w ciągu 10 lat w danej klasie wieku obliczono dla każdego gatunku i każdego wieku rębności w zależności od wieku gatunku panującego w drzewostanie. Zastosowano regresję logistyczną – wykonując obliczenia oddzielnie dla drzewostanów młodszych i starszych ze względu na przewidywaną różnicę wyników, przy czym podział na te dwie grupy został dokonany po zastosowaniu średnich ruchomych (ryc. 2). Stwierdzono, że prawdopodobieństwo przeżycia drzewostanu różni się w zależności od gospodarstwa, gatunku panującego i wieku rębności. I tak dla drzewostanów sosnowych w gospodarstwach zrębowych o wieku rębności 110 lat prawdopodobieństwo ich przejścia z pierwszej (dziesięcioletniej) klasy wieku do klasy drugiej wynosiło tylko 96,4%, a następnie nieznacznie się zwiększało (ryc. 3). Prawdopodobieństwo przeżycia drzewostanów świerkowych w średnich klasach wieku (4-5) w gospodarstwach z wiekiem rębności 90 lat było mniejsze i wynosiło około 95%. W drzewostanach bukowych w gospodarstwach przerębowo-zrębowych odnotowano mniejsze prawdopodobieństwo przeżycia w pierwszej i drugiej klasie wieku w przypadku wieków rębności 100 i 110 lat (ryc. 4). Przy wieku rębności 110 lat udział cięć zupełnych był zni-

komy we wszystkich klasach wieku, w odróżnieniu od gospodarstw z wiekiem rębności 100 lat, gdzie był on znaczny nawet w drzewostanach przeszłorębnych. W drzewostanach świerkowych w gospodarstwie przerębowo-zrębowym prawdopodobieństwo rozpoczęcia użytkowania rębniami złożonymi było relatywnie duże już w średnich klasach wieku, a w przypadku gospodarstw z wiekiem rębności 80 lat było duże już w 5 klasie wieku. Prawdopodobieństwo wykonania cięcia zupełnego wynosiło w tej klasie wieku od 2 do 5% (ryc. 5a, b). Drzewostany brzozowe charakteryzowały się stosunkowo małym prawdopodobieństwem przejścia do klasy odnowienia (największa wartość 12,5% w 9 klasie wieku) (ryc. 5c) i było ono mniejsze od prawdopodobieństwa cięcia zupełnego w drzewostanach rębnych i przeszłorębnych. W drzewostanach dębowych prawdopodobieństwo przejścia do klasy odnowienia lub wykonania cięć zupełnych było największe w drzewostanach przeszłorębnych i osiągało kulminację w 15 i 16 klasie wieku w gospodarstwach z wiekiem rębności 140 lat oraz w 17 i 18 klasie wieku w gospodarstwach z wiekiem rębności 160 lat, następnie zmniejszało się wraz z wiekiem (ryc. 6a, b), przy czym w gospodarstwach z wiekiem rębności 160 lat prawdopodobieństwo wykonania cięcia zupełnego wynosiło ponad 10% w najstarszych klasach wieku, a przy wieku rębności 140 lat nie przekroczyło 3,5%. W drzewostanach olszowych w gospodarstwie przerębowo-zrębowym prawdopodobieństwo wykonania cięcia zupełnego lub zainicjowania cięć złożonych nie przekroczyło 50% (ryc. 6c). W młodszych klasach wieku było ono niewielkie, a po kulminacji w 10 klasie wieku zmniejszało się. W drzewostanach sosnowych w gospodarstwach przerębowo-zrębowych największe prawdopodobieństwo przejścia do klasy odnowienia stwierdzono w drzewostanach klas wieku, które przekroczyły wiek rębności o 10-20 lat, a następnie prawdopodobieństwo to zmniejszało się do poziomu nawet poniżej 10% w najstarszych klasach wieku w gospodarstwach z wiekiem rębności 100 lat (ryc. 7).