

## Peat excavations on fens – potential role of anthropogenic peat pools in supporting Odonata in Poland and central Europe

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**Abstract:** Peatlands are one of the most threatened habitats in Europe. They have been dried and changed into hay meadows and the peat was extracted for heating purposes. Climatic changes have also contributed to the vanishing of peatlands. This is why, water organisms are becoming endangered or extinct. In Poland, fens are the most common among peatlands, yet still, the fauna of invertebrates, in this case Odonata, is not fully examined, especially in anthropogenic habitats such as peat excavations. Such water bodies seem to be the last hope for typhophiles, since the pits are deep and the water mirror is visible which ensures reproduction. On account of degradation of natural habitats, anthropogenic waters are in the center of attention; they may become the secondary habitats for aquatic organisms, including dragonflies. Peat excavations are able to support populations of plants and animals. Nevertheless, they are still a by-product of extracting peat for a fuel and horticultural purposes and not the object of deliberate protection. Still, more have to be explored in the context on specific factors important for dragonflies living in peat excavations, in order to plan the conservation in a directed way. There are only few articles particularly about that subject in Poland and most of the authors concentrate mainly on peat pools on sphagnum bogs. There are some publications in Europe, though, with the ideas for protection and conservation of dragonflies. Nevertheless, more should be added concerning dragonflies on peat excavations specifically, since the naturalness of the habitat is not the main issue as far as biodiversity of odonatofauna is concerned. The aim of this article is to find available articles and papers which are focused on odonatofauna of peat excavations on fens (alkaline fens, where possible) to evaluate such habitats as useful anthropogenic water bodies in conservation of dragonflies.

**Keywords:** dragonflies, peatlands, mires, alkaline fens, conservation, biodiversity

### Introduction

Fresh water covers only 0.8% of the Earth's surface, but such ecosystems are among the most severely threatened in the world (Termaat *et al.* 2019). Peatlands are the most widespread type of wetlands worldwide, representing 50–70% of global wetlands (Chapman *et al.* 2003). They are one of the most precious habitats for aquatic invertebrates since they support almost 6% of all described species (mostly insects), nevertheless they are globally endangered (Termaat *et al.* 2019). These ecosystems are vulnerable towards changes such as lowering the water level, vegetation succession,

eutrophication and anthropopression (Chmiel & Urban 1993, Buczyński & Staniec 1998, Bernard & Buczyński 2008, Minayeva *et al.* 2008, Janssen *et al.* 2016, Szumińska *et al.* 2022, Tarkowski 2023).

Among the types of wetlands, fens are the most common, yet, nowadays, there are in majority, transformed into agricultural lands. The process of degradation is still ongoing on different scales, depending on the method of extraction (Lamers *et al.* 2015). The new threat is the global warming and droughts caused by this process (Dokulil 2014). Therefore, organisms connected with fens, especially

aquatic ones, are becoming threatened in many areas.

Fens in Poland are supposed to be one of the richest in peat in central Europe (Jasnowski 1977). In Poland, there are 152.964 ha of wetlands classified as fens (Ramsar 2025). According to Natura 2000 criteria, there are only 9% of wetland habitats in good condition in Poland (FV), 48% is unsatisfactory (U1), and 43% in bad condition (U2) (Stańko *et al.* 2018). It is all due to the changes in hydrobiological conditions – drying out and overgrowing with trees and bushes. Dry alkaline fens are more prone to be overgrown by eutrophic plants. Fens in good quality need to be cut only once for 3 to 5 years (Stańko *et al.* 2018).

The large-scale excavation of peat for fuel on peatbogs in Europe began in the eighteenth and nineteenth centuries (Ilnicki 2002). Since 19<sup>th</sup> century, over 82% of Poland has been transformed, mainly, for agricultural purposes. Additionally, meliorations and regulations of ditches, canals and rivers are some of the main causes of changes on wetlands, since they alter the conditions of habitats. The situation is similar in Slovakia, where it has been estimated that approximately 90% of the mires were lost as a result of human impact (Madaras *et al.* 2012a). This process of degradation causes great losses in odonatofauna, most of all, in populations of stenotopic species (Harabiš & Dolný 2011).

Dragonflies are considered to be good bioindicators of the condition of the environment, water pollution and climatic changes (Harabiš *et al.* 2023, Kietzka *et al.* 2023, Pinkert *et al.* 2023, Šigutová *et al.* 2023). Their occurrence and number of populations in a given habitat may suggest its shape, threats and needs for protection (Corbet 1993, Chovanec & Raab 1997, Samways 2008, Kutcher & Bried 2014, Termaat *et al.* 2015, Buczyński *et al.* 2017, Termaat *et al.* 2019, Veeken & Wassen 2020, Monzó & Verdú 2022). Odonata are indicators of different freshwater systems as they are sensitive to local abiotic conditions and to the surrounding

landscape (Kutcher & Bried 2014, Elo *et al.* 2015, Termaat *et al.* 2015). Dragonflies are diadromous invertebrates: larvae live in water, adults on earth, being among the best dispersers in the animal world (Corbet & Brooks 2008, Harabiš & Dolný 2010, Paulson 2019, Assandri 2021, Šigutová *et al.* 2023). This group of insects is well-known and described in details, they are quite easy to identify among other Insecta and attractive to look at (Paulson 2019, Termaat *et al.* 2019). Odonata are also very important organisms in a food chain. They are predators so decrease of their populations may have a strong impact on other water invertebrates (Elo *et al.* 2015).

Odonatofauna of peatlands is strongly endangered. Areas surrounding wetlands have become drained by intensive meliorations, which caused the peat layers to dry out (Buczyński 1997). It has been shown that loss of water determines the survival of dragonfly species. That can be seen while comparing data collected during dragonfly research projects from Lublin Voivodeship, Poland in 2007-2009 (wet years), and later, 2015-2017 (drier years) (Tarkowski 2023). The ones most prone to drying were meliorated odonatocoenoses, then used as hay meadows. It seems that unchanged areas, especially the ones located in nature reserves and other forms of protection and conservation, were in better condition, yet they were still endangered because of the lack of management of the land and secondary succession. The most important issue considering conservation is to keep the continuity and heterogeneity of habitats. For that reason, the matter of crucial role of peat excavations as secondary habitats has been taken up (Buczyński & Tarkowski 2018, Tarkowski 2023).

There are only few published data on Odonata on such anthropogenic habitats in Poland (Wendzonka 2001, Brulińska *et al.* 2005, Marczak 2008); the vast majority of them come from few macroregions in Lublin Voivodeship, mainly Western Polesie,

Volhynian Polesie, Lublin Upland and Volhynian Upland (Buczyńska & Buczyński 2006, Buczyński 1993, Buczyński 1995, Buczyński 1997, Buczyński 2000, Buczyński 2004, Buczyński 2008, Buczyński 2015, Buczyński & Staniec 1998, Buczyński *et al.* 2017). It is a deficiency in ecological texts with analyses of factors influencing the population abundance and species composition in peat excavations on fens, especially alkaline or calcareous ones which are rare types of fens in Poland. Even in central Europe, mostly in German-speaking countries, texts concerning Odonata, are mainly faunistic, often about endangered species, and to which data were gathered mainly from sphagnum bogs and not fens (Clausen 1984, Bönsel 1998, Olthoff & Ikemeyer 2011, Westermann & Westermann 2014).

Considering the vanishing and degradation of natural habitats, anthropogenic waters are drawn to attention more often – they can become secondary habitats for organisms typical for natural waters (Harabiš & Dolný 2011). In case of fens, peat pools are water bodies which sustain populations of tyrphophilic animals and plants. However, it is still a side-effect of agricultural management and not organized and carefully planned conservation, which demands a proper knowledge and insight of ecosystems of such water bodies and organisms occupying specific habitats, including factors shaping their occurrence and abundance (Buczyński 2015, Sievers *et al.* 2017, Mainstone *et al.* 2016).

It is important to explore the topic of anthropogenic water bodies in order to introduce active protection of dragonfly species by managing the already existing waterbodies or creating the new ones. To sustain the biodiversity and species composition, it is crucial to pay attention to the degree of flora succession surrounding the edges of the peat pool, but also physical and chemical properties of water (turbidity, conductivity, pH etc.). Additionally, elements of the landscape should be examined, which

are integral part of the habitat as a whole (Wildermuth 1994, Harabiš & Dolný 2011, Rannap *et al.* 2011a, Buczyński 2015, Buczyńska & Buczyński 2019, Tarkowski 2023). The main focus should be put on predictors dragonfly assemblages depend on. Only then, the specific protection of habitats and their residents would be possible and effective.

Climatic changes are pointed out as the main reason for changes in the odonatofauna of fens and peat excavations on fens; indeed droughts as consequences of global warming contribute to that, but it is not only because of rising water temperatures (Termaat 2023). The real threat for Odonata is the loss of habitats as well as their fragmentation and isolation (Assandri 2021, Assandri & Bazzi 2022, Pinkert *et al.* 2022). Excessive peatland terrestrification is harmful for most dragonfly species (Harabiš & Dolný 2010). Moreover, transformation of the environment and pollution, cause degradation of water habitats which has a measurable effect on Odonata (Buczyński & Czachorowski 2000, Harabiš & Dolný 2010, Assandri 2021, Šigutová *et al.* 2023). Neither intensification nor abandonment of land use for farming entail positive aspects for dragonflies. However, degradation of landscape caused by human activity, leads not to depletion of dragonfly species diversity, but alters species composition – there are more generalists than specialists of habitats (Dolný *et al.* 2021).

The confusion in classification of peatlands, in numerous occasions, enabled the author to enucleate which water body described in the articles, exactly fits the subject of this review. Fens as habitats for stenotopic species of dragonflies are described in general as a whole ecosystem and rarely, peat excavations are emphasized. Even the authors of very useful and composite guidebook to alkaline fens, provide no information about peat excavations; this term is mentioned only once without a definition or further analysis of fauna (Wotejko *et al.* 2019).

For this reason, most parts of the paper will be focused on Odonata on peat excavations on fens in general, though, the main interest of the author are such water bodies on alkaline fens. It will be pointed out in the text, what type of fen is being described, if there is an indication of it in the original paper. Moreover, the short subchapter concerning the classification of peatlands will be provided.

The main aim of the paper is to analyze the texts concerning odonatofauna in peat excavations on fens (alkaline fens, if possible) from Poland and central Europe. My main focus is on central-eastern parts of the continent since there are major changes in fauna between various geographical regions and it would be incomparable. However, I added some important, new research on that issue, from southern Europe as well (Italy).

### Classification of peatlands

Wetland is defined as an “area that is inundated or saturated by water to the extent that its vegetation is dominated by plants that are adapted to life in anoxic soil condition”. Peatlands are understood as wetlands “with naturally accumulated peat layer” and mires are specific kinds of peatlands “with vegetation that forms peat”. There is also the term “swob” which means “wetland with vegetation that may form peat” (Joosten *et al.* 2017, *distinction by the author*). The basic division of peatlands, is into fens and raised bogs; there is also an intermediate type of these two: transitional peat bogs (Okruszko *et al.* 2011). This division is known since the 16<sup>th</sup> century, first described by John Leland and then applied in other countries by e.g. Ramann (Hochmoore, Flachmoore). Fens are based on mineral soil water and have more diverse vegetation than bogs which are powered by rain water (Joosten *et al.* 2017). It seems that not only flora of fens is more diverse, but also fauna, including odonatofauna which will be described in this paper. In Poland, the peatland

area is as follows: 92,4% fens, 3,3% transitional peatlands and 4,3% bogs (Joosten *et al.* 2017).

Specific type of fens are alkaline fens or calcareous fens (Pietruczuk 2020). They can be found all over Europe, but the largest areas of these mires in EU are found in Sweden and Finland (Madaras *et al.* 2012a). EU Habitats Directive marked such areas with code 7230 and also gave them a specific term “*rich fens*” or “*extremely rich fens*”; the name reflects the higher pH >5,5 and the richness in mineral compounds (Wołejko *et al.* 2019, Pietruczuk 2020, Assandri 2021). As far as vegetation is concerned, alkaline fens may be characterized by brown mosses and low sedges (Wołejko *et al.* 2019). In 2012, the total area of habitat 7230 in EU was estimated at 534 600 ha, in Poland – 25 600 ha (Wołejko *et al.* 2019). In Poland, the habitat 7230 occurs across the country. Although, alkaline fens have large biodiversity of flora and fauna, including rare and endangered species, their conservation status is unfavourable both in Poland and in Europe (Wołejko *et al.* 2019).

### The role of peat excavations

In the face of climatic changes, especially droughts, peat excavations are the only places where aquatic insects may live and reproduce (Fig. 2). They are basically deep holes filled with water, artificially made by digging out the peat, mostly by hand (Moore 1976, Buczyński 2015). In Great Britain, researchers noticed that in places where peat has been excavated, dragonflies have a permanent access to the water surface, so their living cycle is not inhibited (Moore 1976). It appears that by creating peat pools, natural water networks are being filled with more places for insects to reproduce (Rannap *et al.* 2011a, b). Moreover, Italian research showed that odonatofauna of excavated sites may be even more abundant than the one of non-excavated fens (Assandri & Bazzi 2022). The reason for this is that excavation pools are usually colonized by plant communities of earlier successional stages,

resulting in increased habitat heterogeneity and availability of breeding sites for dragonflies (Assandri & Bazzi 2022).

Obviously, extraction of peat has to be done with a specific plan and supervision, without a heavy equipment. Moreover, it is important to monitor such sites to prevent them from secondary succession. The presence of plants, especially in the coastal zone, is important,

but, at the same time, it cannot, by overgrowing, interfere in the reproduction of dragonflies. Swiss rotating model of reducing vegetation shows that such species as *Leucorrhinia pectoralis* (Charpentier, 1825) (Fig. 1), prefers habitats in the middle stages of succession (3<sup>rd</sup> or 4<sup>th</sup>), where the relation between the open water surface and the plant cover is in balance (Wildermuth 2001).



Fig. 1. *Leucorrhinia pectoralis*, male.

Though digging is a clear interference in natural habitat, waterbodies formed in that way, may become, the only place for tyrphophiles and tyrphobionts to remain on overdried fens. Moreover, Moore suggests that the majority of waterbodies, were, at some point of time, created by human hands, and now, may be considered as examples of balanced and biodiverse habitats (Moore 1976). It has also been stressed once more, that species richness does not correspond to habitat naturalness, though endangered species are positively correlated with increasing naturalness. Species richness remains more or less the same in number, but the composition is changing (Dolný *et al.* 2021). Some freshwater ecosystems such as fish ponds (e.g. Dolný & Mižičová 2010, Buczyński 2015), sinkhole ponds (e.g. Miszta *et al.* 2007, Harabiš & Dolný 2012b; Harabiš 2016), stormwater ponds (e.g. Scher & Thiéry 2005, Dolný & Mižičová 2010, Holtmann *et al.* 2018, Šigutová *et al.* 2022) or even rice fields

(e.g. Corbet 1999, Satpathi & Borowski 2017, Huynh *et al.* 2020) that have been modified due to human activities, can serve as important secondary habitats for odonate assemblages.

Bearing in mind, the high significance of anthropogenic waters, the topic of peat excavations on fens as refugia of valuable species of dragonflies, is still analysed and described by only few researchers. Papers about faunistic aspects of dragonflies, where one can find a single reference to dragonflies on peat excavations, are quite numerous, yet they are mostly devoted to raised bogs or transitional bogs and not fens (Mielewczyk 1969, 1970, Jödicke 1999, Buczyński & Tończyk 2004, Bernard & Wildermuth 2005, Śniegula 2006, Harabiš & Dolný 2010, Frąckiel *et al.* 2013, Żurawlew 2013, Henel *et al.* 2015, Dolný *et al.* 2018, Senn 2018, Wilk 2019, Czechowski 2020, Kobyłecki 2020, Pawlak 2020, Tańczuk & Bojar 2021). However, ecological articles with statistical analyses of these types of pools are extremely rare (Buczyński 2015).

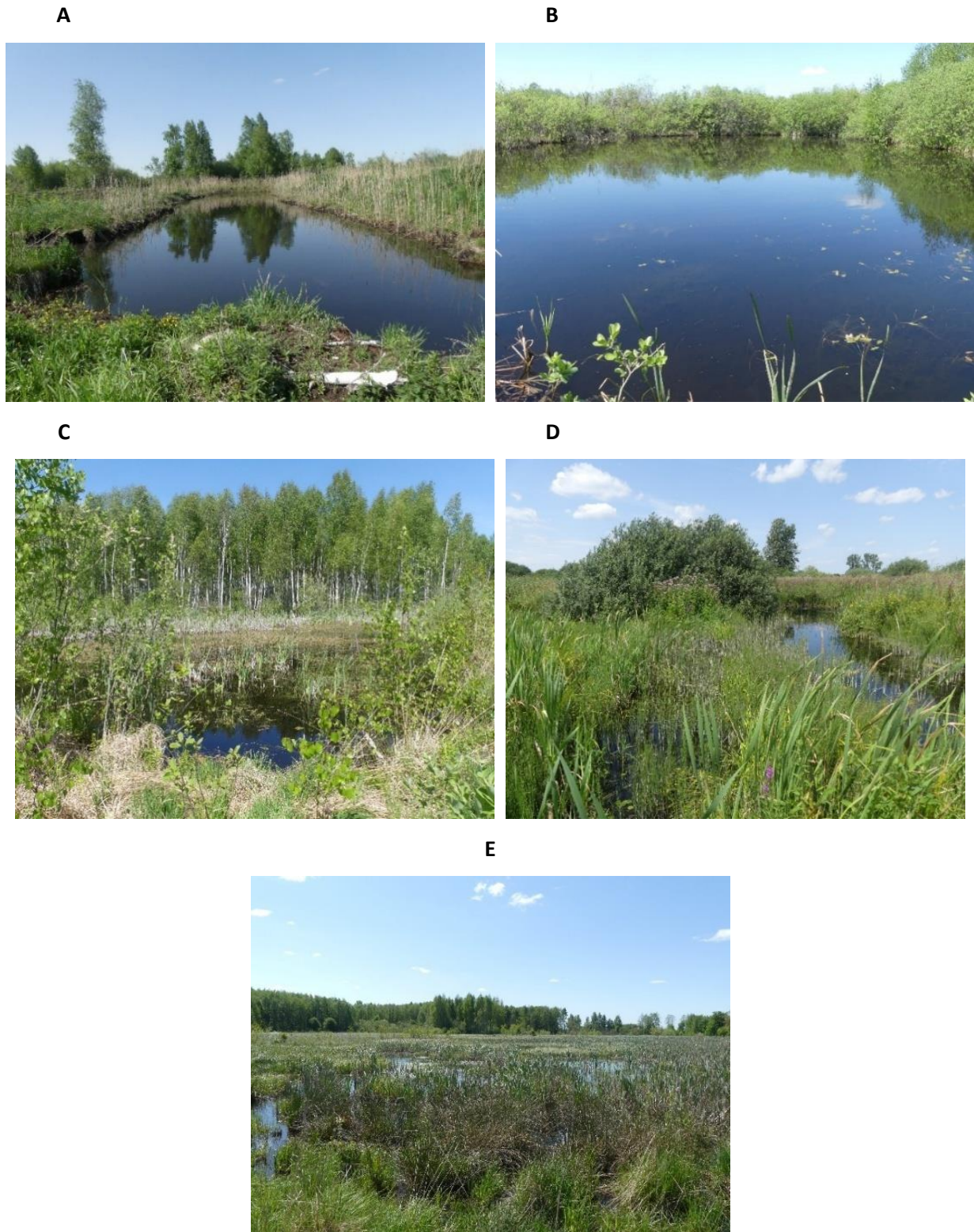


Fig. 2. Peat excavations in five stages of succession on alkaline fens with locations. A – stage 1, Stary Stręczyn (Volhynian Polesie). B – stage 2, Biesiadki (Western Polesie). C – stage 3, Garbatówka (Western Polesie). D – stage 4, Śniatycze (Volhynian Upland). E – stage 5, Syczyn (Western Polesie). Photos by Agnieszka Tańczuk.

There has been a good practice of publishing texts from odonatological symposia field work research, held annually in various regions of Poland; for few years now, some peat excavations are also being included to the research (Rychła *et al.* 2015, Buczyński *et al.* 2022, Tańczuk *et al.* 2023).

In Poland, the anthropogenic water bodies are rarely explored by odonatologists. There are many papers on odonatofauna of fish ponds, yet peat excavations on fens are not sufficiently described. The answer for this may be the fact that peat pools on fens seem to be less valuable, since, quite rarely, some endangered and rare species may be found there, in opposition to such water bodies on sphagnum bogs. Yet, this conviction is not entirely true because some tyrphobionts can also be observed in peat pools on fens (Table 1, Table 2). Such habitats seem to be underestimated, yet their biodiversity is noticeable. The most thorough research concerning peat excavations on alkaline fens are known from Poleski National Park and its vicinities and Lublin Voivodeship in general, e.g. Bagno Bubnów, Durne Bagno, Krowie Bagno or Chełm calcarous fens (Buczyńska & Buczyński 2006, Buczyński 1995, Buczyński 1997, Buczyński 2000, Buczyński 2004, Buczyński 2008, Buczyński *et al.* 2017). These texts describe the role of peat excavations as refugia of fauna, especially Odonata, Trichoptera and Coleoptera (Buczyńska & Buczyński 2019). They are not only faunistic texts, but more importantly, ecological ones, referring to specific factors in shaping the invertebrate fauna such as pH levels, concentration of dissolved oxygen in water, temperature of water, electrolytic conductivity, trophy, succession, vegetation abundance and structural differentiation of

vegetation and shade (Buczyńska & Buczyński 2019, Buczyński 2015). Such information provide important instructions how to modify peat excavations in order to protect odonatofauna.

## Odonatofauna of peat excavations on fens

Peat excavations on fens, in comparison to such pools on bogs, are characterized by greater diversity of dragonflies. Some valuable tyrphophiles may be found there e.g. *Lestes virens* (Charpentier, 1825) and others like: *Sympecma paedisca* (Brauer, 1877) or *Leucorrhinia albifrons* (Burmeister, 1839) (Fig. 7) (Buczyński 1993, Buczyński 1997, Jeziorski 1997, Buczyński & Staniec 1998, Buczyński 2000, Wendzonka 2001, Buczyński 2008, Marczak 2008, Stolarz 2011, Lis 2012, Lis & Buczyński 2012, Bena 2014, Mikołajczuk 2016, Buczyński *et al.* 2017, Wilk 2019, Senn 2020, Tańczuk & Bojar 2023, Tańczuk, unpublished data). The ones considered as “special care” species have been enumerated in Table 1.

Authors of texts concerning dragonflies on peat excavations on fens, located all over Poland, observed various numbers of species from several (Senn 2020), 21 (Stolarz 2011) until 35 (Daraż 2009) and even 44 in larger complexes of peat excavations (Buczyński 2015, Tańczuk *et al.* unpublished data). Most of them were eurytopic species or odonates of small water bodies. Many a time, some tyrphophiles or tyrphobionts are observed, also protected or rare in Poland, registered on the new *European Red List of Dragonflies & Damselflies (Odonata)* (De Knijf *et al.* 2024) (Table 2, Table 3).

Table. 1. The list of “special care” species of dragonflies observed in peat excavations on fens in Poland with the names of authors of data.

Species	Authors
<i>Lestes sponsa</i> (Hansemann, 1823)	Buczyński 1997, 2008, Buczyński <i>et al.</i> 2017, Wilk 2019, Stolarz 2011, Buczyński 2000, Tańczuk, unpublished data
<i>Coenagrion ornatum</i> (Selys, 1850)	Buczyński 2000
<i>Coenagrion hastulatum</i> (Charpentier, 1825)	Buczyński 1993, 1997, 2000, 2008, 2017, Daraż 2009, Stolarz 2011
<i>Coenagrion lunulatum</i> (Charpentier, 1840),	Buczyński 2000
<i>Coenagrion armatum</i> (Charpentier, 1840)	Buczyński 2000
<i>Nehalennia speciosa</i> (Charpentier, 1840) (Fig. 5)	Bernard & Buczyński 1998, Daraż 2011, 2009, Daraż & Bernard 2008, Mikołajczuk 2013, Mikołajczuk 2016, Wilk 2019, Tańczuk, unpublished data
<i>Aeshna juncea</i> (Linnaeus, 1758)	Buczyński 1997, 2008, Buczyński & Staniec 1998, Daraż 2009, Buczyński <i>et al.</i> 2017 Tańczuk, unpublished data
<i>Leucorrhinia dubia</i> (Vander Linden, 1825)	Buczyński 1993, Buczyński 1997, Buczyński <i>et al.</i> 2017, Buczyński & Staniec 1998, Wendzonka 2007
<i>Leucorrhinia rubicunda</i> (Vander Linden, 1825)	Buczyński 1993, Buczyński 1997, Buczyński <i>et al.</i> 2017, Buczyński & Staniec 1998, Wendzonka 2007
<i>Leucorrhinia pectoralis</i> (Charpentier, 1825)	Buczyński 1993, Buczyński 1997, Buczyński 2000, Buczyński 2008, Buczyński <i>et al.</i> 2017, Jeziorski 1997, Lis 2012, Marczak 2008, Mikołajczuk 2016, Senn 2020, Stolarz 2011, Wendzonka 2007, Tańczuk & Bojar 2023, Buczyński & Staniec 1998, Tańczuk, unpublished data
<i>Sympetrum danae</i> (Sulzer, 1776)	Buczyński 1993, 1997, 2008, Buczyński <i>et al.</i> 2017, Wilk 2019, Stolarz 2011 Tańczuk, unpublished data

As it was previously mentioned, peat excavations on fens have a diversified odonatofauna, yet its main core is composed of eurytopes such as: *Sympetrum sanguineum* (Müller, 1764), *Libellula quadrimaculata* Linnaeus, 1758, *Cordulia aenea* (Linnaeus, 1758), *Anax imperator* Leach, 1815, *Aeshna cyanea* (Müller, 1764), *Chalcolestes viridis* (Vander Linden, 1825), *Enallagma cyathigerum* (Charpentier, 1840), *Ischnura elegans* (Vander Linden, 1820), *Erythromma najas* (Hansemann, 1823), *Coenagrion pulchellum* (Vander Linden, 1825), *C. puella* (Linnaeus, 1758) (Buczyński 2000, Buczyński 2015, Tańczuk, unpublished data).

Rheobionts may also be observed near peat excavations on fens e.g. *Somatochlora metallica* (Vander Linden, 1825), *Calopteryx splendens* (Harris, 1782), much rarer *Gomphus vulgatissimus* (Linnaeus, 1758), *Ophiogomphus cecilia* (Fourcroy, 1785), or *Onychogomphus forcipatus* (Linnaeus, 1758) in the mountainous sites (Boudot *et al.* 2021, Buczyński 2015, Dolný *et al.* 2021). Limnophilic dragonflies such as *Leucorrhinia caudalis*

(Charpentier, 1840) and *Anax parthenope* (Selys, 1839) seem to widen their territories so they are being observed also in peat excavations (Wendzonka 2001, Daraż 2009, Dolata 2011).

Because of climatic changes, after the year 2000, few species of dragonflies have started to settle down in Poland, migrating mostly through Moravian Gate and Przemyśl Foothills. It have become an attractive topic for a short note or longer article with numerous records of such species and their reproduction in Poland (Wendzonka 2007, Buczyński *et al.* 2010, Miszta *et al.* 2012). Southern, thermophilic species such as *Crocothemis erythraea* (Brullé, 1832), *Aeshna affinis* Vander Linden, 1820, *Orthetrum albistylum* (Selys, 1848) or *Erythromma viridulum* (Charpentier, 1840), have inhabited ecological niches like ditches, water bodies in gravel and sandpits, as well as small artificial pools, also in the form of peat excavations on peatlands, including fens (Bernard *et al.* 2002, Wendzonka 2001, 2007, Stolarz 2011, Bena 2014, Tańczuk 2020a i 2020b).

Table. 2. Species observed in peat excavations on fens in Poland and their degree of association with anthropogenic water bodies (classification after Buczyński 2015). Additional information about synecological groups Odonata: \* - tyrrophophile, \*\* - tyrphobiont, \*\*\* - other stenotopic species.

Species	Degree of association
<i>Coenagrion ornatum</i> ***	anthropophiles of the 1 <sup>st</sup> degree (8,1%)
<i>Lestes sponsa</i> , <i>Chalcolestes viridis</i> , <i>Sympecma paedisca</i> , <i>Ischnura elegans</i> , <i>Enallagma cyathigerum</i> , <i>Coenagrion hastulatum</i> *, <i>C. lunulatum</i> , <i>C. puella</i> , <i>C. pulchellum</i> , <i>Erythromma najas</i> , <i>Erythromma viridulum</i> , <i>Aeshna cyanea</i> , <i>Anax imperator</i> , <i>Anax parthenope</i> , <i>Cordulia aenea</i> , <i>Somatochlora metallica</i> , <i>Orthetrum albistylum</i> , <i>Crocothemis erythraea</i> , <i>Leucorrhinia albifrons</i> *	anthropophiles of the 2 <sup>nd</sup> degree (51,6%)
<i>Lestes virens</i> *, <i>Aeshna affinis</i> ***, <i>Somatochlora flavomaculata</i> *, <i>Libellula quadrimaculata</i> , <i>Sympetrum danae</i> *, <i>S. flaveolum</i> ***, <i>S. sanguineum</i> , <i>Leucorrhinia caudalis</i> , <i>L. dubia</i> ***, <i>L. pectoralis</i> *	anthropotolerant species (19,4%)
<i>Calopteryx splendens</i> ***, <i>Coenagrion armatum</i> , <i>Nehalennia speciosa</i> *, <i>Aeshna juncea</i> *, <i>Gomphus vulgatissimus</i> , <i>Ophiogomphus cecilia</i> ***, <i>Leucorrhinia rubicunda</i> **	anthropoxenes (17,7%)
<i>Onychogomphus forcipatus</i>	anthropophobes (3,2%)

In last two decades, some species which have been present on fens in Poland and central Europe, are decreasing, especially stenotopic ones (De Knijf *et al.* 2024): *Coenagrion hastulatum* (Fig. 8), *Aeshna juncea* (Fig. 9) and *Sympetrum danae* (Fig. 3) (De Knijf

*et al.* 2024). Species which once were observed in large populations in fens, nowadays are decreasing, but the mechanism of such process is not fully understood: *Sympetrum danae* and *S. flaveolum* (Linnaeus, 1758) (De Knijf *et al.* 2024).



Fig. 3. *Sympetrum danae*, male.

## Odonata in peat excavations in central Europe

In peat excavations on fens in central Europe, similar species of Odonata may be observed. There is a negative trend for many

Siberian species which is noticeable both in Poland and central Europe. Dragonflies are among the most endangered groups of Insecta, with the decrease of species richness up to 45% (Maes *et al.* 2010). In early 2000s. in Belgium, *Aeshna subarctica* (Walker 1908),

*Coenagrion hastulatum* and *Leucorrhinia pectoralis* have been declining. In the Netherlands five species were considered extinct, four in West Germany and France and three species in the United Kingdom and Ireland (De Knijf *et al.* 2003). New research confirm this situation in the Netherlands, adding *Coenagrion lunulatum*, and some moorland species such as *Aeshna juncea*, *Leucorrhinia dubia*, *L. rubicunda* (Fig. 4) and *Somatochlora arctica* (Zetterstedt, 1840) to

that list (Termaat 2023, van Grunsven *et al.* 2020). Droughts are pointed out as the cause of species regression (van Grunsven *et al.* 2020). In Italy, lowland areas lost some of populations from the Lestidae family, often present in peat excavations on fens: *Lestes dryas* Kirby, 1890, *L. virens* and *L. sponsa* (Fig. 6) (Assandri 2021). In the Alps, their numbers are rather stable and *Chalcolestes viridis* increased on fens (Assandri 2021).



Fig. 4. *Lucorrhinia rubicunda*, male.

The authors of the new *European Red List of Dragonflies & Damselflies (Odonata)* inform that out of 137 species observed in EU, almost 22% are now threatened by extinction (De Knijf

*et al.* 2024). In the table below, there are some species which may be found in peat excavations on alkaline fens with their current status.

Table. 3. Species of dragonflies occurring on alkaline fens with their status in Europe (after Knijf *et al.* 2024).

Species	Europe	EU27
<i>Aeshna juncea</i>	EN	EN
<i>Sympetrum danae</i>	EN	EN
<i>Sympetrum flaveolum</i>	EN	EN
<i>Coenagrion hastulatum</i>	VU	VU
<i>Aeshna grandis</i>	VU	VU
<i>Somatochlora metallica</i>	VU	VU
<i>Leucorrhinia rubicunda</i>	VU	VU
<i>Sympetrum vulgatum</i>	VU	VU
<i>Lestes sponsa</i>	NT	NT
<i>Leucorrhinia albifrons</i>	NT	NT
<i>Coenagrion armatum</i>	LC	NT
<i>Nehalennia speciosa</i>	LC	NT

It seems that main threats to dragonflies of central and north western Europe as well as Poland are similar in nature – eutrophication and acidification of waters, drainage, regulation of running waters, pollution, deforestation and afforestation in certain areas (Assandri 2022, Bernard *et al.* 2002, Madaras *et al.* 2012a, Madaras *et al.* 2012b, Madaras *et al.* 2012c). The loss of natural habitats for dragonflies, and what follows, the

reduction of their populations are the effects of such problems. In EU, the proper state of habitat conservation number 7230 (alkaline fens) was declared only by Sweden and Finland and also by Greece for 150 ha of alkaline fens in the Mediterranean region (Wołejko *et al.* 2019). The need of taking care of anthropogenic habitats such as peat excavations may stabilize the regression of dragonfly populations on fens.



Fig. 5. *Nehalennia speciosa*, male.

## Conservation and reconstruction

The peatlands in Latvia, Lithuania, France, Germany, Austria or Italy, have been devastated by human interference, including mostly drainage, peat mining, afforestation and intensive agriculture (Pakalne 2017). The conservation measures, in that respect, are often very similar, and may be grouped in four grounds: stopping the vegetational succession, the elevation of water, establishing new sanctuaries for active protection and restoring the traditional agricultural methods (Bernard *et al.* 2002, Grootjans *et al.* 2012, Madaras *et al.* 2012b, 2012c, Pakalne 2017).

Creating new waterbodies, as a way to enrich the species biodiversity and maintaining the already existing ones, are popular ways to deal with the problem in western Europe, and

its first attempts are becoming adapted also in Poland (Fijewski & Socha 2008, Madaras *et al.* 2012a, b, c, Assandri 2022). In Switzerland, in the 80. of the 20th century, a project was conducted which resulted in the full recovery of *Lestes virens* and *Leucorrhinia pectoralis* populations (Wildermuth 1994). In the research from 1984, one year after the construction of a water body, 7 pioneer species of dragonflies came back to the habitat (Wildermuth 1994). After three years, *Libellula depressa* Linnaeus, 1758, being a pioneer species, disappeared, and *Leucorrhinia pectoralis* emerged. Observations of *Leucorrhinia pectoralis* demonstrated that the populations grew after the regeneration of peat-diggings, and after that, dragonflies dispersed to newly established ponds nearby (Wildermuth 1994). Exuviae of *Cordulia aenea*

were found only after the fifth or sixth year after the construction of the pool (Wildermuth 1994). Although, the rotation method of reducing stages of succession has more than

forty years, it is still mentioned by odonatologists as the one of the most successful one in dragonfly protection.



Fig. 6. *Lestes sponsa*, male.

Also in Poland, *Leucorrhinia pectoralis* is protected and monitored systematically (Rozporządzenie... 2011). This dragonfly has a high dispersion potential and its habitats may be additionally expanded with artificial water bodies of similar factors. The analysis conducted by the Slovak team confirmed that also artificially created habitats are suitable for the reproduction of *Leucorrhinia pectoralis* (Šíbllová *et al.* 2021) which, once again, direct the attention to peat excavations as secondary habitats for valuable species.

In Britain, there were some projects done to restore peat bogs by damming drainage ditches and giving rise to pools of water behind the dam (Beadle *et al.* 2015). Restoration was done by filling in the ditches with peat, construction of dams and removal of trees (Elo *et al.* 2015).

Another problem considered as a threat to dragonflies is pollution. In Great Britain,

Ukraine and Finland, researches draw attention to the usage of pesticide and artificial manure on a large scale and destroying plants on the banks of water bodies by farm animals (Moore 1976, Khrokalo & Krylovskaya 2008, Elo *et al.* 2015). Because of pollution, with industrial and agricultural chemicals, the marsh lands of East Sussex lost 40% of *Lestes dryas* population; similar problems are visible in other European countries (Moore 1976, Grootjans *et al.* 2012, Assandri 2022, Šigutova *et al.* 2023, De Knijf *et al.* 2024). Researchers in Slovakia who took on the task of regular mowing the fen meadows of Abrod, predict that restoration of this important wetland would not be completed if the surrounding lands were managed with the use of chemical fertilizers (Madaras *et al.* 2012c). The effort of the entomologists and farmers should be combined to keep those areas in proper conditions.



Fig. 7. *Leucorrhinia albifrons*, male.

What should be taken into consideration is that each program developed for creating protected areas should be modified by constant monitoring and some actions ought to be introduced to facilitate balance in the mosaic of habitats. Odonates are ideal restoration indicators, yet such a process must take time, and an objective success may be achieved after inferring dragonfly reproduction on a given site (Harabiš *et al.* 2023).

It is often neglected by the authorities that habitats should be protected together with the species. Taking into consideration the fact that anthropogenic water habitats are mostly unstable because of succession of plants, human interference is crucial to keep such pools in good conditions for dragonflies to reproduce. Moreover, new protected wetland areas are necessity for endangered species and biodiversity of Odonata (Assandri 2021, Maes *et al.* 2010). Such places should be treated as a whole – water bodies together with their nearest surroundings.

In many regions, the survival of fens fauna may not be possible without an active conservation, i.e. damming or creating artificial pools (Buczyński *et al.* 2019). Controlled cutting of peat pools that were covered by trees and bushes, may be the solution to the problem of lacking natural habitats (Buczyńska & Buczyński 2019). To maintain biodiversity of dragonflies, interference in stages of

succession should be applied. Important is the fact, that peat pools in the middle stages of succession keep species and assemblages of dragonflies characteristic for fens in proper numbers (Buczyński & Tarkowski 2018, Assandri 2021). Otherwise, because of the lack of open surface waters that bring light and warmth for dragonflies, only eurytopic species could be sustained (Bernard *et al.* 2002, Buczyński 2015).

Overgrowing of habitats, may be stopped or reduced by cutting sprouts of willows and trees coating, as it was done in Biebrza valley for aquatic warbler (*Acrocephalus paludicola* (Vieillot, 1817)) (Tobolski 2012). Also Poleski National Park organized programs, e. g. cutting birches around Długie Lake. In Slovakia, the calcareous spring fen Belianske lúky Meadows, the largest and best preserved spring-fed fen in the country, was the object of restoration measures, including mulching – a type of mowing, but without removing the biomass. However, it may be used only on flattened areas of mires, where tree stumps have been removed (Assandri 2022, Madaras *et al.* 2012a).

The lowering of the water level, drying out fens and coastal zones of lakes, are leading to higher concentration of nutrients from mineralized organic matter and, as a result, cause eutrophication of habitats. The decline of *Aeshna juncea* in many European countries, may be one of the many examples of such a

process (Knijf *et al.* 2024, Ott 2007, Rychła 2009, Termaat 2023, Van Grunsven *et al.* 2020). Drainage is changing the hydrology and chemistry of peatland (Elo *et al.* 2015). Alternative vegetation, non-native and

stenotopic to wetlands, but introduced by human activity, is a destructive factor for fens because it quickens grinding and mineralization of peat (Jasnowski 1977).



Fig. 8. *Coenagrion hastulatum*, male.

What can be done right now, is to properly manage and recultivate the old peat excavations (Buczyński 2004, Veeken, & Wassen 2020). There is no need to create new ones, particularly because the entire habitat could be destroyed, but, it is important to manage the old ones to bring the lower stages of succession, and therefore make them attractive to aquatic organisms. Only hand-made peat excavations, dug on well-preserved fens, may be valuable for dragonflies (Buczyński & Tończyk 2004). Such an attempt was undertaken by the Dutch researchers on a vulnerable rich fen in the Naardermeer nature reserve in the Netherlands. After comparing water quality and vegetation structure before and after the research, it appeared that restoration of this part of the fen was effective (Veeken, & Wassen 2020). Yet, the question arises, if good conditions of the fen remain in that way, since the climatic changes and high atmospheric N-deposition, keep the place rich in nutrients; further monitoring management is crucial (Veeken, & Wassen 2020). Anthropogenic waterbodies in the late stages

of succession are characterized by qualitative and quantitative poorness of odonatocenoses, represented mainly by eurytopic species, the least sensitive to unfavorable habitat conditions (Bernard *et al.* 2002, Tańczuk unpublished data). However, such areas, protected by law, are simply abandoned, which results in the expansion of shrubs (Madaras *et al.* 2012b). Peatland restoration, through peat pools management, has a potential to lead to a relatively rapid recovery of Odonata abundance and species richness (Assandri 2022, Elo *et al.* 2015).

The last issue concerning conservation is the *citizen science* practice. Ecological research should be published, also as popular science articles, to draw people's attention – *citizen science* data is a genuine form of information to be used by professionals (Baeta *et al.* 2024, Didham *et al.* 2020, Šigutová *et al.* 2023, Tańczuk & Tończyk 2023). Articles are also the foundation for future generations to be educated and to act globally. The knowledge of anthropogenic habitats is crucial to sustain biodiversity.

## Conclusion

Wetlands are the most threatened habitats in the world. The main threats may be eliminated by active protection of both organisms and habitats. Meliorations are a problem, not only for dragonflies and water invertebrates, but also for amphibians, plants and fungi (Czucha 2016). Peat excavations or peat pools seem to be the last hope for the species living there (tyrphobionts, tyrphophiles) since the pits are deep and the water stays there for a longer period of time to ensure reproduction. Man-made small water bodies often contain a high diversity of species and can also host those endangered ones (Koszałka & Jabłońska-Barna 2020). Traditional ways of conservation, including creating national or landscape parks and nature reserves, seem to be not enough. Monitoring of places with abundant populations of aquatic animals show that active protection is not very well-developed in Poland and still needs modifications. There has to be genuine research conducted on such places systematically. There is also a need to explore the areas and examine them carefully as the whole ecosystems, taking into consideration the connections between the various biotic and abiotic elements.

The presence of protected species in anthropogenic water bodies such as peat excavations, is an optimistic prognosis for the future. However, it is also connected with a careful planning and major input of labour, to keep the habitat stable and diversified. The problem of homogeneity of areas is very serious and negatively correlated with dragonflies (Termaat 2023). The biologists should remember about the obligation to monitor the habitats (Buczyńska & Buczyński 2006). Still, the most widespread wetlands in Poland such as fens are the least protected habitats (Wołejko *et al.* 2019). The choice of location of sanctuary network is accidental and unproportional in relation to diversified typology of wetlands (Jasnowski 1977, Wołejko *et al.* 2019, Pietruczuk 2020).

To make active protection of dragonflies successful, one has to take into consideration several issues, grouped and synthetically described by Wildermuth (1994). Firstly, protection of animals themselves is needed, both imagines and larvae involving prohibitions of catching, keeping and killing. Secondly, the biotopes where dragonflies reside have to be protected; in this case fens or wetlands in general, where the most precious stenotopic species assemble. Finally, the protection of the entire environment, water, air and land should be planned and executed (Wildermuth 1994). Although Wildermuth wrote about the environment in general, those points should be also taken into account when creating new peat excavations or sustaining the existence of already dug up ones.

Further ecological research is needed to analyze factors that shape the abundance and structure of populations of dragonflies in peat excavations on fens, including alkaline and calcareous fens, which have been described in detail from the floristic and botanical point of view (Sugier 2014). It has to be established which predictors affect dragonflies and which are not; such research are now in progress (Tańczuk unpublished data). Heterogeneous natural vegetation is the one factor which helps to increase the biodiversity of the odonates (Monzó & Verdú 2022, Tańczuk unpublished data). Additional waters surrounding peat excavations have a positive effect on many dragonfly species, including tyrphophilic *Leucorrhinia pectoralis* (Harabiš & Dolný 2011, Rannap *et al.* 2011b, Tańczuk unpublished data). Dragonflies prefer lower stages of succession and that is why reducing reedbeds, shrublands and woods on peat excavations on fens is needed (Assandri 2021, Grootjans *et al.* 2012, Tańczuk unpublished data).

Knowledge about peat excavations as secondary habitats for dragonflies, and their role in the environment, should be passed for next generations. Researchers in many countries, including Poland, see the need to

educate the society, to show that human actions may be beneficial for nature conservation (Baeta *et al.* 2024, Didham *et al.* 2020, Šigutová *et al.* 2023, Tańczuk & Tończyk 2023). Development of a very broad educational program for the local community in peatland conservation, including anthropogenic waters, is needed to show what has been done, and what else can be performed, in order to restore valuable habitats in Europe. It might work both ways, since scientists need volunteers e.g. for gathering data in a quicker way and to apply the results as soon as possible.

The original research of the author of the present review on peat excavations on alkaline fens, conducted in 2022-2023, has finally showed the results about the predictors that shape dragonfly populations and assemblages. Factors analyzed were e.g. the structure of vegetation as a part of the water body (emerged, submerged, floating, *Chara* spp.), including succession (Fig. 2), the vicinity of it, the surroundings of the peat pool and the further landscape (e.g. forest, meadow, water, peatland). Some of the analyses confirm the results from literature and will be described in the nearest future.



Fig. 9. *Aeshna juncea*, male.

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