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REVIEW

Rare wetland grass *Coleanthus subtilis* in Central and Western Europe – current distribution, habitat types, and threats

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Abstract

The moss grass *Coleanthus subtilis* (Tratt.) Seidl is a rare, diminutive grass which grows on wet muddy bottoms of drained water bodies displaying a high degree of water level dynamics, such as fishponds or water reservoirs. Due to the temporal character of its habitat, *C. subtilis* has a very short life cycle of only a few weeks. Therefore, the species and its habitats are legally protected on both national and international levels. This paper focuses on habitats and the conservation of *C. subtilis* in Central and Western Europe.

For the period of 2000–2013, the Czech Republic with more than 200 sites represents the main distribution area of this species in Central and Western Europe. During the same period, *C. subtilis* was recorded from 45 sites in three regions of Germany (33 Lusatia, 11 Ore Mountains, 1 Mid-Elbe River), 16 sites in France, 13 sites in Poland, and four sites in Austria. Since 2000, the number of records within these seven regions seems to have followed different trends: whereas two regions (Lusatia, Germany and southern Poland) became newly colonized and many populations established, in one region (Ore Mountains, Germany) the number of records diminished. Owing to its specific life cycle, both reproduction success and maintenance of *C. subtilis* populations are closely linked to the prevailing water level regime, mainly dependent on the management of the water body. Management for the conservation of *C. subtilis* populations should consider the entire complex of water bodies, as well as individual ponds. For the preservation of the species, at least one pond in each complex should be drained every year and each pond should be drained at least once within 5 years. Depending on local climatic conditions, ponds should be drained for 8–10 weeks during the time period from mid-March to mid-November.

Keywords

EU Habitats Directive; fishponds; *Isoëto-Nanojuncetea*; management; species protection; temporary wetland vegetation

Introduction

The moss grass *Coleanthus subtilis* (Tratt.) Seidl (Poaceae) [1], was discovered in 1811 by C. B. and J. S. Presl, who found the species growing on the bottom of a dried-out pond in the western part of the Czech Republic. The tiny grass (height 2–8 cm) can be identified by the shoots arranged in a rosette, the broadened leaf sheaths, and the curved leafs (Fig. 1).

Based on present information, *C. subtilis* has a wide but disjunctive distribution area and occurs only in the Northern Hemisphere: besides the known former or recent populations in Western and Central Europe (France, Austria, Czech Republic, Poland, Slovakia, Germany, and Italy), the species has been recorded also from southern Norway (Nittelva River), Russia (in the west: Ilmen Lake, Volkhov River; in the east: rivers Ob, Irtysh, Amur, Kamchatka peninsula, Sakhalin Island), China (Amur River, Jiangxi Province), USA and Canada (Columbia River and Fraser River) [2].

Coleanthus subtilis is an annual grass species with a life cycle lasting only a few weeks. The species usually forms low-growing stands amongst other short-living species and is typically found in communities of the class *Isoëto-Nanojuncetea* Br.-Bl. et Tüxen ex Br.-Bl. et al. 1952 [3–7]. Its primary habitats are the exposed, muddy areas of intermittently flooded depressions that are generally located alongside streams or rivers, and are typical of old river and stream floodplains [4,8]. However, *C. subtilis* is also known from man-made ponds and water reservoirs characterized by a significant and regular variation of the water level resulting in the creation of open, wet, muddy surfaces, at least in some periods of the growing season [9,10]. Currently, in Central Europe, *C. subtilis* can be found predominantly in such secondary, anthropogenic habitats [2,11].

One of the first studies on the ecology of *C. subtilis* was that of Hejný [9]. Due to its interesting ecological status, several studies have been carried out on the ecology, distribution and seed dispersal strategy of *C. subtilis* in the recent years (e.g., [2,12–18]).

Both the species and its habitats are legally protected at national and international (EU) levels: *Coleanthus subtilis* is listed in the Annexes II and IV of the EU Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora) and in Appendix I of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). Furthermore, the typical habitat of *C. subtilis*, "oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoëto-Nanojuncetea*", is listed in the Habitats Directive Annex I (code 3130). Being a rare and ecologically specialized species, *C. subtilis* is also listed in the red data books / red lists of endangered plants in Germany [19], the Czech Republic [20,21], Austria [22], Poland [23], and France [24]. In the *European red list of vascular plants*, it is classified under species of "least concern" (LC) [25].

Due to this international protection status, EU member states are highly liable for the preservation of *C. subtilis* populations and habitats. In order to properly meet this responsibility, fundamental knowledge is needed on the distribution of *C. subtilis*, its habitats and on potential threats. Furthermore adequate management guidelines are indispensable, because almost all current habitats of the species in Europe are anthropogenic.

The aims of this review are: (***i***) to compile the most recent data on the distribution of *C. subtilis* in Central and Western Europe, (***ii***) to characterize its habitats and vegetation types with its occurrence, (***iii***) to identify the major potential threats to the species, and (***iv***) to recommend appropriate management and conservation measures for anthropogenic water bodies inhabited by *C. subtilis* populations.

Methods

All currently available data on the ecology, habitats and distribution of *Coleanthus subtilis* in Europe were compiled, and an extensive literature and data survey on the occurrence of *C. subtilis* populations was undertaken for Central Europe (Germany,

Czech Republic, Poland, Austria) and adjacent states (e.g., France, Russia). All sites with records of *Coleanthus subtilis* since 2000 are regarded as "recent localities" in this paper. For the time period from 2000 to 2013, the species databases of nature conservation authorities (Germany: Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie; Czech Republic: AOPK ČR; France: Conservatoire botanique national de Brest) as well as literature sources were used to compile the current distribution of *C. subtilis*. Moreover, many of the sites were visited by the authors (all sites in Germany and Poland, most in France, and numerous sites in various regions of the Czech Republic).

Life cycle and ecology of *Coleanthus subtilis*

Coleanthus subtilis (Fig. 1) is an annual grass (Poaceae) which colonizes the surface of wet, preferably muddy substrates, usually having a high organic content, in intermittently flooded habitats. Its primary habitats are located in the flood plains of large rivers, whereas its secondary habitats are generally (fish) ponds or water reservoirs. Once the water level drops, exposing wet muddy surfaces, seeds present in the soil germinate. Consequently, *C. subtilis* is amongst the first colonizers in these temporary habitats [9].

Since both growth and development of *C. subtilis* depend on a high water content of the substrate, its entire life cycle, comprising germination, vegetative growth and reproduction, is completed within (5)6 to 7 weeks in Central Europe [9] and within 8 to 10 weeks in Siberia [5,26]. Furthermore, for germination the seeds require diurnal temperature fluctuations of at least 20°C [9], which occur mainly in spring, late summer and fall. Consequently, the potential growing season of *C. subtilis* reaches from mid-March / beginning of April to the end of October/mid-November, depending on local climatic conditions.

With up to 12 000 individuals per square meter as observed in primary habitats (Russia, Ob) [27], and up to 7700 individuals per square meter in secondary habitats, (Poland, fishponds; Dajdok and Klink, unpublished), plant density can be very high. Under optimal conditions, an individual plant can produce 2500 or more seeds [9]. Soil seedbank density values estimated for the upper 3 cm of mud layer in several South-Bohemian fishponds (Czech Republic) and expressed as number of emerged seedlings varied between approximately 6200 and 24 500 seeds per square meter [28]. It has been proposed that *C. subtilis* seeds can persist in the soil seedbank for decades [9], as has been demonstrated for other mud-colonizing species of the *Isoëto-Nanojuncetea* [29,30].

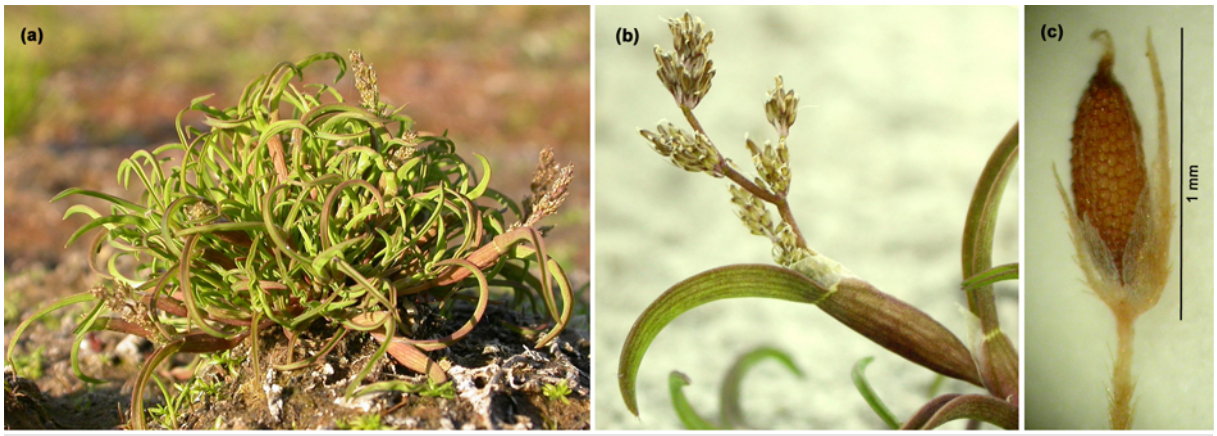

Fig. 1 The moss grass *Coleanthus subtilis* – plant (**a**), inflorescence (**b**), caryopsis (**c**).

General remarks on the phytosociology of *Coleanthus subtilis*

For Central Europe, first analyses describing the alliances of the class *Isoëto-Nanojuncetea* and including plant communities with *Coleanthus subtilis*, were performed in the first half of the twentieth century by Koch [31], Uhlig [32–34], Klika [35], Moor [36], and Ambrož [37], and later revised and extended, e.g., by Pietsch [38,39], Pietsch and Müller-Stoll [3], and Täuber and Petersen [6]. In this chapter, classification and nomenclature follow the synopsis of Chytrý [40].

Coleanthus subtilis is usually considered as characteristic species of the alliance *Eleocharition ovatae* Philippi 1968 (syn. *Elatino-Eleocharition ovatae* Pietsch 1973; class *Isoëto-Nanojuncetea*). It finds optimal conditions for its development in the association *Polygono-Eleocharitetum ovatae* Eggler 1933 (syn. *Eleocharito ovatae-Caricetum cyperoidis* Klika 1935, *Peplido portulae-Eleocharitetum ovatae* Pietsch 1973) which is a moisture and relatively nutrient demanding plant community (e.g. [7,41]). In Europe, these plant communities can be mainly found on exposed bottoms of fishponds, and outside of Europe on lake margins and in large riverbeds [4,39]. Some authors classify the stands predominated by *C. subtilis* as a specific sub-association or even association in its own right (e.g., [3–5,42]). However, from major part, the basic species composition of the stands is always very similar: *Carex bohemica* Schreb., *Elatine hydropiper* L. emend. Oeder, *E. triandra* Schkuhr, *Eleocharis ovata* (Roth) Roem. & Schult., *Gnaphalium uliginosum* L., *Juncus bufonius* L., *Limosella aquatica* L., *Peplis portula* L., *Spergularia echinosperma* Čelak. and *S. kurkae* Dvořák are among the most abundant characteristic species of this alliance and of the *Isoëto-Nanojuncetea* class. The combination of these species accompanying *C. subtilis* varies in space and time, according to substrate type and moisture conditions. For example, *E. hydropiper*, *E. triandra*, and *L. aquatica* are typical for the early stages of vegetation development on deep muddy substrates with high moisture. The species *J. bufonius*, *G. uliginosum*, *S. echinosperma*, and *S. kurkae* accompany *C. subtilis* on sands with only shallow layers of mud (up to ca. 5 cm), subjected to faster desiccation. *Carex bohemica* and *E. ovata* occur only as young plants in the stands predominated by *C. subtilis* and produce more biomass, flowers and fruits after *C. subtilis* has died off.

Additionally, the stands of *Coleanthus subtilis* are often accompanied by species of the classes *Bidentetea tripartitae* Tüxen et al. ex von Rochow 1951, *Littorelletea uniflorae* Br.-Bl. et Tüxen ex Westhoff et al. 1946, *Phragmito-Magno-Caricetea* Klika in Klika et Novák 1941 and *Potametea* Klika in Klika et Novák 1941. Species of the class *Bidentetea tripartitae* are very common components of the vegetation with *C. subtilis*. Examples are *Alopecurus aequalis* Sobol., *Bidens radiatus* Thuill., *B. tripartitus* L., *Chenopodium rubrum* L., *Persicaria lapathifolia* (L.) Delarbre, *Ranunculus sceleratus* L., *Rorippa palustris* (L.) Besser, and *Rumex maritimus* L. However, the establishment of tall and dense stands of highly competitive *Bidentetea* species takes place after *C. subtilis* has already completed its life cycle.

Under specific conditions, *Coleanthus subtilis* may also occur in perennial stands of the classes *Littorelletea* and *Phragmito-Magno-Caricetea*. For instance, in Poland and the Czech Republic the species is known from short reed beds of the association *Bolboschoenetum yagarae* Eggler corr. Hroudová et al. 2009 (alliance *Eleocharito palustris-Sagittarion sagittifoliae* Passarge 1964, class *Phragmito-Magnocaricetea*), predominated either by *Bolboschoenus yagara* (Ohwi) Y. C. Yang & M. Zhan or by *B. laticarpus* Marhold, Hroudová, Zákravský & Ducháček ([43]; Šumberová, unpublished). Although *Bolboschoenus* spp. usually form dense stands, in the time of flowering and fruiting of *C. subtilis* they are only resprouting from the underground tubers and thus are not competing with the annual grass species.

Recent data on the distribution of *Coleanthus subtilis*

The data set relating to the distribution of *Coleanthus subtilis* in Central and Western Europe presented in the following chapters is based on contributions by Woike [10] for whole Europe and by Hejný [9] for the former Czechoslovakia. A recently updated

general survey of its global distribution is given by John [2], and this is supplemented here by new data.

In Central and Western Europe, recent localities (records since 2000) for *C. subtilis* with former records are known from the Czech Republic, Austria, Germany, and France (Fig. 2). In the Czech Republic, 200 sites are listed in the national database (AOPK ČR), but it can be assumed that at least 250 ponds are populated by this species (Turoňová, AOPK ČR, personal communication, 2014). Therefore, the Czech Republic covers the main distribution area for this species in Central and Western Europe (see also [10]). Most of the populations are located in the southern and southwestern part of the country (Třeboň basin, Českobudějovická basin, Blatná region, Bohemian-Moravian Uplands). The majority of *C. subtilis* populations are found in fishponds and other water bodies associated with fish farming.

Since 2000, *C. subtilis* was rediscovered (plants, seeds) in at least four fishponds in Upper Austria (Waldviertel) with former records from the 1970s or even the 1930s [44,45]. They occur in close vicinity to the Czech fishpond systems in the Třeboň basin (Fig. 1).

In Germany, records of *C. subtilis* for the period 2000–2013 exist for 11 water bodies in the Ore Mountains in southern Saxony [11]. The last record at the Elbe River (Saxony-Anhalt), in an abandoned meander, was in 2003 ([46]; Jage, personal communication, 2011).

In Western Europe, *C. subtilis* is known from Brittany in western France [14,47]. In the period from 2000 to 2005, this species was documented for 14 water reservoirs [14], and in 2011, a survey by one of the authors (AH) and others revealed that it was still present in six of them and in two reservoirs without former records (Tab. S1).

A recent expansion of its range can be observed in two regions that have been newly colonized by *C. subtilis*: in Lower Silesia (southwestern Poland) and in the Lusatia region (eastern Saxony/Germany). In Lower Silesia, *C. subtilis* was first discovered in the late 1990s [13]. Since the ponds of this region had occasionally been observed previously by one of the authors (ZD) and other botanists, it is unlikely that the species had been overlooked previously. Regular surveys of drained ponds began in 2011. Here, *C. subtilis* has been recorded for three fishpond complexes located in Lower Silesia. The first record of its occurrence was for Borowa Oleśnicka, near Wrocław [13], where

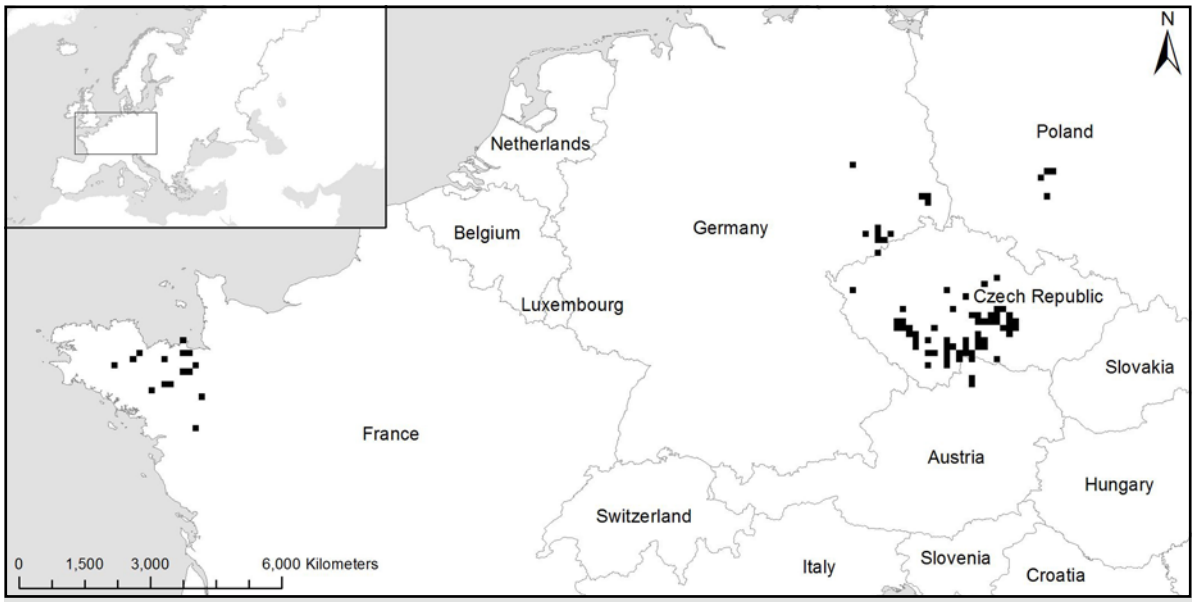

Fig. 2 Distribution of *Coleanthus subtilis* in Central and Western Europe. All known recent records (since 2000) from France, Germany, Czech Republic, Austria, and Poland (10 × 10 km grid) are shown. Data sources: (***i***) France: Conservatoire botanique national de Brest; personal communication – AH: Marion Hardegen, 2011; present authors' investigations in 2011; (***ii***) Germany: [11]; Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie; (***iii***) Czech Republic: AOPK [Turoňová, AOPK ČR (Nature Conservation Agency of the Czech Republic), personal communication, 2014]; Poland: [13,48]; Fabiszewski, unpublished; Kącki, 2007, unpublished.

five ponds within this small fishpond area had been colonized by *C. subtilis*. Two other sites are located in two larger fishpond complexes in the Barycz River valley, some 15 km apart: the first is Ruda Milicka, where two populations were detected in 2008 and 2013 ([16]; Dajdok, unpublished), the other is Ruda Sułowska, where *C. subtilis* was found first in 2012 [48], and is now known from six fishponds.

In the Lusatia region in eastern Saxony (Germany), *C. subtilis* was discovered in 2001 for the first time, growing on the open mud of a drained fishpond [12]. Since then, it has been regularly discovered in a total of 33 fishponds [11,49–51]. Owing to the fact that almost all the ponds are located in the "Oberlausitzer Heide- und Teichlandschaft" biosphere reserve, and have previously been intensively studied by several botanists, it can be excluded that the species occurred in this region before 2001 [50].

Characterization of habitats

Floodplains, tributaries of large rivers, and cut-off meanders

Floodplains, tributaries, or meanders represent the primary habitats of *Coleanthus subtilis*. All primary habitats are flooded annually by snow-melt flood and become exposed following a lowering of the water level [11]. Due to the regulations of European rivers and streams, almost all primary habitats of *C. subtilis* got lost and can now be found only outside of Europe at Siberian streams [4,52–54], Sakhalin (1992, 1994) and Kamtchatka (1992; W. Pietsch, personal communication, 2011), and China [52,55]. In Europe, primary habitats of *C. subtilis* are represented only by rivers in Norway, Slovakia (populations extinct [9,10,56]), Germany, and the Czech Republic. In Germany, *C. subtilis* was observed at the Middle Elbe floodplain, at abandoned meanders and natural oxbow lakes [46,57,58]). In the Czech Republic, this species is known from the muddy river deposits occurring in the active courses of the smaller rivers of South Bohemia, especially in those of the Lužnice River [59]. In Central Europe, both flooding and a drop in water level are correlated with extraordinary weather conditions, which can occur at any time of the year.

Water reservoirs

Water bodies used for water storage purposes (reservoirs) containing *Coleanthus subtilis* populations are known from the German Ore Mountains (here termed mining ponds) and from Brittany (western France). In the Ore Mountains, *C. subtilis* populations are known from ponds built in the sixteenth century, primarily as water reservoirs for driving water-wheels at the silver ore mines and metallurgical plants near Freiberg, Saxony (overview in John et al. [18]). The entire water system consists of several ponds connected by ditches and trenches. Seeds found in sediment cores from the oldest ponds [2] show that ponds were inhabited by *C. subtilis* soon after their construction at least 450 years ago. The water level in the mining ponds was influenced by two factors: the water requirements of the ore mines and precipitation. Usually, the discharge of water took place during the dry summer season and the lowest water level regularly occurred during September and October. Even though the mining was abandoned in this region about the middle of the last century, some changes in water levels still occur. Since 1990, the water management regime changed, and the frequency and the extent of changes in the water level became reduced according to changes in water demand. Consequently, the frequency in records of *C. subtilis* also diminished [2,11]. Remarkably, in this region, *C. subtilis* is only found in ponds that are directly connected to the historical pond system [2].

In Brittany, *C. subtilis* occurs in water reservoirs that provide drinking water, general water supply, and water for the Nantes-Brest channel [60]. In contrast to the ponds of the Ore Mountains, these water reservoirs are much larger and deeper, but due to a comparable management the water level dynamics can be assumed as similar. In these reservoirs, *C. subtilis* populations can be found growing on shallow shores

comprising accumulated mud where seeds can germinate, even when the water level has dropped only slightly.

Fishponds

In the Czech Republic, Austria, Poland, and Lusatia (Germany) various types of ponds used for the traditional spawning and rearing of common carp (*Cyprinus carpio*) were investigated in order to assess their importance for the maintenance of *C. subtilis* populations. In previous centuries, a sophisticated system of differently managed pond types was established in order to reflect the requirements of carps at different stages of their development (see Tab. 1):

- Spawning ponds: these ponds are used for spawning and rearing the spawn (eggs) to fry (hatched larvae). Since higher water temperatures are required for spawning and hatching, these ponds are small and flat. After hatching, the fry spend only a few days in these ponds. When not in use, the spawning ponds are drained; this period usually lasts for more than 11 months (Tab. 1).
- Nursery ponds (fry and fingerling ponds): in nursery ponds, which are larger than spawning ponds, the carp fry are reared for 1 or 2 years until they become juvenile carp. Every year, or every second year, the ponds are drained, mainly in fall or spring (Tab. 1), and the fish are harvested. The nursery ponds are then left to dry throughout the winter (if ponds drained and fish harvested in fall) or in early spring (if ponds drained and fish harvested in spring) and in many cases also throughout the entire or parts of the growing season (summer drainage or short summer drainage which usually continues until the end of May to mid-June; Tab. 1).
- Stocking ponds (main ponds): the 1- or 2-year-old carp are transferred to stocking ponds, which are usually the largest and deepest ones. Here the carps grow, eventually becoming marketable fishes at the age of 3 or 4 years. The stocking ponds are emptied either annually or biennially and in the same periods of the year as the nursery ponds.
- Fish storage ponds: these ponds are built for short-term storage of marketable fish [61]. Fish storage ponds are usually small, and sometimes bordered by stony or concrete walls. The fish are transferred from the stocking ponds to the storage ponds, mainly in fall, but occasionally in early spring. Therefore, fish storage ponds are most frequently used from fall to spring [15]. Traditionally, fish storage ponds are then drained and some are ready for use in December, the others from March/April until September/October. As a result of this management regime, fish storage ponds are kept dry for 6 to 10 months each year.

In addition to the water regime, further management is required to ensure an efficient functioning of the different pond types and the quality of the fish: so shallow ploughing or raking of the pond bottom is practiced in order to stimulate mineralization and thus prevent the accumulation of mud (Tab. 1). These practices are currently much less frequently used than in the past. Also lime is added to all types of ponds, mainly to stabilize the water pH and increase nutrient mineralization of the sediment to avoid the accumulation of mud [62]. Lime is also used for disinfection purposes, especially in storage ponds. A special management is needed for fish storage ponds when they are not in use: traditionally, the vegetation of empty fish storage ponds has to be mown and raked several times a year. Currently, many fish farms use herbicides, often combined with mowing or, alternatively, grazing (mainly by sheep), or the ponds are drained for a very short period (2–4 weeks) in advance of the fish storage season in order to inhibit the plant growth or to totally remove the vegetation [63]. The latter approach has become more popular in recent years.

The occurrence and abundance of *C. subtilis* differs considerably between the four pond types and is greatly affected by the water regime: due to the regular draining, which corresponds with fish harvesting (either in fall or in early spring) and continues until the end of May or June, most populations of *C. subtilis* can be found in nursery ponds (Tab. 1). For example, in Borowa Oleśnicka (Poland), draining starts at the end of October, and ponds are refilled at the end of May of the following year. During this

period (mainly in spring), *C. subtilis* completes its entire life cycle, from germination to the development and ripening of new seeds (Tab. 2). When nursery ponds are emptied every second year as, for example, in Ruda Sułowska (Poland), suitable habitat conditions for the development of *C. subtilis* are provided in every second year. In stocking ponds, *C. subtilis* can develop during the dry period of fall following fish harvesting (the plants survive the winter in their vegetative form and become fertile and complete their life cycle in the spring), or in spring before refilling in April or May (Tab. 1). Although a few *C. subtilis* populations in fish storage ponds are known from the Czech Republic [62,64], these ponds in general are not suitable habitats for several reasons: the water regime (drainage period is either too long or too short), the very shallow or absent mud layer, the development of dense vegetation in ponds during a long, dry period, the application of herbicides, and intensive liming [15,63,64]. Due to the long draining period, *C. subtilis* is not known from spawning ponds (Tab. 1).

Population trends in selected regions since 2000

In this chapter, we present data on the records of *Coleanthus subtilis* from years 2000–2013 for Germany (Ore Mountains and Lusatia; Tab. 2 and Tab. 3) and Poland (Tab. 4). The most comprehensive data set is available for the complex of mining ponds in the Ore Mountains (Germany), since these sites have been examined each year in this time period (Tab. 2). For this pond complex, the frequency of *C. subtilis* records has diminished significantly, especially during the last 8 to 10 years. The last record of *C. subtilis* with mature seeds dates from 2013, when only a single plant was found in one pond. During certain years (2006, 2012) with constantly high water levels, no *C. subtilis* populations could be found [11].

In contrast to the mining ponds in the Ore Mountains, the fishponds in the Lusatia region (Germany) have not been surveyed systematically and continuously (Tab. 3, Tab. S2). For example, no data exist for the period of 2002–2004. The highest number of records was found in 2007 (Tab. 3), but thereafter, the number of records per year declined until 2012. The high number of nine records in 2013 clearly indicates that the records reflect more the varying monitoring activities than a real decline in population size.

In Poland, *C. subtilis* has been regularly observed in the fishpond complex of Borowa Oleśnicka since 2000 (Tab. 4). In some of these ponds, *C. subtilis* was neither recorded in 2012 nor in 2013, even though the water level has been dropped. In the other pond complexes the species was first discovered in 2008 (Ruda Milicka) and 2012 (Ruda Sułowska). In 2013, most of these ponds had a high water level which prevented the development of *C. subtilis* (Tab. 4).

Specific threats to *Coleanthus subtilis* in anthropogenic water bodies

Depending on the type of the water body and its specific management regime, different factors can pose threats to *Coleanthus subtilis* populations, in particular, the frequency, timing, duration, and extent of the draining.

Water reservoirs in France

In water reservoirs, the lowering of the water level due to evaporation and water consumption during summer ensures that sufficient suitable muddy surface for the development of *C. subtilis* populations is available. Since the reservoirs are increasingly used by tourists and anglers, high water levels are often maintained also throughout the summer, resulting in reduced areas of drying mud. Furthermore, Lacroix et al. [14] suppose that the increasing eutrophication of sediments stimulates the growth of annual nitrophilous plants such as *Bidens* spp. and *Persicaria* spp., which might replace smaller plants such as *C. subtilis*. It has been proposed that this process is

Tab. 1 Characteristics of pond types and suitability for the development of *Coleanthus subtilis* (after Šumberová et al. [15] and present authors' observations).

Characteristics	Spawning ponds	Nursery ponds	Stocking ponds	Fish storage ponds
Period of draining	May/June (after fish hatching) – May/June	(***i***) September/October – May/June (fall fish harvesting) (***ii***) March/April – May/June (spring fish harvesting)	October/November – April/May	Between December and March/April – fall (traditional model)
Duration of draining	11–12 months	2–3 months, sometimes the whole growing season	2–3 months, sometimes the whole growing season	6–10 months (currently, usually much less, in some cases up to 1 month)
Rhythm of draining (years)	1	1–2	1–2	1
Further management of the pond bottom	Growing perennial wet meadow grasses and graminoids, mowing, occasional liming	Ploughing/raking, fertilization (dung, compost), growing cereals, occasional liming	Fertilization (dung, compost), supplemental fish feeding (with cereals), occasional liming	Mowing and raking, grazing, spraying with herbicides, regular liming
Frequency of *C. subtilis*	Not populated	High	Medium	Low

Tab. 2 Records of *Coleanthus subtilis* in selected ponds in the Ore Mountains (Germany). Only ponds with records from 2000 onwards and with available data on water levels are listed (based on data from Richert et al. [11], database Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie).

Pond name	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Dittmannsdorfer Teich	≈	⦸	○	•	≈	•••	⦸	••	≈	••	••	≈	≈	≈
Dörnthaler Teich	○	≈	≈	⦸	••	≈	≈	≈	○	≈	≈	≈	≈	≈
Oberer Großhartmannsdorfer Teich	•••	≠	≈	≈	≈	≈	≈	○	≈	≈	≈	≈	≈	○
Großhartmannsdorfer Großteich	•	•••	•	○	≈	•••	≈	≈	≈	≈	○○	≈	≈	≈
Berthelsdorfer Hüttenteich	≈	≈	•••	≈	⦸	≈	≈	≈	○	≈	≈	≈	≈	≈
Rothbächer Teich	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	*•	≠	≈	≈
Konstantinteich	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈	*•

Legend: ••• – large population (more than 50% of the area of the muddy bottom of the pond), seed maturity reached; •• – small-area population (less than 50% of the area of muddy bottom of the pond), seed maturity reached; • – single individuals, seed maturity reached; ○○ – large population, seed maturity not reached; ○ – small-area population, seed maturity not reached; ⦸ – no individuals of *C. subtilis* found during monitoring; ≠ – absence of *C. subtilis* due to long-term absence of water; ≈ – absence of *C. subtilis* due to high water level; * – first observation of *C. subtilis* in the pond; - – no data (not monitored).

responsible for the disappearance of more than the half of the known populations of *C. subtilis* since 1999 [14].

Water reservoirs in the Ore Mountains

Currently, the main functions of the historical system of mining ponds in the Ore Mountains are to provide drinking water and water for industry, fishery and recreational purposes [18]. For these, a continually high water level needs to be maintained, which contrasts markedly with the habitat requirements of *C. subtilis*. In recent years, the water level of most ponds has been lowered only occasionally for the harvesting of fish, for reconstruction works, or for nature conservation purposes, but in many cases the draining was done at unfavorable times, or was too short to ensure the germination and maturation of *C. subtilis* seeds (see Tab. 3; [65]). Even in ponds where *C. subtilis* usually occurred regularly, only a few or no individual plants have been reported in recent years. Consequently, it has to be assumed that *C. subtilis* populations of these ponds are highly vulnerable. Most of the ponds colonized by *C. subtilis* belong to a Natura 2000 site (Freiberg mining ponds, site code DE5045301). A management plan is available for this site since 2010 with requirements and recommendations for specific conservation measures necessary for the preservation of both *C. subtilis* and its habitat. But due to conflicts with other uses such as water resource management, fishery, and tourism the management plan has not yet been implemented completely.

Fishponds

The populations of *C. subtilis* in fishponds are considered to be safe for extended periods if the traditional water level management described, especially that of nursery ponds, is maintained. However, since the 1950s, fish-farming in Central Europe has experienced significant changes. Management changes have affected the populations of a number of plant species in various ways [62].

For example, during the last few decades, rearing fry in fish hatcheries under artificial conditions became increasingly common. As this in some cases could result in the premature release of fry, nursery ponds would be refilled before the life-cycle of *C. subtilis* is completed, and consequently, the seedbank would not be refreshed.

Ploughing the bottom of a populated pond leads to a loss of large areas of the (potential) habitat of *C. subtilis*. Usually, ploughing is done when *C. subtilis* seeds have already germinated, but since the plants have generally not completed their life cycle, seeds are lost. Ploughing is currently used much less frequently than in the past (e.g., the first half of the twentieth century), which represents a positive change in management.

As yet, the long-term effects of liming on *C. subtilis* are not known in detail. According to Hejný [9], von Lampe [66], and Šumberová et al. [15], *C. subtilis* avoids regions formed of calcareous bedrocks. Thus, liming can potentially lead to a reduction in the number and density of *C. subtilis* populations. However, the impact of liming in

Tab. 3 Number of fishponds containing *Coleanthus subtilis* populations in the Lusatia region (Germany) from 2001 (first record) to 2013 [based on data from Richert et al. [11], administration of the biosphere reserve "Oberlausitzer Heide- und Teichlandschaft", and personal communication (2013); detailed overview in Tab. S1].

	2001	2002–2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
New records	1		2	7	11	3	3	1	2	1	2
Records for known sites/ ponds				2	4	9	7	6			7
Total number of records	1	0	2	9	15	12	10	7	2	1	9

Tab. 4 All known records of *Coleanthus subtilis* from fishponds in Lower Silesia (Poland) based on data from Fabiszewski and Cebrat [13], Fabiszewski (unpublished), Kącki (2007, unpublished), Dajdok [48], and present authors' investigations in 2013.

Pond complex	Pond name	2000	2001	2002	2003	2004–2006	2007	2008	2009	2010	2011	2012	2013
Borowa Oleśnicka	Staw Kolejowy	* •••	•••	•••	•••	•••	•••	•••	•••	-	•••	•••	•••
	Staw Borowski	* •••	•••	•••	•••	•••	•••	•••	•••	-	•••	⦸	•
	Staw Łąkowy	* •••	•••	•••	•••	•••	•••	•••	•••	-	••	⦸	⦸
	Staw Bielawski	* •••	•••	•••	•••	•••	•••	•••	•••	-	••	⦸	⦸
	Staw Raków	⦸	⦸	⦸	⦸	-	* •••-	•••	-	-	•••	⦸	⦸
Ruda Milicka	Staw Polny	-	-	-	-	-	⦸	* •	≈	≈	≈	•	•
	Staw Jaskółczy	-	-	-	-	-	-	-	-	≈	⦸	≈	* ○
Ruda Sułowska	Staw Trześniówka Dolna A	-	-	-	≈	-	-	-	-	-	-	* •••	≈
	Staw Trześniówka Dolna B	-	-	-	≈	-	-	-	-	-	-	* ••	≈
	Staw Trześniówka Średnia	-	-	-	≈-	-	-	-	-	-	-	* •	≈
	Staw Płytki	-	-	-	≈	-	-	-	-	-	-	* •••	≈
	Staw Zewnętrzny	-	-	-	≈	-	-	-	-	-	-	* ••	≈
	Staw Przydrożny	-	-	-	⦸	-	-	-	-	-	-	* ••	••

During the period 2004–2006, only four ponds in Borowa Oleśnicka complex were managed, and the situation was the same for each year; consequently, the data for those 3 years are combined in one column. Legend: see Tab. 2.

particular depends on the amount of lime added as well as on the buffering capacity of the substrates.

In general, herbicides are only rarely used in fishponds and in nursery ponds in particular, because of the sensitivity of fish fry to herbicides. Therefore, the main habitats of *C. subtilis* are mainly protected against herbicide application. Much more frequent is the use of herbicides in fish storage ponds, but such ponds are not suitable for *C. subtilis*.

Climate change may potentially influence *C. subtilis* populations in direct (i.e., interactions with the temperature requirements and life cycle of the species) as well as indirect way (i.e., the influencing the hydrodynamics of its habitats). Extreme climate events such as intense flooding or prolonged periods of dry weather can only be modified to a limited degree by pond management. Frequent occurrence of such situations could even result in the abandonment of fish farming for economic reasons. As traditionally managed fish farming ponds are essential habitats for *C. subtilis* in

Central Europe, their use for other activities, or even their total abandonment and/or destruction, would present a most serious threat.

Management recommendations

In general, so as to be able to react quickly to potential threats, population trends should be systematically monitored. Recent data on the Ore Mountains population reveal that, owing to changes in the water management regime, it will be necessary to reassign *Coleanthus subtilis* in a few years to the "endangered" category. By contrast, two new pond complexes in Poland and Germany have become newly colonized. It remains unclear what the processes were that led to this more or less synchronous colonization of these pond complexes, nor can it be predicted whether or not these populations will remain stable. Consequently, the protection of long-known populations should be given the highest priority. In secondary habitats, this can only be done by means of selected management measures, and taking into account the ecology of the species.

The hydrochore exchange of seeds between the ponds is limited: firstly, seed transportation cannot take place against the direction of water flow. Secondly, in anthropogenic ponds the water balance is regulated by gates having only a relatively small opening, and these restrict seed transport. Therefore, not only should the entire pond system be considered as highly important when planning management measures, but also each individual pond should be taken into account. Since long-term European data on the longevity of the seedbank of *C. subtilis* under natural conditions are not available, a periodic refreshing of the seedbank is necessary in order to maintain a stable population. In the natural habitats of Siberia, *C. subtilis* develops almost every year at its usual sites, as water level fluctuations occur seasonally [4]. In anthropogenic ponds, *C. subtilis* seeds have the capacity to germinate after being submerged for at least 5 years (Tab. 3). However, the longer the seeds lie at the bottom of the pond, the greater is the probability that they could be covered with sediment and prevented from germination after draining. Based on these considerations and our current knowledge on the ecology of *C. subtilis*, the following management guidelines are proposed:

- at least one pond in each complex should be drained every year to enable sufficient development of *C. subtilis* to produce mature seed;
- each pond should be drained every 5 years, or at least twice every 10 years;
- ponds should be drained for 8 to 10 weeks during the period extending from mid-March / beginning of April to the end of October/mid-November, depending on local climatic conditions;
- in order to meet the pH conditions preferred by *C. subtilis*, the quantity of lime applied in a pond should be adapted to the quantity and the buffer capacity of its bottom sediment;
- application of herbicides should be strictly avoided;
- sediment and vegetation disturbance (e.g., ploughing) should be limited and, if necessary, distinct patches of muddy vegetation should be left undisturbed;
- during periods of restoration works in ponds (e.g., mud removal), patches of vegetation with *C. subtilis* should be left to enable recolonization of the pond.

Conclusions

The review of current situation of *Coleanthus subtilis* in studied countries in Central and Western Europe shows that almost all current habitats of the species are anthropogenic. Owing to its international protection status, EU member states are highly liable for the preservation of *C. subtilis* populations and habitats. They can only meet their responsibilities by predefining the conservation practice and development measures for those – mainly anthropogenic – habitats. As such, the water management regime plays a key role. Thus, conservation measures for *C. subtilis* should be highly

predictable and viable in practice. For the early identification of trends in population development, populations in pond complexes should be monitored systematically. At present, for most pond complexes, the quality of data is inadequate and thus, an assessment of the conservation status of *C. subtilis* is difficult. Furthermore, investigations, for example on the longevity of seed buried in mud, or the sensitivity of *C. subtilis* to climate change, are required.

As the necessary conservation measures often have a negative impact on the current commercial use of water bodies, or reduce the profit gained thereby, financial incentives need to be created for their implementation. Site management, especially for Natura 2000 sites, should guarantee the long-term preservation of populations. Priority should be given to the preservation of long-lasting and highly dense populations of *C. subtilis*. In many cases the continued traditional production of common carp is the most effective way to protect *C. subtilis*.

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Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/asbp/rt/suppFiles/asbp.3511/0:

Tab. S1 Records of *Coleanthus subtilis* in water reservoirs in France from 2000 to 2005.

Tab. S2 Overview of the records of *Coleanthus subtilis* in the Lusatia region (Germany) from 2001 to 2013.

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