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The dynamics of northern red oak (*Quercus rubra* L.) in managed forests of central Poland

Damian Głowacki, Małgorzata Sławska*, Marek Sławski

Warsaw University of Life Sciences, Faculty of Forestry, Department of Forest Protection and Ecology,
ul. Nowoursynowska 159, bld. 34, 02–776 Warszawa, Poland

*Tel. +48 22 5938153, e-mail: malgorzata_slawska@sggw.pl

Abstract. Based on data obtained from the Information System of Polish State Forests (SILP), we compiled a register of segments with northern red oak within the area of the Grotniki Forest District. For all of these stands, the cover of Q. *rubra* in the tree, understory (undergrowth and shrub layer) and herb layer was determined for at least three points and then rated on a ten-point scale (1st class – 10%, 2nd class – 20%, etc.). The current distribution of Q. *rubra* in all forest layers was analysed with respect to the type of forest habitat and stand age. Additionally, a prosperity index of northern red oak was calculated separately for two Forest Inspectorates and for all forest habitat types.

The divisions with Q. *rubra* in the Grotniki Forest District comprise a total area of 4,845,86 hectares, which represents 33% of the forest district's area. In the Grotniki Forest Inspectorate 3,447,75 hectares (38% of the forested area) and in the Glowno Forest Inspectorate 1,398,11 hectares (25%) were inventoried. In all layers of the stands, the second and the third classes of coverage were the most commonly recorded, while Q. *rubra* covered the largest surface area in the herb layer, which confirms that this species is spread continuously in the forest district's stands. In the Grotniki Forest Inspectorate, Q. *rubra* occurred most frequently in stands of the third age class, whereas in the Głowno Forest Inspectorate stands of the fourth age class had the highest rate of occurrence. The forest habitat in which Q. *rubra* achieved the highest prosperity index is a moderately humid mixed coniferous forest.

Keywords: northern red oak, stand layers, cover class, forest habitat type, prosperity index

1. Introduction

Northern red oak (*Quercus rubra*), black cherry (*Prunus serotina*) and false acacia (*Robinia pseudoacacia*) are the most common alien tree species in Poland's forests (Chmura 2004; Czerepko 2008; Gazda, Augustynowicz 2012). They occur in both managed and protected forests, especially in degraded or transformed habitats (Adamowski et al. 2002; Chmura 2004; Matuszkiewicz et al. 2007; Gazda, Augustynowicz 2012; Woziwoda et al. 2014b). Incidence of alien woody species in forest ecosystems is most often perceived as a threat to native phytocoenoses and biodiversity (Król 1988; Szwagrzyk 2000; Kohli et al. 2008; Riepšas, Straigytė 2008; Tokarska-Guzik et al. 2012; Chmura 2013; Woziwoda et al. 2014a). Hence, data on aliens and monitoring of their populations are crucial in the assessment of impacts of invasive species on forest ecosystems (Gazda 2012; Chmura 2013; Woziwoda et al. 2014b). In Poland, northern red oak *Q. rubra* L. used to be planted as admixture in the 1800s–1900s, mainly for the purpose of increasing timber production and forest species richness in our region. Now, 200 years after the introduction, northern red oak trees occur throughout Poland's forests, and in some areas, they form single-species stands. The history of the introduction of *Q. rubra* into Poland's forests was studied by Woziwoda et al. (2014b) with the use of data on the age of forest stands compiled by the Information System of Polish State Forests (SILP).

Currently, in the State Forests, tree stands with northern red oak as a dominant or admixture species cover altogether 14,300 ha, which is 0.16% of the total forest area managed by the State Forests National Forest Holding. At the same time, SILP data indicates more than 80,000 *Q. rubra* sites docu-

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mented in all the Regional Directorates of State Forests. This confirms widespread occurrence of *Q. rubra* in Poland's forests, also reported by Woziwoda et al. (2014b). The paper by these authors provides information on the area covered by northern red oak in different regions of the country and data on *Q. rubra* proportions in regional forests as well as those on the age and habitats of the stands with northern red oak.

Generally, *Q. rubra* is most abundant in the southern and western parts of Poland, where solid stands of this species are often observed on the areas larger than 5 ha. Forest stands in southern provinces show the highest shares of northern red oak, that is, Silesia, Lesser Poland, Opole Province and Lower Silesia (1.04%, 0.56%, 0.39% and 0.28%, respectively). In central Poland, the average percentage of *Q. rubra* in the State Forests ranges from 0.11% to 0.16%, except for the Łódź Province (0.23%) (Woziwoda et al. 2014b). The comparison of data on the present-day occurrence of *Q. rubra* and that in the mid-1900s carried out by Białobok and Chylarecki (1965) showed a gradual increase in northern red oak growing area in Poland (Gazda, Augustynowicz 2012).

Potential benefits and risks because of non-native woody species in Poland's forests have been argued for more than 20 years (Król 1988; Danielewicz 1993; Szwagrzyk 2000; Kohli et al. 2008; Danielewicz, Wiatrowska 2014; Zubkowicz 2012; Kuc et al. 2012; Chmura 2013). Notwithstanding the issues already addressed, according to the data of the Institute of Nature Conservation (the Polish Academy of Sciences), the status of *Q. rubra* in Poland can be described as follows: northern red oak occurs as an alien species on more than 1,000 sites all over the country, with specimen numbers ranging from a few to great numbers in solid stands, and its population has been gradually increasing (http://www.iop.krakow.pl/ias/gatunki/142). In the database of the European and Mediterranean Plant Protection Organization (EPPO), *Q. rubra* has been classified as a medium invasive plant in Europe, taking into account its spread capacity and ability to build dense enduring populations (http://www.NOBANIS.org). In Poland's forests, both protected and managed, natural regeneration of *Q. rubra* has been more and more observed (Gazda, Szlaga 2008; Gazda, Fijała 2010, Fyałkowska et al. 2015). All the aforementioned facts draw attention to the necessity to undertake studies on dynamics of *Q. rubra* spread in our forests. When compared to protected forests, those managed seem to be more vulnerable to *Q. rubra* expansion, because as a general rule, woody alien species are introduced into forests because of human activities aiming at economic gains.

The main objective of the present study was to assess *Q. rubra* expansion in central Poland's managed forests and to determine the size of the area of natural regeneration of this alien species at a forest district level. The Grotniki Forest District was chosen as a study area, for the reason that in the 1900s, northern red oak in different forest habitats was abundantly planted. The study also included an attempt to determine forest habitats with the highest rate of *Q. rubra* spread. The research conducted represents the first step of the monitoring programme on this alien species undertaken in Poland's managed forests.

2. Methods

The Grotniki Forest District is situated in the central part of the Regional Directorate of State Forests in Łódź. The eastern part of the District is located in the Wzniesienia Łódzkie region, western (in the Wysoczyzna Łaska region) and northern (in the Równina Błońska region). In the District, rust soils (68.6%) prevail; however, substantial proportions of podzols (12.8%) and gley soils (5.89%) also occur. Fresh (moderately humid) forest sites (82.67%) prevail. Wet sites comprise 14.81%, and the percentage of other forest sites is quite small (bog sites, 1.45%; flood sites, 0.84%; arid sites, 0.23%). In total, deciduous forest sites comprise 50.05% of the Grotniki Forest District area, and coniferous forest sites 49.95%. The proportions of forest site types are as follows: mixed 32.79% of fresh deciduous forest, 28.15% of mixed fresh coniferous forest, 13.39% of fresh coniferous forest, 8.34% of fresh deciduous forest, 6.90% of mixed wet coniferous forest and 5.94% of mixed wet deciduous forest. A variety of forest site types makes the Grotniki Forest District an exceptional area for studying *Q. rubra* spread. Forests established on post-agricultural lands cover 5,700 ha, which amounts for almost 40% of the District's forests. Within the Grotniki Inspectorate, post-agricultural soils constitute 47%, and in the Głowno Inspectorate, 28%. In the species composition, Scots pine dominates, which covers about 80% of the total area of the District studied (Forest Management Plan 2013 – *Plan Urządzenia Lasu* 2013).

The Grotniki Forest District database comprising information on 1,473 forest segments with *Q. rubra* was built based on the SILP records. Each segment was evaluated with regard to *Q. rubra* cover in the following forest layers: young natural regeneration in the herb layer, understory (undergrowth and shrub layer) and canopy (tree layer). The evaluation was carried out diagonally between two points 50 m apart (or 100 m in the case of larger *Q. rubra* segments). The assessment area comprised forest layers within sight of the examiner. *Q. rubra* cover was expressed as the percentage (whole numbers). In each of the segments, at least three assessment points were designated (in larger segments, maximum seven). Field works were performed in the period of August–November 2014.

For all the segments studied, the mean values of *Q. rubra* cover (area of its occurrence in the forest layers examined) were computed. On the basis of the results obtained, *ZRQr* index of natural *Q. rubra* regeneration was calculated, which

depicts the actual area (ha) covered by naturally spreading young generation of *Q. rubra*. *ZRQr* index values were obtained as the products of multiplication of the area (ha) of a given segment and the mean value of *Q. rubra* cover (% expressed as decimal value) within this very segment. Analogous calculations concerning the actual area taken up by *Q. rubra* in understory and the total crown projection area of this species in the District's stands were performed.

The analysis of the occurrence of northern red oak in different forest layers depending on stand-site conditions included data on the type of forest site and stand age obtained from the current Forest Management Plan of the Grotniki Forest District. The results were presented in figures prepared separately for Grotniki and Głowno Inspectorates, so as to better illustrate spatial distribution of *Q. rubra* within the area of the District. The forest sites with minor incidence of this species were not incorporated in the figures presented in the paper.

Dynamics of *Q. rubra* spread in different forest habitats was evaluated with the use of the species prosperity index (*WP*) developed for the present study as the following quotient:

$$WP = ZRQr / UTSL$$

where
ZRQr is the proportion of the area covered by *Q. rubra* in a forest habitat in the total area covered by this species in a given inspectorate (%),
UTSL is the proportion a forest habitat area in the total forest area in a given inspectorate.

WP index was computed for lower stand layers, that is, young natural regeneration, undergrowth and brush layers in all the forest sites in the Grotniki and Głowno Inspectorates. It was concluded that the obtained index value above 1 denoted good site conditions for *Q. rubra* growth and spread. At the same time, it was assumed that planted in the past northern red oaks and now observed in the canopy (tree layer) were the main producers of seeds, whereas young specimens in the lower forest layers (irrespective of their origin – planted or self-sown) would be presumably involved in seed dispersal in the future. Therefore, the proportion of *Q. rubra* in the undergrowth and brush forest layers was also reflected on in the assessments of this species spread within the District. All the calculations were performed using Microsoft Excel Software 2010.

3. Results

In the Grotniki Forest District, the segments with northern red oak comprised 4,845.86 ha, that is, 33% of the total area of the District. In the Grotniki and Głowno Inspectorates, 3,447.75 ha and 1,398.11 ha of the segments were examined, respectively. The majority of stands with *Q. rubra* occurred in the Forest Sub-district : Krzemień (820 ha), Smulsko (692 ha), Głowno (567 ha) and Chrośno (566 ha) (Fig. 1).

In both inspectorates, *Q. rubra* occurred in all stand layers (Figs. 2 and 3), usually concurrently in the herb, undergrowth, brush and tree layers (20–30% ubiquitously). In both inspectorates, forest segments with *Q. rubra* were most often situated in fresh mixed deciduous and fresh mixed coniferous habitats. In the Grotniki Inspectorate, a considerable proportion of *Q. rubra* in fresh coniferous forest habitat was also observed (Fig. 2). In general, within the area of the entire District, *Q. rubra* was observed in middle-aged and older stands: in the Grotniki Inspectorate, mostly in the stands of third age class, and in the Głowno Inspectorate, in those of fourth age class (Fig. 4). At the same time, within the whole examined area, *Q. rubra* was hardly ever observed in forest stands of first class of age.

The calculated *ZRQr* indexes showed that in the Grotniki Inspectorate, *Q. rubra* took up 628.19 ha in the tree layer, whereas in the Głowno Inspectorate, 219.10 ha. In the Grotniki Inspectorate and Głowno Inspectorate taken as a whole, *Q. rubra* areas in undergrowth and brush layers were 597.13 and 230.46 ha, respectively. *Q. rubra* young natural regeneration occurred on 686.67 ha in the Grotniki Inspectorate and 250.19 ha in the Głowno Inspectorate.

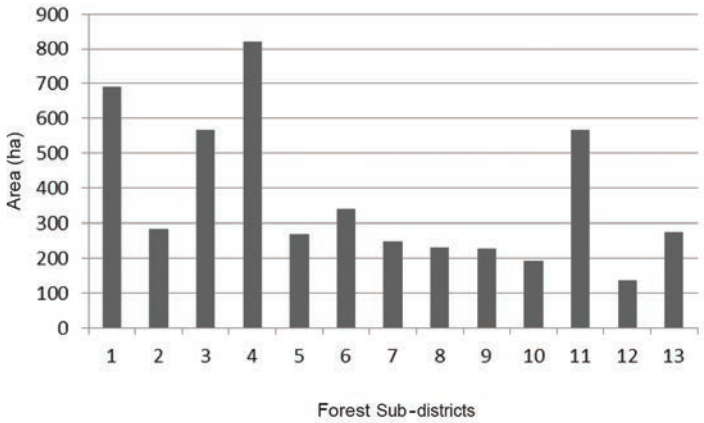
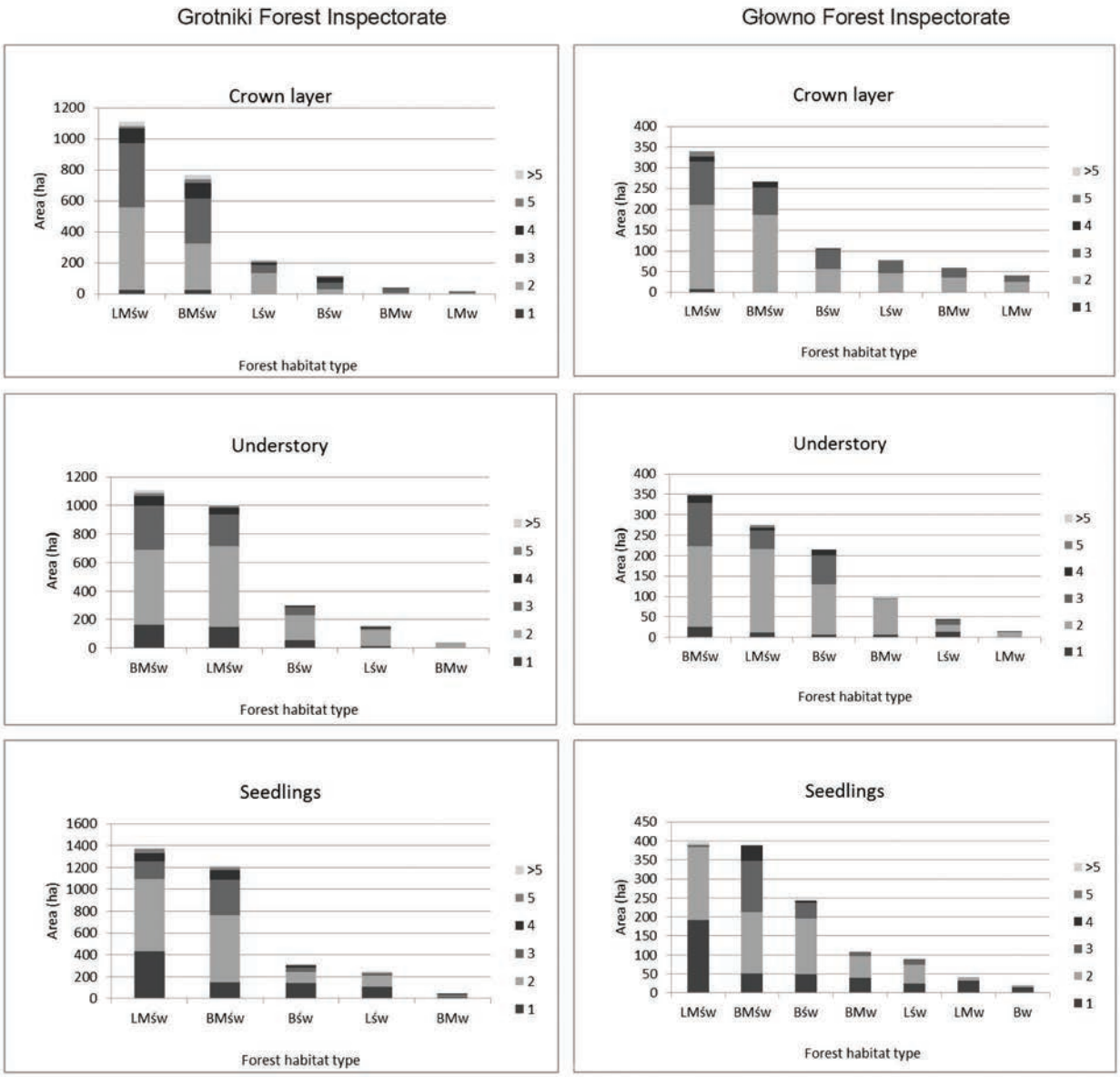


Figure 1. The area of stands with *Q. rubra* in particular forest sub-districts in Grotniki and Głowno Inspectorates. Numbers of forest sub-districts in Grotniki Forest Inspectorate: 1 – Smulsko, 2 – Bełdów, 3 – Chrośno, 4 – Krzemień, 5 – Zimna Woda, 6 – Chociszew, 7 – Sokolniki, 8 – Zgierz and in Głowno Forest Inspectorate: 9 – Szczawin, 10 – Wole Błędowa, 11 – Głowno, 12 – Polesie, 13 – Gieczno



* Explanations of forest habitat type see table 1, 2.

Figure 2. Area of forest subcompartments with *Q.rubra* of different cover class in crown layer, undergrowth and shrub layer and natural seedling on chosen forest habitat types in Grotniki and Głowno Forest Inspectorates. Cover classes: 1 – 10%, 2 – 20%, 3 – 0%, 4 – 40%, 5 – 50%, >5 – more than 50%

The values of species prosperity index (*WP*), calculated separately for forest habitats in the two inspectorates examined, are presented in Tables 1 and 2. With regard to young natural regeneration of *Q. rubra* in both inspectorate, the highest *WP* values were obtained in fresh mixed coniferous forest (1.88 in Głowno and 1.28 in Grotniki). In the Głowno Inspectorate, *WP* values above 1 were also obtained in the following sites: fresh deciduous forest (1.27), fresh coniferous forest (1.09) and fresh mixed deciduous forest (1.05). In the Grotniki Inspectorate, the *WP* value was above 1 only in fresh deciduous forest (1.06). In both inspectorates, the highest *WP* values concerning *Q. rubra* in forest understory were obtained in fresh mixed coniferous forest (1.76 in Głowno and 1.34 in Grotniki). At the same time, in the Głowno Inspectorate, *WP* values were higher than 1 also in fresh coniferous forest and fresh mixed deciduous forest (1.25 and 1.10, respectively).

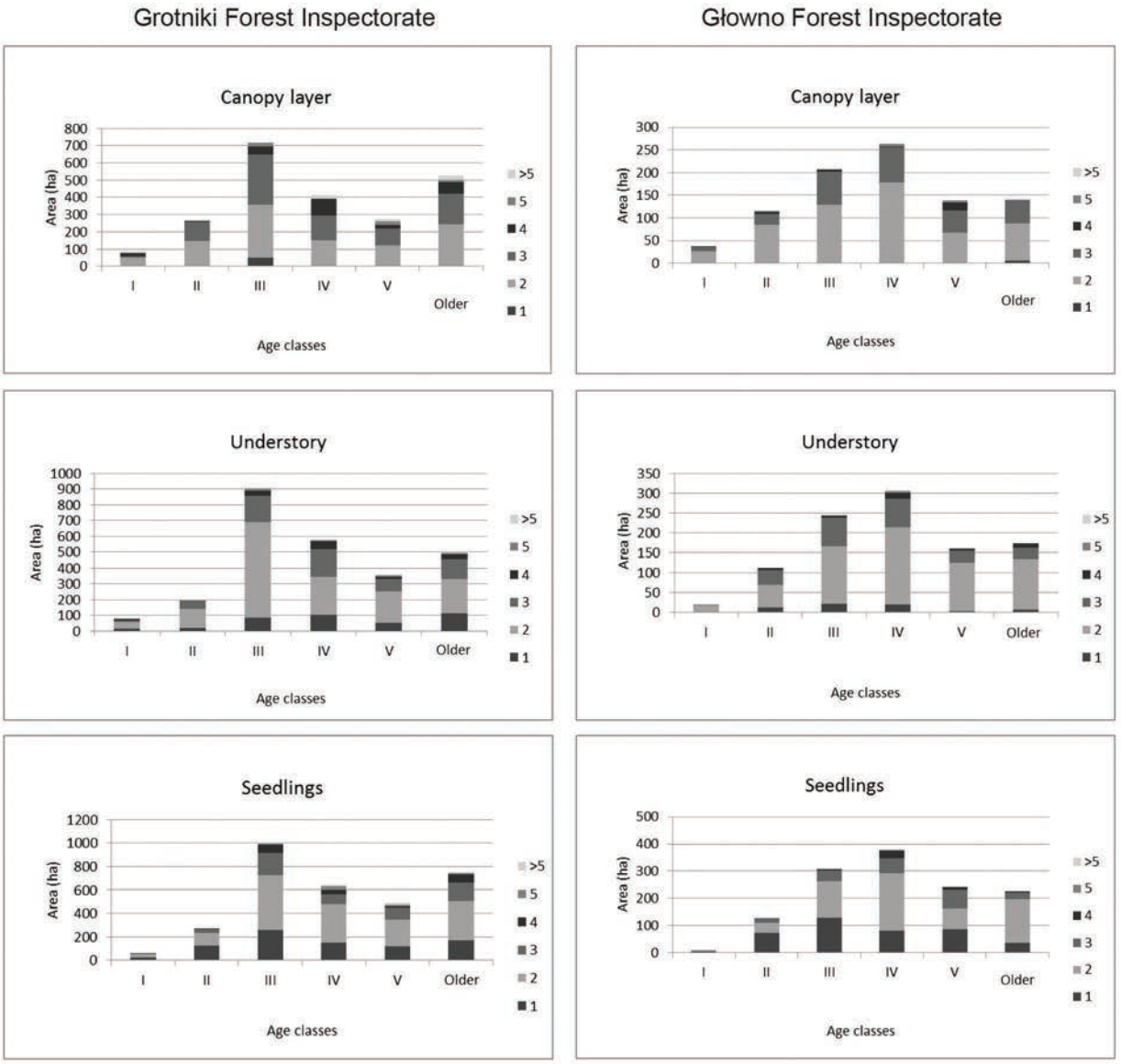


Figure 3. Area of forest subcompartments with *Q.rubra* of different cover classes in crown layer, undergrowth and shrub layer and natural seedling in stands of different age classes in Grotniki and Głowno Forest Inspectorates. Cover classes: 1 – 10%, 2 – 20%, 3 – 30%, 4 – 40%, 5 – 50%, >5 – more than 50%

4. Discussion

In Poland, the issue of occurrence of alien woody species in forests has been addressed in geobotanical studies (Matuszkiewicz et al. 2007; Tokarska-Guzik 2005; Myśliwy 2014) as well as those on phytocoenosis degradation (Król 1988; Chmura 2013). A number of alien species most often occurring in Poland's forests have been described in specific reports on invasive species spread (Gazda, Augustynowicz 2012; Woziwoda et al. 2014b), based on SILP database that comprises comprehensive information on Poland's forests – compiled in line with forest management methodology included in the formal Forest Management Guidelines (*Instrukcja Urządzania Lasu*).

According to the forest appraisal data (age class area, dominant species), in the Grotniki Forest District, tree stands with prevailing northern red oak cover 13.85 ha in the Grotniki Inspectorate and only 3.39 ha in the Głowno Inspectorate, that is, 0.15% and 0.06% of the sub-districts' areas, respectively (Forest Management Plan as of 1.01.2014). On the basis of the SILP data, Gazda and Augustynowicz

Table 1. Prosperity index (*WP*) of natural regeneration of *Q.rubra* on various forest habitat types in Grotniki and Głowno Forest Inspectorates. Explanations of abbreviations: *TSL* – forest habitat type, *ZRQr* – share of area with *Q.rubra* on forest habitat types, *UTSL* – share of forest habitat types in inspectorate's forest area.

Seedlings	Forest Inspectorate			Forest Inspectorate		
TSL	*ZRQr* (%)	*UTSL* (%)	*WP*	*ZRQr* (%)	*UTSL* (%)	*WP*
Bśw MHC	8.15	10.50	0.78	19.68	18.01	1.09
Bw HC	0.07	0.26	0.28	1.04	2.16	0.48
BMśw MHMC	42.58	33.29	1.28	37.49	19.89	1.88
BMw HMC	1.40	1.84	0.76	7.44	15.00	0.50
LMśw MHMD	40.56	38.11	1.06	25.53	24.26	1.05
LMw HMD	0.31	3.63	0.09	2.01	9.64	0.21
LMb BMD	0.00	0.11	0.01	0.00	0.04	0.00
Lśw MHD	6.87	10.23	0.67	6.73	5.30	1.27
Lw HD	0.02	0.39	0.06	0.03	1.95	0.01
Ol AB	0.02	0.82	0.02	0.04	1.51	0.03
OlJ AAS	0.02	0.70	0.03	0.00	1.06	0.00

* MHC – Moderately Humid Coniferous Forest; HC – Humid Coniferous Forest; MHMC – Moderately Humid Mixed Coniferous Forest; HMC – Humid Mixed Coniferous Forest; MHMD – Moderately Humid Mixed Deciduous Forest; HMD – Humid Mixed Deciduous Forest; BMD – Bog Mixed Deciduous Forest; MHD – Moderately Humid Deciduous Forest; HD – Humid Deciduous Forest; AB – Alder Bog Forest; AAS – Ash-alder Streamside Forest.

(2012) estimated the area of solid *Q. rubra* stands in every part of Poland's State Forests as 3,900 ha. As said by Woziwoda et al. (2014b), within the State Forests, stands with *Q. rubra* as a dominant or admixture species cover in total 14,300 ha, and their proportion in the forest cover is no more than 0.16%. In view of the aforementioned statistics, *Q. rubra* resources in the Grotniki Forest District represent the countrywide average.

Within the Grotniki Forest District area, 1,473 forest segments with *Q. rubra* occurring in forest herb layer, understory and canopy were examined. The results of the surveys carried out in the segments showed a real picture of the occurrence of this species at a level of the studied District. It was found that the segments with northern red oak covered 4,845.86 ha, that is, 33% of the District's entire area. When compared to the average in the State Forest, the value obtained is sixfold higher. According to the SILP data, *Q. rubra* forest segments in total constitute

5% of the State Forests area (Gazda, Augustynowicz 2012). At the same time, Gazda and Augustynowicz (2012) reported that *Q. rubra* occurs most frequently (77% segments) as individual trees or small groups. The paper by these authors also includes the maps of *Q. rubra* occurrence in the forest layers (tree, brush, undergrowth and young natural regeneration) at a forest district level. These show that northern red oak commonly occurs in higher forest layers and is observed in the herb layer only in some forest districts – mainly in western and southern parts of Poland.

In the forest segments examined in the Grotniki Forest District, northern red oak was observed in all the forest lay-

Table 2. Prosperity index (*WP*) of understory of *Q.rubra* (undergrowth and shrub layer) on various forest habitat types in Grotniki and Głowno Forest Inspectorates. Explanations of abbreviations: *TSL* – forest habitat type, *ZRUQr* – share of stands with *Q.rubra* on forest habitat types, *TSL* – share of forest habitat types in inspectorate's forest area.

Understory	Forest Inspectorate			Forest Inspectorate		
TSL	*ZRQr* (%)	*UTSL* (%)	*WP*	*ZRQr* (%)	*UTSL* (%)	*WP*
Bśw MHC	10.52	10.50	1.00	22.57	18.01	1.25
Bw HC	0.14	0.26	0.53	1.45	2.16	0.67
BMśw MHMC	44.45	33.29	1.34	35.04	19.89	1.76
BMw HMC	1.25	1.84	0.68	8.24	15.00	0.55
LMśw MHMD	37.33	38.11	0.98	26.67	24.26	1.10
LMw HMD	0.26	3.63	0.07	1.42	9.64	0.15
LMb BMD	0.00	0.11	0.00	0.00	0.04	0.00
Lśw MHD	5.94	10.23	0.58	3.98	5.30	0.75
Lw HD	0.05	0.39	0.13	0.06	1.95	0.03
Ol AB	0.04	0.82	0.05	0.58	1.51	0.38
OlJ AAS	0.01	0.70	0.02	0.00	1.06	0.00

* MHC – Moderately Humid Coniferous Forest; HC – Humid Coniferous Forest; MHMC – Moderately Humid Mixed Coniferous Forest; HMC – Humid Mixed Coniferous Forest; MHMD – Moderately Humid Mixed Deciduous Forest; HMD – Humid Mixed Deciduous Forest; BMD – Bog Mixed Deciduous Forest; MHD – Moderately Humid Deciduous Forest; HD – Humid Deciduous Forest; AB – Alder Bog Forest; AAS – Ash-alder Streamside Forest.

ers examined, and usually, it occurred concurrently in the tree, brush, undergrowth and herb layers. The largest area was taken up by the youngest *Q. rubra* generation – spreading out spontaneously. Hence, in all the forest segments with northern red oak in higher forest layers, the process of its natural regeneration has also been ongoing. Taking into consideration the area taken up by *Q. rubra* in the District observed (one-third of the total area), the high proportion of this species is worth considering. The actual area covered by the alien youngest generation can be even larger, as the segments marked in SILP database were only examined. Gazda and Fijała (2010) observed *Q. rubra* natural regeneration in the Niepołomice Forest also in the stands where this species was not found in the canopy. On moderately fertile forest sites in Lithuania, numerous young *Q. rubra* specimens were observed 100 m from parental stands and individual seedlings even further (Straigyté, Žalkauskas 2012). Thus, similar patterns of natural regeneration spread can be expected within the area of the Grotniki Forest District as well.

In tree stands of the Grotniki Forest District, a non-uniform distribution of *Q. rubra* young natural regeneration (average proportion in the segments examined: 20%) was observed. As *Q. rubra* segments take up one-third of the total forest area in the District, it was assumed that the youngest generation comprised about 6.6%. Such abundant natural regeneration of alien species observed in managed forests is not unusual in view of studies carried out in other regions of Europe. Considerably high populations of northern red oak young specimens were recorded in Germany and France, both in lowland and highland areas (Steiner et al. 1993; Vor 2005; Major et al. 2013). Young

natural regeneration of *Q. rubra* was unevenly distributed in forest stands observed in Germany; however, in some regions, dense vegetation carpets were observed. Average seedling density observed by Vor (2005) was 20 specimens/m^2, and that reported by Major at al. (2013) was 24 specimens/m^2. In France, *Q. rubra* seedlings formed even more dense cover, ranging from 21 to 40 specimens/m^2 (Steiner et al. 1993).

In Poland, detailed studies on natural regeneration of alien woody species in managed forests were carried out on circular plots in the Niepołomice Forest (southern Poland) (Gazda, Szlaga 2008; Gazda, Fijała 2010). The methodology used in this study was different from that used in the present study; therefore, only approximate comparison could be performed. Nonetheless, the results obtained by the authors cited highlight interesting aspects of *Q. rubra* spread. Northern red oak (young natural regeneration and mature trees) was the most abundant alien species in wet deciduous forest habitats (northern complex of the Forest), in terms of population and site numbers observed in 1-are circular plots. On the other hand, in coniferous mixed forest (southern complex), natural *Q. rubra* regeneration was observed only in 1 in 10 plots examined, and no mature trees of this species were found in the canopy surveyed within the area of the study plots (Gazda, Fijała 2010). In the Niepołomice Forest, *Q. rubra* young natural regeneration and undergrowth are most often observed in the stands with single or a few mature trees of this species. Within the plots surveyed, *Q. rubra* natural regeneration under same species mature trees comprised up to several dozen specimens, and these were the youngest trees only (Gazda, Fijała 2010). Studies by other authors showed that *O. rubra* young natural regeneration deteriorate in solid parental stands, and therefore, brush layer of this species is almost never observed in solid parental stands (Bellon et al. 1977; Jaworski 1995). In the Grotniki Forest District, the proportion of forest stands with dominant northern red oak was diminutive, and generally, the species occurred as admixture. According to the present knowledge, such status supports further spreading of *Q. rubra* throughout forest stands.

In the Grotniki Inspectorate, *Q. rubra* occurred most frequently in the stands of the third class of age in all the forest layers examined, whereas in the Głowno Inspectorate, it occurred in the stands of the fourth class of age. In such stands, northern red oak shows high intensity of seed production, followed by the development of numerous seedlings. The occurrence of *Q. rubra* young specimens in the herb layer does not assure the incidence of this species in expected mature stands; nevertheless, it increases species chances to survive (e.g. in case of disturbances because of strong winds or pest infestations). Furthermore, dense young natural regeneration of this alien species supports its endurance, as it holds back the development of native brush and tree species (Bzdęga et al. 2012).

In Poland, northern red oak was planted on a variety of soils: from dry and unfertile coniferous to rich deciduous sites including floodplains. According to SILP data, the majority of present-day forest stands with *Q. rubra* grow on the following forest sites: fresh mixed deciduous forest, mixed coniferous forest and fresh deciduous forest (Woziwoda et al. 2014b). In the Grotniki Forest District, forest segments with *Q. rubra* were located mainly in fresh mixed deciduous and mixed coniferous stands. In the Głowno Inspectorate, the segments with *Q. rubra* were also recorded in fresh coniferous stands. Both the age structure and site characteristics of the stands with *Q. rubra* indicate that these forests were established on post-agricultural soils afforested later than the year 1945 (after the World War II). In fact, almost 40% of forests in the Grotniki Forest District grow on post-agricultural lands. Such habitats are especially vulnerable to invasive alien species, considering soil degradation and biodiversity reduction – largely attributable to unnaturally stimulated succession because of human activity (Sierota, Zachara 2011),

One of the aims of the present study was to identify forest habitats with the highest rate of spontaneous spread of *Q. rubra.* Methodological obstacles during the assessment of natural regeneration of this species were connected with the fact that at first, great abundance of *Q. rubra* seedlings in the herb forest layer most often declines with time. Under the conditions of the present study, it was not possible to distinguish which parts of the undergrowth and brush layers had been planted and which had regenerated naturally. However, regardless of their origin, *Q. rubra* young trees are a potential source of future seeds and offshoots, and that is why, the species prosperity index *WP* was calculated for trees in the lower stand layers. The highest *WP* values were obtained in fresh mixed coniferous forest in all the layers observed (herb, undergrowth and brush layers). Higher index values were obtained in the Głowno Inspectorate. In view of the results obtained, it can be concluded that fairly fertile and moderately wet habitats offer the best conditions for the development and spread of northern red oak. The lack of competitors can be a favourable factor in the development *Q. rubra* seedlings under the conditions of fresh mixed coniferous forest. Another habitat vulnerable to *Q. rubra* spread was fresh mixed deciduous forest, where the *WP* value obtained was higher when compared to other forest segments with *Q. rubra*. Additionally, in the Głowno Inspectorate, the *WP* values obtained were higher than 1 in the undergrowth and brush layers of fresh coniferous forest.

Taking into account conditions of the Forest District Grotniki, the proportion of northern red oak in the Grotniki Inspectorate (38% of the total forest inspectorate area) was larger than that in the Głowno inspectorate (25 %). Nevertheless, *Q. rubra* spread in the sub-district Głowno was comparatively more extended. In the Grotniki inspectorate, afforested post -agricultural lands constitute almost 50%, and the present-day proportion of *Q. rubra* in the canopy indicates that in the past, this species was an important admixture species in afforested

areas. Abundant occurrence of northern red oak on degraded sites indicates favourable conditions for its spread. On the other hand, in the Grotniki Inspectorate, the area taken up by *Q. rubra* young natural regeneration calculated with reference to the proportion of *Q. rubra* mature trees (producing seeds) was smaller (9.3%) when compared to that (14.2%) in the Głowno Inspectorate (with 28% afforested post-agricultural lands). In view of the aforesaid differences, it is quite possible that a higher proportion of coniferous forest sites along with a greater diversity of forest habitats in the Głowno Inspectorate (Table 1) supported enhanced spread of *Q. rubra*.

In closing, one more aspect of the existence of woody alien species in forests should be underlined. In the Grotniki Forest District, the highest proportion of northern red oak was observed in fresh mixed deciduous or fresh mixed coniferous forests. These are habitats where a variety of native tree species can successfully form the undergrowth forest layer as well as play a role of admixture species. Eutrophication of forest ecosystems – recently increasing in Poland – enhances the growth of deciduous tree species. In the meantime, the presence of northern red oak in the lower forest layers can effectively hinder the process. Starfinger et al. (2003) showed plant biodiversity loss in forests with alien woody species in understory vegetation. Even though decreased plant biodiversity has no direct effect on economic forest productivity, it plays an important role in biological resilience of forest communities.

5. Conclusion

The results of the study showed that in the Grotniki Forest District, *Q. rubra* occurred on one-third of the District's area as a vital component of all stand layers. The largest areas of the inspectorates (Grotniki and Głowno) were taken up by *Q. rubra* young natural regeneration, which indicates spontaneous spread of this species in the District. The area taken up by *Q. rubra* young natural regeneration calculated with reference to the proportion of *Q. rubra* mature trees (producing seeds) in the Grotniki and Głowno inspectorates was 9.3% and 14.2%, respectively. Northern red oak showed the highest values of prosperity index (*WP*) in fresh mixed coniferous forest in both young natural regeneration and understory vegetation (undergrowth and brush layers). Higher *WP* values were observed in understory vegetation in the Głowno Inspectorate when compared to the Grotniki Inspectorate. It seems that fairly fertile and, at the same time, moderately wet forest habitats offer optimal conditions for *Q. rubra* spread. Taking into consideration the age structure of stands as well as a variety of forest habitats in the Forest District Grotniki, an increase in the northern red oak proportion can be expected. In view of current knowledge, enhanced spread of invasive alien species can disturb and diminish plant communities in forest ecosystems. This problem concerns not only forest stands with *Q. rubra* as a dominant or admixture species in State Forest (according to SILP database – in total 14,300 ha, Woziwoda et al. 2014b). The results obtained on this alien species in the Forest District Grotniki indicate an increasingly challenging problem.

Conflict of interest

No potential conflicts are declared by the authors.

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References

Adamowski W., Dvorak l., Ramanjuk I. 2002. Atlas of alien woody species of the Białowieża Forest. *Phytocoenosis* 14 (N.S.), Supplementum Cartographiae Geobotanicae 14: 1–303.

Bellon S., Tumiłowicz J., Król, S. 1977. Obce gatunki drzew w gospodarstwie leśnym. Państwowe Wydawnictwo Rolnicze i Leśne. Warszawa.

Białobok S., Chylarecki, H. 1965. Badania nad uprawą drzew obcego pochodzenia w Polsce w warunkach środowiska leśnego. *Arboretum Kórnickie* 10: 211–276.

Bzdęga K., Pajdak E., Tokarska-Guzik B., Chmura D., Woźniak G. 2012. Zależność odnawiania się rodzimych gatunków roślin od rodzaju i wielkości nekromasy w lasach mieszanych z dominacją inwazyjnego dębu czerwonego, in: Obce gatunki w lasach. Materiały VIII Konferencji Naukowej: Aktywne Metody Ochrony Przyrody w zrównoważonym leśnictwie. Rogów, 29–30.03.2012r.

Chmura D. 2004. Penetration and naturalisation of invasive alien plant species (neophytes) in woodlands of the Silesian Upland (Southern Poland). *Nature Conservation* 60: 3–11.

Chmura D. 2009. Differences in invasiveness of alien woody plants in forest communities of the Silesian Upland (Southern Poland).The role of geobotany in biodiversity conservation, University of Silesia, Katowice, 297–302.

Chmura D. 2013. Impact of alien tree species *Quercus rubra* L. on understory environment and flora: a study of the Silesian Upland (Southern Poland). *Polish Journal of Ecology* 61(3): 431–442.

Danielewicz W. 1993. Występowanie drzew i krzewów obcego pochodzenia jako problem ochrony przyrody w rezerwatach i parkach narodowych. *Przegląd Przyrodniczy* 4(3): 25–32.

Danielewicz W., Wiatrowska B. 2014. Inwazyjne gatunki drzew i krzewów w lasach Polski. *Peckiana* 9: 59–67.Fyałkowska K.,

Wroniewski M.R., Obidziński A. 2015. Gatunki roślin obcego pochodzenia w Puszczy Ladzkiej. *Studia i Materiały CEPL w Rogowie* 42(1): 95–109.

Gazda A. 2012. Stan badań nad obcymi gatunkami drzew w polskich lasach taksonów. *Studia i Materiały CEPL w Rogowie* 33(4): 44–60.

Gazda A., Augustynowicz P. 2012. Obce gatunki drzew w polskich lasach gospodarczych. Co wiemy o puli i o rozmieszczeniu wybranych taksonów. *Studia i Materiały CEPL w Rogowie* 33(4): 53–61.

Gazda A., Fijała M. 2010. Obce gatunki drzewiaste w południowym kompleksie Puszczy Niepołomickiej. *Sylwan* 154(5): 333–340.

Gazda A., Szlaga A. 2008. Obce gatunki drzewiaste w północnym kompleksie Puszczy Niepołomickiej. *Sylwan* 152(4): 58–67.

Jaworski, A. 1995. Charakterystyka hodowlana drzew leśnych. Gutenberg. Kraków, 237 s. ISBN 83-86310-03-0.

Kohli R.K., Jose S., Singh, H.P., Batish, D.R. (eds.). 2008. Invasive plants and forest ecosystems. CRC Press, 456 s. ISBN-13:978-1-4200-4337-2.

Król S. 1988. Synantropizacja fitocenoz leśnych przez introdukcję obcych gatunków drzew. *Wiadomości Botaniczne* 32(2): 115–124.

Kuc M., Piszczek M., Janusz A. 2012. Znaczenie dęba czerwonego w ekosystemie leśnym i rachunku ekonomicznym nadleśnictw Regionalnej Dyrekcji Lasów Państwowych w Katowicach. *Studia i Materiały CEPL* 33(4): 152–159.

Major K.C., Nosko P., Kuehne C., Campbell D., Bauhus J. 2013. Regeneration dynamics of non-native northern red oak (*Quercus rubra* L.) populations as influenced by environmental factors: A case study in managed hardwood forests of southwestern Germany. *Forest Ecology and Management* 291: 144–153. DOI 10.1016/j.foreco.2012.12.006.

Matuszkiewicz J.M., Solon J., Orzechowski M., Kozłowska A., Różański W., Szczygielski M., Kowalska A. 2007. Geobotaniczne rozpoznanie tendencji rozwojowych zbiorowisk leśnych w wybranych regionach Polski. Monografie IGiPZ PAN, 8, 980 s.

Myśliwy M. 2014. Plant invasion across different habitat types at floristic survey. *Applied Ecology and Environmental Research* 12(1): 193–207.

Riepšas E., Straigyté L. 2008. Invasiveness and ecological effects of red oak (*Quercus rubra* L.) in Lithuanian forests. *Baltic Forestry* 14(2): 122–130.

Sierota Z., Zachara T. 2011. Drzewostany na gruntach porolnych – dawniej i dziś, in: Zmiany w środowisku drzewostanów sosnowych na gruntach porolnych w warunkach przebudowy częściowej oraz obecności grzyba *Phlebiopsis giganea* (red. Z. Sierota). Prace Instytutu Badawczego Leśnictwa, Rozprawy i Monografie 17: 15–22.

Starfinger U., Kowarik I., Rode M., Schepker H. 2003. From desirable plant to pest do accepted addition to flora? The perception of alien tree species through centuries. *Biological Invasions* 5: 232–335.

Steiner K.C., Abrams M.D., Bowersox T.W. 1993. Advance reproduction and other stand characteristics in Pennsylvania and French stands of northern red oak, in: Proceedings of the 9th Central Hardwood Forest Conference; General Technical Report NC-161. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 473–483.

Straigyté L., Žalkauskas R. 2012. Effect of climate variability on *Quercus rubra* phenotype and spread in Lithuanian forests. *Dendrobiology* 67: 79–85.

Szwagrzyk J. 2000. Potencjalne korzyści i zagrożenia związane z wprowadzaniem do lasów obcych gatunków drzew. *Sylwan* 144(2): 99–106.

Tokarska-Guzik B. 2005. The establishment and spread of alien plant species (kenophytes) in the flora of Poland. Wydawnictwo Uniwersytetu Śląskiego, Katowice, 192 s.

Tokarska-Guzik B., Dajdok Z., Zając M., Zając A., Urbisz A., Danielewicz W., Hołdyński Cz. 2012. Rośliny obcego pochodzenia w Polsce ze szczególnym uwzględnieniem gatunków inwazyjnych. Generalna Dyrekcja Ochrony Środowiska, Warszawa, 197 s. ISBN 978-83-62940-34-9.

Vor T. 2005. Natural regeneration of *Quercus rubra* L. (Red Oak) in Germany. *Neobiota* 6: 111–123.

Woziwoda B., Kopeć D., Witkowski J. 2014a. The negative impact of intentionally introduced *Quercus rubra* L. on a forest community. *Acta Societatis Botanicorum Poloniae* 83(1): 39–49. DOI: 10.5586/asbp.2013.035.

Woziwoda B., Potocki M., Sagan J., Zasada M., Tomusiak R., Wilczyński S. 2014b. Commercial forestry as a vector of alien tree species – the case of *Quercus rubra* L. Introduction in Poland. *Baltic Forestry* 20(1): 131–141.

Zubkowicz R. 2012. Gatunki obce i inwazyjne – Wywiad z Wojciechem Solarzem z IOP w Krakowie. *Las Polski* 6: 20–21.

Other sources

http://www.iop.krakow.pl/ias/gatunki/142 [2.02.2015].

http://www.NOBANIS.org [12.02.2015].

Plan Urządzenia Lasu sporządzony na lata od 2014–2023 dla Nadleśnictwa Grotniki w RDLP w Łodzi na podstawie stanu lasu w dniu 1 stycznia 2014 r. Opis ogólny lasów nadleśnictwa (elaborat). BULiGL, Warszawa, Wydział Produkcyjny w Łodzi.

Authors' contribution

D.G. – field works, database, M.Ska – study conception, analysis of data and literature, preparation of manuscript, text editing, M.Ski – methodology, text editing.

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