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The Palaearctic dragonfly (Insecta: Odonata) fauna of the lands north of the Arctic Circle — a critical synopsis

Аналитический обзор фауны стрекоз (Insecta: Odonata) территорий Палеарктики севернее Полярного круга

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Abstract. Forty dragonfly (Insecta: Odonata) species have been found north of the Arctic Circle between the Lofoten archipelago in the West and the Chukchi peninsula in the Russian Far East. This analysis is based on a critical evaluation of the available literature, data bases as well as my own observations in northern Fennoscandia and in the Polar Urals. The species *Aeshna caerulea* (Ström, 1783), *A. subarctica* Walker, 1908, *A. juncea* (Linnaeus, 1758) and *Cordulia aenea* (Linnaeus, 1758) were found in all regions. *Somatochlora arctica* Zetterstedt, 1840 and *S. sahlbergi* Trybom, 1889 are also widespread throughout the northern Palearctic. Only observations from the East Siberian mountain region and the East Siberian lowlands are missing. The two damselflies, *Coenagrion johanssoni* (Wallengren, 1894) and *Enallagma cyathigerum* (Charpentier, 1840), occur north of the Arctic Circle in both the western and the eastern Palearctic. The present analysis is a basis for the recording of potential changes in fauna because of climate change.

Резюме. Представлен анализ фауны стрекоз (Insecta: Odonata) территории Палеарктики, расположенной севернее Полярного круга, выполненный на основе изучения доступной литературы и по наблюдениям автора в Фенноскандии и на Полярном Урале. Между архипелагом Лофотенские острова на Европейском западе и Чукотским полуостровом на Дальнем Востоке России к северу от Полярного круга обнаружено 40 видов стрекоз. Виды *Aeshna caerulea* (Strцm, 1783), *A. subarctica* Walker, 1908, *A. juncea* (Linnaeus, 1758) и *Cordulia aenea* (Linnaeus, 1758) были обнаружены во всех регионах территории исследования. Два вида: *Somatochlora arctica* Zetterstedt, 1840 и *S. sahlbergi* Trybom, 1889 также широко распространены на территории северной Палеарктики, но отсутствуют в Восточно-Сибирском нагорье и Восточно-Сибирской низменности. Две стрекозы *Coenagrion johanssoni* (Wallengren, 1894) и *Enallagma cyathigerum* (Charpentier, 1840) обитают к северу от Полярного круга как в западной, так и в восточной частях Палеарктики. Проведённый анализ послужит вкладом в фиксацию происходящих фаунистических изменений и позволит в будущем установить тренды трансформации фауны в условиях глобального изменения климата.

Zusammenfassung. Die paläarktische Libellenfauna der Gebiete nördlich des Polarkreises — eine kritische Zusammenschau. Zwischen dem Archipel der Lofoten im Westen und der Tschuktschen-Halbinsel im Russischen Fernen Osten wurden in den Gebieten nördlich des Polarkreises 40 Libellenarten gefunden. Grundlage für diese Analyse sind eine kritische Auswertung der verfügbaren Literatur, von Datenbanken sowie eigene Beobachtungen im Norden Fennoskandiens und im Polar Ural. In allen Regionen wurden die Arten *Aeshna caerulea* (Ström, 1783), *A. subarctica* Walker, 1908, *A. juncea* (Linnaeus, 1758) und *Cordulia aenea* (Linnaeus, 1758) nachgewiesen. *Somatochlora arctica* Zetterstedt, 1840 und *S. sahlbergi* Trybom, 1889 sind ebenfalls in der gesamten nördlichen Paläarktis verbreitet. Von ihnen fehlen lediglich Funde aus der Ostsibirischen Bergregion und dem Ostsibirischen Tiefland. Die beiden Kleinlibellen *Coenagrion johanssoni* (Wallengren, 1894) und *Enallagma cyathigerum* (Charpentier, 1840) wurden sowohl in der West- als auch in der Ostpaläarktis nördlich des Polarkreises gefunden. Die vorliegende Analyse ist eine Grundlage, um mögliche Faunenveränderungen im Zuge des Klimawandels zu erfassen.

Introduction

The arctic and sub-arctic regions of our planet are particularly affected by climate change [Gore, 2006; Boltunov et al., 2008; Box et al., 2019]. In the context of climate change, studies omits influence on the spread of insects are increasing [Wilson et al., 2007; Stange, Ayres, 2010; Andrew, Terblanche, 2013; Halsch et al., 2021]. This also applies to the order Odonata [e.g. Ott 2001, 2010; Hickling et al., 2005; Flenner, Sahlen, 2008; De Knijf et al., 2011; Schröter et al., 2012]. However, little is known about the Palearctic boreal and sub-arctic faunas, despite the fact that these regions offer a wide variety of dragonfly habitats [May 1932; Gloyd, 1939; Walker, 1943; Ander, 1950; Cannings, Stuart, 1977; Cannings, Cannings, 1997; Kosterin, Sivtseva, 2009; Paulson, 2009; Borisov et al., 2014; Brockhaus, 2018].

Boreal and sub-arctic dragonfly species are adapted to cold habitats [Sternberg 1990; Corbet, 1999; Sformo, Doak, 2006; Suhling et al., 2015; overview in Brockhaus, 2018]. We know nothing about the possible effects of climate change on these dragonfly communities. First and foremost, a critical analysis of our knowledge of the dragonfly species that occur there is required. Although information on dragonflies spreading into the North and boreoalpine areas has been collected in the past [Holdhaus, 1912; May, 1932] and current findings are available for some regions [Borisov et al., 2014; Tatarinov et al., 2013; Tatarinov et al., 2015], a critical overview of the entire Palearctic region north of the Arctic Circle is lacking. Such an overview is presented below. Last but not least, it serves to develop a better zoogeographical understanding of the dynamics of northern area boundaries of western Palearctic [Boudot, Kalkman, 2015; Brockhaus, 2018] and eastern Palearctic [Belyshev, 1973a; Kosterin, 2005] species.

Materials and methods

All available records of Odonata north of the Arctic Circle have been compiled. For this purpose, databases, if available, were evaluated, and the assignable data in faunal works, checklists and other papers were researched. In individual cases in which only data from areas south of the Arctic Circle were available, these were also used. The information was checked for plausibility and verifiability. All sources used are named in the results in the respective regional reports. My own travels took me to north of Fennoscandia (2010, 2018, 2021) and the sub-polar region of the Urals near Vorkuta (2012, 2017).

For a better overview, the entire Palearctic area north of the Arctic Circle has been subdivided into regions. In Fennoscandia, the data were assigned to the respective sub-polar regions of Norway, Sweden and Finland. By far the largest part of the northern regions is in the Russian Federation. Here the information was assigned to six regions. Following the Russian scientific literature, a distinction was first made between the European and the Siberian part of Russia. In the European subpolar area of Russia, the two geographically well-separated regions of the Kola Peninsula and the Eastern European subpolar area to the ridges of Polar Ural were distinguished. The part east of the Ural Mountains is subdivided into four regions: between the eastern side of the Ural Mountains and the Yenisey estuary incl. Yamal Peninsula; Taymyr Peninsula and the North Siberian Plain; the East Siberian Mountains and East Siberian Lowlands as one region; and the Chukotka region. Figure 1 shows an overview of the regions. A species checklist was prepared for each region.

Habitats above the Arctic Circle

The Arctic Circle lies roughly latitude 66°33' North. Here the sun no longer rises (winter solstice) or sets (summer solstice) on the days of the solstice. The extent of land north of the Arctic Circle varies greatly depending on the region. From Rovaniemi, the most famous place on the Arctic Circle in Finland, it is a good 500 km to the Barents Sea. In the Polar Urals, the landscape extends more than 700 km from the Arctic Circle to the northern tip of the Jamal Peninsula. In the Krasnoyarskii Krai, it is as much as 1400 km from the Arctic Circle on the Yenisei to Vilkitsky Strait, between the Kara- and Laptev seas. From western Lofoten in Norway to eastern Chukotka, the area north of the Arctic Circle extends about 8000 km. Only two vegetation zones are characteristic of the entire region: the taiga or the northern coniferous forest and, north of this, the tundra.

The taiga defines the boreal zone, which experiences its greatest extent in northern Siberia; it is mainly «dark taiga» characterized by spruce, pine and larch trees. Most of the Siberian taiga lies on permafrost soils. For four to six months of the year, average temperatures are around 5 °C. During the summer months, the sun's radiation increases because the sun does not set. The annual rainfall is low; snow cover lasts six to seven months [Schultz, 2016]. The aquatic landscape consists of numerous rivers, a vast number of oxbow lakes, lakes and mires. To the north the taiga meets the tree and shrub tundra.

In the extreme north of the tundra, the vegetation is characterized by shrubs such as dwarf birch as well as mosses and lichen. The permafrost, which is prevalent everywhere, thaws in the course of the summer to varying depths — between 60 centimeters in Karesuando, Sweden and two meters in Vorkuta, Russia. The growing season in the tundra has temperatures mostly above 0 °C and lasts three to four months (May to August) [Schultz, 2016]. The annual rainfall is low. The waters lying above permafrost were created and are created by frost-dynamic processes over long periods of time. The northern regions of Norway, Sweden and Finland are core areas for mires [Seppälä, 2006; Laitinen et al., 2007; Vorren et al., 2007; Joosten et al., 2017]. In the European part of Russia [Sirin et al., 2017] and large parts of northern Siberia [Novikov, 2009] also have vast mires.

Results

Faunistics in the regions

Troms and Finnmark region, Norway (number 1 in Fig. 1). In addition to the entire province of Troms and Finnmark, the northern parts of the province of Nordland, including the islands of Lofoten and Vesterålen, lie north of the Arctic Circle.

May [1932] reports historical dragonfly records from northern Norway. The comprehensive Norwegian database (https://artsdatabanken.no) contains all 56801 dragonfly records known for Norway as of September 15, 2021. Twenty-three species are reported beyond the Arctic Circle. Among these, one of the oldest records is a specimen of *Libellula quadrimaculata* from July 28,

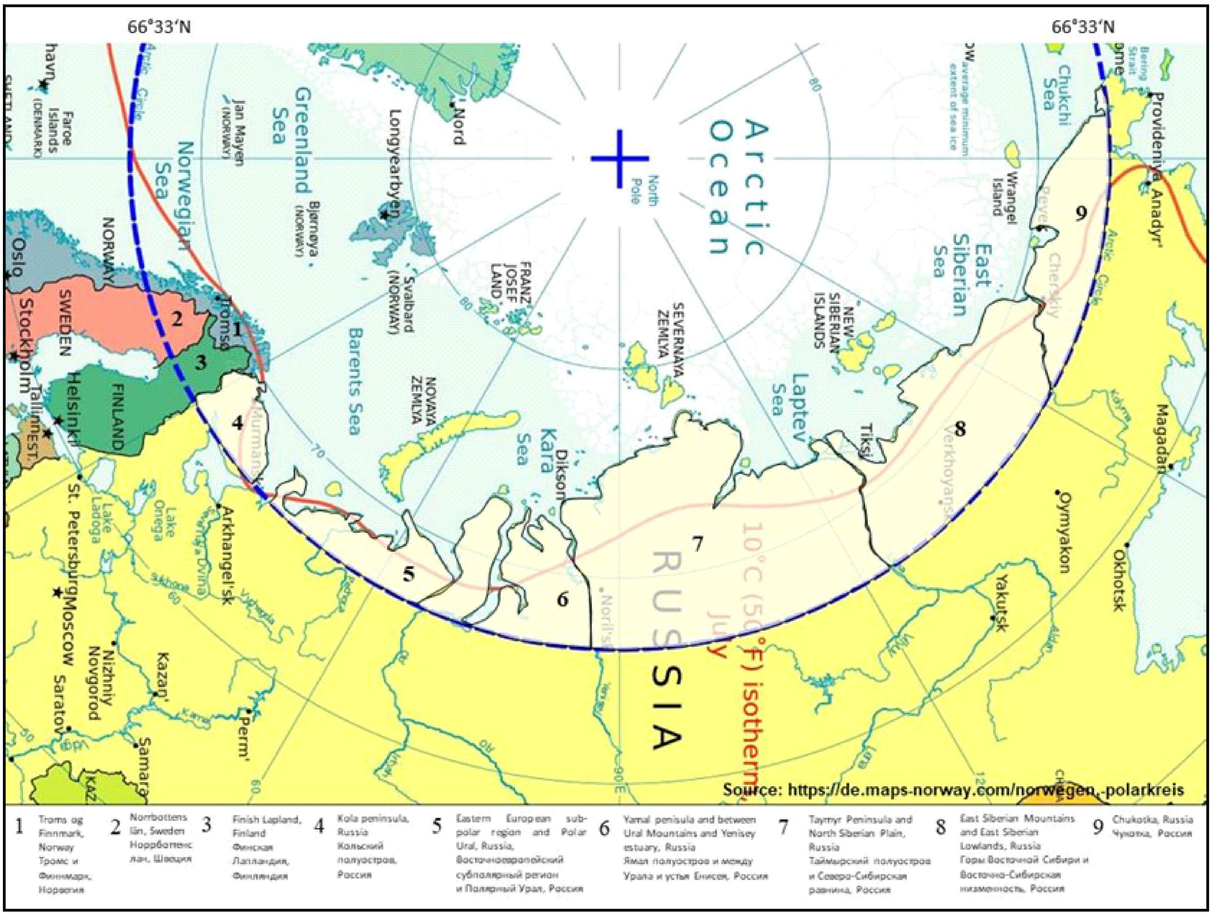

Fig. 1. Palaearctic regions north of the Arctic Circle.
Рис. 1. Районы Палеарктики к северу от Полярного круга.

1932 on Ullsfjorden (69°38' N), east of Tromsø (leg. K. Bræck). Four species have only recently found their way across the Arctic Circle. *Pyrrhosoma nymphula* was detected here for the first time in 2017 (11 June 2017, leg & det. Per Hansen, Finn O. Mosti, Hamarøy, 67°58' N, photographic evidence). *Lestes sponsa* (12 August 2018, unknown collector, Narvik, 68°26' N), *Coenagrion pulchellum* (6 August 2018. leg. & det. Markus Kristoffer Dreyer, Steigen, 67°44' N) and *Aeshna cyanea* (12 August 2018, unknown collector, Narvik) were first observed in 2018.

On my own excursions to Finnmark and Vardø (2010), to Vesteralen Island Andøya (2018) and again to Finnmark (Upper Pasvikdalen, Neiden, 2021), I found 10 of the species known from northern Norway. One observation is a mystery: on July 16, 2018 on Andøya in the area around the Oklevatnet (69°07' N), I discovered the wing of a female *Orthetrum coerulescens* lying between nine *Libellula quadrimaculata* exuviae. Since its origin is completely unclear, this observation is not dealt with any further in the checklist. Billqvist et al. [2019] state that *Enallagma cyathigerum* occurs in low densities in northern Norway. In 2021 I found the species in Upper Pasvikdalen (69°12' N) and near Neiden (69°43') in large numbers. Many males of the «*nigrolineatum*» form flew at the latter location. Such specimens were also found in northern Siberia, in Chukotka and on the island of Sakhalin [Haritonov, Malikova, 1998]. Dumont et al. [2005] show that these specimens from northern regions belong to the nominate form of *E. cyathigerum*. Barnard et al. [2015] use North American *Enallagma* forms to show that the tendency to melanism is not genetically based and therefore is not taxonomically relevant. To date, 23 species have been recorded north of the Arctic Circle in Norway.

Norrbottens län region, Sweden (number 2 in Fig. 1). The north of the province of Norrbottens län, with Lapland as the main part, forms the Swedish area north of the Arctic Circle.

Ander [1944] gives a first overview of the dragonfly fauna in Sweden. Using the two species, *Aeshna caerulea* and *Somatochlora alpestris.* Kjell Ander also dealt intensively with the disjunct distribution of species in the high mountains and in the northern parts of Europe [Ander, 1950]. For the region north of the Arctic Circle, 23 species were identified [Sahlén, 1996; Billqvist et al., 2019]. It is questionable whether *Erythromma najas* occurs north of the Arctic Circle, as can be seen from the map by Sahlén [1996: 83]. According to the current state of knowledge, this is probably not the case [Billqvist et al., 2019]. However, *Ophiogomphus cecilia* is confirmed here, although the evidence for it north of the Arctic Circle at Torne älf May (1932) still appears questionable, as the river crosses the Arctic Circle and no exact location was presented. Twenty-three species are now definitely recorded north of the Arctic Circle in Sweden.

Finnish Lapland region, Finland (number 3 in Fig. 1). Most of Finnish Lapland lies north of the Arctic Circle. One of the well-known places there is Rovaniemi.

Kaarlo Johannes Vallé presented the first documentation of the dragonfly fauna of Finland as early as 1921 [Vallé, 1921]. In his third addition, he lists the then known sites for Finnish Lapland, the Murmansk region and parts of Russian Karelia [Vallé, 1927]. The current state of knowledge of the distribution of dragonflies in Finland is noted by Karjalainen [2010] and Billqvist et al. [2019]. Information is also provided on the website https://laji.fi.

My own observations were made in July 2021 west of Lake Inari in Lemmenjoki (68°49' N), in the tundra south of Nuorgam (70°03') and at Karesuvando (68°27'). In Karesuvando, the only zygopteran was *Coenagrion hastulatum* and, in addition to the three aeshnids, *Aeshna caerulea*, *A. grandis* and *A. juncea*, the corduliids *Somatochlora arctica* (Lemmenjoki) and *S. metallica* (Nuorgam) also flew. Several freshly emerged females of *S. sahlbergi* were also found here. They are remarkably similar to those of *S. alpestris* and can only be distinguished by the stronger indentation of the subgenital plate. *Leucorrhinia dubia* and *L. rubicunda* have also been found in Karesuvando. Twenty-three dragonfly species are known for Finland north of the Arctic Circle.

The following regions are in the Russian Federation.

Murmansk region, Kola peninsula region, Russia. (number 4 in Fig. 1). The northern part of the Republic of Karelia and the entire Murmanskaya Oblast lie north of the Arctic Circle.

The earliest information for this region comes from the Finnish entomologist Vallé [1927, 1952]. He gives the area around lake Imandra (approximately 67°48'N) in the Murmansk region as the only known site in northern Europe, at that time, for *Somatochlora sahlbergi* [Vallé, 1927: 25]. May [1932: 181] then incorrectly transfers this information to Finland, because parts of the Kola Peninsula were Finnish territory until 1944. However, the Imandra lake was already at that time on the territory of the former Soviet Union. With reference to Vallé [1927], May mentions a find of *Erythromma najas* from the place «Konta» in Russian Karelia (66°40' N). Vallé includes a footnote: «…kommt aber in Russisch-Karelien noch bei Kouta (ca 66°40' n. Br.) vor» [Vallé, 1927: 15]. In northern Russian Karelia, near the Finnish border at 66°40'N, there is a place «Kauttio» («Кауттио» respectively «Урочище Кауттио»). It's always the same place. In Fridolin [1934] there is an indication of *Aeshna crenata*, which, however, cannot be clearly assigned to the region. V.E. Skvortsov [2010] summarizes the previously known evidence for the Murmansk region in a rough map. Despite the inclusion of *Coenagrion pulchellum*, it is unlikely that it occurs near the Arctic Circle [Skvortsov, 2010, map: 551]. The information on *Libellula quadrimaculata* and *Sympetrum flaveolum* are not specified and cannot be checked. In addition to the sources mentioned above, Skvortsov presents some information of his own; for example, the only place where *Cordulegaster boltonii* has been recorded near the Arctic Circle is documented (Chernaya Guba bay on the White Sea coast, 66°31' N, Skvortsov, Matyokhin [2008: 23]). With some uncertainties, 18 species are known for this region. There is a great necessity for faunistic research in the Murmansk region.

Eastern European sub-polar region and Polar Ural, Russia (number 5 in Fig. 1). This region, which extends from west to east over 1240 km, ranges from the northern part of Arkhangelskaya Oblast east over the entire Nenetskii Autonomnyi Okrug, including the northernmost part of the Komi Republic in the Polar Ural, and is bordered by the crest of the latter.

Belyshev et al. [1974] and Stronk [1977] give the first information about the dragonfly fauna of the European part of the Polar Ural. They report *Aeshna crenata*, *A. subarctica*, *Somatochlora arctica*, *S. alpestris* and *S. sahlbergi* in the region. In an evaluation of a small collection of dragonflies from the Nenetskii Autonomous district, Skvortsov [2008] lists nine species that V.V. Gorbatovsky and B.A. Filippov had found on the lower reaches of the Pechora River and on the Konin Peninsula, including *Aeshna grandis* at 67°42' N and *Sympetrum flaveolum* at 67°55' N. Tatarinov, Kulakova [2009] provide a summary of the dragonfly fauna of the Eastern European subpolar region east of the Murmansk region; the information on *Coenagrion pulchellum*, *Erythromma najas* and *Gomphus vulgatissimus* in the northwest of the Komi Republic («Новый Бор» (Novy Bor) (66°42' N, 52°18' E) is questionable. Stronk [1977] collected around 500 adults and 3000 larvae in various regions of the Komi Republic between 1969 and 1975 and, therefore, can be considered an expert on the odonate fauna of the region. He does not mention these species so far north. His northernmost location of *C. pulchellum* is «Белый Бор» (Bely Bor), several hundred km south of the Arctic Circle. All other records of this species and those of *E. najas* and *G. vulgatissimus* in the Komi Republic are also far south of the Arctic Circle. Since *G. vulgatissimus* was not found in any of the other regions north of the Arctic Circle, this species is ignored here. Tatarinov et al. [2015] give an overview of the dragonfly fauna of the Eastern European Hypoarctis (= subpolar area). In addition to the above-mentioned species, they mention *Sympetrum sanguineum* north of the Arctic Circle on the Bolshaya Rogovaya River in the Komi Republic. Neither Tatarinov, Kulakova [2009] nor Stronk [1977] documented such northern occurrences and the species has not been found in any of the other regions north of the Arctic Circle; thus, it is also not considered further here. Tatarinov et al. [2015] do not mention *Enallagma cyathigerum*, which is included in Tatarinov et al. [2013] for the Subpolar Ural. However, the geographical limits of the Polar Ural and Subpolar Ural are not precisely defined in their paper. The species is present in the neighboring regions and its occurrence north of the Arctic Circle can be assumed with some certainty. Tatarinov et al. [2015] name two localities for *Leucorrhinia orientalis* a species (or subspecies) closely related to *L. dubia*. One of them was a larval found on lake Nishne Maerskoye (Нижнее Маерское). The other one was on the lake Malaya Lokhota (Малая Лохота, 66°31' N, 63°40' E, 295 m NN). He lies on a headwater to the Ussa river system. These proofs are the first for Europe for this species/subspecies [see Malikova, Kosterin, 2019]. Bernard, Daraż [2010] examined the dragonfly fauna of the region around Pinega village in the taiga about 150 km south of the Arctic Circle. If this area is included, *Coenagrion glaciale*, *Aeshna serrata*, *Libellula quadrimaculata* and *Somatochlora graeseri* [Bernard, 2012] can be added to the list.

During two research trips to the tundra around Vorkuta in the Polar Ural, I found *Coenagrion armatum, C. hylas, Aeshna caerulea*, *A. juncea*, *Somatochlora sahlbergi* and *Leucorrhinia rubicunda* [Brockhaus, 2013, 2019].

Including the findings of Bernard [2012] and Bernard and Daraż [2010], 27 species have been identified with some certainty for the Eastern European Subpolar Area and the European part of the Polar Ural.

Yamal peninsula and between Polar Ural and Yenisey estuaries, Russia (number 6 in Fig. 1). This region lies between the crest of the Ural and the Yenisei Rivers estuary open to the Arctic Ocean (The Yenisey valley itself is included into this region). It includes the eastern foothills of the Polar Ural and the lowland tundra of the Yamal Peninsula (полуостров Ямал) and the Gydan Peninsula (Гыданский полуостров). It is almost identical to the administrative unit of the Yamalo-Nenetskii Autonomnyi Okrug.

Belyshev and Korshunov [1976] reported six dragonfly species from the south of the Yamal Peninsula: *Leucorrhinia dubia*, *L. rubicunda*, *Somatochlora sahlbergi*, *Aeshna squamata* (= *A. caerulea*), *Agrion hylas* (= *Coenagrion hylas*) and *Agrion concinnum* (= *Coenagrion johanssoni*). In 1876 a Swedish entomological expedition explored the Yenisey (sites at both its banks) from Yenisseisk in the south to Dudinka (69°25' N) in the north. Trybom [1890] reported 11 species of dragonflies found near and north of the Arctic Circle. Three of them, *Somatochlora sahlbergi*, *S. sibirica* and *S. theeli*, were new descriptions by Trybom. Vallé [1931b] recognized the *S. theeli* from Chantaika (68°25' N, leg. J. Sahlberg) as a female of *S. sahlbergi*. The same applied to a *S. theeli* female from Potapovskoe (68°55' N). Finally, an *S. sahlbergi* female specimen collected near Dudinka was assigned to *S. alpestris* by the same author. Erich Schmidt [1957] identified the *S. sibirica* male from Insarova (62°05' N) as *S. graeseri* described by Selys-Longchamps [1887]. The place is far south of the Arctic Circle, but Belyshev and Haritonov [1980] gave the area for *S. graeseri* here up to the far north without naming concrete findings. Only *S. sahlbergi* remained as a new species. Haritonov [1974a, b] reported six species from the lower reaches of the Ob', *Coenagrion hylas*, *Aeshna squamata* (= *A. caerulea*), *S. sahlbergi* and *Leucorrhinia orientalis*. These reports were based on Haritonov's investigations in the Toi-Pugol River system and the surrounding area (about 28 km north of Salekhard on the lower Ob, 66°53' N). The larval data from these expedition were later publihsed by Haritonov [1975], who found *Aeshna squamata* (= *A. caerulea*), *A. juncea*, *A. subarctica*, *Somatochlora sahlbergi*, *Agrion* (= *Coenagrion*) *hylas*, *A. concinnum* (= *C. johanssoni*), *C. vernale* (= *C. lunulatum*), *Leucorrhinia rubicunda*, *L. orientalis* and *L. dubia*. How the larvae of the three *Leucorrhinia* species were differentiated from one another is not mentioned. The information in Belyshev [1973a] was probably based predominantly on the sources mentioned above. One of the study areas by Tatarinov et al. [2015] lies east of the Ural ridges: the place Sob' (a railway station on the Transpolyarnaya Magistral (Трансполярная магистраль, 67°03' N, 65°30' E). Nearby flows the river Sob', which drains into the Ob to the south-east. In this area, they found a total of 15 species. In addition to those already known from other areas of this region, these were *Coenagrion hastulatum*, *Aeshna crenata*, *A. grandis*, *Somatochlora metallica*, *Libellula quadrimaculata*, *Sympetrum danae* (only larvae), *S. flaveolum* and *S. vulgatum*. On the internet platform https://www.inaturalist.org under the project «projects/strekozy-yamalo-nenetskogo-ao-dragonflies-of-yamalo-nenets-autonomous-district-russia» four species are listed, all of them were found in 2021: *Aeshna caerulea*, *A. juncea*, *Leucorrhinia dubia* and *L. rubicunda*. Therefore, 23 dragonfly species are known in this region.

Taymyr Peninsula and North Siberian Plains, Russia (number 7 in Fig. 1). This extensive subpolar landscape comprises the Siberian lowlands between the lower reaches of the Yenisey River in the west and the Lena River in the east. It includes the northern Putorana Mountains in the southwest. The region extends 1500 to 1600 km west to east and over 1200 km north to south from the Taymyr Peninsula to the Arctic Circle. Due to the extreme continental climate that prevails here, it is one of the coldest regions on earth. Administratively the Taymyr Peninsula and the westernmost North Siberian Plain belong to Krasnoyarskii Krai and most of the North Siberian Plain to Republic of Sakha (Yakutia).

Knowledge of the dragonflies in this vast region is sparse. Gorodkov [1956] recorded three species for the Taymyr Peninsula: *Aeshna subarctica elisabethae*, *Aeshna squamata* (= *A. caerulea*) and *Somatochlora arctica*. Belyshev [1965] found 14 species on the Nuorda (Norda) River near the village of Zhigansk (66°46' N). After revising the collected material, Belyshev [1973b:

25, 29] reidentified *Coenagrion lanceolatum* as *C. hastulatum* and noted that a *Somatochlora metallica* female was *S. metallica exuberata*. The information compiled by Bartenev [1911] and Belyshev [1973a, b] for Yakutia was assembled and updated in an overview of the dragonflies of Yakutia by Kosterin and Sivtseva [2009]. The records in Northwest and North Yakutia related to the region under consideration here. The few localities yielded 15 species based on the sources mentioned. In addition, *Somatochlora sahlbergi* was found on the Taymyr Peninsula [Pospelova, 2007] and there are a few species that are specified for the northern part of the Krasnoyarsk region on the website https://www.inaturalist.org/projects/strekozy-krasnoyarskogo-kraya-dragonflies-of-the-krasnoyarsk-territory-russia. In addition to those mentioned above, this resource added *Sympetrum danae* and *S. flaveolum*, which were also documented in 2020 east of the city of Snezhnogorsk (68°05' N) in the Putorana Mountains. There are 18 dragonfly species recorded in this region.

East Siberian Mountains, East Siberian Lowlands, Russia (number 8 in Fig. 1). This is a mountainous landscape, with the Verkhoyansk Mountains stretching from west to east between the Lena and Kolyma rivers; it includes the Tschersky Mountains, where the Indigirka River originates. To the north lies the East Siberian Lowland, completely north of the Arctic Circle. The entire region is part of the Republic of Sakha (Yakutia).

Information about dragonflies can only be found in the summary by Belyshev [1973a] and in the work on the dragonflies of Yakutia by Kosterin and Sivtseva [2009], which includes both the information from Belyshev and that from Bartenev [1911]. Of the ten localities listed here north of the Arctic Circle and east of the Lena, ten dragonfly species are reported. The evidence for *Epitheca bimaculata* on the Yana River near Verkhoyansk (67°32') from June 1954 given by V. Mutsetoni [Kosterin, Sivtseva, 2009: 124] is the only evidence of this species north of the Arctic Circle. This region has fewer known species than any other — only ten are reported. There is a significant need for more knowledge of the fauna.

Chukotka, Russia (number 9 in Fig. 1). East of the Kolyma River, there is the territory of Chukotka Autonomous Region, or Chukotka in the broad sense, which extends to the Chukotka Peninsula. About half of Chukotka is north of the Arctic Circle.

A first comprehensive listing of the dragonflies detected here can be found in Malikova [1995]. Elena Malikova reported nine reliably identified species and another six questionable ones. Some of the subspecies mentioned by her are now revised. *Coenagrion concinnum bartenevi* is a synonym for *C. johanssoni* and *Coenagrion hylas* is also a monotypic species [Lohmann, 1992]. *Enallagma antiquum* is a synonym for *E. cyathigerum* [Paulson et al., 2022]. In the paper on the dragonfly fauna of the Russian Far East [Haritonov, Malikova, 1998], *Enallagma nigrolineatum* (this taxon corresponds to the nominate form of *E. cyathigerum,* see above), *Aeshna crenata*, *Somatochlora graeseri*, and *Leucorrhinia dubia orientalis* are newly recorded. *Sympetrum danae* mentioned by Malikova [1995] is missing here. The most recent collections were made in 2013 and 2014 by A.V. Barkalov and V.K. Zinchenko at two places on the Anadyr River [Borisov et al., 2014], about 150 to 200 km south of the Arctic Circle. Summarizing all available material, Borisov et al. [2014] listed 17 species for the region. Newly added are *Aeshna caerulea*, *Cordulia aenea* (which, however, was already mentioned in Malikova [1995] under *Cordulia aenea amurensis,* but with questionable evidence), and *Somatochlora exuberata*. The status of *Sympetrum danae* and *S. flaveolum*, for which there is no new information, remained open. Including the two species in question, 19 species have been recorded for this region.

Checklists of the regions

In the Palearctic, 40 species of dragonflies have so far been recorded north of the Arctic Circle. However, this number also includes those species that were collected in Arkhangelskaya Oblast [Bernard, 2012; Bernard, Daraż, 2010] and at Anadyr in Chukotka [Borisov et al., 2014]. There is a total of 15 species of Zygoptera and 25 species of Anisoptera. Table 1 lists the species found in the regions. A distinction is made between the ecological groups of cold-adapted and cold-tolerant species [Brockhaus, 2018].

Four species were found in all regions north of the Arctic Circle: *Aeshna caerulea*, *A. subarctica*, *A. juncea* and, surprisingly, *Cordulia aenea*. *Somatochlora arctica* and *S. sahlbergi* are only missing in the little-studied region of the East Siberian Mountains and the East Siberian Lowlands, as are the zygopteran species *Enallagma cyathigerum* and *Coenagrion johanssoni.*

Discussion

The dragonfly species found north of the Arctic Circle in the Palearctic represent around 28 % of the species documented in Europe (excluding the European part of Russia, 144 species, Boudot, Kalkman [2015]) and 26 % of the species documented for the entire Russian Federation (156 species, Onishko, Kosterin [2021: 36]). They belong to two ecological groups. The cold-adapted species have developed specific adaptations to cold climates. These act during various ontogenetic development phases or/and are determined by the population ecology (overview in Brockhaus [2018]). They live in boreo-subpolar areas and are transpalaearctic or holarctic, often with disjunct occurrences in mountains. Thirteen of the species listed here can be included in this group (Table 1). The most representative species is *Somatochlora sahlbergi* (see [Schröter, 2011]). The Zygoptera *Coenagrion johanssoni* [Schröter 2011], *C. armatum* and *C. hylas* (my own observations in the Polar Ural), which are occasionally associated with it, also belong to this group. All other species are cold tolerant; their ranges often extend far to the south.

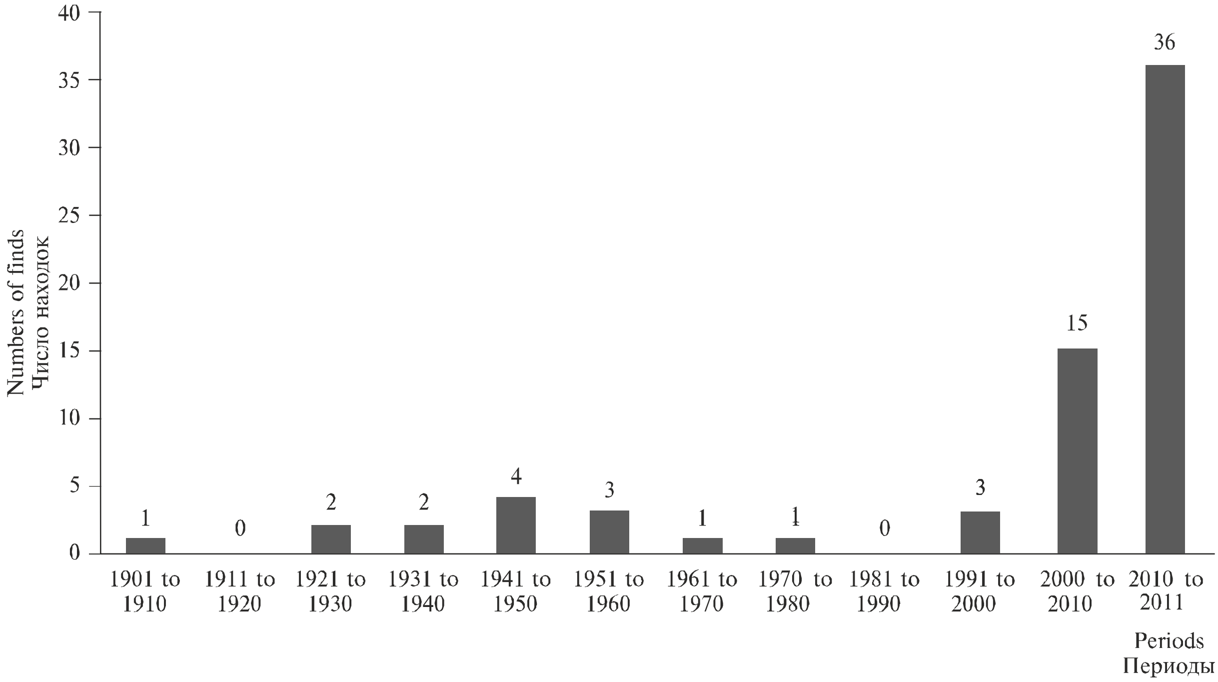

Fig. 2: Records of *Enallagma cyathigerum* up to 2021 in Norway, north of the Arctic Circle. Source: https://artsdatabanken.no. Status as of January 5, 2022.

Рис. 2: Находки Enallagma cyathigerum до 2021 года в Норвегии, к северу от полярного круга. Источник: https://artsdatabanken.no. Данные на 5 января 2022 г.

The highest number of species occurs in the European part of subpolar Russia, including the Polar Ural; 27 species are recorded here. However, this total also includes four species from the Arkhangelskaya Oblast, south of the Arctic Circle [Bernard, 2012; Bernard, Daraż, 2010]. One of these species is *Aeshna serrata*, but there is evidence that the other three occur in other regions north of the Arctic Circle. The question remains if the relatively high number of species in Fennoscandia compared to that in the Siberian part of Russia is due to the influence of the Gulf Stream or merely to different recording intensities. The northernmost records of dragonflies in the Palearctic are for *Aeshna subarctica* and *Somatochlora arctica*, made in 1948 by B.N. Gorodkov and E.S. Korodkyewitsch and verified by K.B. Gorodkov [1956]. On August 23, 1948 at an air temperature of around 24 °C, Gorodkov and Korotkewitsch saw many *A. subarctica* individuals flying at Cape Chelyuskin (77°42' N) and on August 7 they collected a male *S. arctica* on the island of Ostrov Russkii (Остров Русский, 77°10' N). The exact breeding locality is uncertain. In 2006 A.V. Kuvaev and M.N. Korolyov found *Enallagma cyathigerum*, *Aeshna caerulea* and *Somatochlora sahlbergi* in the «Taymirsky» biosphere reserve (around 74° N) [Pospelova, 2007]. Perhaps this is also the breeding place of the other two species.

Faunal change through climate change

Changes in dragonfly faunas in the subarctic regions of the Palearctic due to climatic conditions can only be documented through international research projects and intensive monitoring [see Korotyaev et al., 2017; Hodkinson, 2018]. Thus, only a few indications can be given here. As recently as the early 1980s, *Lestes sponsa*, *Coenagrion pulchellum*, *Pyrrhosoma nymphula* and *Aeshna cyanea* were absent from the boreal taiga of northern Fennoscandia [Hämäläinen, 1984] and they only reached the Arctic Circle in the last five years (Table 1). They are all cold-tolerant species whose ranges extend far to the south. The same applies to *Erythromma najas* and *Somatochlora flavomaculata*, which have only recently been found in the far north of Finland [Karjalainen, 2021]. Perhaps in the course of climate warming, cold-tolerant species will expand their ranges to the north. Species that were previously only rarely found in the north can now be detected much more frequently. A well-documented example is the status of *Enallagma cyathigerum* in northern Norway shown in Fig. 2. From the first documented observations on the beginning of the 20. Century, up to the present, significantly more evidence was provided in the last 20 years.

Schröter et al. [2012] fear that cold-adapted species, especially *Somatochlora sahlbergi* in Fennoscandia, may be displaced from their habitats by more competitive species (*S. metallica*) as climates warm. The specific dry and cold conditions that predominate in northern Siberia can also change in the long term and thus impair the habitats of cold-adapted species. There could be northward shifts in ranges for both cold-adapted and cold-tolerant species. The latter could expand their ranges.

Table1. Overview of the dragonfly species in the Arctic Circle. Grey: cold-adapted species, white: cold-tolerant species

Таблица 1. Обзор видов стрекоз, обитающих за Полярным кругом. Экологические группы: серый фон — холодоадаптированные виды, белый — холодоустойчивые виды

	Species	Region								
		Troms og Finnmark, Norway	Norrbottens län, Sweden	Finnish-Lappland, Finland	Kola Peninsula, Russia	Eastern European subpolar region and Polar Ural, Russia	Yamal Peninsula and between Polar Ural and Yenisei estuaries, Russia	Taymyr Peninsula and North Siberian Plainstia, Russia	East Siberian Mountains and East Siberian Lowlands, , Russia	Chukotka, Russia
1	*Calopteryx virgo* (L., 1758)	x	x	x						
2	*Lestes dryas* Kirby, 1890									x
3	*Lestes sponsa* (Hansemann, 1823)	x*	x	x	x					
4	*Coenagrion armatum* (Charpentier, 1840)	x	x	x		x				
5	*Coenagrion glaciale* (Selys, 1872)					x		x		x
6	*Coenagrion hastulatum* (Charpentier, 1825)	x	x	x		x	x	x		
7	*Coenagrion hylas* (Trybom, 1889)					x	x	x	x	x
8	*Coenagrion johanssoni* (Wallengren, 1894)	x	x	x		x	x	x		x
9	*Coenagrion lunulatum* (Charpentier, 1840)	x	x	x		x	x			x
10	*Coenagrion puella* (L., 1758)				x					
11	*Coenagrion pulchellum* (Vander Linden, 1825)	x*				x?				
12	*Enallagma cyathigerum* (Charpentier, 1840)	x	x	x		x	x	x	x	x
13	*Erythromma najas* (Hansemann, 1823)			x	x	x?				
14	*Pyrrhosoma nymphula* (Sulzer, 1776)	x*								
15	*Aeshna caerulea* (Ström, 1783)	x	x	x	x	x	x	x	x	x
16	*Aeshna crenata* Hagen, 1856				x?	x	x	x	x	x
17	*Aeshna cyanea* (Müller, 1764)	x*								
18	*Aeshna grandis* (L., 1758)	x	x	x	x	x	x			
19	*Aeshna juncea* (L., 1758)	x	x	x	x	x	x	x	x	x
20	*Aeshna serrata* Hagen, 1856					x				
21	*Aeshna subarctica* (Walker, 1908)	x	x	x	x	x	x	x	x	x
22	*Ophiogomphus cecilia* (Fourcroy, 1785)		x	x						
23	*Cordulegaster boltonii* (Donovan, 1807)		x		x					
24	*Epitheca bimaculata* (Charpentier, 1825)								x	
25	*Cordulia aenea* (L., 1758)	x	x	x	x	x	x	x	x	x
26	*Somatochlora alpestris* (Selys, 1840)	x	x	x		x	x			
27	*Somatochlora arctica* (Zetterstedt, 1840)	x	x	x	x	x	x	x		x
28	*Somatochlora exuberate* Bartenev, 1911							x		x
29	*Somatochlora flavomaculata* (Vander Linden, 1825)		x	x						
30	*Somatochlora graeseri* Selys, 1887					x	x?	x	x	x
31	*Somatochlora metallica* (Vander Linden, 1825)	x	x	x	x	x	x			
32	*Somatochlora sahlbergi* (Trybom, 1889)	x	x	x	x	x	x	x		x
33	*Libellula quadrimaculata* L., 1758	x	x	x	x?	x?	x			
34	*Leucorrhinia dubia* (Vander Linden, 1825)	x	x	x	x	x	x			
35	*Leucorrhinia (dubia) orientalis* (Selys, 1887)					x	x	x	x	x
36	*Leucorrhinia rubicunda* (L., 1758)	x	x	x	x	x	x			
37	*Leucorrhinia intermedia* Bartenev, 1911							x		x
38	*Sympetrum danae* (Sulzer, 1776)	x	x	x	x	x	x	x		x?
39	*Sympetrum flaveolum* (L., 1758)				x?	x	x	x		x?
40	*Sympetrum vulgatum* (L., 1758)						x?			
	Number of species	23	23	23	18	27	23	18	10	19

* first discovered in 2017 (*P. nymphula*) or 2018 (*Coenagrion pulchellum*, *Aeshna cyanea*), ?: presence uncertain.

* первые находки в 2017 г. (*P. nymphula*) или 2018 г. (*Coenagrion pulchellum*, *Aeshna cyanea*), ?: в настоящее время не определено.

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