

Contribution of selected lichens species of the genus *Cladonia* on the heathlands in Toruń (N, Poland)

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Abstract. The study presents data on the distribution of selected species of lichens – *Cladonia furcata* (Huds.) Schrad., *C. rangiferina* (L.) Weber ex F.H. Wigg. and *C. uncialis* (L.) Weber ex F.H. Wigg. in Toruń and along its southern boundary – on a heathland on the military training ground. A comparison was carried out of the research findings on the occurrence of the analysed species against variable habitat conditions over a period of nearly 40 years. The occurrence of *Cladonia uncialis* was most frequently observed within the city, in the habitats of *Calluna vulgaris*. A tendency was shown of selected lichen species to spread in the investigated area.

Key words: lichens, *Cladonia*, epigeic, *Calluna vulgaris*, heathlands, psammophilous grasslands, urban.

1. Introduction

Over the years, the quality of the environment in urban areas has declined. Due to a rapidly growing industrialisation of the city, the quality of the atmospheric air in Toruń also deteriorates (Report, 2015). Bioindication methods with the use of lichens were applied in urban areas, mostly with epiphytic lichens serving as bioindicators. Terricolous lichens observed in urban areas, occurring mainly on infertile soil, in the vicinity of forest complexes have not yet been considered bioindicators of urban areas. The data on the occurrence of the terricolous lichens have been collected in many Polish cities, eg. Słupsk (Śpiewakowski & Izydorek, 1981), Olsztyn (Kubiak, 2005), Kielce (Toborowicz, 1976), Tarnów (Kozik, 1970), Nowy Tomyśl (Zarabska, 2008), Białystok (Matwiejuk, 2007), Kraków (Kiszka & Kościelniak, 1996) and Toruń (Adamska, 2014).

In general, the further from the city centre, the more abundant the terricolous lichen biota (Toborowicz, 1976; Kozik, 1970; Zarabska, 2008). The occurrence of the terricolous lichens is also closely related to the lighting conditions, as confirmed, among others, by Kiszka (1999) in his research on lichens in Przemysł.

The terricolous lichens are mostly associated with psammophilous grasslands and heathlands. The heathlands are subject to long-term global changes (Fangúndez, 2013). Studies on heathlands in the scope of succession – dynamics of woody species of heathlands, were carried out e.g. in the Fontainebleau forest in France over a period of 60 years (Mobaied et al., 2015).

The dynamics of the changes in habitat conditions of the European heathlands, and in their exploitation, management and preservation, have constituted a subject of numerous studies (Alonso et al., 2001; Ascolo & Bovio,

2010; Bristton & Fisher, 2008; Calvo et al., 2007; Cristofoli et al., 2010; Härdtle et al., 2009; Mitchell et al., 2000; Roem et al., 2002). The data on the occurrence of the lichens on the heathlands are scant (Boom & Boom, 2009; Adamska & Deptuła, 2015a,b; Adamska et al., 2015), even more in the urban areas (Adamska, 2014).

The most common in Poland, also in Toruń, are dry heaths *Calluno-Ulicetalia*. The vegetation of heathlands is being stabilised and shaped mainly by human activity. The observation of the changes occurring in these communities allows for investigation of the habitat diversity of the city. Moreover, in comparison with other communities, the heath lands are characterised by high species biodiversity of plants as well as of lichens. Therefore, it is crucial to study flora and biota of the, as on this basis the changes in the ecosystem can be predicted (Kujawa-Pawlaczyk, 2004).

A part of the urban area of Toruń consists of psamphilous grasslands and heathlands populated by numerous species of terricolous lichens (Adamska, 2014). There are several areas in Toruń with the occurrence of *Calluna vulgaris*, such as 'Glinki' on the south-western boundary of the city; a former military area – JAR situated in the

northern part of the city; and the military training grounds, in large part situated along and outside the southern administrative boundary of Toruń; and also an area along Łódzka street situated underneath an electric traction (Adamska, 2010, 2013; Adamska et al., 2015; Adamska & Deptuła, 2015a, b; Gungacka-Fiedor & Adamska, 2010; Nienartowicz et al., 2010; Kunz & Nienartowicz, 2010).

It was assumed that the occurrence of the selected terricolous lichen species from the genus *Cladonia* – *C. furcata*, *C. rangiferina* and *C. uncialis* evolves over time due to the expansion of Toruń, and the occurrence of selected taxa at the sites with the presence of *Calluna vulgaris* will be more abundant compared with the localities where the heather is absent.

The objective of the study is to determine the existing distribution of the selected lichen species from the genus *Cladonia* on the heathlands in Toruń and in the area of the military training ground situated on the southern boundary of the city, and to analyse the changes in their distribution that occurred in the city within the last 40 years.

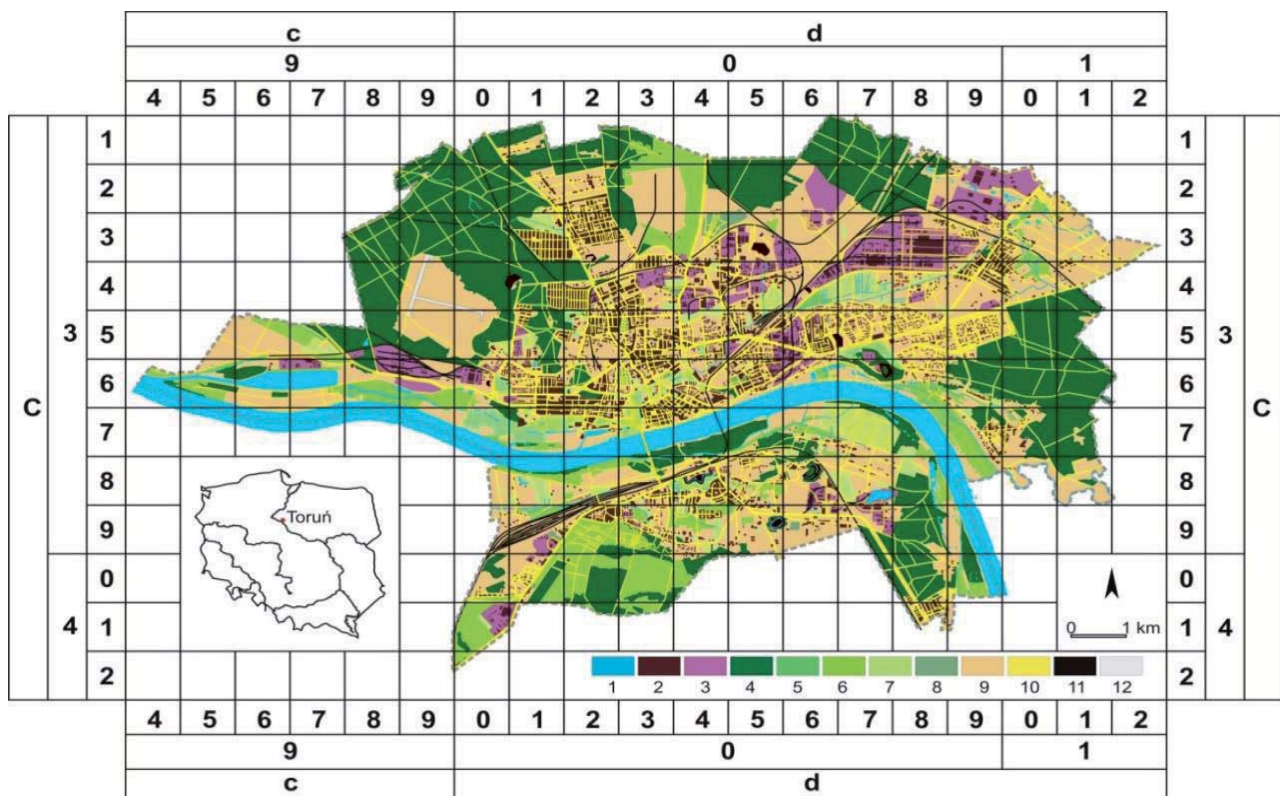


Figure 1. Map of Toruń in the grid of ATPOL squares (acc. Adamska, 2014); 1 – waters, 2 – buildings, 3 – industrial areas, 4 – forests, 5 – parks, 6 – unlandscaped green areas, 7 – allotment gardens, 8 – graveyards, 9 – urban areas, 10 – roads, 11 – railways, 12 – airstrip

2. The study area

According to the physical and geographical regionalization of Poland, Toruń is situated in the mesoregion of the Kotlina Toruńska Basin, the macroregion of the Pradolina Toruńsko-Eberswaldzka Proto-Valley, included within the subprovince of the Pojezierza Południowobałtyckie – South Baltic Lakelands. The city of Toruń is situated between 52°58' and 53°04' of latitude north and between 18°32' and 18°43' of longitude east. Within the current administrative limits, the city covers an area of over 115 km² inhabitants. Toruń is situated on river terraces and dunes. Green areas cover 30% of the city (Andrzejewski & Kot, 2006).

Toruń is situated in a warm temperate climate zone – a transitional climate between the oceanic climate of Western Europe and the Continental climate of Eastern Europe and Asia. Generally the climate of Toruń is characterised by low mean values of precipitation and many days of warm weather, and considerable insolation (cf. Woś, 1999). There are heathlands and psammophilous grasslands within the administrative boundaries of Toruń (Adamska, 2013, 2014).

3. Material and methods

The data on the occurrence of the analysed lichen species were collected over a period of time between 2015 and 2017 within the administrative boundaries of Toruń, with particular reference to the heathlands, and just outside the southern boundary, on the military training ground (Bieniek, 2017).

An ATPOL grid of squares was drawn over a map of Toruń (Adamska, 2014; Adamska & Juśkiewicz, 2018; Zając, 1978; Cieśliński & Fałtynowicz, 1993). The city encompasses four squares: Cd-30, Cd-31, Cd-40 and Cc-39 divided into 1 km² fields – research sites (Fig. 1). Within each research site, the occurrence of *C. furcata*, *C. uncialis* and *C. rangiferina*, their abundance (Table 1) and the lighting conditions at the locality (Table 2) were analysed. The historical data on the occurrence of the selected lichen species were obtained from the study of Adamska (2014) and Wikoń-Michalska et al. (1988). The collected specimens have been deposited in the NCU Herbarium in Toruń (TRN). The nomenclature is in compliance with Index Fungorum (2018).

Table 1. Approximate scale of average abundance of occurrence

Cover %	<1	2-4	5-15	16-30	> 30
Factor of abundance	1	2	3	4	5

Table 2. Light conditions classes

Schare of light	strongly shaded	shaded	semi-shaded	lit	well-lit
Factor of light	1	2	3	4	5

4. Results

The analysis of the occurrence of selected lichen species – *Cladonia uncialis*, *C. furcata*, *C. rangiferina* was carried out during lichenological studies performed in the years 2015-2017. The study area consists of 144 sites; the data were collected from 121 sites. The analysed *Cladonia* species were found at 40 sites. *Calluna vulgaris* occurred at 13 analysed sites, most often at the forest edge.

The largest occurrence of all three species was recorded at the sites numbered: 4,7, 17, 16, 27, 28, 32, 62, 78, 88, 89, 90, 115, 117, 118, 127, 136, 138, 139. At the analysed sites, *Cladonia uncialis* was particularly abundant. In the course of the study, the occurrence of *C. rangiferina* was reported at 6 sites, *C. furcata* – at 26 sites and *C. uncialis* – at 31 sites. At 21 sites the occurrence of only one of the three analysed lichen species was recorded, at 15 sites two species were found, whereas, all the analysed species were present collectively only at 4 sites.

In terms of both the number of localities and the average coverage, these species preferred areas without residential development or with low-density housing.

The relationship between the occurrence and average coverage of the analysed lichens from the genus *Cladonia* and the type of roads and traffic volume shows that their most frequent occurrence was reported in the proximity of dirt roads with low traffic volume. In such habitats, the average coverage was the largest.

All the analysed species preferred illuminated or strongly illuminated habitats.

The collected data on the distribution of the analysed species within the boundaries of Toruń were shown on a cartogram against the ATPOL grid of squares (Figs 2, 3 and 4).

C. uncialis occurred in green areas mostly on the forest edge and was the most abundant at 11 sites with *Calluna vulgaris* – representing 35% of all occurrences.

C. furcata was reported in total at 26 sites of which 30% were associated with patches of *Calluna vulgaris*. The closest relationship with heathlands was shown by *Cladonia rangiferina*, of which half of the 6 occurrences were reported on the heaths.

5. Discussion

The biota of the lichens constitutes a subject of research in many Polish cities. Their main objective is the inventory of lichens in the urban areas and the overview of the issues related to the use of the lichens as bioindicators of the state of the environment (Fałtynowicz, 1995). The subjects of these studies were individual habitat groups of urban lichens, mainly epiphytes. The studies carried out in cities also related to the entire biota of lichens, including terricolous lichens (Matwiejuk & Korobkiewicz, 2012). Those cities were e.g.: Ustka, Łeba (Rydzak, 1956; Izydorek, 2005), Kraków (Zurzycki, 1950; Kiszka, 1977), Poznań (Dziabaszewski, 1962; Kepel, 1999), Słupsk (Śpiewakowski

& Izydorek, 1981; Izydorek & Zduńczyk, 2007), and also Toruń (Wilkoń-Michalska et al., 1988; Adamska, 2014). Among the epigeic lichens found in urban areas in Poland, the lichens from the genus *Cladonia* were analysed most frequently (Matwiejuk & Korobkiewicz, 2012). According to Boom & Boom (2009), on the heathlands they have analysed, there occurred mainly the well-developed thalli of *Stereocaulon saxatile* and *Cladonia borealis*, and previously recorded *Cetraria islandica* is now extinct.

The analysis of the results of the studies on the occurrence of the terricolous lichens in Toruń shows that the occurrence of this lichen group is strongly related to the presence of barren dry soil and forest complexes (cf. Adamska, 2014). In cities, the diversity of terricolous lichen biota has been increasing most frequently with

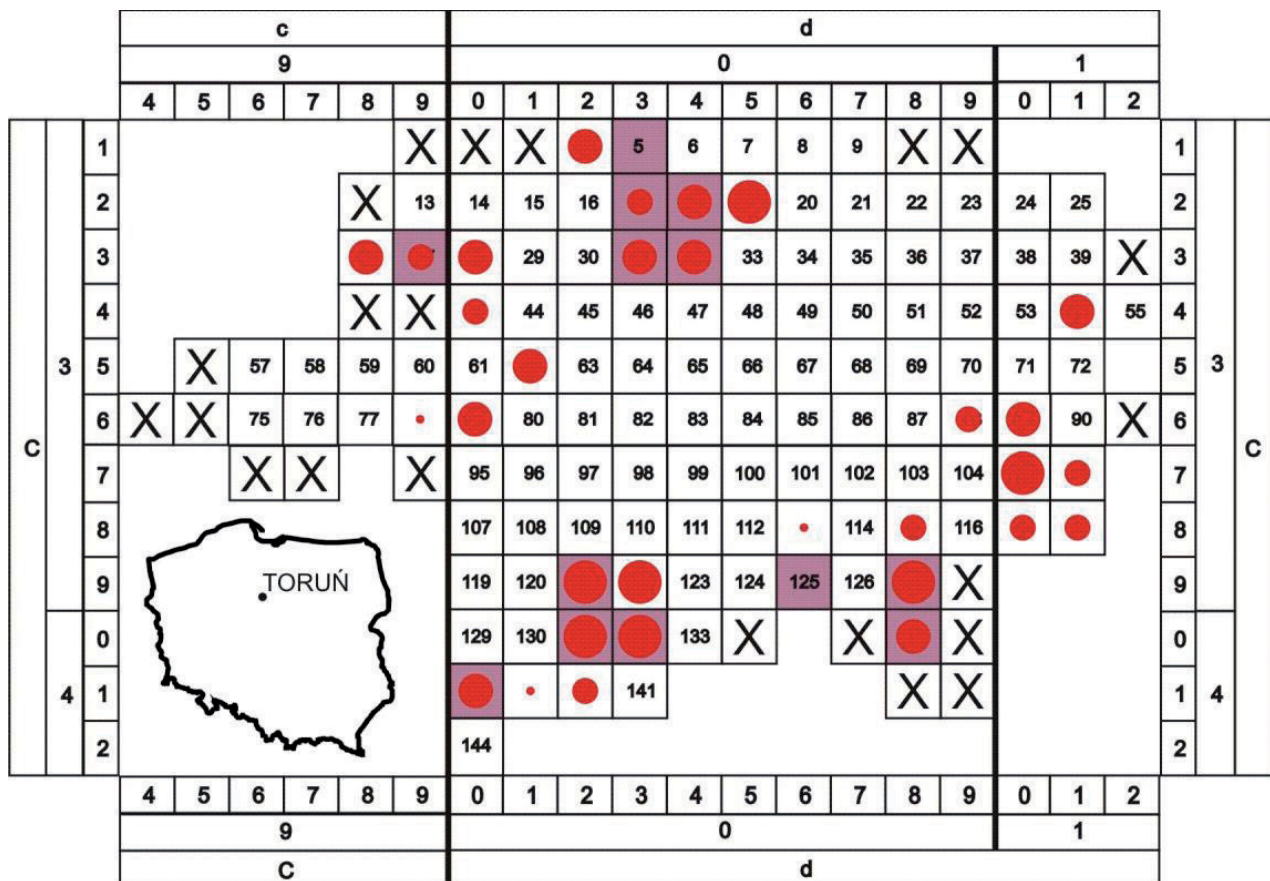
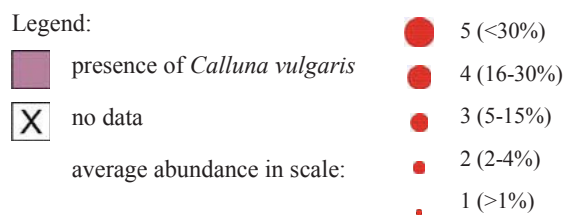


Figure 2. Occurrence of *Cladonia uncialis* in Toruń in the grid of ATPOL squares in 2015-2017



the distance from the city centre (Śpiewakowski & Izydorek, 1981; Toborowicz, 1976; Zarabska, 2008; Kiszka & Kościelniak, 1996; Matwiejuk, 2007; Kozik, 1970; Adamska, 2014).

Toruń is one of the few cities that can pride itself in extensive heathland areas within its administrative boundaries (Kunz & Nienartowicz, 2010). In Toruń, the terricolous lichen species are very abundant (Gugnacka-Fiedor & Adamska, 2010; Adamska, 2014, 2013; Adamska & Deptuła, 2015a, b). The analysis of the occurrence of the selected *Cladonia* species in Toruń over individual study periods indicates that none of the analysed taxa was reported in the 1950s, presumably due to the fact that the studies have then been carried out in the city centre and were mainly concerned with the epiphytic lichens (Wilkoń-Michalska et al., 1988; Adamska, 2014).

As shown in Table 3, in the 1980s the occurrence of *C. uncialis* was reported at 10 sites, representing 10% of all analysed sites (Wilkoń-Michalska et al., 1998; cf. Adamska, 2014). In the years 2000-2006 *C. uncialis* occurred at 21 (29%) of 137 analysed sites (Adamska, 2014). Whereas in the years 2015-2017, 121 sites were analysed, whereof,

at 38% of the sites (31 records) the occurrence of this species was recorded (Fig. 2). Therefore, a trend of slight increase in the number of *C. uncialis* localities in Toruń is apparent. This species is closely associated with the presence of forest complexes and psammophilous grasslands. Only individual occurrences were described in the built-up areas.

In the 1980s, *C. furcata* occurred at 8.73% of analysed sites (Wilkoń-Michalska et al., 1998; Adamska, 2014). In the research carried out by Adamska (2014) in the years 2000-2006, *C. furcata* was reported at 25 out of 137 analysed sites (Table 3). This species is associated with the presence of forest complexes. In the current studies, the number of localities of this species increased by one site and it constitutes about 32% of all the analysed sites (Fig. 3).

Of the 3 analysed taxa, *Cladonia rangiferina* is the least recorded species in the area of Toruń. In the subsequent research periods (Table 3), it has been reported at only 2 sites, representing less than 2% of the sites analysed then (Wilkoń-Michalska et al., 1998; cf. Adamska, 2014). The increase in the number of *C. rangiferina* localities in Toruń has been reported in the studies carried out by Adamska (2014) in the years 2000-2006. This taxon was

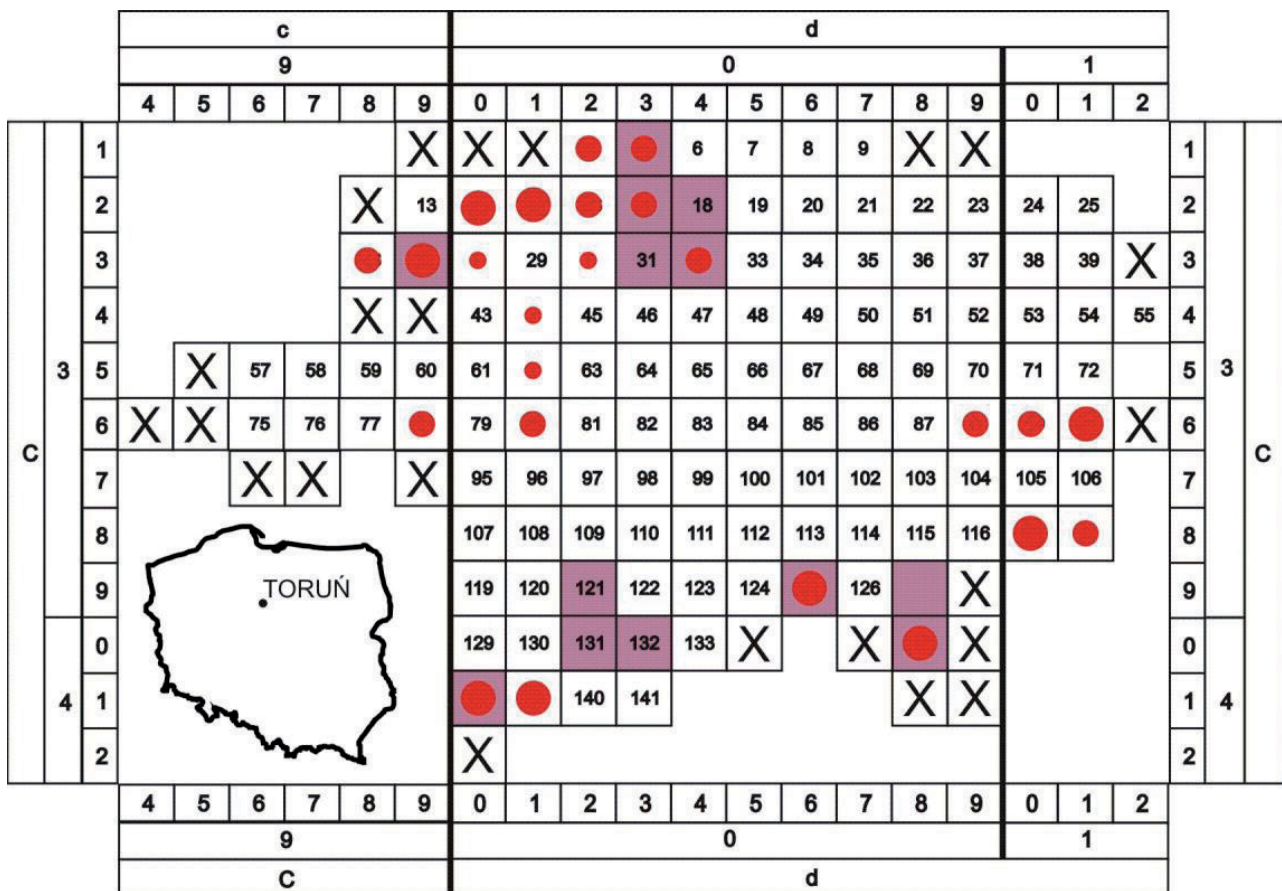


Figure 3. Occurrence of *Cladonia furcata* in Toruń in the grid of ATPOL squares in 2015-2017. Legend as in Figure 2

then reported at 7 (10%) of 137 analysed sites (Fig. 4). The studies conducted in 2015-2017 report the occurrence of *C. rangiferina* at 6 sites. The occurrence of *C. rangiferina* is associated with the presence of forest complexes. Based on the analysis of Ellenberg indicator acc.to Fabiszewski & Szczepańska (2010), one can state that all the studied lichen species from the genus *Cladonia* in Toruń are photophilous. All of them prefer dry habitats. *Cladonia uncialis* and *Cladonia furcata* prefer habitats of poor trophic conditions, whereas *Cladonia rangiferina* – of extremely poor, weak trophism. No significant change in the number of *Cladonia uncialis* and *C. furcata* localities has been observed, but the fractional increase in the number of *Cladonia rangiferina* localities was recorded. Habitat preferences of the analysed species fully correspond to the conditions of the habitats where their occurrence was recorded.

At each of the 13 sites of the occurrence of *Calluna vulgaris*, a presence of at least one of the analysed lichen species from the genus *Cladonia* was recorded. At 6 sites on the heathlands, there was only one of the species reported and most frequently it was *Cladonia uncialis* – this species was absent only at two sites on the heathlands. Therefore,

a conclusion can be made that *C. uncialis* is most closely associated with the presence of heaths. At two sites (127 and 136) the occurrence of all the three analysed species was reported. All the sites with the occurrence of *Calluna vulgaris* are vicinities of forest complexes. In total, *Cladonia rangiferina* was recorded at 6 sites; as much as half of which are heathlands. *Cladonia furcata* also prefers heathlands. It has not occurred only at 5 of all the sites where the occurrence of heather was recorded. Sites located at the southern boundary of the city of Toruń (numbered: 125, 131, 132) also encompass the area of military training ground mainly covered with heaths. In this area located in the immediate proximity of the city, the occurrence of numerous species from the genus *Cladonia* was reported (Adamska & Deptuła, 2015b), including species analysed in the present study. The results of human activity, including climate change and succession processes, affect heathland communities in time and space (Fangúndez, 2013; Mobaied et al., 2015). Unfortunately, at present, due to strong anthropopressure, the heathland areas in Toruń are being reduced as a result of road and housing development.

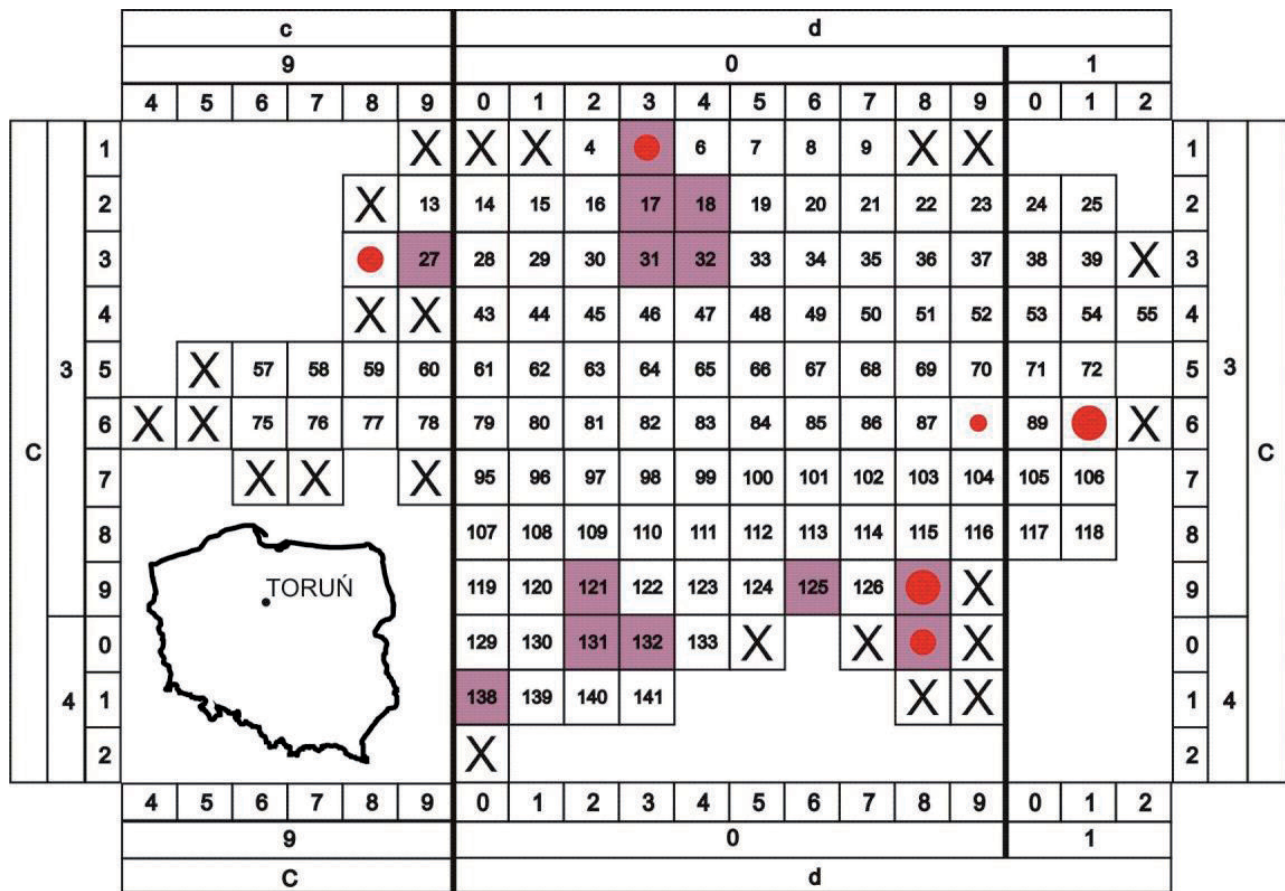


Figure 4. Occurrence of *Cladonia rangiferina* in Toruń in the grid of ATPOL squares in 2015-2017. Legend as in Figure 2

Table 3. The numbers of sites of the analysed species from the genus *Cladonia* reported in Toruń over a period of nearly 40 years

Study period	numbers of analyzed localities (ATPOL squares)	numbers of localities [%]		
		<i>Cladonia furcata</i>	<i>Cladonia rangiferina</i>	<i>Cladonia uncialis</i>
80s.*	97	9	2	10
2000-2006*	137	34	10	29
2015-2017**	121	32	7	38

*sources of data acc. to Adamska (2014) and Wilkoń-Michalska et al. (1988); ** data acc. to Bieniek (2017).

6. Conclusions

Terricolous lichen species – *C. furcata*, *C. rangiferina*, *C. uncialis* are the lichens associated with the presence of forest complexes, including heathland and grassland communities. The occurrence of the analysed species on the territory of the city depends on the type of development, type of roads and traffic volume, and also on the lighting conditions. Over the years, there is observed an increase in the frequency of the occurrence of these taxa in Toruń. The number of localities and abundance increases with the distance from the city centre towards the boundaries and in its immediate vicinity. They are most numerous in the wooded peripheries of Toruń. The most frequently recorded is *Cladonia uncialis* and the least frequently recorded is *Cladonia rangiferina*. All the analysed species occur widely in the areas with the presence of *Calluna vulgaris*; however, a recently observed reduction in heathland areas of the city may in time also affect the decrease in the occurrence of the analysed lichen species.

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