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The distribution of *Salvinia natans* (L.) All. in the Odra and the Oława River valleys in Wrocław area (Poland)

Mirosława Pietryka*, Dorota Richter & Magda Podlaska

Wrocław University of Environmental and Life Sciences, Department of Botany and Plant Ecology, pl. Grunwaldzki 24a, 50-363 Wrocław, Poland

* corresponding author (e-mail: miroslawa.pietryka@upwr.edu.pl)

Abstract. The data presented in this paper concern the occurrence of *Salvinia natans* (L.) All. in Wrocław area. Field research was conducted in the vegetation season (June-September) between 2013 and 2017 in water bodies (natural and artificial), in the main river beds of the Oława and the Odra Rivers and in the Odra canals in Wrocław. The study provided 32 *S. natans* locations in the city area. The studied species occurred in various plant communities accompanied by numerous species which were also under protection, increasing the ecological value of the habitats. Additionally, a stable *S. natans* site was confirmed by the study in a location where aquatic fern had previously been recorded in Wrocław. The research indicates numerous populations of the species along the Odra and the Oława and in many old river beds and artificial water bodies in Wrocław and the results confirm the visible trend of a growing number of *S. natans* sites in all of Poland.

Key words: floating fern, water ecosystems, Lower Silesia, Poland

1. Introduction

Salvinia natans (L.) All. from the Salviniaceae family is an annual plant floating on the surface of water. It is one of two indigenous floating fern species with a natural reach from northern China, through India, to southern and eastern Europe and northern Africa (Herzog 1938). In Europe, it occurs mainly in canals, slowly flowing rivers, ponds and lakes, in pleustonic communities (Casper & Krausch 1980; Szmeja 2006). The species occurs in a broad range of habitat conditions, but the optimal conditions are in placid, shallow and eutrophic water with a thick layer of sediments. It is most often recorded in communities of the *Lemnetea* classes [within which, it is a species characteristic of *Lemno minoris-Salvinietum natantis* (Slavnić 1956) Korneck 1959 association] and, less often, of the *Potametea* R.Tx. et Prsg 1942 class. Due to waves, it also infiltrates rush communities of the *Phragmitetea* R.Tx. et Prsg 1942 class (Dostál 1989; Oberdorfer 1994; Matuszkiewicz 2008).

In Poland *S. natans* belongs to strictly protected species (Regulation 2014). In the first decade of the 21st century, it was noted as a vulnerable species ["V" category on a national level] (Zarzycki & Szeląg 2006). Its occurrence was mainly limited to the Odra, the Wisła and the Bug river valleys (Zając & Zając 2001; Proćków 2002; Wierzba *et al*. 2008; Krechowski *et al*. 2010; Gałka & Szmeja 2012). Numerous recent updates on the occurrence of new *Salvinia natans* populations inhabiting various water basins in southern Poland (Walusiak *et al*. 2011; Wojton & Kubejko 2012; Marciniuk *et al*. 2012) caused the species not to get included in the newest *Polish red list of pteridophytes and flowering plants* (Kaźmierczakowa *et al*. 2016).

In Lower Silesia, at the beginning of the 21st century, *S. natans* was still recorded in few locations in the basin of the Stobrawa and the Barycz rivers as well as in some well described populations in the Odra valley (Proćków 2002; Dajdok & Proćków 2003). In recent years, this location has shown a clear increase of the species occurrences (Spałek 2008; Stajszczyk *et al*. 2010a, 2010b; Stajszczyk & Fujarczuk 2013; Łukaszek & Kołodziejczyk 2016), and, yet, it is still listed as vulnerable species (VU category) (Kącki *et al*. 2003; Dajdok & Proćków 2003) in the regional list of species.

In comparison with the published data from all over Lower Silesia, there is little information on the

occurrence of *S. natans* in the vicinity of Wrocław. German archives noted the presence of the species near Rędzin, Psie Pole, Swojczyce, Sępolno and Biskupice Wrocławskie (Milde 1857; Schube 1903). An analysis of herbal archives (Herbarium Musei Historiae Naturalis Universitatis Wratislaviensis) indicates that *S. natans* was recorded in the Odra next to Rędzin neighborhood (1836) and in the Oława and the Oławka rivers (1952, 1954, 1979). More contemporary studies conducted in Wrocław recorded the presence of the species only in the following six locations: in the north-western Wrocław, in the sandpit (Proćków & Proćków 2005; Majszak 2014) and the Odra bay (Matuła 2012); in the east of Wrocław in three locations in old riverbeds and branches of the Oława river (Dajdok & Proćków 2003; Szczęśniak 2013; Kiełbasińska 2014); and in small water basins occurring in aqueous areas (Kamińska 2011; Fałtyn *et al*. 2013). A small number of known *S. natans* locations results from incomplete studies in small parts of the city. Only complex floristic analyses in the whole city, including the whole course of the Odra and its tributaries, accurately showed the richness of *Salvinia natans* populations. Consequently, the data presented in this paper contribute to the knowledge of *Salvinia natans* (L.) All. occurrences in Wrocław.

2. Materials and methods

Field research in Wrocław area was conducted in vegetation seasons (June-September) between 2013 and 2017. Artificial and natural reservoirs located in the valleys of Wrocław rivers along with the main canals and streams of the Odra, the Oława, the Widawa, the Ślęza and the Bystrzyca rivers were selected for widely understood research of macrophytic and aquatic vegetation. The layout of localities was based on a net of ATPOL squares (Zając 1978). In order to characterize the patches of macrophytic vegetation with *S. natans*, phytosociological relevés were taken using the Braun-Blanquet method (Dzwonko 2007). It allowed the phytocenotic characteristics of the species new localities. The systematics was taken from Matuszkiewicz (2008) and the botanical nomenclature – from Mirek *et al*. (2002).

3. Results

The study conducted between 2013 and 2017 in various water basins, rivers, riverbeds and canals of Wrocław recorded 32 locations of *S. natans* (Fig. 1),

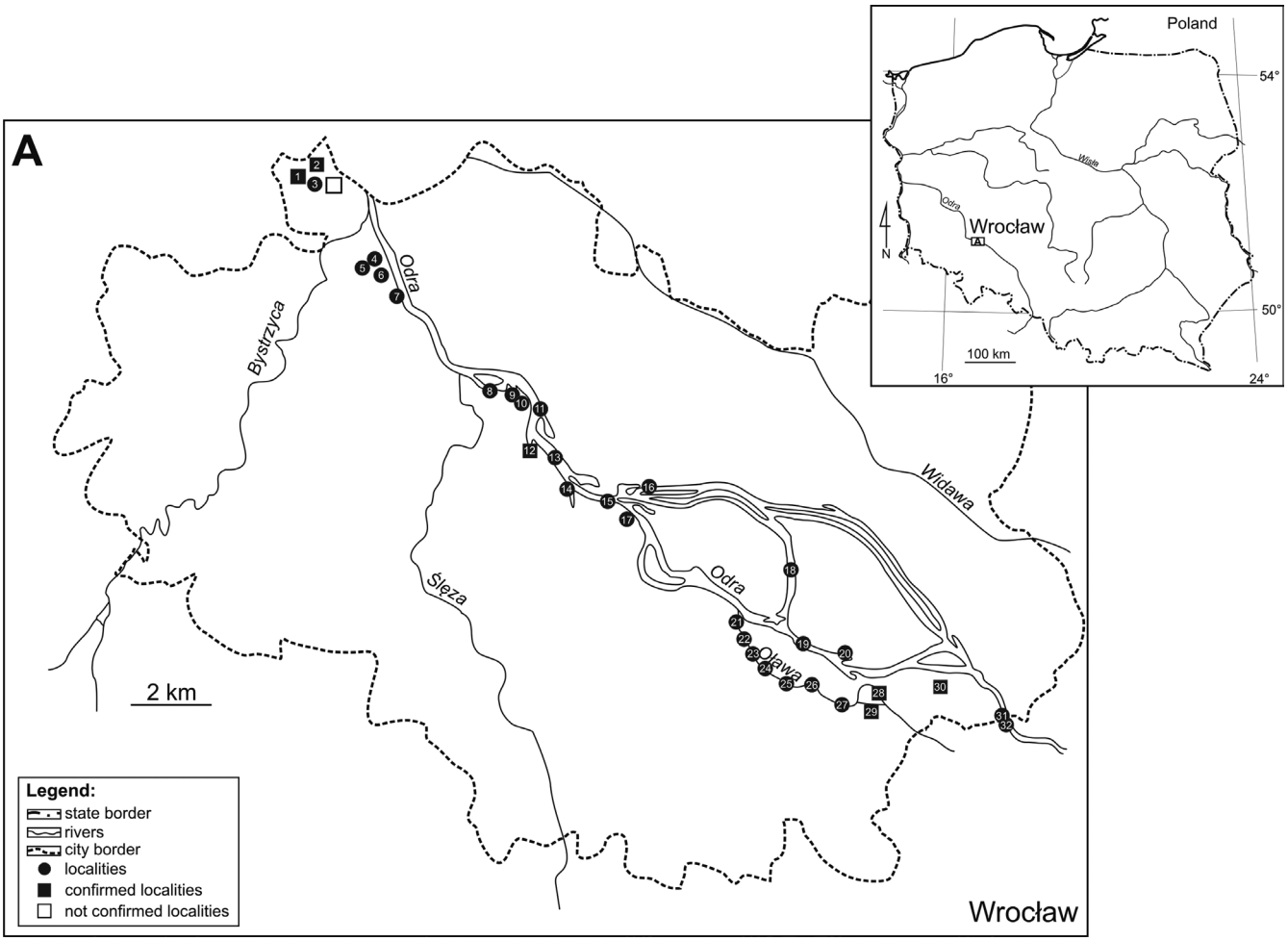

Fig. 1. Location of *Salvinia natans* (L.) All. localities in the study area (Wrocław). Localities 1-32 described in Appendix 1

which suggests a significant spread of the species in recent years. *S. natans* in Wrocław is strictly connected only with the Odra and the Oława valleys and was found in the stream and in the various water reservoirs of these rivers in the whole city. The species was not recorded in the valleys of the Ślęza, Bystrzyca and Widawa rivers nor in the smaller branches flowing directly into the Odra. Populations of various sizes were recorded in locations with strong current (in rivers and canals), in habitats with slow current (the Odra bays) and in natural and artificial basins with stagnating water [old riverbeds, ponds, excavation sites]. The recorded population differed in size, from very small clusters with only several specimens [mainly in the current and in the riversides of rivers and canals] to dense populations covering large areas of the water surface [in bays, slow current and stagnant waters].

Within the *S. natans* locations, the study recorded numerous pleustonic and rhizophyte communities (Appendix 1). *S. natans* populations usually occurred in the presence of *Lemna minor* L. and *Spirodela polyrrhiza* (L.) Schleid. On the water surface, the study recorded *Nuphar lutea* (L.) Sibth. & Sm. and *Nymphaea alba* L. and *Hydrocharis morsus-ranae* L., especially in the old riverbeds and bays of the Odra and the Oława (with extremely rare occurrences of *Stratiotes aloides* L.). In some locations, it was also accompanied by submerged plants *Potamogeton natans* L., *Ceratophyllum demersum* L., *Najas marina* L. and increasingly common in the Odra invasive *Elodea canadensis* Michx. Some locations, particularly the old riverbeds and bays, also had well developed rush communities with species such as the following: *Phragmites australis* (Cav.) Trin. ex Steud., *Typha latifolia* L., *Phalaris arundinacea* L., *Glyceria maxima* (Hartm.) Holmb. Other locations were poor in rush vegetation but rich in grass communities, probably due to mowing and river-flow regulation.

The range and distribution of *S. natans* in the waters of the Odra and the Oława means that a part of the population moves and spreads in the currents of these rivers and forms lasting and well developed communities in friendly and stable habitats of stagnating waters of old riverbeds and bays.

4. Discussion

Until the end of the 20th century, majority of Polish *S. natans* locations was recorded in southern and central parts of the country (Ochyra 1985; Macicka & Wilczyńska 1993; Macicka-Pawlik & Wilczyńska 1996). They were long-known, usually small but stable populations. In the last two decades in Poland, over 50 new and often rich sites were discovered (Pawlikowski & Szewczyk 2003; Markowski *et al*. 2004; Spałek 2005, 2006; Krawczyk & Majkut 2008; Nowakowski 2011, Gałka & Szmeja 2012, 2013; Stajszczyk & Fujarczuk 2013; Szmeja *et al*. 2016, Łukaszek & Kołodziejczyk 2016). The increase in *Salvinia natans* sites and the growth of existing populations is also observed in western Europe, e.g. in Baden-Württemberg and Rhineland-Palatinate (Wolf & Schwarzer 2005). The growth in numbers and quantities observed in Wrocław confirms the trend.

One of the reasons for the evident *S. natans* expansion in the Odra and the Oława seems to be climate warming. *S. natans* is a thermophilic species with optimum of occurrence in warm meso- and eutrophic waters (Pieterse & Murphy 1990). An analysis of Polish climate conducted between 1959 and 2008 showed a steady growth of mean annual temperature, especially with reference to spring temperatures (on average 0.35°C every decade) (Marosz *et al*. 2011). According to many researchers, this resulted in the recent emergence of new *Salvinia* sites and in the growth of existing ones over recent years (Marczakowski & Stachyra 2003; Pawlikowski & Szewczyk 2003; Markowski *et al*. 2004; Afranowicz 2007; Święta-Musznicka *et al*. 2011). Mild and short winters visibly influence the growing share of pleustonic species in aquatic plant communities in a given year (Netten *et al*. 2010). The studies of *S. natans* expansion in the Wisła delta (Gałka & Szmeja 2012; Szmeja & Gałka 2013; Szmeja *et al*. 2016) confirmed the positive correlation between temperature and the generative multiplication of the species. For microspores and macrospores, temperatures around 0°C are deadly and cause them to freeze, whereas a young sporophyte developing above 12°C is very sensitive to rapid lowering of temperature. The lack of cold winters and the prolonged vegetation period increase the survivability of the species and aids *S. natans* grow in the Wrocław area.

During the years of studies, it was also observed that every year, the populations were richer in specimens. It is a consequence of the ease of generative multiplication of the species. Additionally, warmer winters cause larger numbers of sporocarps to hibernate at the bottom of the basins, which results in a bigger number of sporangia with spores. Large quantities of quickly formed gametes are transported in the current which causes a rapid growth of populations along the whole water-flow.

Krawczyk & Majkut (2008), who conducted research in the valleys of the Wisła and the San rivers, explain the growing number of *S. natans* sites with the presence of water birds. The process of moving young and small *S. natans* specimens on bodies of wild ducks was observed by Kucharczyk (2003). It may be one of the reasons of the increase of range and population number of the species in the Wrocław area and it corresponds to the growing trend of water birds inhabiting cities

(Bocheński *et al*. 2013). However, the weak adhesion of pleustonic species and their sensitivity to drying out (Wołek 1981) cause the transport to be short-ranged. It is mainly connected with the emergence of new, isolated populations of *S. natans* in small reservoirs and ponds located near the Odra or the Oława and lacking any direct contact with the main current.

The analyzed *S. natans* populations were abundant in the bays of the Odra and the Oława or inhabited small water basins. This fact is connected with the species biology, as it prefers slow laminar flow (Longhi *et al*. 2008). A fast water flow has an adverse effect on pleustonic species due to their exposition to waves and wind (Krawczyk & Majkut 2012). The populations observed in the riverbeds were formed by sparse specimens and located mainly in the shallow riverside areas, often in rush communities of the *Phragmitetea* class. Thick and stiff helophytes provide perfect protection for pleustonic species stabilizing the habitat.

The populations of *S. natans* occurring in Wrocław formed typical and repetitive [in the country scale] communities with pleustonic species such as *Lemna minor*, *Hydrocharis morsus-ranae* and *Spirodela polyrhiza*, less often with *Riccia fluitans* L., which populate riverbeds, ponds, canals and lakes usually occurring at 10 cm to over 300 cm water depth (Wołek 1997; Michalska-Hejduk & Kopeć 2002; Markowski *et al*. 2004; Spałek 2008; Krawczyk & Majkut 2008, 2012; Afranowicz 2007). The diversity of basins populated by *Salvinia natans* indirectly shows that, similarly to other pleustonic species, it is characterized by a wide ecological amplitude with reference to habitat conditions. Considering recent studies in northern and eastern Poland, the species proves to be surprisingly expansive, significantly growing in range and population quantity (Markowski *et al*. 2004; Krawczyk & Majkut 2008; Spałek 2008; Wojton & Kubejko 2012). The studies in Wrocław showed an identical trend. The Odra and Oława riverbeds had numerous new sites, several of which were rich in specimens and covered large surfaces. Of the previously recorded sites (Dajdok & Proćków 2003; Podlaska 2003; Proćków & Proćków 2005; Matuła 2012; Kamińska 2011; Szczęśniak 2013; Kiełbasińska 2014), only the population from Janówek disappeared (Fig. 1). The remission of *S. natans* from the site was caused by the drying out of the reservoir and the shading of it by *Salicetum pentandro-cinereae* (Alma 1929) communities. Drying out and overgrowth also cause *S. natans* sites in Sandomierz Basin to disappear (Michalska-Hejduk& Kopeć 2002; Krawczyk & Majkut 2008).

The increase in *S. natans* site numbers in Lower Silesia that has been documented recently shows that further observations of the species are required.

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Appendix 1. Description of *Salvinia natans* (L.) All. localities in the Wrocław area

Explanations: the square number in the ATPOL system (after Zając 1978) – **BE38, BE49, CE50**; Location, **(1)-(32)** – number and description of locality; cover of *Salvinia natans* population: + occasionally, 1 – less than 5%, 1+ – about 5%, 2 – 5-25%, 3 – 26-50%, 4 – 51-75%, 5 – 76-100%

Plant communities with *Salvinia natans* participation:
Ac: *Acoretum calami* Kobendza 1948
Af: *Azolla filiculoides* community
Ca: *Caricetum acutiformis* Sauer 1937
Ca-Cg: *Carex acutiformis-C.gracilis* community
Cd: *Ceratophylletum demersi* Hild. 1956,
Cg*:* *Caricetum gracilis* (Graeben. et Hueck 1931) R. Tx. 1937
Ec: *Elodeetum canadensis* (Pign. 1953) Pass. 1964
Gm: *Glycerietum maximae* Hueck 1931,
Hm-r: *Hydrocharitetum morsus-ranae* Langendonck 1935
Ip: *Iridetum pseudacori* Eggler 1933
L-S: *Lemno-Spirodelletum natantis* (Slavnić 1956) Korneck 1959
Lt: *Lemnetum trisulcae* (Kelhofer 1915) Knapp et Stoffers 1962
N-N: *Nupharo-Nymphaeetum albae* Tomasz. 1977
Np: *Nymphoidetum peltatae* (All. 1922) Bellot 1951
Pa: *Phragmitetum australis* (Gams 1927) Schmale 1939
Pc: *Potamogeton crispus* community
Ph: *Phalaridetum arundinaceae* (Koch 1926 n.n.) Libb. 1931
Pl: *Potametum lucentis* Hueck 1931
Pn: *Potametum natantis* Soó 1923,
P-N: *Potamo-Najadetum marinae* Horvatić et Micev in Horvatić 1933 corr.,
Pp: *Potametum perfoliati* Koch 1926 em. Pass.1964
Rn: *Ricciocarpetum natantis* Segal 1963 em. R.Tx. 1974
Se*:* *Sparganietum erecti* Roll 1938
Sp: *Spirodeletum polyrhizae* (Kelhofer 1915) W. Koch 1954 em. R. Tx. et A. Schwabe 1974 in R. Tx. 1974,
Ss: *Sagittario-Sparganietum emersi* R.Tx. 1953
Ta: *Typhetum angustifoliae* (Allorge 1922) Soó 1927
Tl: *Typhetum latifoliae* Soó 1927,

BE38: Pracze Odrzańskie (Janówek) old riverbed, left Odra bank: **(1)** Larger of the water bodies, protected as an ecological area, 1+, L-S, Hm-r, Pn, Pa, N-N, Pa; **(2)** Smaller of the water bodies, protected as an ecological area, 1+, L-S, Sp, Ca; **(3)** A water bodies protected as an ecological area ’Łacha Farna’, 1+, L-S, Cd, Pa, Tl, Ca, Ph; **(4)** A water bodies (former sandpit, outside the ecological area); 3, L-S, Hm-r, N-N, Ta, Pa; (5) A ribbon lake (riverbed lake) on Rogoźówka watercourse, 3, L-S, Ac, Tl, Gm, Ph; **(6)** Ecological area. ‘An area in Nowa Karczma in Wrocław’, 1, L-S, Sp, Cd, Ta, Pa; **(7)** A small water bodies in a field, 1, L-S, Lt, Ph, Ca-Cg;
BE38: Maślice Małe, the main flow of Odra: **(8)** An area near the Rędziński Bridge, 3, L-S, Se, Pa, Gm, Cg, Ph; Kozanów, left Odra bank: **(9)** An old riverbed bay on Odra near Pilczycki Forest, 1+, L-S, Sp, Se, Pa, Tl, Gm, Ph; **(10)** An old riverbed of Odra near Pilczycki Forest, 1+, L-S, Af, Hm-r, Pa, Tl, Gm, Ph; **(11)** The main flow of Odra, between sites 12 and 14, 1, L-S, Ph, P-N, Pn; **(12)** A bay on Odra with yacht harbor near the Wrocław-Fabryczna Police Station, 1-3, L-S, Pl, Hm-r, Pn, N-N, Se, Pa, Tl, Gm, Ph;
BE49: Osobowice, right Odra bank: (13) The main flow of Odra, near Osobowicki forest, 3, L-S, Pa, Cg;
BE49: Popowice, left Oder bank: **(14)** The main flow of Odra, the vicinity of Milenijny Bridge, 2, L-S, Sp, Se, Pa, Ph; **(15)** The Lower Odra, 3, L-S, Pa, Ph;
BE49: Karłowice-Różanka, right Odra bank: **(16)** The vicinity of Osobowicki Cemetary, the Old Odra, 2, L-S, Sp, Pa, Ph;
BE49: Popowice, a bay on the Lower Oder, left Oder bank: **(17)** Scout Water Camp ’Zatoka’, 4, L-S, Hm-r, N-N, Pa, Tl, Gm, Ph;
BE49: Zacisze, Ołbin, left Odra bank: **(18)** The vicinity of Szczytnicki Bridge, the Old Odra, individual specimens (S. natans recorded in 2013-2015, while in 2016, this locality has not been confirmed), L-S, Sp, Ph;
BE49: Main Odra flow, left Odra bank: **(19)** The vicinity of the Wrocław ZOO, 3, L-S, Ph; **BE49:** A bay on the river, right Odra bank: **(20)** Scout Camp ‘Stanica’, 4, L-S, Pn, Ec , Cd, N-N, Pa, Tl, Gm, Ph;
BE49: Grunwaldzki Square, main river flow of the Oława near the mouth of Odra: **(21)** The vicinity of Grunwaldzki Bridge, next to ‘Dom Na Wodzie’, 1, L-S, Sp, Pp, Hm-r, Pn, N-N, Pp**,** Pc, Ss, Tl, Gm;
BE49: Oławskie Suburb, the whole river width: **(22)** The vicinity of Oławski Bridge, +, L-S, Ss, Pa, Gm, Tl, Ip**;**

BE49: Oławskie Suburb, left Oława bank: **(23)** The vicinity of 'Kładka na Groblę' at Szybka St., 3, L-S, Ec, Cd, Pn, Pa, Tl, Gm; **(24)** The vicinity of 'Żabia Kładka', 1+, L-S, Hm-r, Ta, Pa, Tl, Gm;
BE49: Rakowiec, the whole river width: **(25)** The vicinity of Rakowiecki Bridge, L-S, Hm-r, N-N, Pp, Ta, Pa, Tl, Gm;
BE49: Oławskie Suburb, the vicinity of Młoda St., the whole river width: **(26)** Oława extension along the Młoda St., 5, L-S, Sp, Pa, Tl;
BE49: Oławskie Suburb in the vicinity of Siedlecka footbridge, left Oława bank: **(27)** Wilczy Kąt, 3, L-S, Ph;
BE49: Oława Górna, the vicinity of Bierdzańska St., the whole river width: **(28)** Park Wschodni, 5, L-S, Sp, N-N, Ss, Pa, Tl, Gm, Ip;
BE49: Numerous water bodies in water areas: **(29)** Świątniki, 2, L-S, N-N, Pa, Ip, Ac;
BE49: The vicinity of Opatowicka St., left Oława bank: **(30)** Nowy Dwór, 2, L-S, N-N, Hm-r, Pa, Gm, Cd;
CE50: The vicinity of Nadodrzańska St., left Odra bank, shallow part: **(31)** Trestno – Odra, 1, L-S, Sp, Ec, Cd, Hm-r, Pc, Pa, Gm, Ph;
CE50: The vicinity of Nadodrzańska St., a small pond: **(32)** Trestno – a small water reservoir, 3, L-S, Sp, Lt, Rn, Hm-r, Ss Pa, Tl, Ta.