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Designs for Dragonflies – Odonata diversity in Oslo, Norway

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1. INTRODUCTION

A small study on the presence of dragonflies in a small city in the northern latitudes is a merely a modest endeavour to contribute to our knowledge of the world. At the same time, the selection of dragonflies, and the focus on an urban environment, is neither coincidental, nor without relevance to the greater problems that haunt humankind in the 21st century.

Urbanization, loss of biodiversity, diminished human nature experiences, and the need to conserve (and restore) landscapes and species are interrelated issues. These are a subset of significant problems derived from an increasing human population (especially in urban areas), correspondingly greater levels of consumption of material resources, and global climate change.

This study evolved from the idea that cities will become increasingly important loci of biodiversity (Aronson et al., 2017; Ives et al., 2016). As habitats are degraded, diminished, or destroyed beyond urban areas, the city may become a wildlife refuge – except that "the city" as a separate environment is a myth. Urbanization is the process of this mythical "city" absorbing habitats, breaking populations into metapopulations existing on ever-smaller fragments. A key to survival for many species will be connectivity between these patches (LaPoint et al., 2015).

A critical role for ecologists will be working with species conservation measures in urban environments. This raises questions of how ecological studies can be designed for urban environments. There is already a significant body of literature that informs our understanding of urban ecology, and addresses some of the myriad issues that are arising in the changing landscapes humans and wildlife inhabit (Forman, 2014; Pickett et al., 2001; Pickett et al., 2013)

Two ideas underpin this study. The first is that the success of conservation measures in urban areas requires ecologists to understand some aspects of the design and social function of blue-green spaces. They should foster what Opdam et al. (2013) refer to as a "design-oriented approach", and maintain a dialogue with landscape designers, and those involved in urban planning (Ahern, 2013; Beatley, 2008; Felson et al., 2013; Grose, 2014; Nassauer & Opdam, 2008). The success of this dialogue could ultimately enhance stewardship (how much people care about, and care for, species and landscapes), a critical factor in conservation (Felson et al., 2013; Mathevet et al., 2018). This process is depicted in **Figure 1**.

The second idea arose from the question "How can we conserve a species if we do not know it is there?". This was connected to a personal interest in Odonata (dragonflies and damselflies), and an awareness that a species assemblage study for the Oslo municipality had not been conducted. The study that was conceived is the subject of this thesis.

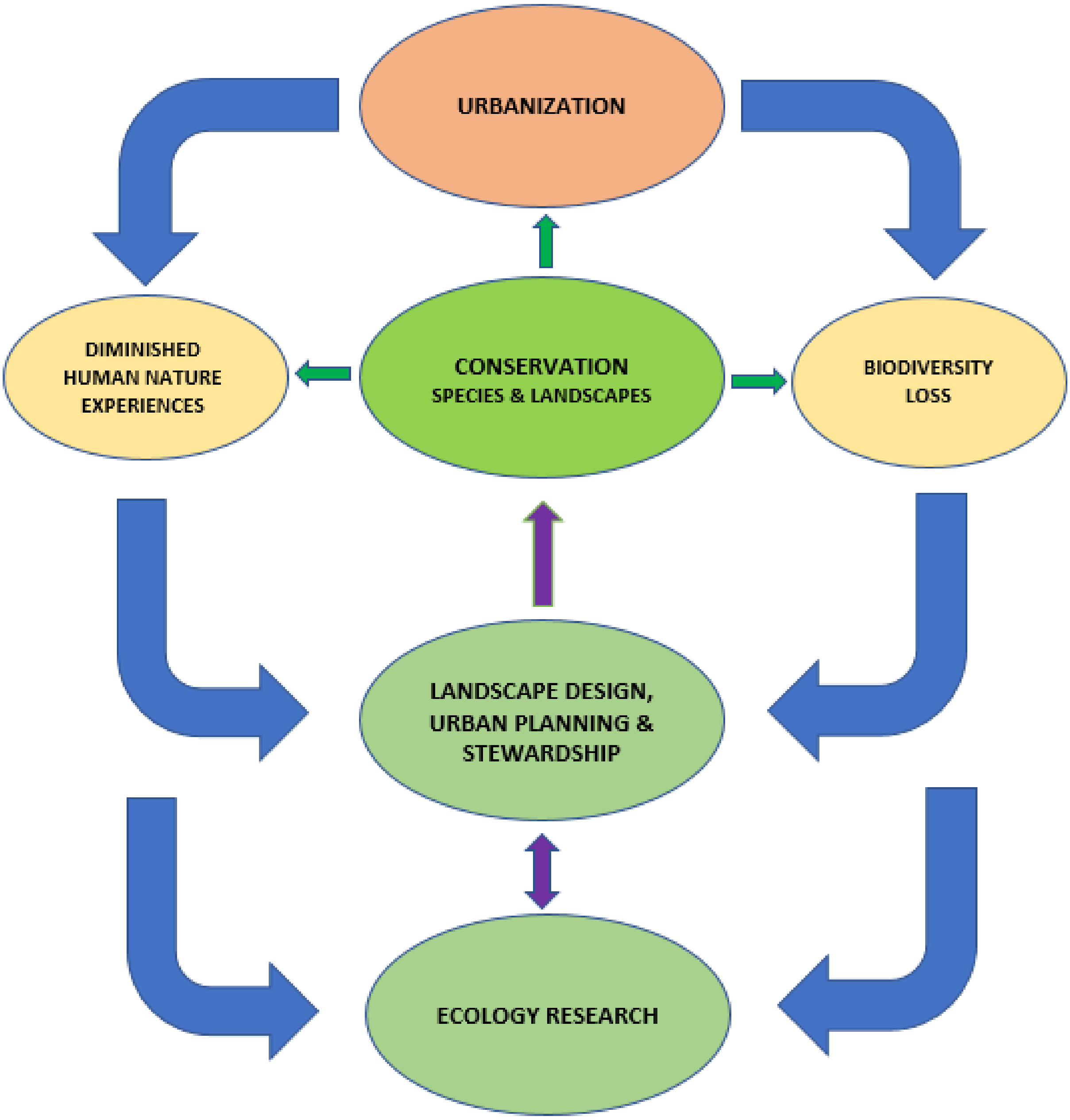


Figure 1 Landscape design, urban planning, and initiatives fostering stewardship, are crucial elements in the effective conservation of species and landscapes. Successful conservation, underpinned by ecology research, can mitigate the negative effects of urbanization, and impact on how urbanization occurs.

1.1 Biodiversity

Biological diversity, or biodiversity, as is the more common term, refers to more than individual species. It comprises the spectrum of biological entities from entire ecosystems, individual species, and single genes (Krebs, 2009). This study considers biodiversity in an urban context, with reference to species in the insect order of Odonata (dragonflies), and the diverse lentic (pond) ecosystems that are habitats for juveniles.

1.1.1 Biodiversity – charting the extent of what we do not know

It is a remarkable fact that in an age where humans seek to identify life on Mars, our catalogue of life on Earth is incomplete. As scientists we seek to identify, measure, and quantify all that exists, and yet the biological diversity of the planetary ecosystem which allows us to breathe, to eat, to reproduce, and in short, to live, is a great unknown. Estimates of species numbers vary from 2 million (Costello et al., 2012; Larsen et al., 2017) to more than 1 trillion when microbial diversity is included (Larsen et al., 2017; Locey & Lennon, 2016). All that science can offer are "best educated guesses", and many of these hover between 9 million (Mora et al., 2011) and 15 million species (Krebs, 2009). Whatever the precise figure, there is some consensus that approximately 1.5 million species have been identified; a mere fraction of that which exists (Larsen et al., 2017).

Our collective ignorance is a cause for concern. It is more than 30 years since the eminent E.O. Wilson (1985) insisted that scientists, supported by governments, must prioritise the identification of new species, and attempt to compile "a complete survey of life on Earth". An ant taxonomist by training, Wilson pointed out the dangers of so little attention being paid to taxonomy, namely the hurdles that lack of species knowledge posed to studies in ecology, biogeography, and behavioural biology. His eloquent plea was supported by economic and humanitarian arguments – the value of undiscovered food crops, and potential cures for human cancers. It was underpinned by a plan of action, and of the greatest relevance to this study, a depiction of the global habitat destruction that threatens biological diversity.

More than three decades later, with all the advances in technology, we have still failed to address what Wilson described as "one of the key problems in science" – the number of species on the planet (Wilson, 1985). Furthermore, without knowing the number of species it is difficult to accurately estimate extinction rates (Costello, 2015). The environmental destruction Wilson deplored continues unabated, and for all the difficulties with accurate predictions, it has nonetheless been established that diversity in ecosystems, species, and genes is being lost at unprecedented rates (Ceballos et al., 2015; Sanders et al., 2018). Even as we chart the loss of known species, we must acknowledge that the existence of others, as yet unidentified, have also been extinguished. Humans are witnessing nothing less than a sixth mass extinction event (Ceballos et al., 2015; Estes et al., 2011; McCallum, 2015; Wake & Vredenburg, 2008).

1.1.2 Biodiversity loss – what's the problem?

This rapid loss of biodiversity is problematic for several reasons. One of the most serious is the effect of extinction cascades (Colwell et al., 2012; Veron et al., 2018). Due to interactions between species, the loss of one species (primary extinction) can lead to the demise of another (secondary extinctions) – this is the beginning of the cascade effect. For this reason, conservation of habitats, and more broadly, landscapes is crucial (Primack, 2012). The conservation of habitats ensures that we are maintaining the ecosystem, with the interrelationships between all the species within it, intact. Our lack of knowledge about the complexities of these interspecies relationships is thus less injurious to their survival.

The consequences of multiple extinction cascades suggests an ecosystem moving towards collapse, and the subsequent cessation of the critical ecosystem services they provide. Ecosystem services are "the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza et al., 1997). They are grouped into supporting, regulating, provisioning and cultural services, and include nutrient recycling, soil formation, primary production, carbon sequestration, climate regulation, water and air purification, pollination, pest and disease control, waste decomposition and detoxification, as well as cultural and recreation services (Costanza et al., 1997; Millenium Ecosystem Assessment, 2005).

Finally, the viewpoint proposed by the philosopher Arne Næss (2005) that organisms have an intrinsic value, is worthy of mention. An organism should not need to have a perceived value for humans for its extinction to be considered a loss.

1.1.3 Mass extinction and biodiversity loss – the causes

This sixth mass extinction event, and the accompanying biodiversity loss, have various causes including: habitat fragmentation and destruction (land-use change); habitat degradation; pollution; climate change; invasive species; and overexploitation of species (Primack, 2012; Rands et al., 2010). However, where terrestrial biodiversity loss is concerned, it is driven primarily by changes at the landscape level, namely changes in land-use (Pereira et al., 2010; Rosa et al., 2014; Titeux et al., 2017). These include deforestation either by conversion to farmland, mine sites, or from illegal logging (Rands et al., 2010); changes in agricultural land – including intensification of farming, or abandonment (Uchida et al., 2018); building infrastructure such as roads (Chen & Koprowski, 2016; Rosa et al., 2014); and of course, urbanization, the sprawl of our ever-growing cities (Forman, 2014; McKinney, 2002).

1.2 Urbanization

It is important to understand urbanization, not simply because it is a driver of biodiversity loss, but because it is a global phenomenon, and occurring at an accelerating rate. In 2018, the percentage of the global population living in urban areas is 55 percent, including 74 percent in Europe. The global percentage is expected to rise to at least 68 percent by 2050 (United Nations, 2018).

The rate of urbanization in Norway is 82 percent. Although this is higher than the average level in Europe, it corresponds to the rate in other Nordic countries (United Nations, 2018).

Urbanized areas are defined as "those in which people live at high densities, or where the built infrastructure covers a large proportion of the land surface" (Pickett et al., 2001). Urbanization is thus the process, and describes both the internal process of densification, and the external process of expansion (Forman, 2008; Forman, 2014). Consequently, urban areas and populations vary dramatically in size. Almost 50 percent of the global urban population live in cities of less than 500,000 inhabitants, and "around one in eight live in 33 megacities with more than 10 million inhabitants" (United Nations, 2018).

It should be noted that the European Commission defines a city in the European Union (EU), Switzerland, Croatia, Iceland and Norway as having "an urban centre of at least 50 000 inhabitants" (Dijkstra & Poelman, 2012). They identified 828 urban centres as fulfilling the criteria for city status, thus underlining the relevance of this study in examining the nexus between urban areas, landscape design, and the conservation potential of cities.

1.2.1 Urbanization models and Oslo

There are different models for describing the way in which urbanization takes place. It has been argued that although all cities initially expand outward, "sprawl" is not necessarily the most appropriate term to describe European cities, which in many cases may be more compact (Catalan et al., 2008). This certainly seems to be the case for Oslo, especially as the city aims that new buildings and developments shall occur within existing urbanized areas (Kommunal- og moderniseringsdepartementet, 2015).

Furthermore, the model of a city that "bulges" seems to also most typify Oslo. This is a city where "outward urbanization occurs in planned or unplanned patches adjoing the urban fringe, and in different directions over time" (Forman, 2008; Forman, 2014). Oslo, with its location at the end of a fjord, and surrounded by high hills, has developed outwards from the fjord, and "bulges" have formed alongside rivers, initially in flatter areas where the landscape is more hospitable for building. Less accessible areas have been developed later, and this has seen the peculiar situation, particularly at one study site (Lillevannet), at 426 metres, where houses are packed tightly around a small lake surrounded by peat moss (*Spagnum spp*). Some decades ago, when there was less awareness of the need to preserve such sites, endangered ecosystems like these may well have been filled in.

The relevant points are that cities are different, and urbanization is not itself a uniform process. It is important to keep this in mind when evaluating literature on urban biodiversity.

1.2.2 Urbanization and biodiversity within cities

As urban areas expand, habitats become fragmented, degraded, or destroyed. Native species are usually replaced with non-native species, and this leads to a homogenization of nature in urban areas (Forman, 2014; McKinney, 2002; McKinney, 2006). Certainly, McKinney (2008) in a review of 105 studies, confirmed a trend that shows a decline in species richness associated with intense urbanization. However, it was also noted that the situation is more complex at moderate levels of urbanization. This last point supports the idea that urban areas have the potential to function not just as conservation areas, but perhaps, with appropriate design, planning, and stewardship interventions, even as biodiversity-rich refugia.

Although urbanization is a cause of biodiversity loss, its ubiquitous and growing presence on our planet means that over the past 25 years scientists have devoted increasing attention to the biodiversity that exists within urban areas (**Figure 1.1**). In the ten years since McKinney published the review article, studies with the keywords "urban biodiversity" have quadrupled.

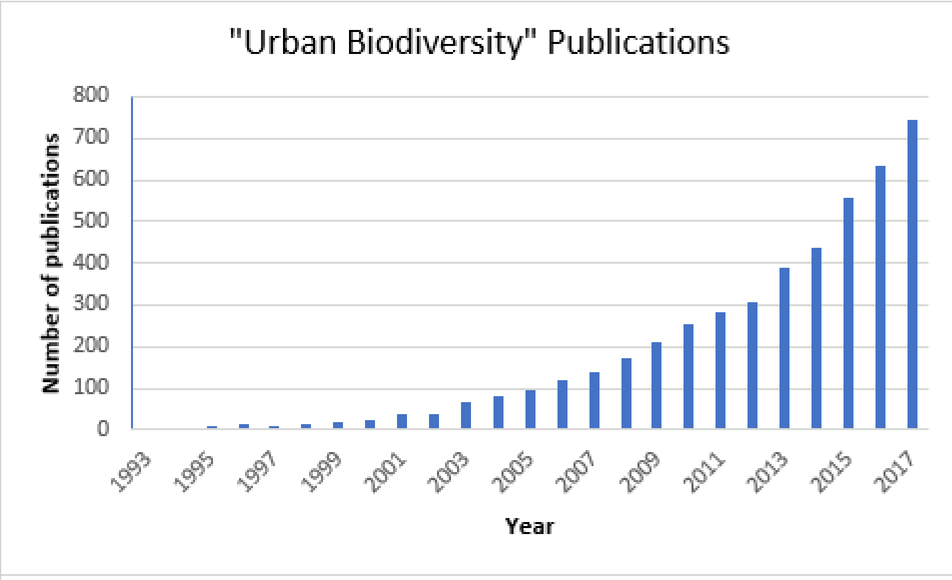


Figure 1.1 Publications (1993 – 2017) containing the keywords "urban biodiversity" in the Web of Science database.

1.2.3 Urban areas as biodiversity conservation zones

Whilst many of these articles describe species attrition, there are some good news stories, like the study by Ramirez-Restrepo et al. (2017). This describes the phenomenon of the *Eumaeus* butterflies of Mexico hunting down their vital, but endangered, host plants within the city. These plants, cycads, are often poached from the wild. Although the *Eumaeus* butterflies would normally avoid urban environments, they have been recorded visiting ornamental plants in the city. One of the recorded species, *Eumaeus childrenae,* is a International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

The appearance of such an article suggests that ecologists are moving away from mapping the disappearance of species in urban areas, to investigating the possibility of a presence of species that would not be expected to exist there in the first place.

A further example is an Australian study (Maclagan et al., 2018) examining the presence of the endangered southern brown bandicoot (*Isoodon obesulus obesulus*) in novel habitats in urban Melbourne, a city with a population of approximately 5 million inhabitants.

Another recent change in the literature is the growing body of articles examining the ecology of green roofs (Blaustein et al., 2016; Francis & Lorimer, 2011; Lundholm, 2016; Mayrand & Clergeau, 2018; Rosenzweig, 2016; Washburn et al., 2016), and even "skyrise greenery" (Oh et al., 2018).

It would appear that the idea of urban areas functioning as biodiversity conservation zones is finally being taken seriously (Miller & Hobbs, 2002; Sanderson & Huron, 2011).

1.2.4 Ponds – the missing element in urban ecology research

Urban ecology research suffers from biases like every other field of study, and there is a clear preference for data being collected from terrestrial and riparian ecosystems. Otherwise, most of the related literature seems to explore the ecosystems of stormwater ponds (16 articles, from 2009-2017, were identified in a search in the Web of Science database).

Indeed, the authors of a recent study examining the aquatic biodiversity of 240 urban ponds, and 782 non-urban ponds in the United Kingdom, note that "little is known regarding the consequences of urbanization on freshwater habitats, especially small lentic systems" (Hill et al., 2017).

In addition to the study by Hill et al. (2017), the only other studies that could be identified which examine the ecology and biodiversity of urban ponds, are extremely recent: (Hill & Wood, 2014; Holzer, 2014; Mimouni et al., 2015; Ngiam et al., 2017; Thornhill et al., 2017; Thornhill et al., 2018).

The absence of information on the biodiversity of urban lentic systems presents a challenge for those with responsibility for managing our urban areas. It also poses difficulties for those designing them. However, it is also possible that this lack of interest reflects a conglomeration of circumstances – the role of small water bodies in cities, urban planning and landscape design trends, the differing perspectives of nature in cities, and of course, the recent development of urban ecology as a valid field of scientific study.

Nonetheless, given urbanization trends, and established links between the quality of urban ecosystems and human health and well-being (Douglas, 2012), filling this data gap should be a priority for ecologists. This study is a small contribution.

1.2.5 Urban nature encounters, cultural services, and stewardship

A highly relevant concept in the context of urban ecological studies concerned with some aspect of conservation, is its link with stewardship. The subject is discussed within the context of cultural ecosystem services by Musacchio (2013) in an article entitled "Cultivating deep care". Cultural ecosystem services are described in detail in the Millenium Ecosystem Assessment (2005). They encompass the "non-material benefits people obtain from ecosystems through: spiritual enrichment; cognitive, emotional and social development; reflection; recreation; and, aesthetic experiences" (Tengberg et al., 2012).

Musacchio argues that the cultural services aspect of ecosystem services has often been given less attention than the other services which support our biosphere. The author considers this problematic as "deep care" is an essential component of "maintaining and improving biodiversity, ecosystem services, and human well-being". Musacchio cites cultivating community gardens, and restoring remnant habitats as examples of this "deep care".

As Andersson et al. (2014) discuss, such activities also have embedded within them motivations to create a "sense-of-place, memory, and meaning". The creation of collective memories reinforces the sense of connection, and supports the conservation of these sites (Andersson et al., 2014; Kremen, 2005). Urban nature encounters are thus both a catalyst for stewardship, and intrinsic to it.

Of relevance to Odonata, as a species, is the article by Primack et al. (2000) which describes the conversion of urban ornamental ponds into dragonfly habitats. This was founded in the aesthetic appreciation that the Japanese have for Odonata. Perhaps this appreciation could be cultivated in Norway?

Although this study is not about urban gardens, or restoration of habitat areas by civic groups, the idea of collective memories and meaning is highly relevant. It could be argued that sites like Slottsparken (A04, A05, A06), Frogner park (B04, B05), and the Botanic Garden (A02, A03), which are central and universally accessible, belong to the collective memory of all Oslo residents. Local parks (for example sites at Grorud (D05) and Årvoll (B12) embody local memories.

Indeed, community engagement has been high when the Slottsparken ponds have been drained and repaired, as evidenced by contemporary newspaper articles (Hegna, 2003; Henriksen, 1999; Olsen, 2003; Riaz, 2003). Plans to make Årvoll bathing pond more "natural", and replace the asphalt basin with vegetation and sand were met with strong resistance (Badedammens venner, 2016). In the case of Årvoll badedam (B12) (a swimming pond located on a stream), the arguments for not changing the structure of the pond were rooted both in an attachment to communal memories of place, and a fear of disrupting the ongoing social functions of the site.

Caring is thus the essence of stewardship. The examples of Årvoll (B12) and Slottsparken (A04, A05, A06), also indicate why landscape design is such a powerful influence in our cities. Poor design (from an ecological perspective) might be accepted if it supports social and aesthetic requirements. Yet excellent design – functional, inclusive, aesthetically-pleasing, and based on sound ecological principles – has the potential to make urban dwellers care not just about the landscape they inhabit, but also about the landscapes and species beyond the fringes of the city they inhabit. In the case of urban ponds, excellent pond and park (landscape) design could provide habitats for "flagship" species – like dragonflies. For the purpose of flagship species is to persuade people to care, and hence their importance in conservation.

1.3 Dragonflies – an ideal study organism for urban ponds

Dragonflies have an ancient lineage, dating back to the Triassic Period, some 245 million years ago (Gullan & Cranston, 2010). In this respect they are an insect that has demonstrated a remarkable evolutionary capacity, withstanding as they have enormous shifts in climate, geology and the survival pressures that more recent species have placed upon them. At the same time, dragonflies are still bound to their primeval element – water. Without water they cannot complete their life-cycle, indeed they cannot begin it, as their eggs are either laid in or adjoining an aquatic habitat.

They are an excellent study organism for urban ponds, not least because their scintillating beauty has long fascinated naturalists, both amateur and professional. Consequently, there is a significant amount of literature available on their biology, ecology, and in more recent times, their presence in urban environments. Furthermore, the beauty of dragonflies makes them an ideal flagship species group for the conservation of urban ponds (Janssen et al., 2018).

Furthermore, "many Odonata species are able to live in partially degraded habitats, are capable of rapidly colonising new or restored habitats, and when compared with birds, mammals, and amphibians, can maintain viable populations in relatively small remnants of habitat" (Clausnitzer et al., 2009).

1.3.1 Classification of European dragonflies and damselflies (Odonata)

Dragonflies belong to the order Odonata and in Europe traditionally contain the suborders Zygoptera (known as "Damselflies") and Anisoptera (referred to as "Dragonflies proper"). Over the years there has been debate concerning the allocation of four species to a possible third suborder – the Anisozygoptera (Askew, 1988; Dijkstra et al., 2013; Dijkstra & Kalkman, 2015). In more recent times these species have either been combined with the Anisoptera, or listed with them under a new suborder, the Epiprocta (Dijkstra et al., 2013; Kalkman et al., 2008). However, as these species are found only in Japan and the Himalayas, and most of the literature consulted refers to Anisoptera, the traditional system of classification has been used in this study.

1.3.2 Number of species in Europe and Norway

The number of species present in Europe has expanded over the past decades. The 137 species listed by Askew (1988) , have increased to 143, of which 52 belong to the Zygoptera (5 genera, 13 families) and the remainder (91 species) to the Anisoptera (7 genera, 28 families) (Dijkstra & Kalkman, 2015). Some of these species have a limited distribution in Europe eg. the Mediterranean islands, southernmost Spain or European Turkey (Askew, 1988; Corbet and Brooks, 2008). It should be noted that Odonata classification and nomenclature are still being updated, especially with the use of molecular methods to test phylogenetic reconstructions (Dijkstra & Kalkman, 2012; Dijkstra & Kalkman, 2015).

As of 2017, there are 50 species registered in Norway (Elven & Aarvik, 2018) . See **Appendix 1** for the complete list.

1.3.3 Conservation status of Odonata

As with many species, dragonflies are under threat. According to the International Union for the Conservation of Nature (IUCN) there are 5680 known species of Odonata across all continents except Antarctica (Clausnitzer et al., 2009; IUCN, 2015). On a worldwide basis, most of the threatened species are located in the Indonesian-Malayan archipelago and Australia: the former being vulnerable due to logging activities and the latter affected by the negative effects of climate change on freshwater ecosystems (Clausnitzer et al., 2009).

The Global Red List, from which the European Red List is derived, contains nearly all of the 143 species in Europe. Most of the listed species are ranked as being of "least concern". The organisation notes that improved water management, as well as decreasing eutrophication, appear to have halted the severe species decline that was evident from the 1960s to 1980s (European Commission, 2015). The majority of species which are most endangered (15 of 22) are those dependent on swiftly running water, and all have distribution areas around the Mediterranean (European Commission, 2015).

The Norwegian species currently listed on the Red List (2015) are: *Coenagrion lunulatum* (VU), *Epitheca bimaculata* (VU), *Gomphus vulgatissimus* (NT), *Lestes dryas* (VU), *Onychogomphus forcipatus* (NT), *Orthetrum cancellatum* (VU), *Somatochlora flavomaculata* (VU), *Somatochlora sahlbergi* (NT) (Kjærstad, G & Olsvik, H, 2015). This list is reduced from seventeen species in 2010.

1.3.4 Present knowledge about dragonflies (Odonata) in urban areas

Various studies of Odonata assemblages in urban areas in Europe have been undertaken. The most important of these, in terms of relevance to this project, are: (Chovanec, 1994; Funk et al., 2009; Goertzen & Suhling, 2013; Goertzen & Suhling, 2015; Jeanmougin et al., 2014). Furthermore, a useful review article on dragonflies and damselflies in urban ecosystems was published in 2016 (Villalobos-Jimenez et al.).

1.3.5 Odonata habitats

Dragonflies are first and foremost aquatic insects. Most species require freshwater environments for juveniles, however some few can tolerate brackish water, including salt marshes and mangroves (Kalkman et al., 2008).

In tropical regions, some of the more unusual larval habitats comprise water at the bases of palm and bromeliad leaves, in tree holes and more seldom in rainforest leaf-litter (Askew, 1988). This suggests interesting possibilities, from a conservation angle, for introducing threatened tropical species into large glasshouses in urban areas, preferably in tropical zones where they are endemic. (In temperate zones, such a conservation solution would at best serve no other function than that of an exotic zoological garden for arthropods, and at worst might falsely suggest to non-ecologists that there are technical, artificial solutions to all our ecological conundrums).

However, the overwhelming majority of Odonata inhabit freshwater systems which may be described as either lotic or lentic. The former describe ecosystems with flowing water, such as streams, canals and rivers, and the latter non-flowing water systems, including wetlands, ponds and lakes (Smith & Smith, 2012). In an urban environment specific habitats include garden ponds, ornamental pools in parks, canals, ditches, streams, rivers, water treatment wetlands, natural wetlands and floodplains (Chovanec, 1994; Jeanmougin et al., 2014; Simaika et al., 2016; Solimini et al., 1997). Furthermore, *Sympetrum striolatum imitoides*, which does not require its eggs to be laid in vegetation, has been known to use swimming pools (Corbet, 1999; Matsura et al., 1995), as has *Ischnura elegans* (Primack et al., 2000).

1.3.6 Habitat threats

Destruction of habitat, through pollution from agriculture, the drainage of wetlands, and the conversion of land for agriculture or infrastructure development are among the reasons that have long been major causes of Odonata species attrition (Samways & Steytler, 1996). Habitat fragmentation, concretisation of stream beds in urban areas, and fluctuating flow-regimes in rivers used for hydro-electricity have also been detrimental (Hawking & New, 1999)

1.3.7 Habitat issues in urban areas

Whether the above-mentioned aquatic environments are actually suitable for Odonata, in urban areas, depends on the quality of the water (pollution and oxygen levels), the type, extent and location of emergent and waterside vegetation, and the level of disturbance by waterfowl, dogs and humans.

Water quality is the key issue, for although juvenile dragonflies are aquatic by nature they must still address the two primary challenges that face all water-dwelling insects: respiration and osmoregulation (Williams & Feltmate, 1992). Dragonfly nymphs are hydropneustic, that is they extract dissolved oxygen from the water in which they live. Their respiratory processes are facilitated by internal (rectal) tracheal gills in Anisoptera, or in Zygoptera, three ovoid gills at the end of the abdomen. Habitats with very low oxygen levels are therefore likely to be unsuitable for many species.

Aquatic ecosystems in urban areas are subject to eutrophication, acidification, and pollution by heavy metals. Eutrophication is caused by high levels of nutrients, mostly excess nitrogen in the form of air pollution (nitrogen oxide (NOx) from fuel combustion), and ammonia (NH_3) from agricultural fertilisers, as well as phosphates (European Environment Agency, 2014). The key problem with eutrophication is that it changes the nutrient balance in the ecosystem, favouring the growth of algae. Algal "blooms" may form, which in turn affect the viability of existing plants. When these plants, and the algae, eventually die, the levels of dissolved oxygen in the water are depleted by the decomposition process (European Environment Agency, 2014; Krebs, 2009). This makes the ecosystem unsuitable for many species, including dragonflies.

Although Odonata species such as *Aeshna subarctica* and *A. viridis* thrive in the acidic environment of peat bog pools, most dragonflies, especially those likely to be found in the ponds, streams and rivers of urban areas, require neutral conditions in order to survive. Acidification of water and soils is the result of sulphur emissions from fossil fuel combustion being oxidised to sulphate and returned to soils, the ocean, and freshwater ecosystems through precipitation (Krebs, 2009).

Pollution in the form of heavy metals is also problematic for Odonata. Cadmium, mercury and nickel are some of the heavy metals which are especially toxic to aquatic life, including dragonflies (European Environment Agency, 2014).

1.3.8 Expanding range of lentic (pond) species
Of particular interest is the expanding range of many European dragonfly species. A study by Grewe et al. (2013) examined the distribution of European dragonflies between 1988 and 2006. They found that lentic species, in the southern grouping, expanded the northern limit of their range by approximately 115 km per decade. Although there was no "consistent trend" for the northern grouping, it is not improbable that such a trend might emerge in future years.

1.3.9 Climate change impacts.
Climate change and longer seasons mean that dragonflies, like butterflies and other insects, have the opportunity to produce more seasons per year (Feehan et al., 2009).

1.4 Parks and gardens in Oslo

1.4.1 Early parks and gardens
The first city park, Grønningen, was established in 1805-1806 on reclaimed land at the harbourside in Bjørvika (Bruun, 2007). In 1812, the newly established local neighbourhood association (Selskabet for Christiania Byes Vel) took responsibility for developing the park, and by 1819 the work was completed (Hanssen, 1987). Also known as Esplanaden ("The Esplanade") it rapidly became popular both as a walking place, and for attending concerts given by the military. This lasted until it disappeared beneath the bricks and mortar of the growing city, and in 1826 became the site of the new Stock Exchange (Hanssen, 1987).

One can imagine how the loss of this park was felt, particularly when the social function of walking or "promenades" is taken into account. Consider how the employment opportunities offered by Christiania drew unmarried men and women from the districts. The city was a marriage market (Myhre, 1990), and one that could not function in the traditional way where families or acquaintances made the necessary introductions that would lead to matrimony. Public parks, and the art and exercise of promenades, offered a socially acceptable arena for personal display, and the forming of new acquaintances.

Three key parks were established in the 1800s – the Botanic Gardens (1814), A02 & A03; Slottsparken (1838), A04, A05, A06; and St. Hanshaugen (1865), A07. It should be noted that St. Hanshaugen had been used by the public for midsummer celebrations from the 1840s (Hanssen, 1987), and prior to that had been a sacrificial site, a burial ground, a drill ground for troops (from 1795), and later a site for burning rubbish and straw from the town (Hanssen, 1987).

1.4.2 Spikersuppa - Eidsvollplass

Spikersuppa (A01) in Eidsvollplass is the site of one of the ornamental ponds investigated in this study. The pond, in its existing form, is the centrepiece of a rectangular open space that stretches from the parliamentary building, "Stortinget", to the palace.

Figure 1.2 "Spikersuppa" (1960) the pond in Eidsvollsplass in central Oslo when it had more natural edges. This is site A01. (Photo: Unknown photographer, 1960, Oslo Museum).

1.4.3 Landscape style and Slottsparken

The English landscape style has particular relevance for Oslo, as Slottsparken, the park surrounding the palace was designed on these principles (Bruun, 2007). Several designs were initially proposed by the palace architect, Hans Ditlev Linstow, and Johan Siebke, the head gardener at the Botanic Gardens, but none of these were realised. It was the king himself, Karl Johan, who decided, in 1845, that the areas later known as "Abelhaugen" and "Nisseberget" should be laid out as "English gardens" (Bruun, 2007).

Martin Mortensen was promoted to palace gardener in 1849, and undoubtedly used his experience with the English landscape style in Germany and Denmark. He presided over the planting of the lawns, and magnificent flowerbeds which made Slottsparken "the most popular promenade" in the city (Bruun, 2007; Skard, 1963).

A focal point of landscape gardens are the water features, and Slottsparken contains three ponds, all of which were investigated during this study. They were designed by Linstow and Mortensen, and built in 1838 (Oslo elveforum, 2017). The northern pond, unofficially known as "Isdammen" (ice pond) was filled in for many years, and then reconstructed in 1999 (Dahl, 1999).

Figure 1.3 Slottsparken (ca. 1910) (Photo: Unknown photographer, 1910, Oslo Museum).

1.5 Opening streams within the City of Oslo

It is a stated aim of the City of Oslo is to gradually uncover and restore many of the historical streams within the boundaries of the municipality (Fagernæs, 2015). The city has been active in planning and implementing this process over the past ten years. The reasoning is that uncovering these streams will increase biological diversity, and support recreational activities, as well as being a means of dispersing runoff water at the local level. More broadly it is seen as part of a climate change adaptation strategy, given that modelling indicates that Oslo will experience greater precipitation (Fagernæs, 2015).

The Oslo Miljøetaten have also insisted that the restoration of streams should support the establishment of the riverine brown trout (*Salmo trutta* morpha *fario*), and that appropriate vegetation should be selected (Nyhuus & Ovesen, 2015).

As such this study may be a contribution to the existing body of knowledge concerning biodiversity of ponds along these streams.

1.6 Designing ponds for dragonflies

Ponds that are suitable breeding habitats for dragonflies have characteristics that correspond, at least, to the juvenile stage of their life-cycle. The key requirement for dragonfly larvae must be that there is sufficient vegetation in the water, and along the edge. Such vegetation provides shelter from predators such as ducks, fish and conspecifics ie. fellow dragonflies (Corbet, 1999; Corbet & Brooks, 2008), as well as a place to conceal themselves while seeking their own prey.

Corbet (1999) suggests four categories to describe the predatory behaviour and microhabitat occupancy of Anisoptera nymphs: claspers (visual foragers that cling to vegetation near the water surface); sprawlers (visual and tactile foragers that inhabit vegetation near the water surface); hiders (tactile foragers that either inhabit fine detritus or coarse leaf litter); and burrowers (tactile foragers that use their legs to dig and can be found in sand or amongst fine stones).

Consequently, the type of vegetation and substrate will also impact on the species of dragonflies that are likely to inhabit an urban pond. It is quickly apparent that Corbet's "burrowers" are likely to be omitted from dragonfly assemblages found in ornamental city ponds. Such ponds will lack the necessary sand substrate. Indeed, a brief survey of studies of urban assemblages in European cities reveals not a single species of *Cordulegaster boltonii* – a typical burrower, and a European species that is also endemic in Norway (Chovanec, 1994; Goertzen & Suhling, 2013; Jeanmougin et al., 2014). Other burrower species belong to the Gomphidae family, and as they inhabit lotic (river/stream) environments, it is not unexpected that they do not make an appearance.

These same studies reveal the presence of several species of Aeshnidae (claspers), Sympetrinae (sprawlers), and *Cordulia aenea* (a hider). This profile also matches that which was obtained during this study in Oslo.

Vegetation also serves two other important functions. It provides a support for juveniles when they undergo ecdysis, and the adult insect emerges from the larval shell (Askew, 1988). If such a support is not to be found in the water, the juvenile will begin a terrestrial search, sometimes travelling several metres (Corbet & Brooks, 2008). In an exposed urban environment such a prolonged search is even more undesirable, as the journey exposes the insect to predators and other dangers (being squashed).

In the adult phase, aquatic vegetation provides oviposition sites for some species, and a resting place for species that prefer to "perch" in their territory, rather than patrol it on the wing.

1.7 Laws and regulations governing pond depth in Norway

The existence of ponds is not separate from legislation, and the introduction of a law, in 1957, on wells, ponds, and pools (commonly called "Brønnloven" in Norwegian), had a dramatic impact on the number of ponds in Norway. Under this law, land-owners were required to ensure the safety of wells and ponds on their property, and this resulted in many ponds being filled in. In one municipality, close to Oslo, the number of ponds decreased from 44 in 1955 to three in 1992: a reduction of 93% (Fjellstad & Dramstad, 1999).

This law has been superseded[1] and the requirements have been tightened. The updated regulations from 1 July 2017 require that pond owners restrict access to ponds, either by covering them, or with a solid fence, at least 1.5 metres high (Kommunal- og moderniseringsdepartementet, 2017). However, there are three ways in which fencing may be avoided. These include: restricting the depth to no more than 20 cm; placing a grating no more than 20 cm below the water surface; "using vegetation or other means" to prevent children accessing the water (Kommunal- og moderniseringsdepartementet, 2017).

This has particular implications for the design of new ponds in urban areas, as well as the management of existing ponds. Indeed, the three ponds in Slottsparken (Royal Palace Park) have had gravel placed in their basins, and the depths measured during this study were recorded to be between 9 – 16 cm. The lower pond in the Botanic Gardens was also re-landscaped in 2017 in order to comply with this regulation (Lofthus, 2017). In this case vegetation has been used to prevent children easily accessing the water. The park is also closed during the evening, and access is restricted by solid, high fences.

In terms of urban ponds providing the breeding habitats for dragonflies, this new regulation poses some challenges. Dragonflies require vegetation for shelter, and when undergoing metamorphosis. Pond designers would need to ensure that they select cold-tolerant floating plants such as common frogbit (*Hydrocharis morsus ranae*), or hornwort *Ceratophyllum demersum* to provide shelter. Other plants that tolerate shallow water such as bullrush (*Typha latifolia*), tufted loosestrife (*Lysimachia thyrsiflora*) and bogbean (*Menyanthes trifoliata*) should be planted along the edge to meet the need for supports during metamorphosis (the dragonfly juvenile climbs up out of the water, and the adult emerges from a crack in the larval shell).

These solutions are far from ideal, as floating plants can lead to blockages in pump filtration systems. Many shallow water plants that tolerate depths of 0-20 cm require a mud substrate, and this is may detract from the perceived aesthetic qualities of the pond. Furthermore, the heat retained in shallow water may exacerbate the potential for algal blooms.

It is therefore possible that these new regulations will lead to a reduction in the biodiversity potential of centrally-located ponds, because those responsible for pond management will be under pressure to uphold aesthetic standards. The cost of doing this in a way that maximises the biodiversity potential of the water may be considered prohibitive. Indeed, three of the eight ornamental pond sites (Type A) sampled in this study are drained weekly and replenished with chlorinated water (St. Hanshaugen (A07), Kampen (A08) and Spikersuppa (A01)). These ponds, as well as those in Slottsparken (A04, A05, A06), are drained in winter.

[1] Lov om planlegging og byggesaksbehandling (Plan- og bygningsloven; Byggteknisk forskrift (TEK 17).

1.8 Reconstructing existing ponds to improve biodiversity?

The possibility of reconstructing or replanting existing ponds to improve biodiversity in the city should not be overlooked. Nonetheless, this is unlikely to be realistic for Type A "Ornamental" ponds. These ponds occupy a central place in the city landscape and have been adapted to comply with the relevant safety regulations, or to meet aesthetic standards.

Furthermore, the history of the ponds in Slottsparken is educational as to why the ponds exist in their current form. The ponds were initially constructed with a 30 cm thick layer of clay in the base (Olsen, 2003; Riaz, 2003). This is a reliable and reputable method known as "puddling" which was used very effectively in the 1800s (Taylor, 2000). It has but a single fallibility: a susceptibility to cracking during periods of drought (Taylor, 2000). This is precisely what happened to the ponds in Slottsparken. The subsequent leakage resulted in costly annual water expenses, until the foundation and pipe system was replaced in 2003 for 3.2 million crowns (Riaz, 2003).

The risk of damage to the subterranean pipes during winter has been cited as the reason why the ponds are drained in winter, and have not been converted into skating rinks for the public (Hegna, 2005). Certainly, the ponds are so shallow that this risk that they would freeze solid renders them unsuitable all-year habitats for dragonflies, other insects, fish, and amphibians.

2. METHODS

2.1 Study design

The key reason for undertaking this study was to establish whether Odonata (dragonflies and damselflies) breed in freshwater habitats in the Oslo urban region, especially the city centre, and if so, to determine a species assemblage, and breeding habitats. To date, no such survey has been undertaken.

There were two hypotheses:

1. Odonata larvae do not exist in ponds in the Oslo urban area (Oslo municipality).
2. Odonata larvae do not exist in ornamental ponds in Oslo city centre (2 km radius of Spikersuppa)

Secondary to this aim, and of broader significance, was the desire to identify elements that could be adjusted to support greater Odonata diversity in the municipality. This was grounded in an awareness of the species conservation potential of cities, the "flagship" status of dragonflies as a species group, and a desire to enhance the quality of wildlife experiences of urban dwellers. Consequently, the elements that were envisaged included both pond variables (for example, vegetation, substrate, and edge quality), and human behaviour.

Potential Odonata breeding habitats sites were selected along an urban to rural gradient (north, south, east, and west) from a starting point at the ornamental "Spikersuppa" pond (site A01) in the Oslo city centre. A larval sampling plan was devised, and a survey form designed to map pond variables, the presence of other wildlife, and human behaviour at the sites. The survey encompassed observations about human interaction with the water.

To provide a more comprehensive understanding of the Odonata assemblage in Oslo municipality, study data was compared with, and supplemented by, Odonata species observations registered with the Norwegian Biodiversity Information Centre (Artsdatabanken). The quality of this data was also analysed.

Finally, an index tool was developed to evaluate the habitat variables of the surveyed ponds, and statistical analysis was conducted to ascertain if there was a correlation between habitat quality scores, and the presence of Odonata larvae.

This study aims to to enhance knowledge about Odonata diversity and abundance in Oslo, and to provide a tool (the Odonata Habitat Ecological Index) which could be used by biologists, urban planners, and landscape architects, to assist and enhance the evaluation, management, and design of urban ponds. This enhancement is envisaged as concrete actions that could improve Odonata biodiversity, and the human nature experience at urban ponds, and in cities. This is important both from the perspective of human well-being in an urban context, and the vital need to tackle biodiversity loss at local, national, and global scales.

2.2 Study area

The study area comprised thirty-five (35) sites within the municipal boundaries of the City of Oslo, Norway. Oslo is situated at 59°56'N, 10°43'E, at the end of a fjord, surrounded by low hills. Consequently, the elevation of the sites varies from 4 m to 477 m, with an average height of 111 m. The climate is temperate, with cold winters, or "Dfb" on the Köppen climate classification. The City of Oslo contains eight key watercourses (Lysakerelva, Mærradalsbekken, Hoffselva, Frognerelva, Akerselva, Hovinbekken, Alna, and Ljanselva), and their subsidiaries. Many of the subsidiaries have been covered in the process of urbanisation (Fagernæs, 2015). The population of Oslo was 673 469 as at 1 Janury 2018 (Oslo kommune, 2018). It is expected to reach approximately 854 000 by 2040 (Oslo kommune, 2017).

2.3 Site selection

An initial survey identified forty (40) sites for sampling. This included "Spikersuppa" which had been identified as a desirable testing site when the research idea was conceived. Sites were selected by identifying "blue" sites, indicating freshwater bodies, using the following resources:

1. Kommunedelplan for den blågronne strukturen i Oslos byggesone
   – plankart ytre by øst, Plan- og bygningsetaten, 19.05.2009
   – plankart ytre by sør, Plan- og bygningsetaten, 19.05.2009
   – plankart indre Oslo, Plan- og bygningsetaten, 19.05.2009

2. Oslo kartboka 2017 (Rønneberg, 2017)

3. Google earth and Google maps

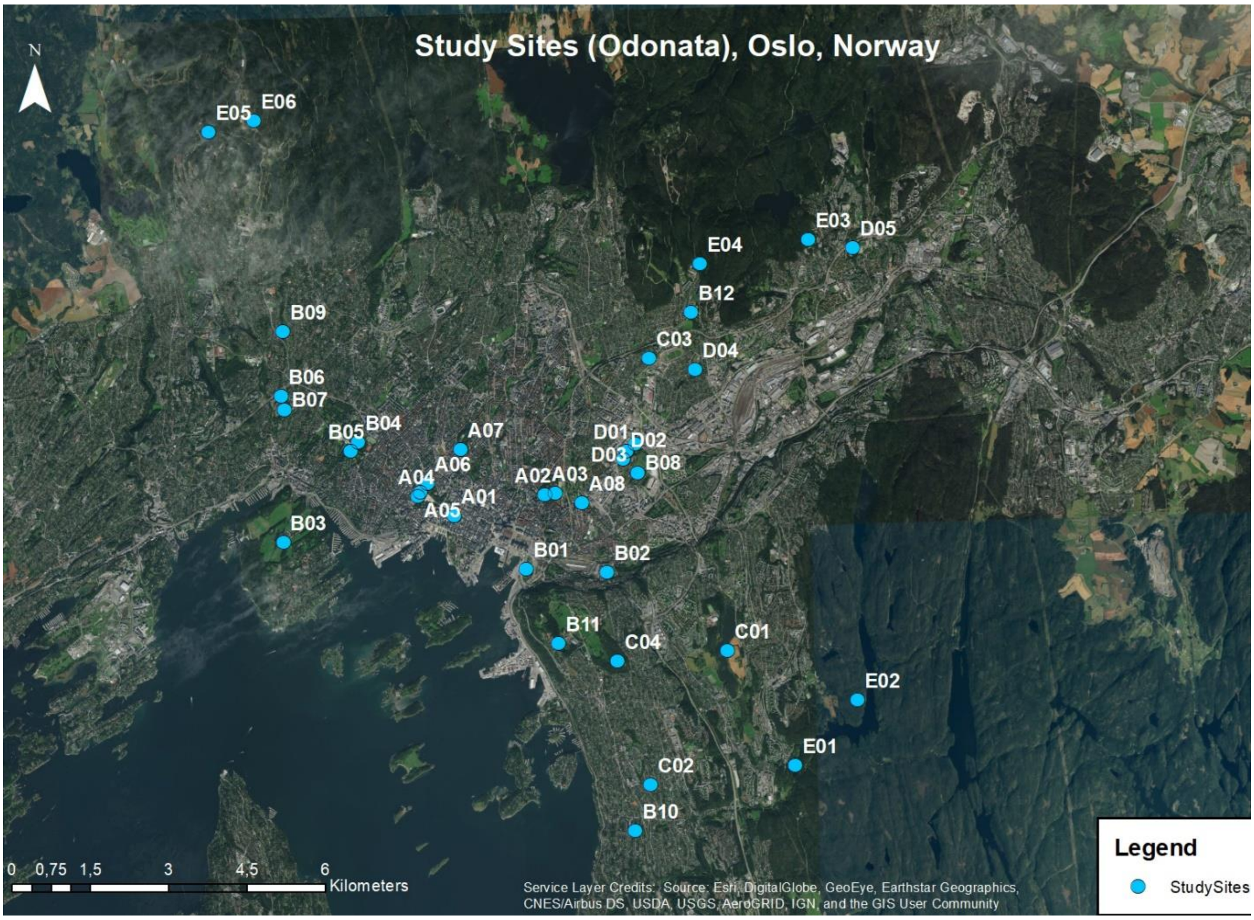
Five of the sites were removed due to access restrictions (physical and legal). Three ponds were privately owned, and it was not possible to come in contact with two of the owners. The owner of the third pond declined to give access. The final group of 35 study sites are shown on the map in **Figure 2.1**.

2.3.1 Site typology

The sites were grouped into five categories, as shown in **Table 2.1**. The category descriptions are presented in **Table 2.2**. The development of categories was a process that took place after the data was gathered, in order to understand and present it in a meaningful manner. This is why there is no standardization of site numbers in each category. The complete list of sites, with name and category, is presented in **Appendix 2**.

Table 2.1 Pond categories and number of sites

Pond categories	
Pond type	**Sites**
Type A - Ornamental	8
Type B - Natural (landscaping)	12
Type C - Natural	4
Type D - Restored	5
Type E - Forest	6



Type		Site	Ornamental	Altitude (metres)
A	Ornamental	A01	Spikersuppa	6
		A02	UiO - øvre dam	16
		A03	UiO - Fjellhagen	25
		A04	Dronningdammen	27
		A05	Kongespeilet	28
		A06	Slottsdammen	31
		A07	St. Hans-Haugen	52
		A08	Kampen	76
			Landscaping	
B	Natural (landscaping)	B01	Vannspeilet	4
		B02	Kværnerdammen	21
		B03	Bygdø Kongsgård	24
		B04	Frogner - nord	34
		B05	Frogner - sør	29
		B06	Smestad - øvre	56
		B07	Smestad - nedre	46
		B08	Hovindammen	88
		B09	Holmendammen	113
		B10	Andersendammen	121
		B11	Ekeberg friområde	129
		B12	Årvoll badedam	182

Type		Site	Natural	Altitude (metres)
C	Natural	C01	Østensjøvannet	109
		C02	Kastellterrassen	143
		C03	Bjerke travbane	154
		C04	Brannfjell	185
			Restored	
D	Restored	D01	Tegl 1 - Hoved	77
		D02	Tegl 2 - Grense	77
		D03	Tegl 3 - Tennis	79
		D04	Bjerkedalen	121
		D05	Grorudparken	169
			Forest	
E	Forest	E01	Skraperudtjern	120
		E02	Nøklevannet	166
		E03	Vesletjern	233
		E04	Årvoll isdam	242
		E05	Lillevann	426
		E06	Øvresetertjern	482

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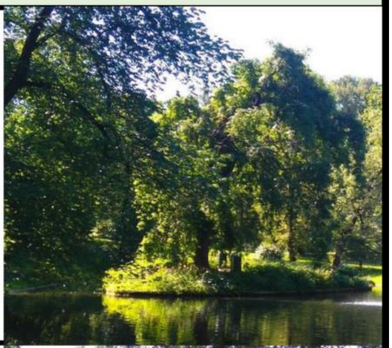
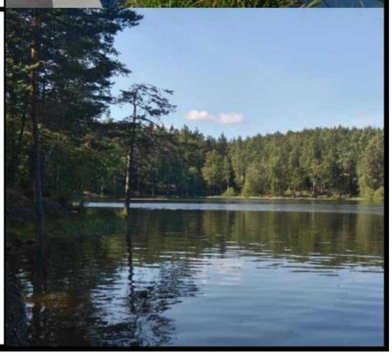
Date: 08.08.2018

Figure 2.1 Map showing the study sites which were sampled for dragonfly (Odonata) larvae in July and August 2017.

Table 2.2 The pond categories, with descriptions, which were developed and used in this study.

Type	Pond type	Description	
A	**Ornamental**	Ornamental ponds within parks, or residential areas, most of which have concrete edges. Some sites are drained in winter, others have a weekly drainage regime. They all have pump systems, and are disconnected from the local network of streams. Altitude range: 6 – 76 metres.	
B	**Natural (landscaping)**	The ponds are located on the network of city streams. They exist within a managed landscape such as a public park, residential area, or private garden. The ponds mostly have vegetation such as rushes, reeds, and floating macrophytes, or it may be a concrete basin. Altitude range: 21 – 182 metres	
C	**Natural**	The ponds are on the network of streams. They may be fenced, but the landscape is not managed. Vegetation includes rushes, reeds, and floating macrophytes. Altitude range: 109 – 185 metres.	
D	**Restored**	The ponds are natural or artificial basins on the stream network. These sites have been developed with the intention of improving their ecological and chemical quality. Altitude range: 77 – 169 metres.	
E	**Forest**	The lake is situated within the forest fringes of Oslo. It feeds into the network of streams that connect with the primary watercourses in the Oslo watershed. Altitude range: 120 – 482 metres.	

Two sites presented challenges in selecting the appropriate category. These sites, Kværnerdammen (B02) and Årvoll badedam (B12), are similar in that they have an artificial appearance (concrete and asphalt basins), and lack emergent vegetation. See **Figure 2.2 (A)** and **Figure 2.2 (B)**.

Figure 2.2(A) – Årvoll badedam (B12) is located on Hovinbekken stream, and receives water flowing from Årvoll isdam (E04). The inflow pipe is circled in red. The pond basin is asphalt and there is no emergent vegetation.

At first it seemed most appropriate to consider them as "ornamental ponds". However, further consideration of the location of the sites, and a realisation that they are located on the Oslo riparian network, led to their allocation in the Type B group – Natural (landscaping). In fact, evaluation of these ponds led to refinement of the pond category descriptions **(Table 2.2),** and the distinction between ponds on pump systems and ponds located on streams.

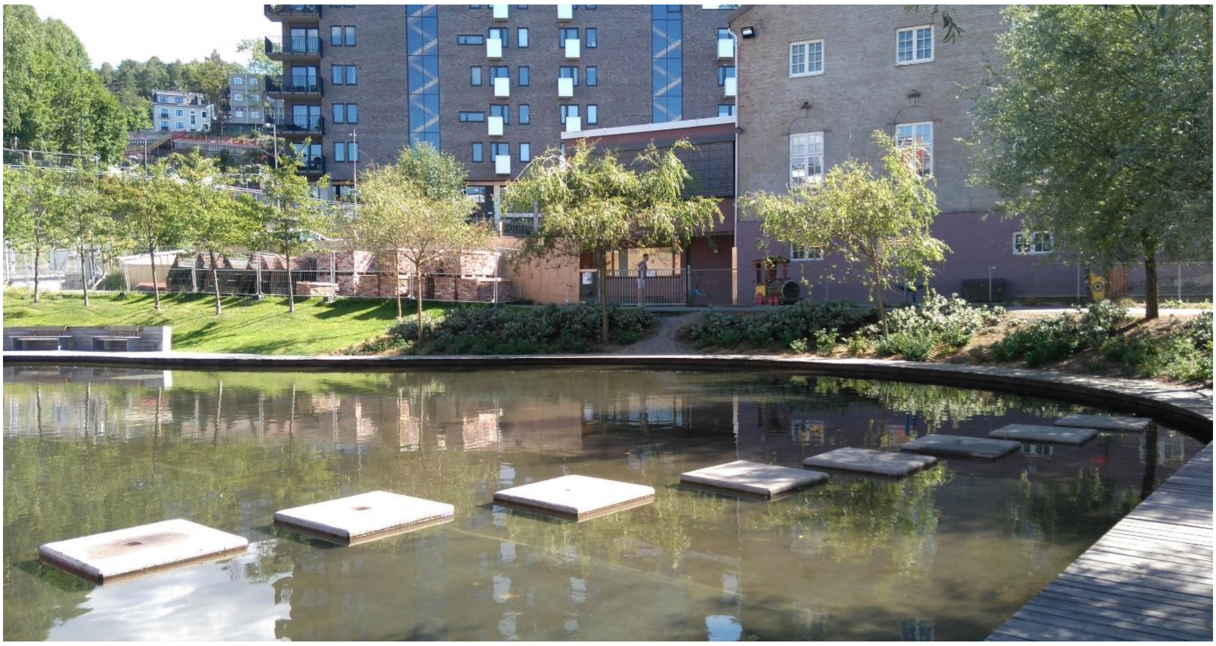


Figure 2.2(B) – Kværnerdammen is located on the Alna water course, at a former industrial site The pond basin is concrete, without emergent vegetation. It is vacuumed to remove algal growth. (Photo: July 2017)

For the purposes of this study, it is also important to include such ponds, as their appearances is the result of design, landscaping, and planning processes.

2.4 Odonata sampling

Sampling was undertaken in an adaptation of the method described by Goertzen and Suhling (2013), and fieldwork was conducted in two periods, in July and August 2017

A circular steel water net (approx. 20 cm diameter, mesh size 1.5 mm) was swept along the shoreline, through different structures (microhabitats). Instead of one sweep per structure, at multiple points, as used by Goertzen and Suhling (2013), three sweeps were made per structure (emergent vegetation, sphagnum, gravel, sand substrate), at three points on the pond perimeter. The "z sweep" movement described by Bang (1999) was employed. This was done by holding the water net 1.5 metres parallel with the shoreline, and then sweeping left, right, left, in a "z" movement.

Where concrete/asphalt basins were sampled, one of the "z sweeps" was substituted with a movement where the steel net was dragged for 10 metres along the perimeter of the basin. This adaptation was made as it was observed on the first sampling day that water boatmen (Corixidae), mayfly nymphs (Ephemeroptera), and small plant particles, collected next to the basin edge. With a solid, artificial substrate, a typical feature of urban ponds, a "z sweep" seemed unlikely to capture any specimens. The sites sampled in this way were: A01, A07, A08, B02, and B12.

Larvae were stored in glass vials (one per study site), in 70 % ethanol.

Exuviae are the larval exoskeletons from which the adult dragonfly has emerged **(Figure 3.2)**. These were collected, if observed, whilst walking along the pond perimeter, sampling for larvae. It proved difficult to access all parts of the shoreline at some sites, and site E02 (Nøklevannet) was too large to circumambulate due to the time constraints of testing 35 sites. This data was therefore qualitative.

2.5 Identification of Odonata samples

All larvae were measured to the nearest millimetre to determine whether they were sufficiently large for reliable identification. Damselflies (Zygoptera) < 10 mm, Aeshnidae < 13 mm (excluding *Aeshna cyanea*), and specimens in the Libellulidae family < 8 mm are considered to lack sufficient characteristics for identification (Bang, 1999), and such specimens were excluded.

Larvae and exuviae were identified using several keys simultaneously (Askew, 2004b; Norling & Sahlen, 1997; Sahlen, 1996). According to Corbet and Brooks (2008), the key developed by Norling & Sahlen (1997) is unusual, if not unique, in that it provides descriptions of larvae that have not yet reached the final instar. Other keys and species descriptions were also available, and sometimes consulted (Brooks & Cham, 2009; Butler, 1998; Chapman et al., 2010; Dannelid & Sahlen, 2005; Fraser, 1956).

2.6 Variables impacting on Odonata diversity

A pond survey form was designed, prior to fieldwork, to register variables known to be correlated with dragonfly diversity. The variables were derived from those used in other studies (Goertzen & Suhling, 2013; Jeanmougin et al., 2014). They included: temperature, depth (30 cm from the water's edge), pH, total dissolved solids (TDS), pond structure (hard edge or natural shoreline), shadowing on the water, substrate type, and an evaluation of aquatic/terrestrial vegetation. The presence of adult dragonflies, waterfowl, fish, birds, and other insects was also noted. The pond survey form is presented in **Appendix 3**.

The survey form was filled out during field work. The vegetation evaluation was supplemented with site photographs, taken in July and August, and hand-drawn sketches. For the sketches, an outline of each pond was downloaded from Google maps, and printed prior to fieldwork. During each site visit, the location of reeds, water lilies, and other vegetation was sketched onto the outline. This was also intended to assist in evaluating the amount of open water at each site.

Water was collected at each site, 30 cm from the water's edge, and stored in a glass vial. The pH was later measured in the laboratory.

2.7 Map-derived variables

Pond area was obtained using ArcGIS 10.6 and data (N20-data and FKB-vann) downloaded from the Norwegian Mapping Authority (Kartverket, 2017a; Kartverket, 2017b).

2.8 Human activity/water interaction and biodiversity observations

Data was collected in July and August on the same survey form used for registering the vegetation variables at each site. Presence/absence was observed, and any activities not itemized on the survey were noted. The data was gathered prior to commencing Odonata sampling, and activities observed during sampling were added to the form before leaving the site.

According to Gehl and Svarre (2013), "registrations [of human activity] are usually made on days with good weather for the time of year". As all sites had sunny weather on at least one occasion, the data sets were combined to provide a summary of all activities observed at each site. One point was assigned for presence of an activity, and the points then added to calculate a recreational activity score for each site.

Observations were also made about the manner in which people interacted with the water. These included whether people were observed undertaking any of the following activities during the site visit (approx. 30 mins): looking at the water, poking the water with a stick, feeding ducks, skimming stones/throwing rocks, playing with boats, splashing, other activity.

Observations of other species present during fieldwork were also noted on the survey form.

2.9 Public data on Odonata registrations in Oslo (Artsdatabanken)

Information about Odonata observations in Norway is available in an online public database administered by the Norwegian Biodiversity Information Centre (Artsdatabanken). The database is located at: http://www.artsobservasjoner.no/ and the data can be exported using the Species Map Service 1.6: http://artskart1.artsdatabanken.no/FaneArtSok.aspx

Several datasets were downloaded during the course of the study. Data analysis was conducted using a dataset downloaded on 24 July 2018, containing the entire dataset of observations for Oslo municipality.

2.10 Statistical methods

Dragonfly diversity was calculated by assessing: the number of individuals and species at each pond site, the Shannon-Wiener index, and evenness.

The Shannon-Wiener index was calculated using the formula:

$$H = -\sum_{i=1}^{s} (p_i)(\ln p_i)$$

where H = index of species diversity, S = number of species, and p_i = proportion of total sample belonging to *i* the species (Krebs, 2009). The Shannon-Wiener index, and evenness was also assessed for the data extracted from Artsdatabanken.

Pond quality was assessed using the Odonata Habitat Ecological Index (OHEI) developed as part of this study (**Section 2.10** in Methods). The values obtained from the OHEI and the number of larval specimens at each site were correlated using non-parametric Pearson's r correlation to assess the degree of relationship.

Pearson's r correlation was calculated using the formula:

$$r = \frac{N \sum xy - \sum (x)(y)}{\sqrt{N \sum x^2 - \sum (x^2)][N \sum y^2 - \sum (y^2)]}}$$

Where r = Pearson r correlation coefficient, N = number of observations, Σxy = sum of the products of paired scores, Σx = sum of *x* scores, Σy = sum of *y* scores, Σx^2 = sum of squared *x* scores, Σy^2 = sum of squared *y* scores.

All data was analysed using Excel. The calculations for the Shannon-Wiener index are provided in **Appendix 5**.

2.11 Odonata Habitat Ecological Index (OHEI) - assessing urban pond quality

It is the habitat features of a pond which determine the range of biological diversity present in the waters. These features include all the physically identifiable features of a pond, such as the pond shape and size, the surrounding vegetation and emergent vegetation, the substrate, and the quality of the shoreline. They also include the water quality, as determined by the pH, pollution levels, algal growth, movement of the water, and other factors.

In urban environments, the physically identifiable variables are often deliberately chosen, or their existence is at least influenced, by the myriad individuals involved in pond design, urban planning and landscape maintenance. These physical features are also impacted by the presence and activities of urban dwellers.

For these reasons it would be useful to have a tool to assist decision makers in all fields, as well as those employed in environmental monitoring, to evaluate pond habitat variables. Although the variables are developed from an understanding of the specific habitat requirements of dragonflies (Odonata), these variables also impact on other invertebrates and amphibians (Holzer, 2014).

The variables comprise: edge quality, floating vegetation (macrophytes), rushes/reeds, dense rushes/reeds, low growing shoreline vegetation, the presence of trees shadowing the water, and pH range. The presence of a stretch of sand beach was also included, as well as the presence of waterlilies, even though these are sub-categories of "edge", and "floating vegetation".

The selection of variables was derived from other studies of urban Odonata assemblages, and the same ones which served as the basis for the fieldwork survey (Goertzen & Suhling, 2013; Jeanmougin et al., 2014). The variables were refined, and allocated values, based on the extensive habitat information provided by recognised Odonata experts (Askew, 2004a; Boudot & Kalkman, 2015; Corbet, 1999; Corbet & Brooks, 2008).

In designing this study, it had been envisaged that the study by Goertzen and Suhling (2013) would serve as a model for interpreting the habitat variables. Hence, their field evaluation (0, 1, 2, 3) was used. However, during the data analysis phase, it emerged that it was not possible to apply their methodology to the interpretation of the data from this study. Other indices were evaluated, and eventually rejected as being unsuitable to the task (Chovanec, 2001; Chovanec et al., 2015; Rosset et al., 2013; Simaika & Samways, 2009). A key reasons for rejecting the other indices was that most were developed for riparian environments, and none were adapted to urban habitats. They also appeared to be developed for complex statistical analyses, rather than evaluations by designers, planners, environmetal monitors, and managers.

The Odonata Habitat Ecological Index (OHEI) was created out of a necessity to weight the habitat variables of the ponds in this study. However, once this need arose, the possible requirements of other potential users were factored into its design.

Each variable was assigned a score up to a maximum of 10 points for ecological quality. The factors governing point allocation are explained below.

1. Edge characteristics

Edge areas are ecological transition zones between two habitat types. They usually contain some species from the adjoining habitats, as well as species that are specific to the transition zone. In the context of a pond environment, the quality of the edge between water and land, two vastly different elements, impacts not only on the species that have their niche in the transition area, but on the survival of species that depend on the buffering qualities of this area.

For dragonflies the edge environment provides oviposition (egg-laying) sites for the many species like *Sympetrum flaveolum* and *Lestes sponsa* which inject their eggs into the stems of vegetation. It offers floating plant debris under which the larvae of *Brachytron pratense* prefer to hide. This same plant debris, and matted vegetation, is an oviposition site for *Somatochlora metallica*, a species which also likes shallow mud zones. The edge environment also provides support structures, like twigs and reeds, which the larvae clasps during the 2 – 3 hours it takes for the adult dragonfly to emerge. If the substrate is hard concrete, or there is a vertical drop from a footpath into the water, there is no place for vegetation to grow.

1a) Edge quality

From an ecological perspective, a soft edge is preferred. However, there may be places in an urban environment where for structural reasons, a hard edge is required. In this context, a hard edge refers to the composition eg. concrete, not the design (straight lines being hard, and wavy/curved lines being soft). See **Figure 2.3.**

If the edge is soft, select "0 = absent" and allocate 10 points. If the edge is hard, select proportion of the perimeter that is hard, and allocate points as indicated in **Table 2.3.**

Table 2.3 Conversion of the field evaluation variable "Hard edge" to points on the Odonata Habitat Ecological Index. This variable is described as "Edge quality" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	100 %	10
1 = < 50 %	80 %	8
2 = 50/50	50 %	5
3 = > 50 %	10 %	1

Figure 2.3 In this photo of Vannspeilet (site B01), in Middelalderen park, a "hard edge" of concrete can be seen on the right side of the pond, below the pedestrian/cycle lane. The sloping lawn down to the water is a "soft edge".

1b) Open banks

Studies have shown that dragonflies (and amphibians) need "structural diversity" in vegetation along shorelines, as well as protection from disturbance by humans and dogs (Chovanec, 1994). Open banks, especially with a silt substrate are a feature that are important to dragonflies in the Gomphidae families during the breeding part of their life-cycle (Askew, 2004a; Corbet, 1999). However, as Gomphidae are associated with running water, ponds are not the most likely location where they will be found.

Nonetheless, the species *Libellula depressa* and *Somatochlora metallica* sometimes also choose to lay their eggs in mud banks, even if this is not their preferred oviposition site. Dragonflies were also observed dropping eggs in the water, and on the mud bank, at the newly landscaped pond (site A03) in the Botanic Garden, in August 2017 **(Figure 2.4).**

Table 2.4 Conversion of field evaluation variable "Open banks" to points on the Odonata Habitat Ecological Index.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	90 %	9
1 = < 50 %	100 %	10
2 = 50/50	50 %	5
3 = > 50 %	10 %	1

Overall, open banks are not an optimal habitat variable for Odonata. However, ecological design, in an urban context, could incorporate intentionally designing an area of the shoreline with open banks, in order to reduce potential disturbance from humans/dogs in the vegetation that Odonata require. There are also aesthetic reasons for having open banks, as well as satisfying a human need to see and touch the water. Points should be assigned as per **Table 2.4.**

1c) Sand beach

The presence or absence of a sand beach is a way of providing more detail about the type of "open bank" that may be present. This is due to dragonflies in the Gomphidae family preferring to use a sand or fine gravel substrate for oviposition (laying eggs). As this group is amongst the most globally endangered group of Odonata (Boudot & Kalkman, 2015), it is worth paying attention to their needs.

Table 2.5 Conversion of field evaluation variable "Sand beach" to points on the Odonata Habitat Ecological Index.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	100 %	10
2 = 50/50	50 %	5
3 = > 50 %	10 %	1

Furthermore, even if it seems unlikely that Gomphidae would be present at pond sites, many of the ponds are situated along watercourses, so it is not impossible. There are also European cases where *Gomphus vulgatissimus*, which is found in Norway, has been recorded breeding "at sandy banks of well-oxygenated standing waters such as lakes, ponded backwaters and gravel pits fed by ground water" (Boudot & Kalkman, 2015). Points should be assigned as per **Table 2.5.**

As shoreline vegetation is required by other species, a sand beach exceeding 50 % of the pond perimeter would be undesirable from an ecological perspective. There is also the urban context to consider: a sand beach designed to be attractive to humans, and to encourage bathing, would not meet the needs of Gomphidae, as the eggs need some protection from disturbance.

Figure 2.4 The lower pond in the Botanic Garden (site A03) was re-landscaped in spring 2017. In this early stage of succession, dragonflies flying in tandem could be seen dropping eggs into the mud.

2. Floating vegetation

This category contains water lilies, and other floating macrophytes (plants), as separate variables, because they serve different ecological roles for Odonata.

2a) Water lilies

Water lilies (*Nymphaea alba* and *Nuphar lutea)* are a separate variable due to the functions they perform in ponds, both ecological and aesthetic, which cannot be wholly reproduced by other floating macrophytes (plants). There is a strong correlation between Odonata presence and water lilies (Goertzen & Suhling, 2013). Points should be assigned in terms of water lily surface area coverage, as per **Table 2.6.**

Table 2.6 Conversion of field evaluation variable "Water lilies" to points on the Odonata Habitat Ecological Index.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	80 %	8
2 = 50/50	50 %	5
3 = > 50 %	20 %	2

Water lilies are important because their shade keeps the water cool during hot summer days. This is not necessarily about temperature tolerances for larvae, as some species, such as the damselflies *Lestes sponsa*, *Ischnura elegans*, and *Coenagrion puella* simply grow faster in warmer water, providing there is sufficient food (Corbet, 1999). The issue is that higher temperatures promote algal growth. Fortunately, water lillies also inhibit algae growth by absorbing nutrients from the water and reducing the sunlight that algae need for photosynthesis (Ji et al., 2016; Pinto et al., 2007).

Table 2.7 An overview of Instagram tags featuring waterlilies indicating their aesthetic appeal and popularity as a photographic subject

Instagram tags - July 2018 (English & Norwegian)	
Tag (#)	**No.**
Waterlilies	130 143
Waterlillies	42 597
Waterlily	355 674
Waterlilly	36 594
Nymphaea	23 872
Vannliljer	6 723
Vannlilje	4 239

Some species use the lily pads as territory. This is particularly the case for *Erythromma najas*, where each male requires its own leaf. The yellow water lily (*Nuphar lutea)*, which is native to Norway, is also one of the plants used by *Platycnemis pennipes* and *Erythromma najas* for oviposition (Corbet, 1999).

Furthermore, the leaves of water lilies (lily pads) provide shelter for juveniles, although other macrophytes may do this more effectively.

Importantly, water lilies contribute aesthetic qualities to a pond. A quick search on Instagram (2018) shows more than 130,000 photos uploaded and tagged as "water lilies" (**Table 2.7**). This suggests their aesthetic appeal and popularity as a photographic subject.

Figure 2.5 Water lilies shade the water and for adults they are an important territory for some species. The males of *Erythromma najas* (above) each require their own lily pad.

2b) Other floating macrophytes

Floating macrophytes provide shelter for the juveniles, helping them to avoid becoming prey for larger species, especially fish. They also provide a habitat in which the cryptic marking of juveniles allows them to camouflage themselves while waiting for prey such as tadpoles.

Table 2.8 Conversion of field evaluation variable "Other floating macrophytes" to points on the Odonata Habitat Ecological Index. This variable is described as "Other floating plants" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	80 %	8
2 = 50/50	60 %	6
3 = > 50 %	10 %	1

Dragonflies need open water (Corbet, 1999; Goertzen & Suhling, 2013; Remsburg et al., 2008) and for this reason dominant coverage of the water body by floating is not positive. A plant such as duckweed (*Lemna minor*), although a useful bioremediator in that it is able to remove heavy metals such as chromium, lead and arsenic from the water (Alvarado et al., 2008; Ucuncu et al., 2013), has a tendency to quickly colonise the entire water surface. Other plants may be less aggressive in their growth, and can be desirable in lesser quantities. Points should be assigned in terms of surface area coverage, as per **Table 2.8.**

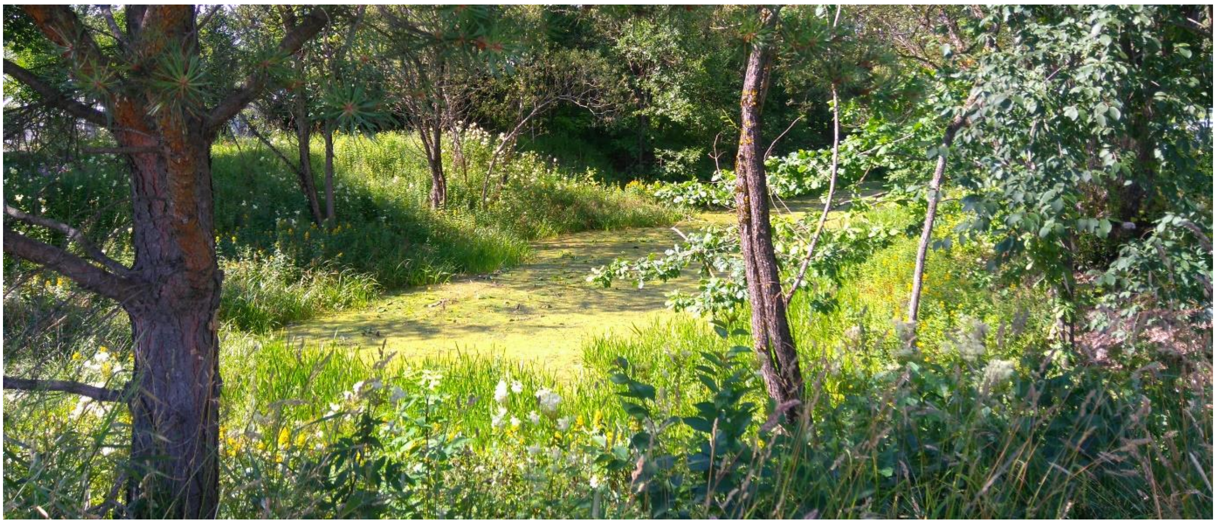


Figure 2.6 The pond at Bjerke travbane (site C03) is completely covered with duckweed (*Lemna minor*).

3. Rushes and reed bed evaluation

3a) Rush/reed presence (emergent vegetation)

The presence of rushes (*Typha spp.*, *Juncus spp.)* and reeds (*Phragmites australis*) have strong associations with Odonata (Goertzen & Suhling, 2013; Hofmann & Mason, 2005). This is not just in terms of larvae shelter, either from predators, or as camouflage waiting for their own prey. Many dragonflies, including all the Aeshnidae, oviposit (lay their eggs) in plants (Corbet, 1999), and among them *Aeshna juncea* has an obligate requirement for either *Typha spp.* or *Iris spp*. (Askew, 2004a).

Table 2.9 Conversion of field evaluation variable "Rush/reed" to points on the Odonata Habitat Ecological Index. This variable is described as "Rushes/reeds" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	30 %	3
2 = 50/50	90 %	9
3 = > 50 %	70 %	7

The rating of "1 = < 50%" indicates any amount of rushes or reeds extending around less than half of the pond perimeter. A rating of "2 = 50/50" indicates that at least half of the pond shoreline has a belt of rushes/reeds with a width of at least 75 cm. Assessed standing at the water's edge, the vegetation zone was considered to be the water surface or vegetation, within an armlength of the edge. The rating of "3 = > 50%" indicates that more than 75% of the pond shoreline has a belt of rushes/reeds with a width of at least 75 cm. Points should be assigned as per **Table 2.9.**

Figure 2.7 The pond created on the re-opened Hovinbekken at Bjerkedalen park (site D04) features a fringe of rushes and Iris. They line approximately three quarters of the shoreline.

3b) Dense rushes/reeds

There are many variables that are required to capture the most influential and important factors that are present in an optimal dragonfly habitat, and they differ between species. This variable, however, has a more universal value as it is included in order to provide for a greater "core area" of rush/reed microhabitat. Consequently, it is theoretically possible that one well-established rush/reed bed might be likely to provide greater Odonata abundance than a thin fringe of rushes along the entire shoreline. However, a pond where these beds dominate would not be aesthetically pleasing, and the volume of decaying vegetation would decrease oxygen levels in the water. This effect is likely to be especially pronounced in a small pond.

Table 2.10 Conversion of field evaluation variable "Dense reed" to points on the Odonata Habitat Ecological Index. This variable is described as "Dense rushes/reeds" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	10 %	1
2 = 50/50	80 %	8
3 = > 50 %	30 %	3

For the purposes of this study, an area of "dense rushes/reeds" with a value of "1 = < 50 %" (**Table 2.10**) is equal to a minimum area of rushes or reeds which could contain an elliptical shape of at least 3.5 m x 2.5 m at its widest points, as per **Figure 2.8**. This area is a minimum, regardless of the size of the pond.

It is not standardized in accordance with pond size because urban ponds come in many sizes, and this is an attempt to allocate points for the presence of a particular habitat variable.

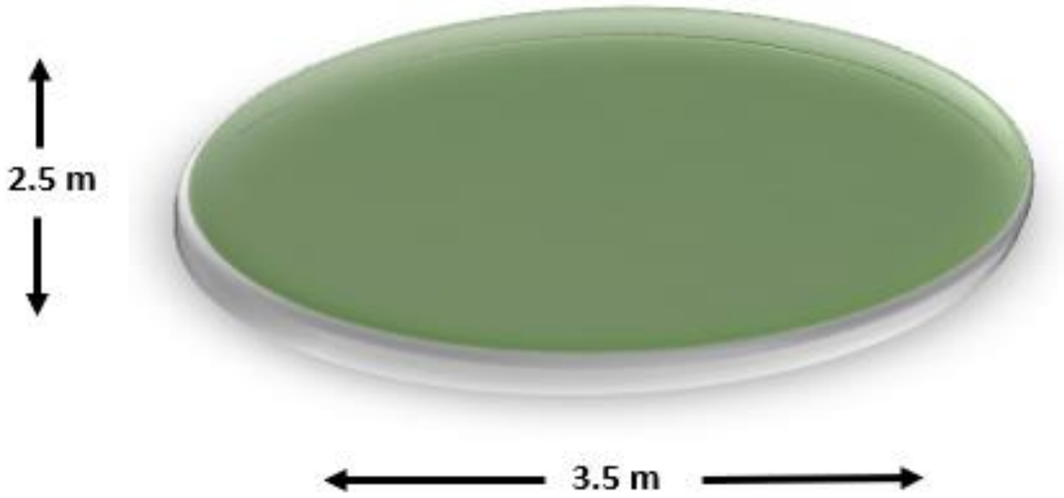


Figure 2.8 For a pond to be allocated the minimum score for having an area of dense rushes/reeds, it must contain a reed/rush bed which could contain an elliptical shape of at least 3.5 m x 2.5 m at its widest points, regardless of pond size.

For the purposes of this study, a value of "2 = 50/50" is allocated to ponds where the minimum area is exceeded (3.5 m x 2.5 m), and up to half of the edge has a belted area at least 3.5 metres in width, as per the reed beds depicted in **Figure 2.9.** This pond, Hovindammen (B08), is not allocated a value of 3, because half the shoreline (not visible in this photo) completely lacks edge vegetation.

A value of "3 = > 50 %" is allocated to ponds where reed beds greater than 3.5 metres in diameter exceed more than half the shoreline.

Figure 2.9 Hovindammen (site B08) contains large beds of rushes along the north-eastern shoreline.

4. Low growing vegetation

Adult dragonflies are categorized as either "fliers" or "perchers" (Corbet, 1999). The former hunt both for prey and mates by flying over their territory. The latter "perch" in vegetation, usually close to the water, only flying when they spot the approach of potential prey or mates.

Table 2.11 Conversion of field evaluation variable "Low growing vegetation" to points on the Odonata Habitat Ecological Index. This variable is described as "Low growing vegetation" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	30 %	3
2 = 50/50	70 %	7
3 = > 50 %	90 %	9

Vegetation also provides a support for larvae when they are about to shed their last cuticle and emerge as adult dragonflies. Although emergent vegetation such as rushes can meet this need, larvae may also exit the water to look for suitable perches on twigs or even tree trunks (Askew, 2004a). A difficulty arises if there is insufficient vegetation, and "the earliest individuals are unable to complete the final moult because individuals arriving slightly later clamber over them and use them as emergence supports" (Corbet & Brooks, 2008). Emergence takes one to three hours, and the dragonfly is extremely vulnerable to predation at this time.

The presence of low-growing vegetation also contributes to structural diversity along the shoreline. Points should be assigned as per **Table 2.11.**

Figure 2.10 This pond in Nordstrand (site C02), is an example of a pond where low-growing vegetation along the shoreline is dominant.

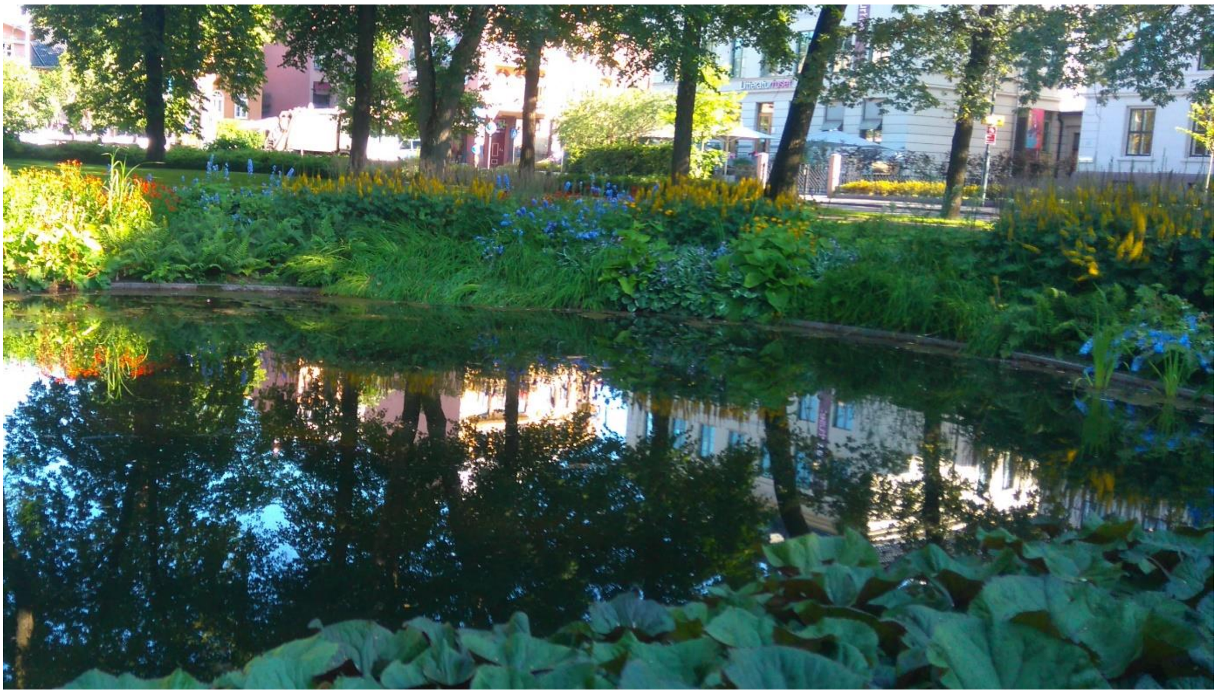


Figure 2.11 The northern shoreline of this pond in Slottsparken (site A06) is an example of low-growing vegetation in the setting of a park created in the English landscape style.

5. Trees shadowing the water

Dragonflies need to thermoregulate; to maintain their body temperature within a range that allows flight and reproduction (Corbet, 1999). They have various stragies including being active during the day, basking in the sun, selecting appropriate perch sites, and using their flight muscles to control their body heat (Corbet, 1999). The issue of shade, sunlight, and the thermal requirements of dragonflies is so complex that this the assessment of this particular variable is worthy of a study in its own right.

For the purposes of this study, there are three factors underpinning the attempt to include and measure this variable. Firstly, there are the results of an experimental study by Remsburg et al. (2008), which concluded that there was "strong evidence for shade avoidance" by the most abundant Anisopteran (dragonfly) species. They used shade cloth (30%, 55%, 75% shade) to limit sun exposure to waterside perches and verified the levels with a light meter. The shade avoidance behaviour was strong at 75% shade, and the authors noted that nearby trees created 96-97% shade. Importantly, this experimental study was designed on the basis of observational studies where Odonata appeared to have a preference for avoiding shade.

Secondly, dragonfly "perchers" also control their exposure to solar radiation by their body position – a term called "obelisking" (Corbet, 1999). Quite simply, dragonflies cannot absorb too much heat, and if the perch becomes too hot, they will seek more shade.

Where "fliers" are concerned, the key strategy for controlling body temperature is by adjusting the activity level of the thoracic muscles that are used for flight (Corbet, 1999). This then leads to the third factor, which is connected to climate change. If a firm trend evolves for warmer summers in Norway, larger dragonflies (all "fliers") may need to rest in the hottest parts of the day to avoid overheating. This is lost time in terms of predation and reproduction. In this case, the impact of higher temperatures might be mitigated by trees shading the water and perches.

Corbet (1999) notes that Zygoptera (damselflies) dominate the fauna of tropical zones, and Anisoptera (dragonflies) are predominant in the cooler latitudes, and he connects this to their thermoregulatory strategies. This should serve as a warning that Europe may see a biodiversity loss among Anisopterans due to rising temperatures, and it makes it more important that urban ponds have at least some shading.

A precise evaluation of tree shade would involve measuring the shade cast by all trees around a pond, over the water and a buffer zone of vegetation, within daylight hours. As this is only one variable, assessment was simplified by asking two questions:

1. Are there established trees (>5 m high, at least approximately 20 years old) surrounding the pond? If yes, go to Question. 2. If no, the value is 0 = absent

2. If these trees were cut at ground level (an imaginary scenario), and the trunk placed on the ground, would they extend at least 2 metres over the edge of the water? (See **Figure 2.12**).

If yes: 1 = 1 tree or more, surrounding up to half the circumference of the pond, 2 = half the circumference of the pond surrounded by established trees, 3 = more than 75% surrounded by established trees.

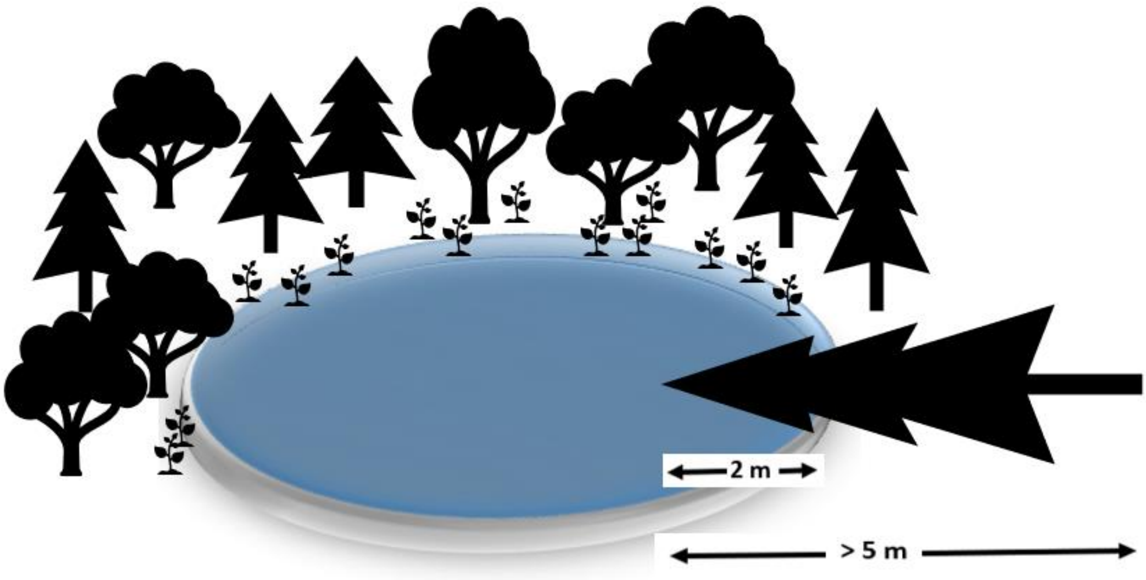


Figure 2.12 A pond with established trees and low vegetation (dragonfly perches) along the shoreline. The length of the shading tree (if it is imagined laid out on the ground) extends 2 metres into the pond. As the tree is >5 m, it is considered "established" and counts as a "shading tree".

Points were assigned for this variable as per **Table 2.12.**

Table 2.12 Conversion of field evaluation variable "Tree shadowing water" to points on the Odonata Habitat Ecological Index. This variable is described as "Tree shadowing" in graphs derived from this data.

FIELD EVALUATION	ECOLOGICAL QUALITY (urban context)	POINTS
0 = absent	0 %	0
1 = < 50 %	60 %	6
2 = 50/50	80 %	8
3 = > 50 %	10 %	10

6. Evaluating the pH range of a pond

pH is a logarithmic measurement of the hydrogen ion concentration of a liquid, and an indicator of its acidity or alkalinity (Pedersen, 2009). In this study, it was decided during the design phase that the pH of each water body would be used as one of the indicators of water quality. Water samples were collected in sterile glass vials at each site, in July and August and the pH was later measured in the lab.

Points were allocated for each reading within the ranges described in **Table 2.13**. This was done as a couple of sites had an extreme variation in their readings. This was not entirely surprising, as one of these sites, Kampen (A08), was being filled with chemically treated water while August fieldwork was being conducted. As pH is a logarthmic measurement, it seemed more logical to assign points based on a pH range, allocated with consideration of Odonata tolerances, rather than two pH measurements.

Table 2.13 Points allocation for pH range of a pond on the OHEI.

RANGE	DESCRIPTION	POINTS
<5,09	increasingly acidic	0
5,10 – 5,29	more acidic	1
5,30 – 5,49	more acidic	2
5,50 – 5,69	more acidic	3
5,70 – 5,89	more acidic	4
5,90 – 6,09	more acidic	5
6,10 – 6,29	slightly acidic	6
6,30 – 6,49	slightly acidic	7
6,50 – 6,69	slightly acidic	8
6,70 – 6,89	slightly acidic	9
6,90 – 7,09	neutral (either side of)	10
7,10 – 7,29	slightly alkaline	9
7,30 – 7,49	slightly alkaline	8
7,50 – 7,69	slightly alkaline	7
7,70 – 7,89	slightly alkaline	6
7,90 – 8,09	slightly alkaline	5
8,10 – 8,29	more alkaline	4
8,30 – 8,49	more alkaline	3
8,50 – 8,69	more alkaline	2
8,70 – 8,89	more alkaline	1
>8,90	more alkaline	0

3. RESULTS

3.1 Odonata sampling – larvae and exuviae

Juveniles and exuviae (exoskeleton of the final larval instar from which the adult emerges) were collected at 14 of the 35 sites investigated in the study. A total of 82 specimens were collected (70 juveniles, 12 exuviae) as per **Table 3.1**. All exuviae were identified. Of the larvae, 58 were identified to species level, and 10 specimens were too small for identification beyond family level. All exuviae were identified to species level. (Hypothesis 1 was disproved. Hypothesis 2 was neither proved nor disproved.)

Among the larvae, two (2) specimens were identified as either *Coenagrion puella* or *C. pulchellum*. These species cannot be distinguished from each other in the larval stage, and it is established practice to merge them when compiling assemblage data from larval samples.

The assemblage of Odonata (dragonflies and damselflies) breeding in Oslo municipality, based on sampling at the study sites, comprises 14 species as shown in **Table 3.1**.

Table 3.1 Species assemblage from the Oslo municipality showing the number of specimens collected, the sites, and pond type at which each species was present.

Species	Larvae	Exuviae	Pond type	Sites
Lestes sponsa	4		B, E	(B03)Bygdø Kongsgård; (B06)Smestad-øvre; (E06)Øvresetertjern
Coenagrion hastulatum	1		C	(C04)Brannfjell
Coenagrion puella & Coenagrion pulchellum	2		B	(B07)Smestad-nedre
Erythromma najas	1		E	(E06)Øvresetertjern
Aeshna cyanea	12		B, C, D, E	(B07)Smestad-nedre; (B09)Holmendammen; (C02)Kastellterrassen; (E04)Årvoll isdam; (D03)Tegl 3 - Tennis; (C04)Brannfjell; (C01)Østensjøvannet; (E01)Skraperudtjern; (E06)Øvresetertjern
Aeshna grandis	5	8	B, E	(B09)Holmendammen; (E01)Skraperudtjern; (E06)Øvresetertjern; (E05)Lillevann
Aeshna juncea	13	1	B, C, E	(B01)Vannspeilet; (B09)Holmendammen; (C02)Kastellterrassen; (B10)Andersendammen; (C04)Brannfjell; (E06)Øvresetertjern; (E05)Lillevann
Aeshna mixta	6		B, C, E	(B07)Smestad-nedre; (C02)Kastellterrassen; (E04)Årvoll isdam; (C04)Brannfjell
Cordulia aenea	4		E	(E01)Skraperudtjern; (E05)Lillevann
Somatochlora metallica	3		B, E	(B07)Smestad-nedre; (E06)Øvresetertjern
Sympetrum danae	1		E	(E01)Skraperudtjern
Sympetrum flaveolum	2		E	(E04)Årvoll isdam
Sympetrum sanguinem	6		B, C	(B03)Bygdø Kongsgårdgdøy; (B01)Vannspeilet; (C01)Østensjøvannet
Sympetrum vulgatum	0	3	B, C	(B01)Vannspeilet; (C01)Østensjøvannet
Unidentified	10		C, E	(C04)Brannfjell; (E04)Årvoll isdam; (E05)Lillevann; (E06)Øvresetertjern
Total	**70**	**12**		

Although it was not possible to standardize sampling of exuviae, they are included in **Table 3.1** and **Figure 3.1** because their presence indicates successful breeding at a pond site. If exuviae are removed the species *Sympetrum vulgatum* disappears from the Oslo municipality assemblage.

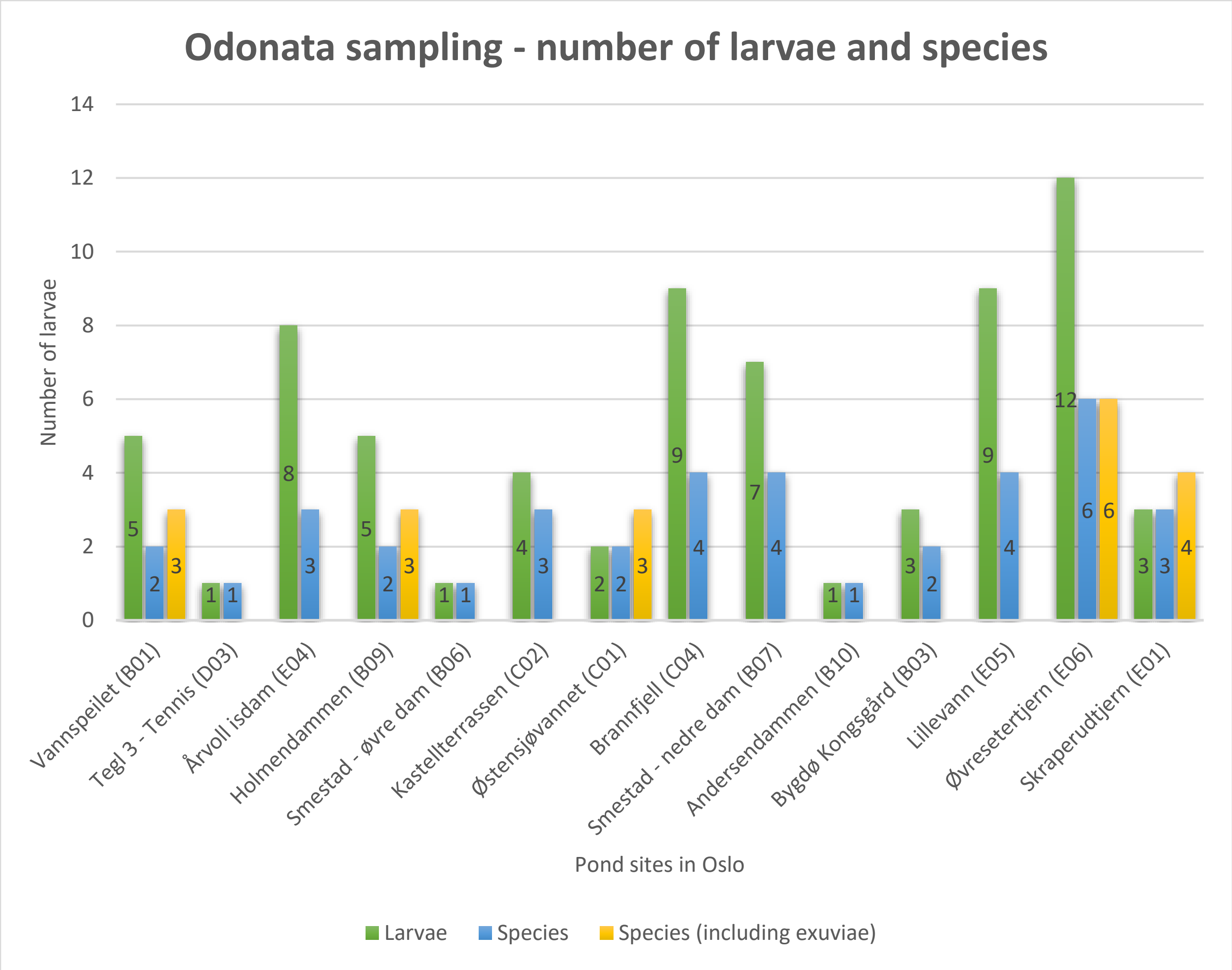


Figure 3.1 Odonata larvae and exuviae were found at 14 of the 35 pond sites. Identification of exuviae added an extra species to the species assemblage for each site.

Figure 3.2 Exuviae of *Aeshna grandis*

Odonata larvae were found in 14 ponds, and exuviae, larval exoskeletons from which the adult dragonfly emerges, were found in the waterside vegetation of five ponds. In each case the identification of exuviae added an extra species to the species assemblage for each site, as shown in **Figure 3.1**.

The ponds in **Figure 3.1** are shown, left to right, in order of their score (lowest to highest) for habitat suitability on the Odonata Habitat Ecological Index (OHEI). Results for the OHEI are provided in section 3.4.

The larval exuviae were in excellent condition, and the features required to identify them to species level (eg. dorsal markings or spines, lateral spines) were intact. Two examples of the eight *Aeshna grandis* exuviae which were collected are shown in **Figure 3.2**.

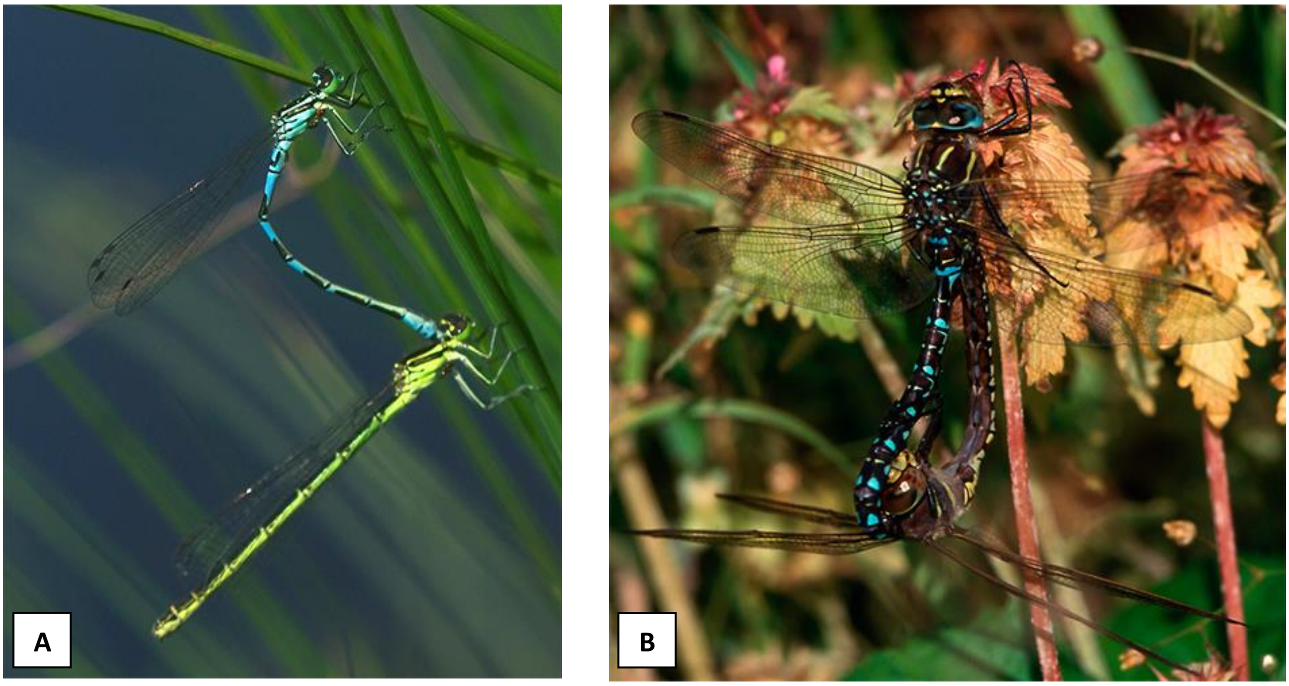


Figure 3.3 Mating pairs of the damselfly *Coenagrion hastulatum* (A) and the dragonfly *Aeshna juncea* (B). Only one larval specimen of *C. hastulatum* was collected during the study, while thirteen larval specimens of *A. juncea* were collected, with samples found at five sites. Photos: Ove Bergesen, Artsdatabanken

Four Zygoptera (damselfly) species and five Anisoptera (dragonfly) species were collected during larval sampling. **Figure 3.3** shows adults of the widespread *Coenagrion hastulatum*, (only one specimen in this study), and *Aeshna juncea*, the species with the highest number of specimens (13). This species has the most extensive distribution of all the Aeshnidae and is found across northern Asia, Europe, and North America (Boudot & Kalkman, 2015). Specimens from the Aeshnidae family comprised 60% of the larval samples in this study, as shown in **Figure 3.4**.

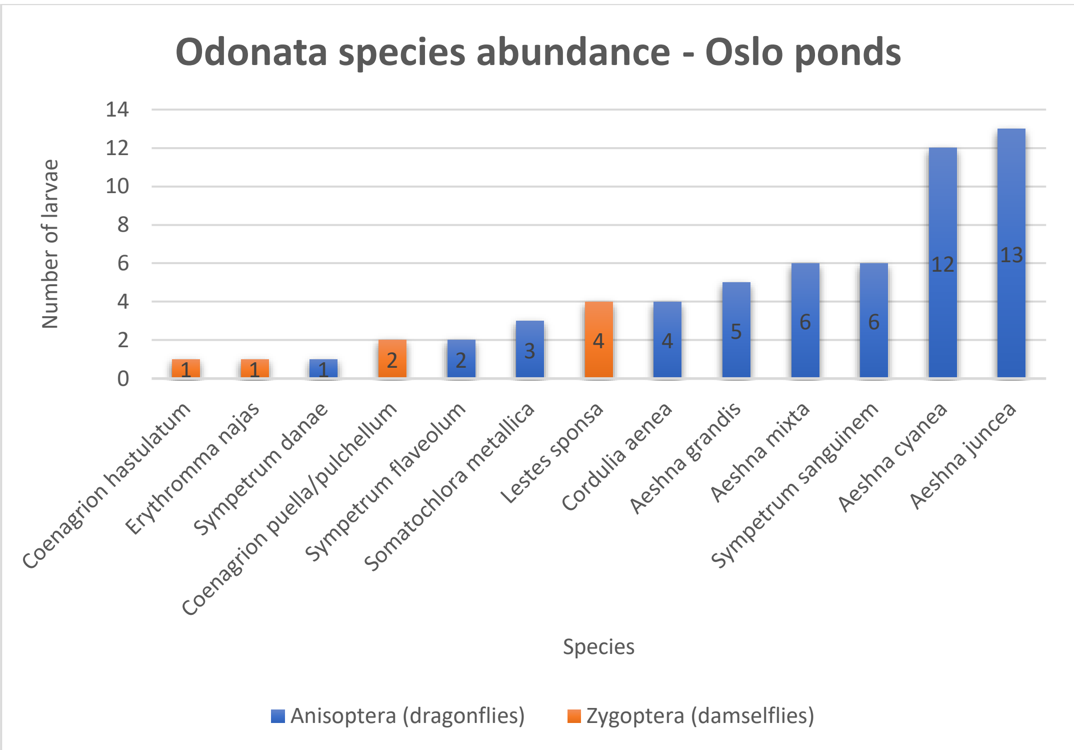


Figure 3.4 Specimens from the Aeshnidae family comprised 60% of the larval samples

The species assemblage for each pond site is shown in **Figure 3.5.**

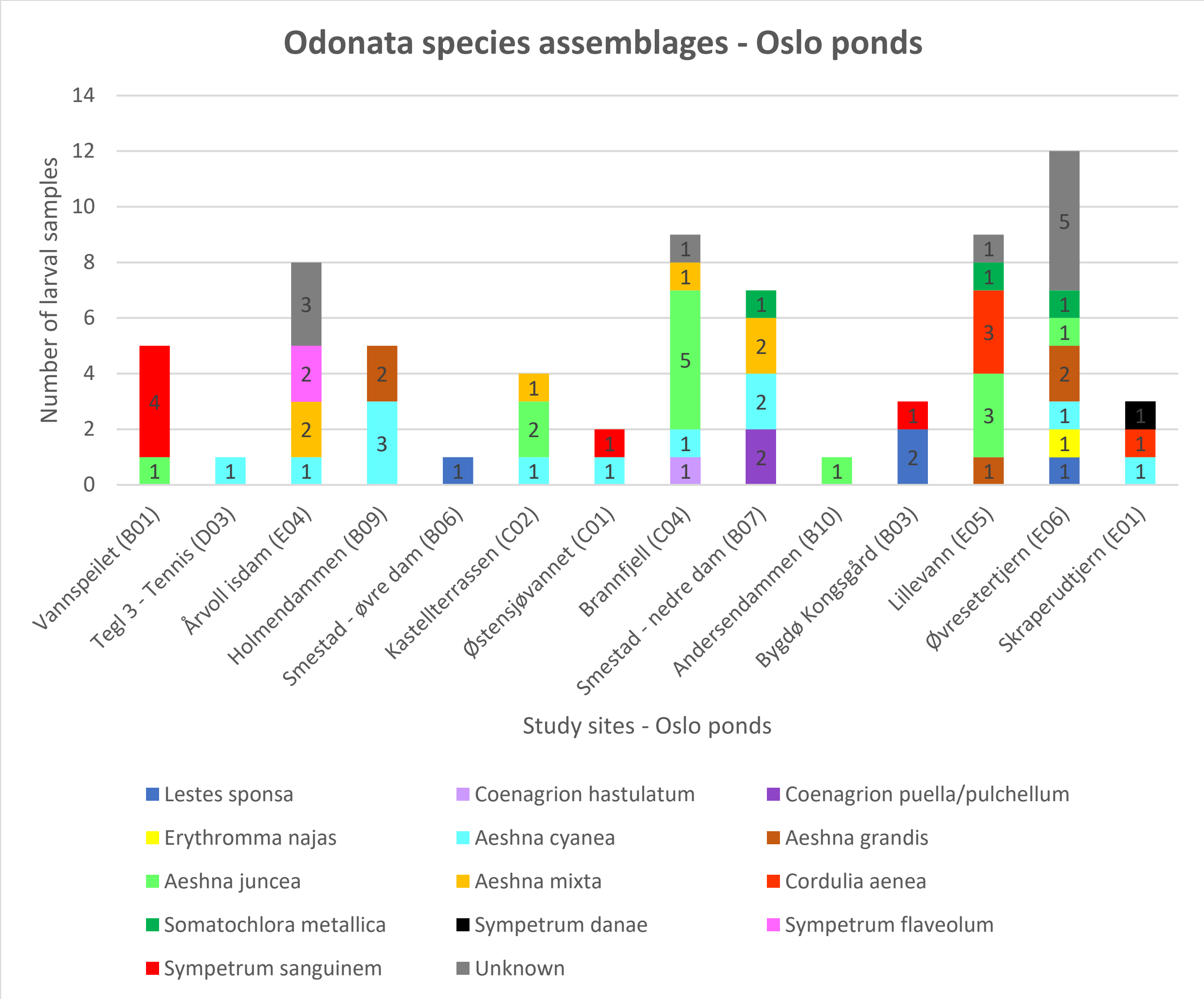


Figure 3.5 The Odonata species assemblage for each study site and the number of specimens of each species collected at these sites.

3.2 Odonata registrations for Oslo (Artsdatabanken)

A search was conducted on 24 July 2018 for all Odonata observed in Oslo municipality using the online public database "Artsobservasjoner". This database is managed by the Norwegian Biodiversity Information Centre, forthwith referred to by its Norwegian name "Artsdatabanken".

The records are based on museum samples and field observations of adults. The search data was exported in an Excel spreadsheet and contained 1931 records. Some of the observations had not been recorded correctly, and could not be used in this analysis. For example, in October 2017 the Norwegian Institute for Water Research (NIVA) recorded "Anisoptera" (damselflies), rather than identifying individual species. When this and similar entries were removed (22 entries in total), there were 1909 registrations for Oslo municipality (1845 – 2018).

There were 377 sites, however many of these were slight variations on the same name, reflecting the preferences of the observer making the registration. Similar names usually had different GPS coordinates, and identical GPS coordinates sometimes had different names. **Table 3.2** presents an extract of the exported records that typifies some of the challenges of using the location data.

Table 3.2 An extract from the public database "Artsobservasjoner" (species observations) highlighting some typical challenges involved in using the data - several names for the same general location, different coordinates for the same name, and different degrees of precision.

Date	Location	Precision	Geometry
16.10.2011	Halsentjern, Bygdøy, Oslo, Os	100 m	POINT (257776 6649568)
09.10.2008	Halsentjern, Oslo, Os	100 m	POINT (257780 6649520)
27.04.2006	Halsentjernet	50 m	POINT (257809 6649454)
08.08.2006	Halsentjernet – Hovedsakelig i den kanalliknende delen i nordøst*	50 m	POINT (257809 6649454)
04.09.2006	Halsentjernet, Bygdøy	71 m	POINT (257805 6649405)
08.08.2007	Halsentjernet, Bygdøy	71 m	POINT (257814 6649504)
English translation: "Halsentjernet - Mainly in the channel-like part in the northeast"			

Of the 50 species of Odonata that are considered to be part of the Norwegian fauna, 31 species are registered in Oslo municipality. The species assemblage and number of observations are presented in **Figure 3.6.**

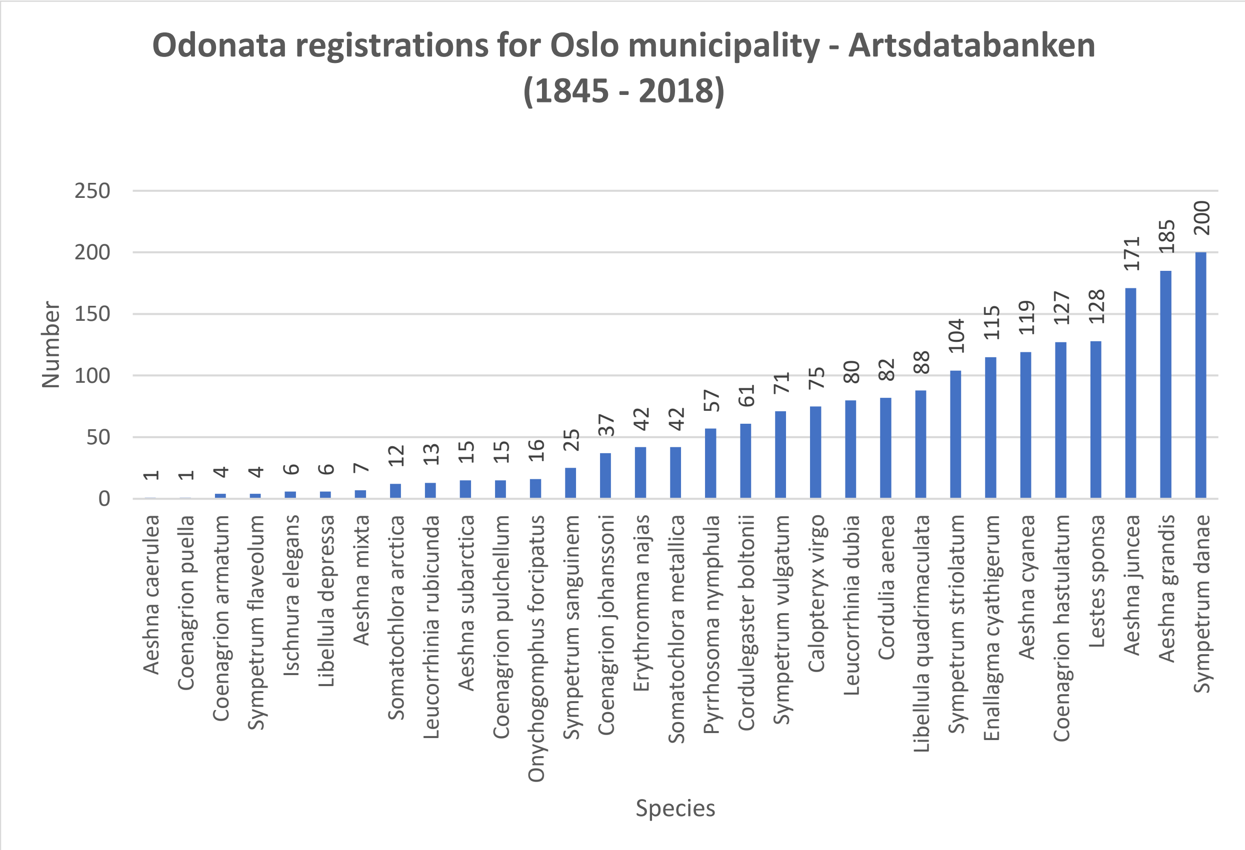


Figure 3.6 Registrations of Odonata in Oslo municipality (1845 – 2018) based on records in the online public database managed by the Norwegian Biodiversity Information Centre (Artsdatabanken).

The first records date from 1845. These are based on two specimens of the damselfly *Lestes sponsa* from the entomological collection at the Natural History Museum (University of Oslo). In fact, all 49 records from the 1800s are based on museum specimens. Only 13 species are represented, seven of which were recorded as larvae in this study (*Lestes sponsa, Coenagrion hastulatum, Aeshna cyanea, A. grandis, A. juncea, Cordulia aenea*, and *Sympetrum danae*).

Figure 3.7 A mating pair of *Sympetrum danae* with the male clasping the twig. This is the most frequently registered species in Oslo.
Photo: Ove Bergesen, Artsdatabanken

The earliest find of *Lestes sponsa* dates from 1872, on Bygdøy, approximately 450 metres from the pond at Bygdø Kongsgård, where a *Lestes sponsa* larva was collected during sampling in July 2017.

The first recordings for the area around Østensjøvannet were made in September 1929, and comprise the species: *Lestes sponsa*, *Aeshna juncea*, *Sympetrum danae*.

The first registration which is not supported by a specimen dates from 1984. This is an observation of the damselfly *Calopteryx virgo*, a striking species which is difficult to confuse with others, and thus likely to be a correct species identification.

The database was opened for public registrations in 2008, and 1368 observations have been recorded for Oslo municipality from 1 January 2008 – 24 July 2018. This includes 21 of the 22 records which lack species information. Consequently, 70.8% of the Odonata registrations for Oslo have been made in the past decade. There were 43 individuals making registrations, and one organisation, the Norwegian Institute for Water Research (NIVA). Only eight of the registrations were made by NIVA.

The most striking observation about the data is that 71.2% of these registrations are made by two individuals, and the five individuals recording the highest number of observations account for 87.2% of all registrations in Oslo. This is shown in **Table 3.3**. I have replaced the full names with initials.

Table 3.3 Observations by the top five Odonata observers in Oslo since the species register was opened to the public.

Registrations of Odonata in Oslo (2008 - 2018)		
Observer ID	**Number**	**Percent (%)**
Observer 1 - F.O.M	811	59.28
Observer 2 - K.S.	203	14.84
Observer 3 - B.N.	71	5.19
Observer 4 - F.A.H.	58	4.24
Observer 5 - H.E.	50	3.66
All others	175	12.79
Total observations	**1368**	**100**

Observers 1 – 4 made their observations on behalf of the Norwegian Entomological Association. Observer 5 made registrations on behalf of the Natural History Museum (University of Oslo), where a biologist of the same name is employed.

The Odonata species registered with Artsdatabanken were compared with the species obtained during fieldwork in 2017. The results are presented in **Table 3.4.**

Table 3.4 A comparison of the Odonata species assemblage for Oslo municipality and the species samples of juveniles and exuviae (empty exoskeletons) collected during fieldwork in 2017.

Species	**Artsdatabanken registrations** (Oslo municipality)	**Fieldwork - summer 2017** (Oslo municipality - 35 ponds)	
		Larvae	**Exuviae**
Aeshna caerulea	1		
Coenagrion armatum	4		
Sympetrum flaveolum	4	2	
Ischnura elegans	6		
*Libellula depressa***	6		
Aeshna mixta	7	6	
Somatochlora arctica	12		
Leucorrhinia rubicunda	13		
Aeshna subarctica	15		
Coenagrion puella/pulchellum	16	2	
*Onychogomphus forcipatus****	16		
*Sympetrum sanguinem***	25	6	
Coenagrion johanssoni	37		
Erythromma najas	42	1	
Somatochlora metallica	42	3	
Pyrrhosoma nymphula	57		
Cordulegaster boltonii	61		
*Sympetrum vulgatum**	71		3
Calopteryx virgo	75		
Leucorrhinia dubia	80		
Cordulia aenea	82	4	
Libellula quadrimaculata	88		
Sympetrum striolatum	104		
Enallagma cyathigerum	115		
Aeshna cyanea	119	12	
Coenagrion hastulatum	127	1	
Lestes sponsa	128	4	
Aeshna juncea	171	13	1
Aeshna grandis	185	5	8
Sympetrum danae	200	1	
Total	**1909**	**60**	**12**

**Red-list 2006, removed 2010* ****Red-list 2006, 2010, 2015*
***Red-list 2006, 2010, removed 2015*

It can be seen that 60% of the Odonata juveniles collected during fieldwork represent the six most common species registered in the Norwegian Biodiversity Information Centre (Artsdatabanken) database.

An overview map of the Odonata registration locations from Artsdatabanken is shown in **Figure 3.8.**

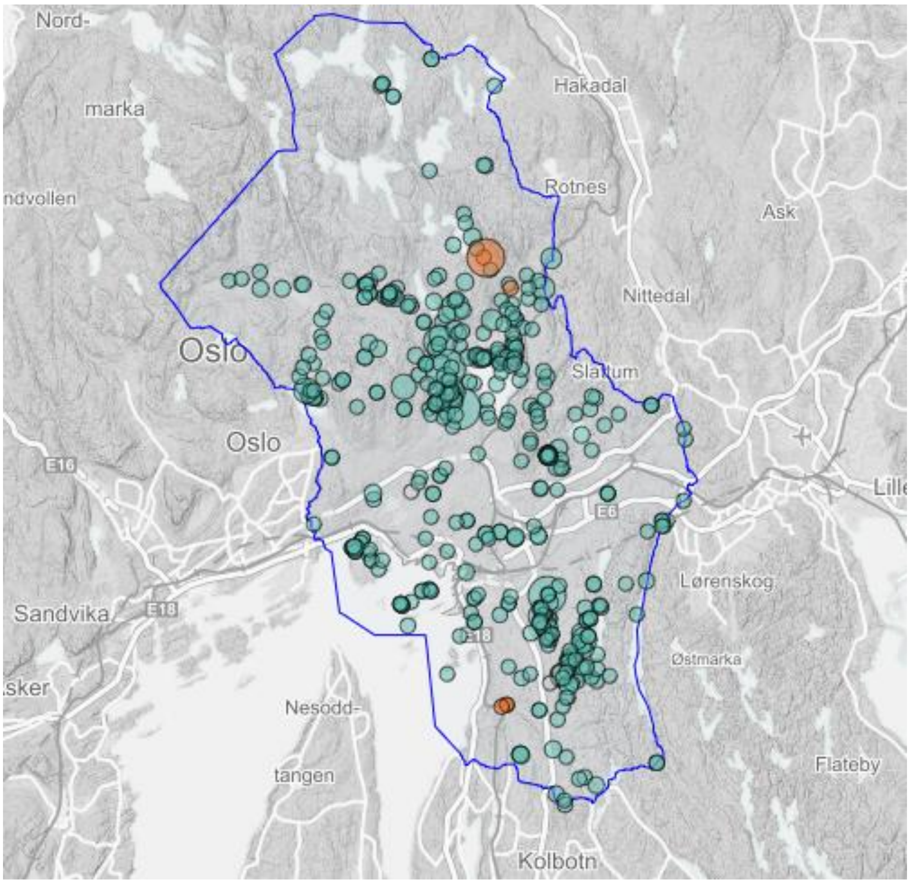


Figure 3.8 Registrations of Odonata in Oslo municipality – Species Map (Artskart)

3.3 Shannon Wiener Diversity Index

The Shannon Wiener Diversity Index was used to calculate Odonata diversity for Oslo municipality using two sets of data. The first set ("Pond sites" in **Table 3.4**) comprised data from the larval sampling of 35 ponds during July and August 2017 (excluding exuviae). The calculations were based on 60 samples and 13 species.

The second data set ("Artsdatabanken" in **Table 3.4**) comprised all Odonata registrations contained in Artsdatabanken from the first registration in 1845 until 24 July 2018. The calculations were based on 1909 registrations (adults) and 31 species. Calculations for both data sets were made in Excel and the results are shown in **Table 3.4**. Tables containing the calculations are available in the appendices.

Table 3.4 Shannon Wiener Diversity Index for Odonata

Shannon Wiener Diversity Index		
	Index (H)	**Evenness**
Pond sites - Oslo	2.26	0.88
Artsdatabanken - Oslo	2.99	0.87

3.4 Pond assessment – Odonata Habitat Ecological Index (OHEI)

Ponds were assigned points for ecological quality using the Odonata Habitat Ecological Index (OHEI) described in the methodology.

The ponds are shown in **Figure 3.9** ranked according to their ecological quality. The least suitable pond obtained 12 points (A08 – Kampen), and the most suitable site obtained 78 points (E01 – Skraperud).

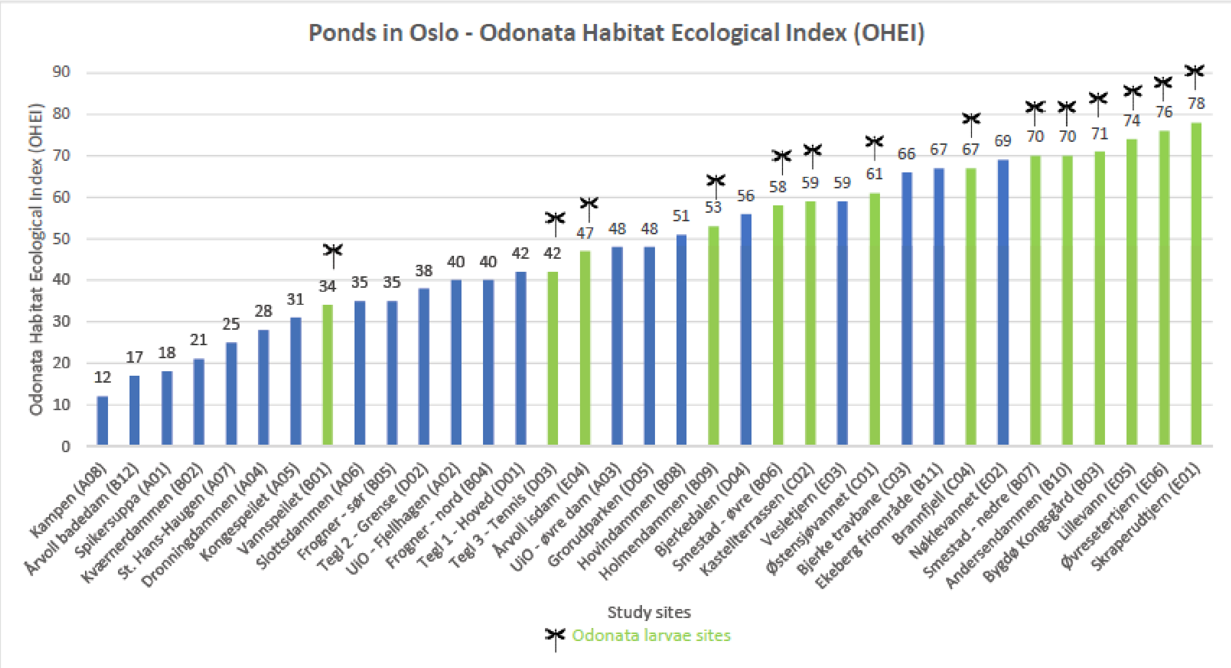


Figure 3.9 Odonata Habitat Ecological Index (OHEI) for all study sites in Oslo municipality. Dragonfly larvae were present at fourteen of the sites (coloured green).

Those sites where Odonata larvae were obtained are coloured green in **Figure 3.9**, and those with no Odonata larvae are marked in blue.

The habitat variables of each of the sites where Odonata larvae were found are presented in **Figure 3.10.** The site with the lowest score (B01 – Vannspeilet) was allocated points for only six variables. The site with the highest socre (E01 – Skraperudtjern) was allocated points for all ten variables.

3.4.1 Statistical analysis

The Pearson r correlation was used to assess the relationship between the score on the Odonata Habitat Ecological Index and the number of larval specimens obtained from sampling. The calculations were made in Excel, and a result of 0.50 was obtained. According to Cohen's standard, a correlation of 0.50 or more indicates a strong relationship between the variables.

The average OHEI score for the ponds is 48.7 points, and the median value is 48 points. Most of the ponds with an Odonata presence (11 sites of the 14 sites, 78.6%) have a score greater than the median value.

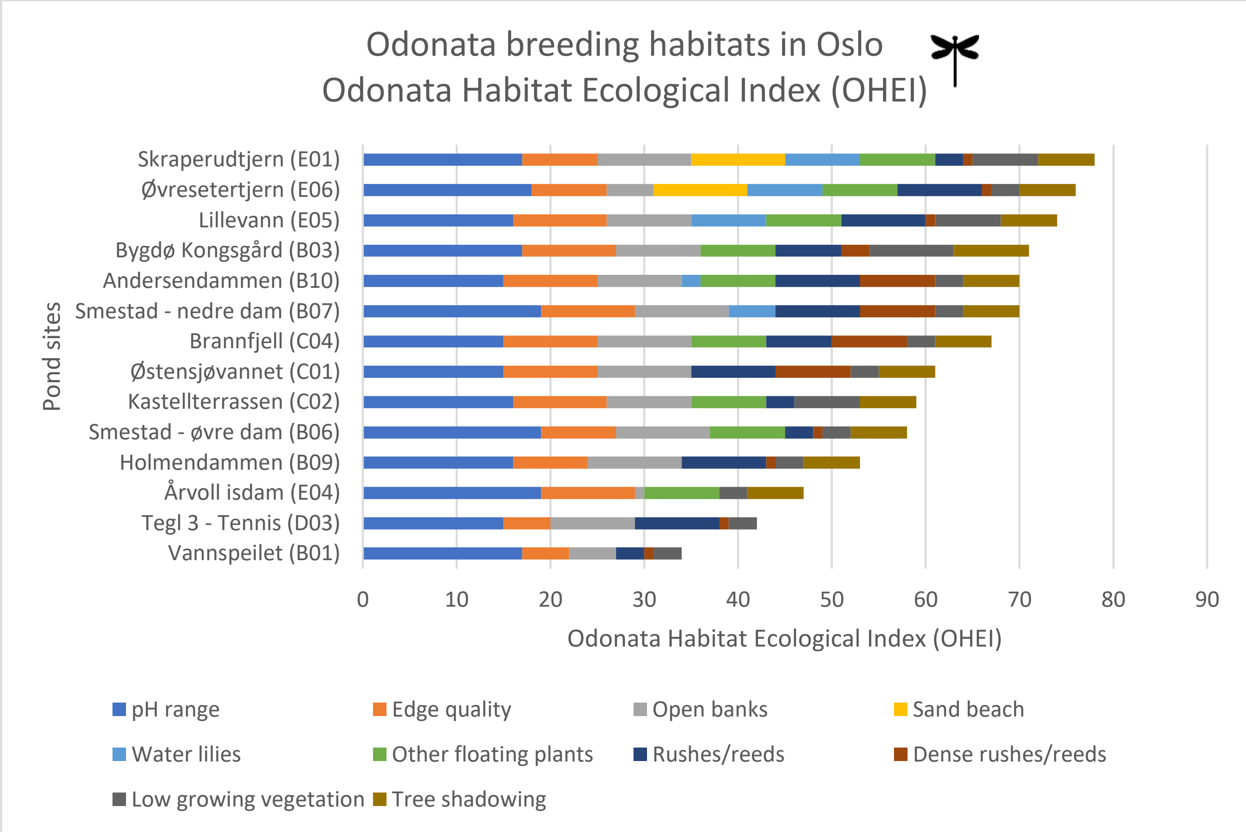


Figure 3.10 The habitat variables and scores on the Odonata Habitat Ecological Index (OHEI) for ponds in Oslo where Odonata larvae were collected.

An overview of the habitat variables of all sites, and their scores on the OHEI, are presented in **Figure 3.11**.

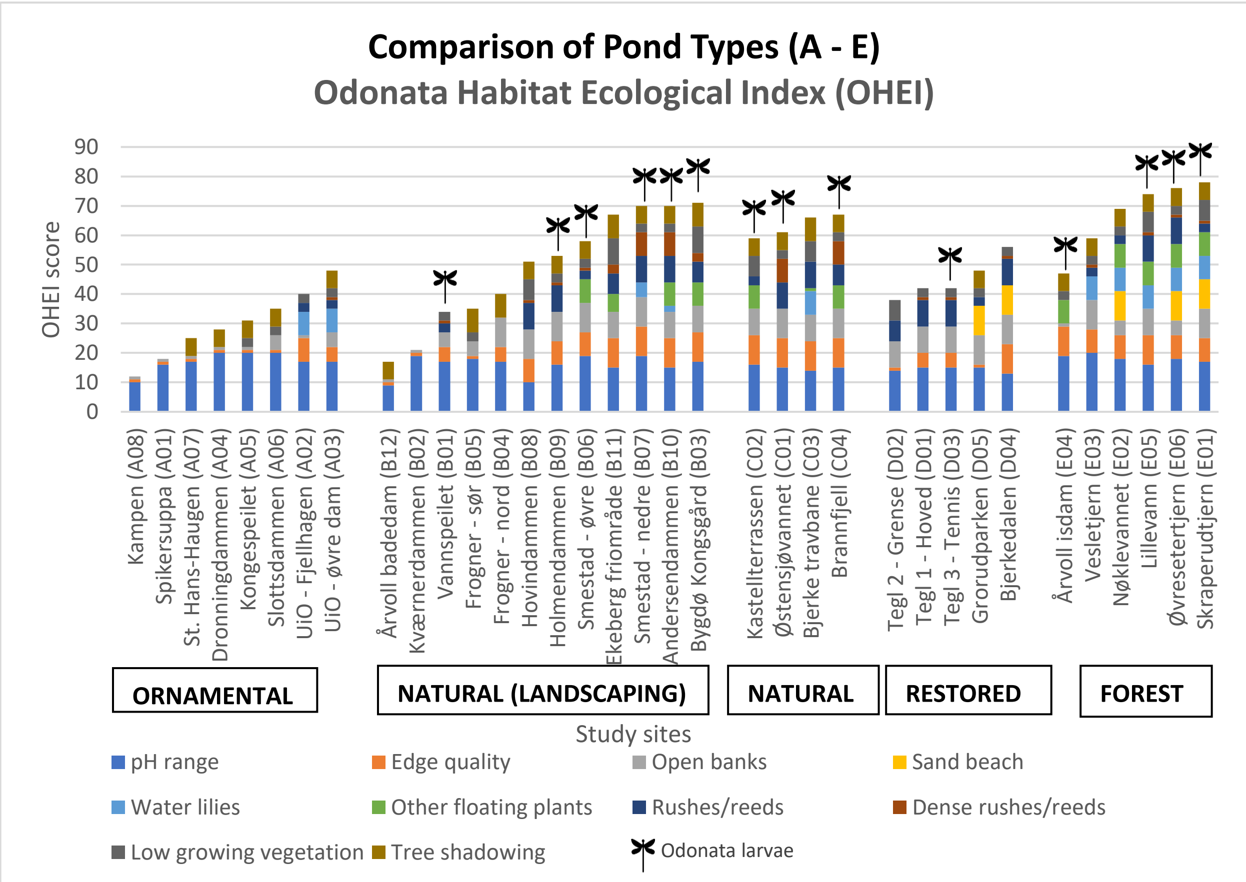


Figure 3.11 The habitat variables of all sites, and their scores on the Odonata Habitat Ecological Index

The habitat variables, and their scores on the Odonata Habitat Ecological Index, for each pond group (Type A-E) are presented in **Figures 3.12 – 3.16**.

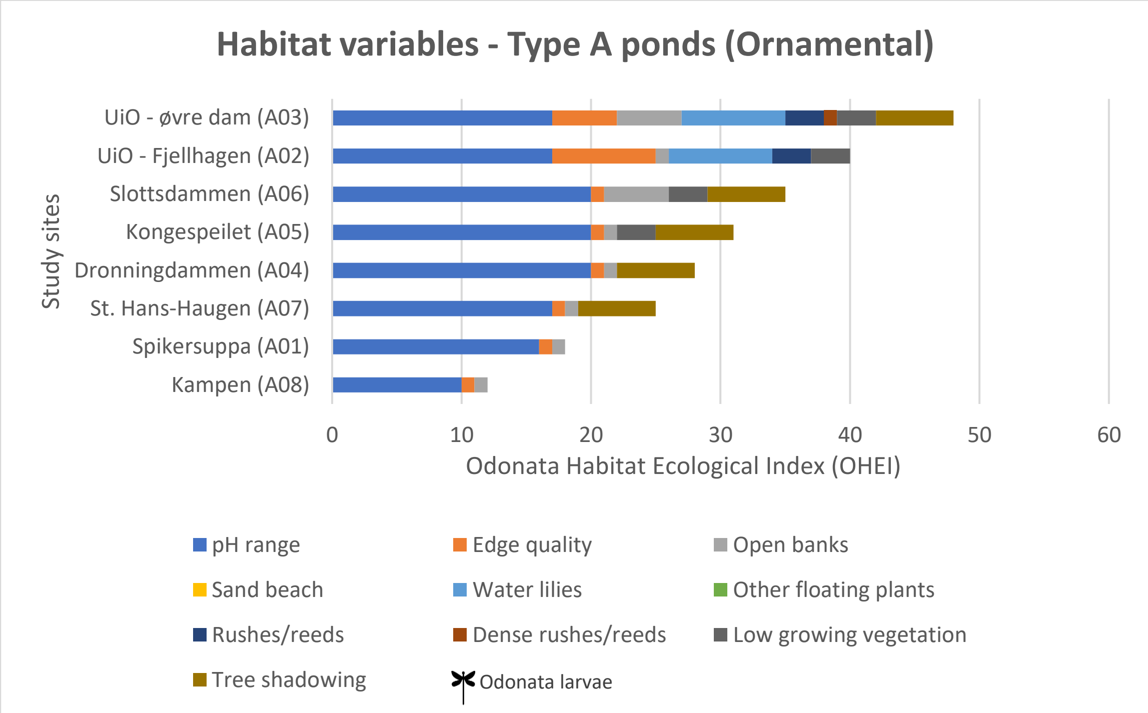


Figure 3.12 Odonata Habitat Ecological Index (OHEI) for Type A ponds (ornamental) in Oslo municipality

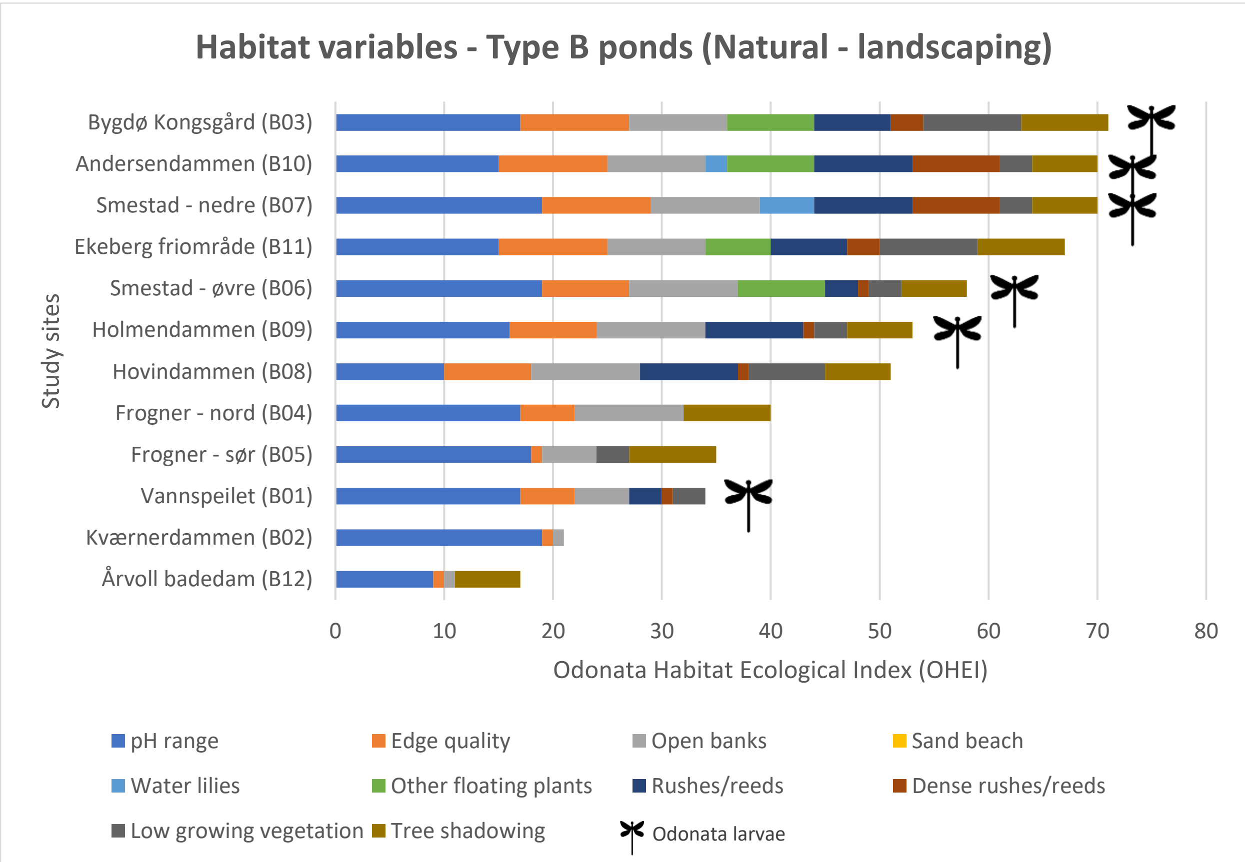


Figure 3.13 Odonata Habitat Ecological Index (OHEI) for Type B (Natural landscaping) ponds in Oslo municipality

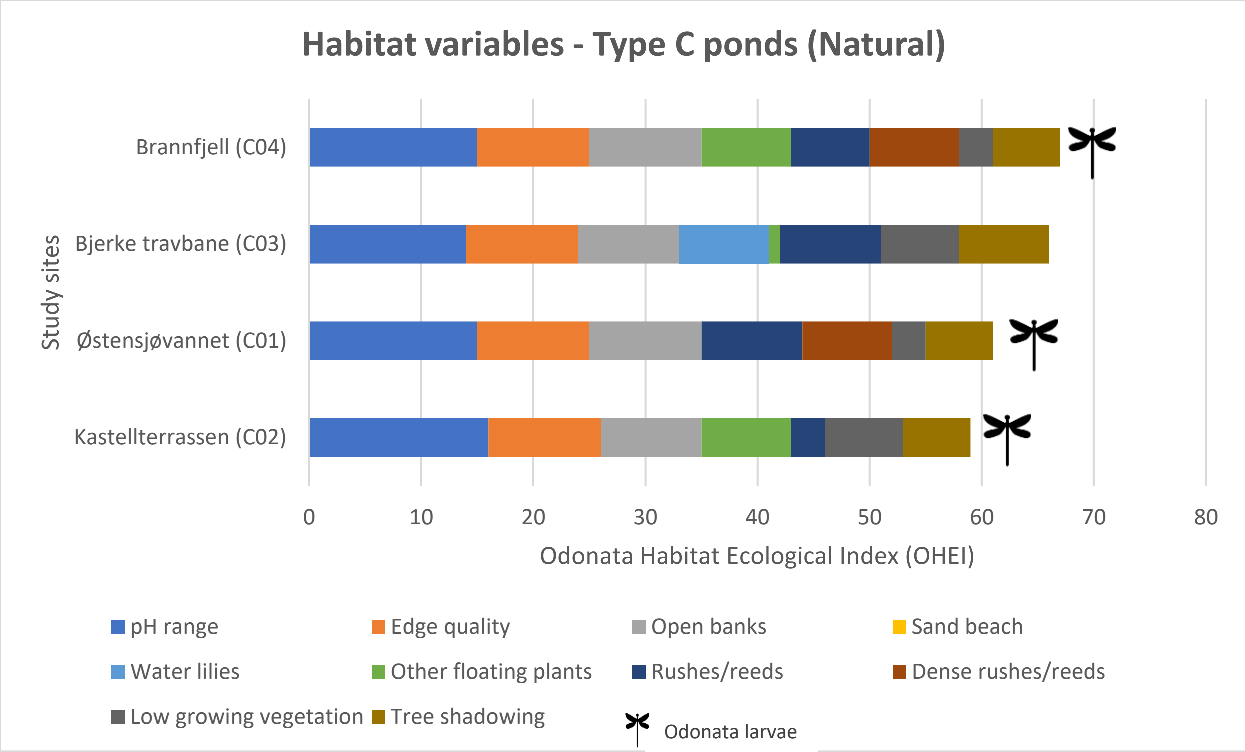


Figure 3.14 Odonata Habitat Ecological Index (OHEI) for Type C (Natural) ponds in Oslo municipality

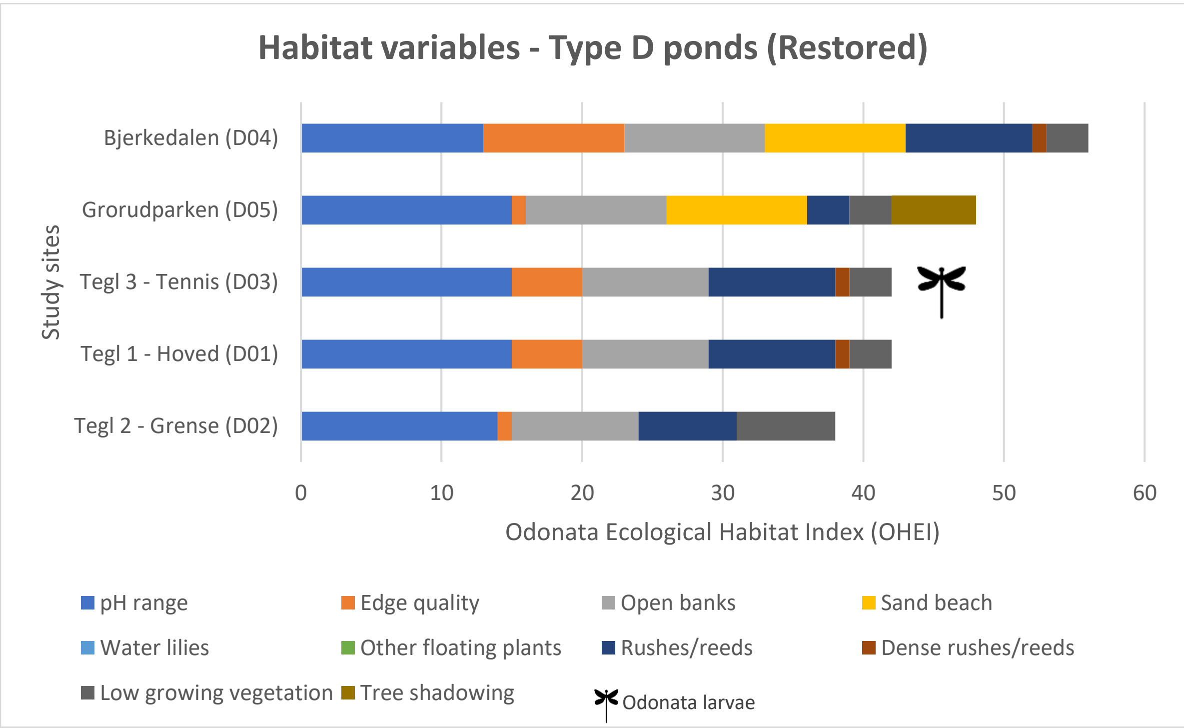


Figure 3.15 Odonata Habitat Ecological Index (OHEI) for Type D (Restored) ponds in Oslo municipality

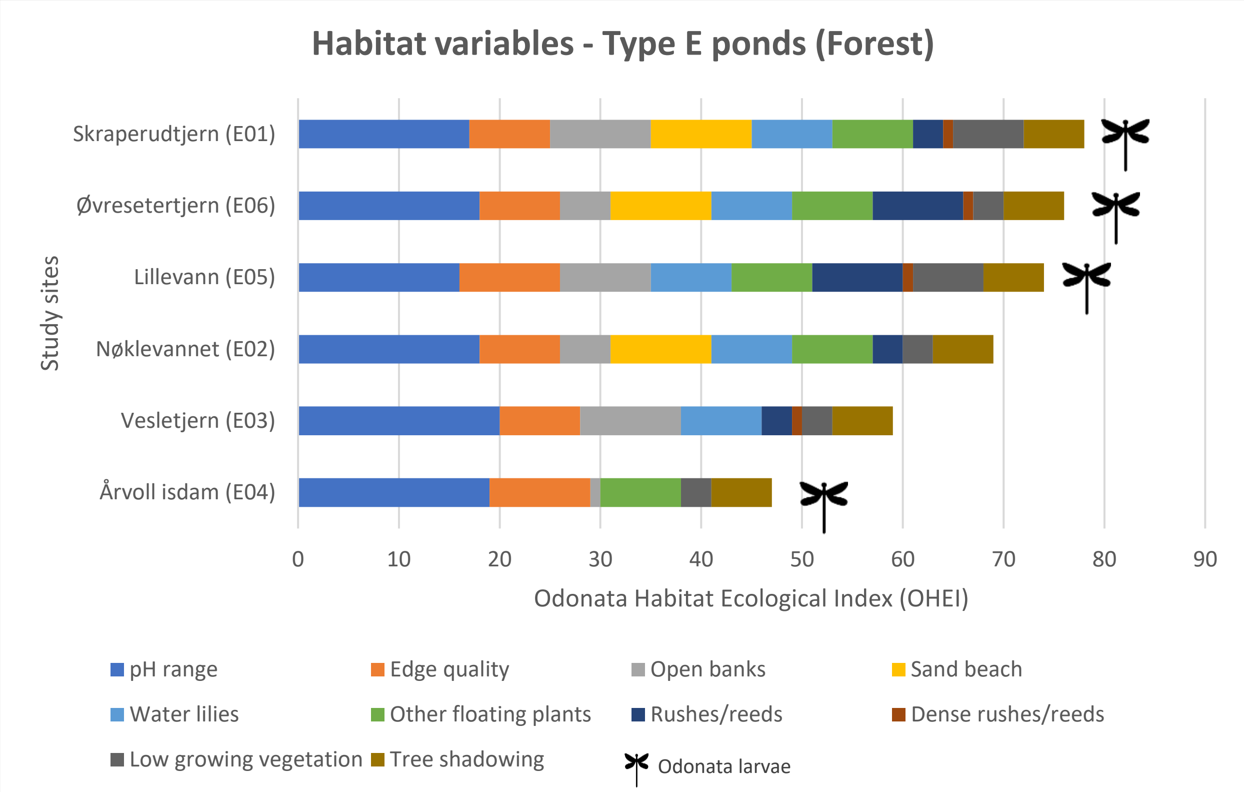


Figure 3.16 Odonata Habitat Ecological Index (OHEI) for Type E (Forest) ponds in Oslo municipality

ArcGis 10.6 was used to extract the area of each pond from the "FKB-vann" map layers which are available as geospatial data from the Norwegian Mapping Authority (Kartverket, 2017a). The water bodies range in size from from 141m^2 (UiO-Fjellhagen, site A02) to 762 940m^2 (Nøklevannet, site E02). The variation is so great that a logarithmic scale is required to present it visually in **Figure 3.17**. The surface area of each site is presented in **Appendix 4**.

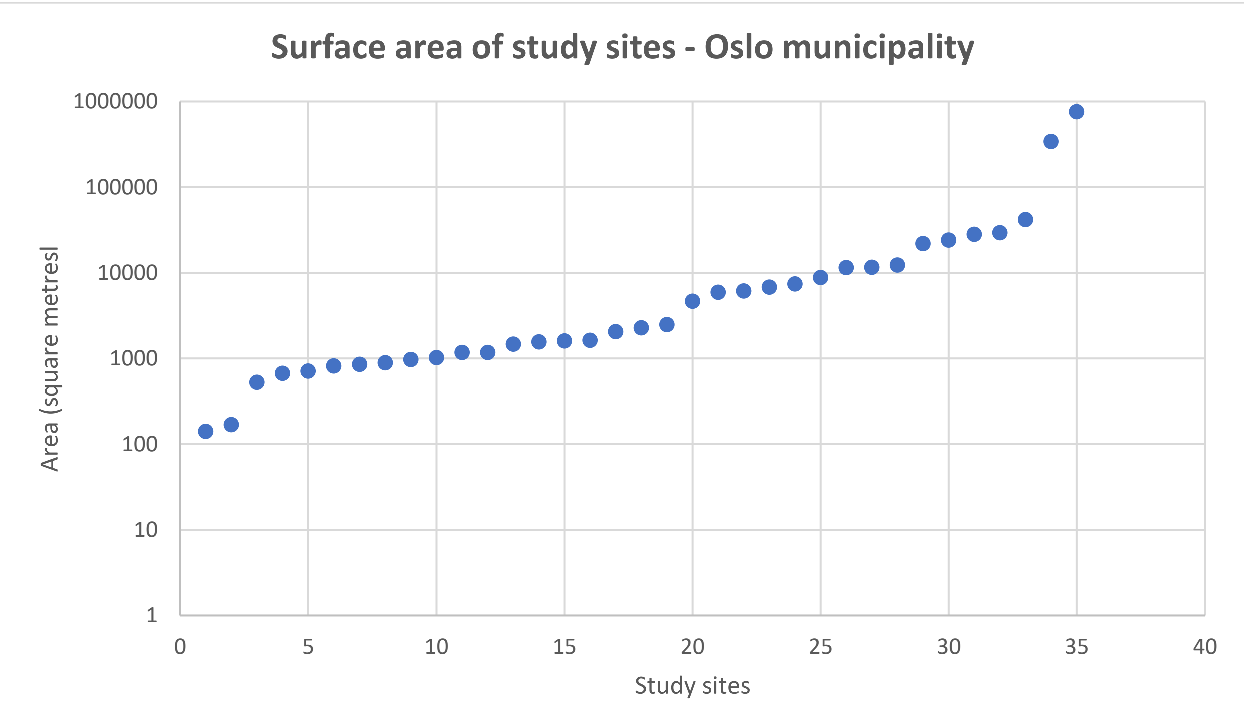


Figure 3.17 – The sites in this study range in size from 141m^2 – 762940m^2 and demonstrate the enormous variation of water bodies in the Oslo municipality.

The term"pond" is used in this study to designate the freshwater sites which were sampled for Odonata, and studied in terms of recreational activities. The surface area data clearly demonstrates that "pond" is a misnomer for water bodies at the upper end of the size range.

The Pearson r correlation was used to test whether there was a relationship between the score on the Odonata Habitat Ecological Index (OHEI) and the size of the water body. The calculations were made in Excel, and a result of 0.25 was obtained. According to Cohen's standard, a correlation of 0.10 – 0.29 indicates a weak relationship between the variables.

3.5 Recreational activities at the study sites

Recreational activities observed at each site, during fieldwork in July and August 2017, are presented in **Figure 3.18** and **Figure 3.19.**

The category "Other exercise" was removed as it was only ticked once [a group playing football, at Vannspeilet (B01)]. This was combined with "other activity" and provided 10 categories. The other activites observed included: swimming (5), taking photos (5), fishing (4), standing with others (3), standing alone (2), sleeping (1), picking raspberries (1), horse riding (1), eating ice cream (1), camping (1).

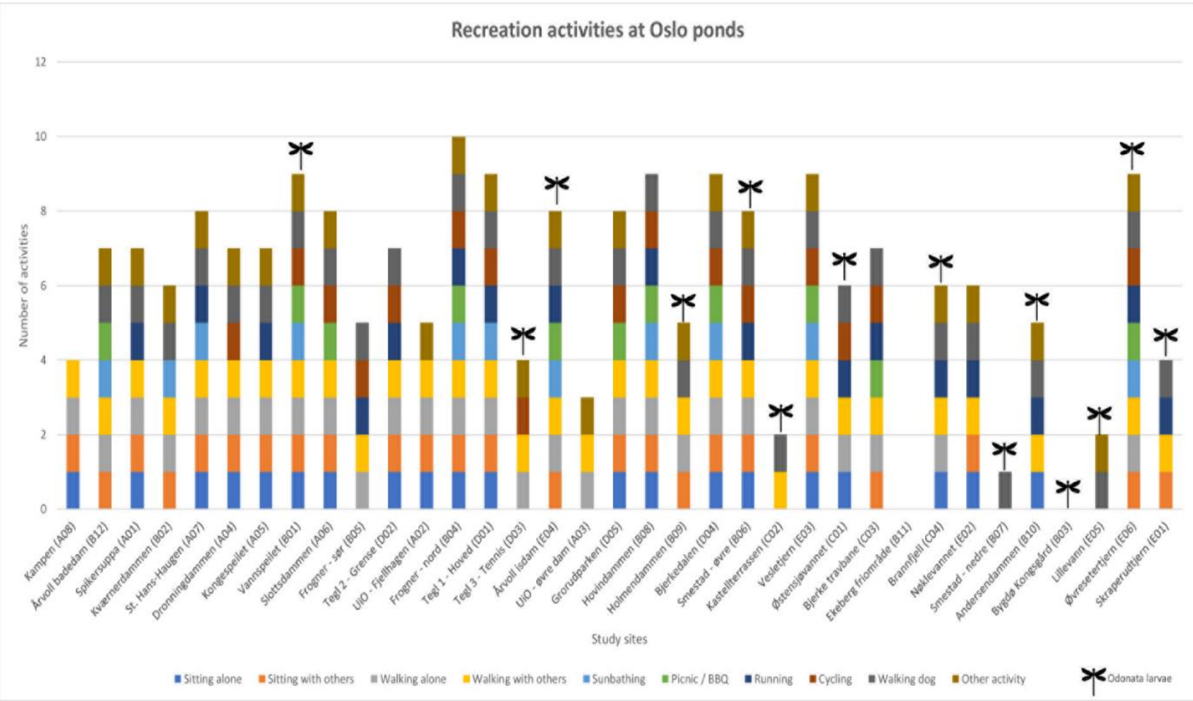


Figure 3.18 Recreational activities at Oslo ponds. The study sites are arranged (left to right) in order of their ranking on the Odonata Habitat Ecological Index (OHEI)

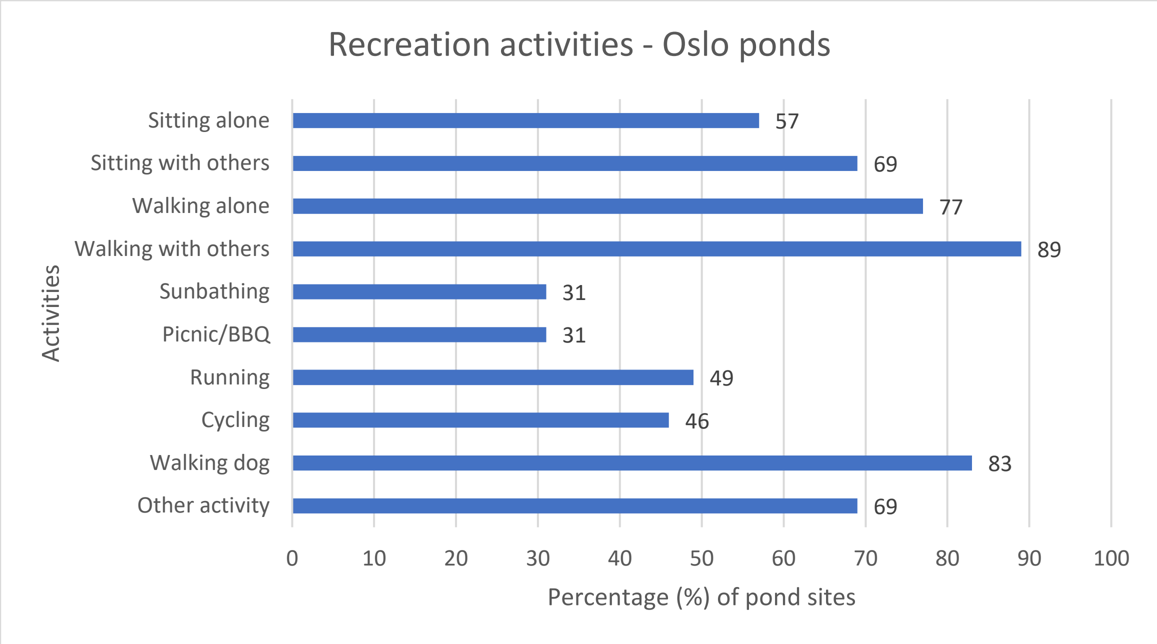


Figure 3.19 Interaction with the water at Oslo ponds. The study sites are arranged (left to right) in order of their ranking on the Odonata Habitat Ecological Index (OHEI)

3.6 Interaction with the water at the study sites

Activities which involved interaction with the water were recorded during fieldwork in July and August 2017. They are presented in **Figure 3.20**. and **Figure 3.21.** The other activites observed included: swimming (5), taking photos (5), fishing (4), observing dogs in the water (2), playing with a puddle (1), throwing sand (1), crossing the stream for fun (1),

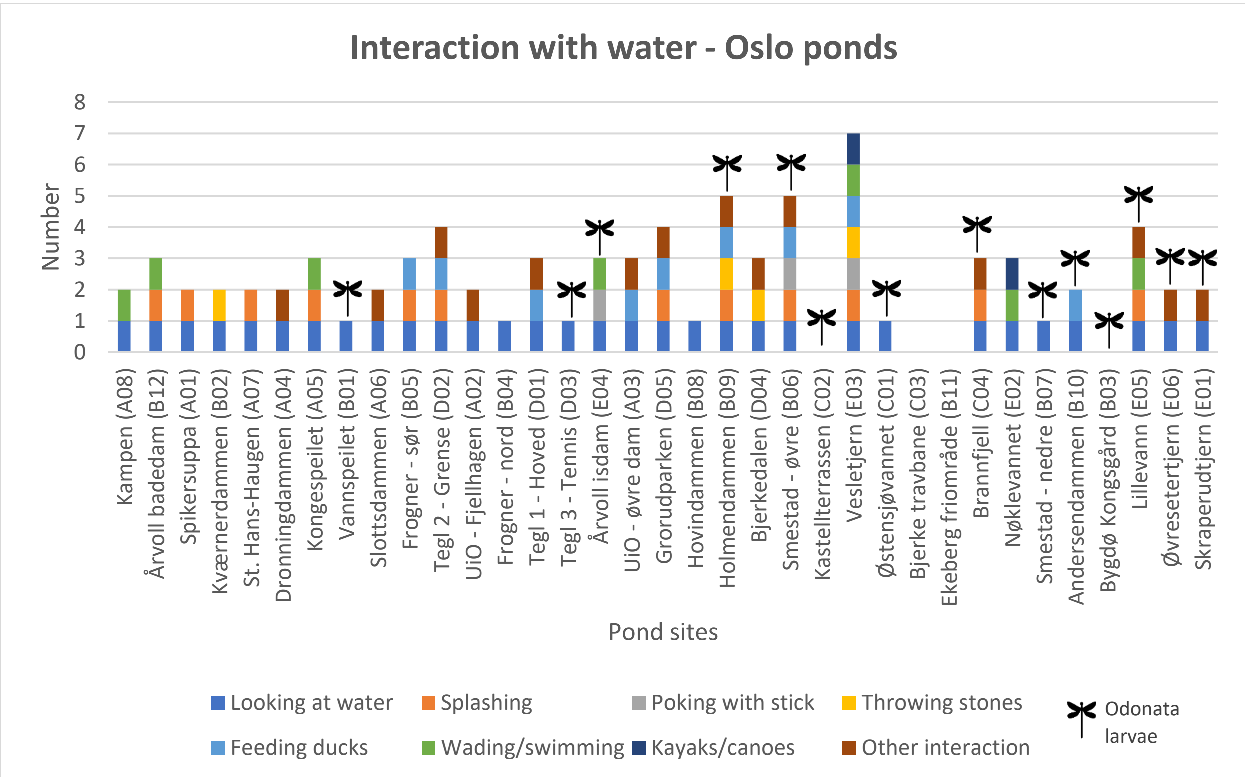


Figure 3.20 Interaction with the water at Oslo ponds. The study sites are arranged (left to right) in order of their ranking on the Odonata Habitat Ecological Index (OHEI)

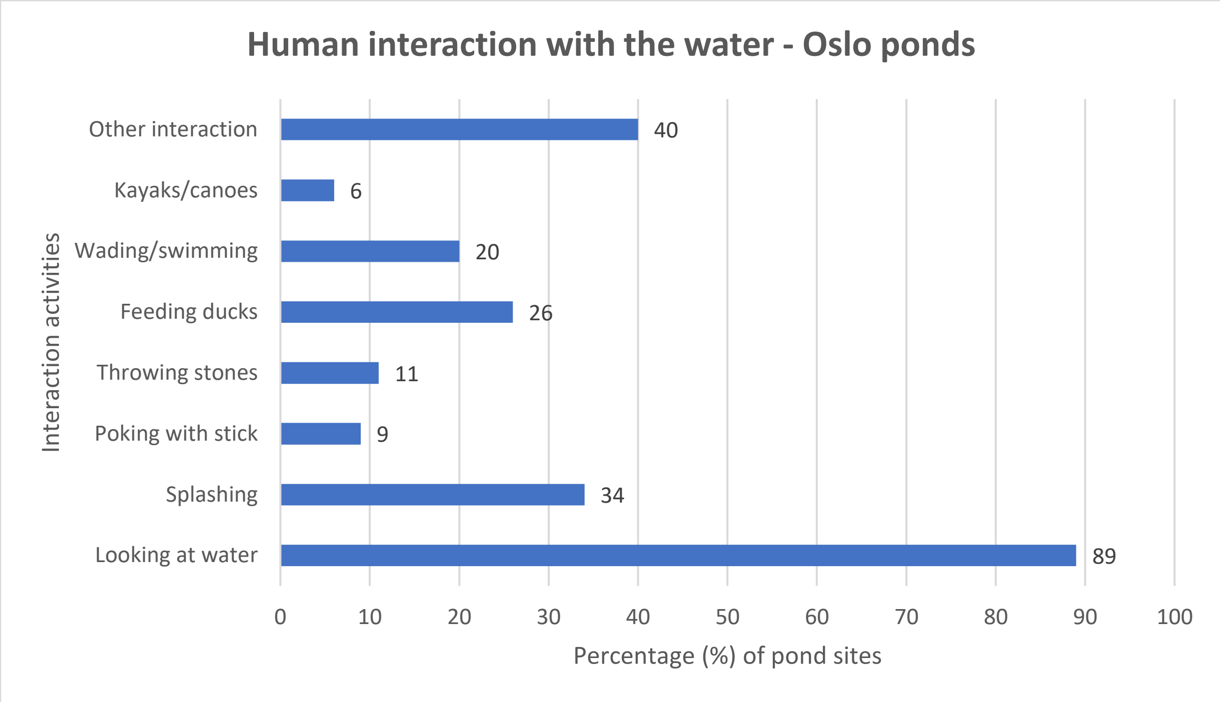


Figure 3.21 Interaction with the water at Oslo ponds. The study sites are arranged (left to right) in order of their ranking on the Odonata Habitat Ecological Index (OHEI)

3.7 Adult dragonflies and other biodiversity at pond sites

The presence/absence of other wildlife was observed at all pond sites in July and August. The survey form recorded adult dragonflies, bumblebees, beetles, waterfowl (ducks, geese), other birds, and other insects. Notes were made of the species (or family group) of observations, where this was possible during fieldwork. When the data was summarised it was noted that seagulls appeared at 21 sites (60 %), so they have been categorised separately in **Figure 3.22.** Data on beetles was combined with "Other insects" as there were few sightings.

Figure 3.22 is one of the more important figures in this study, as it combines data from this study (dragonfly larvae presence), observations of adults (presence/absence, without attempt at species identification) during fieldwork study, and observations of dragonflies at the pond sites extracted manually from Artsdatabanken (1909 records for Oslo municipality were individually read, as opposed to a location being "searched").

Figure 3.22 presents the wildlife experiences available at all pond sites, including adult dragonflies. With the addition of Artsdatabanken data, it shows where Odonata have been sighted at each of the study sites.

During the study, Odonata adults and juveniles were observed (and juveniles sampled) at 18 of 35 study sites (51.4 %). When Artsdatabanken observations are added, adult Odonata have been observed at 21 of 35 study sites (60 %). There is at least one Artsdatabanken observation of "any species dragonfly at a study site" during the past ten years.

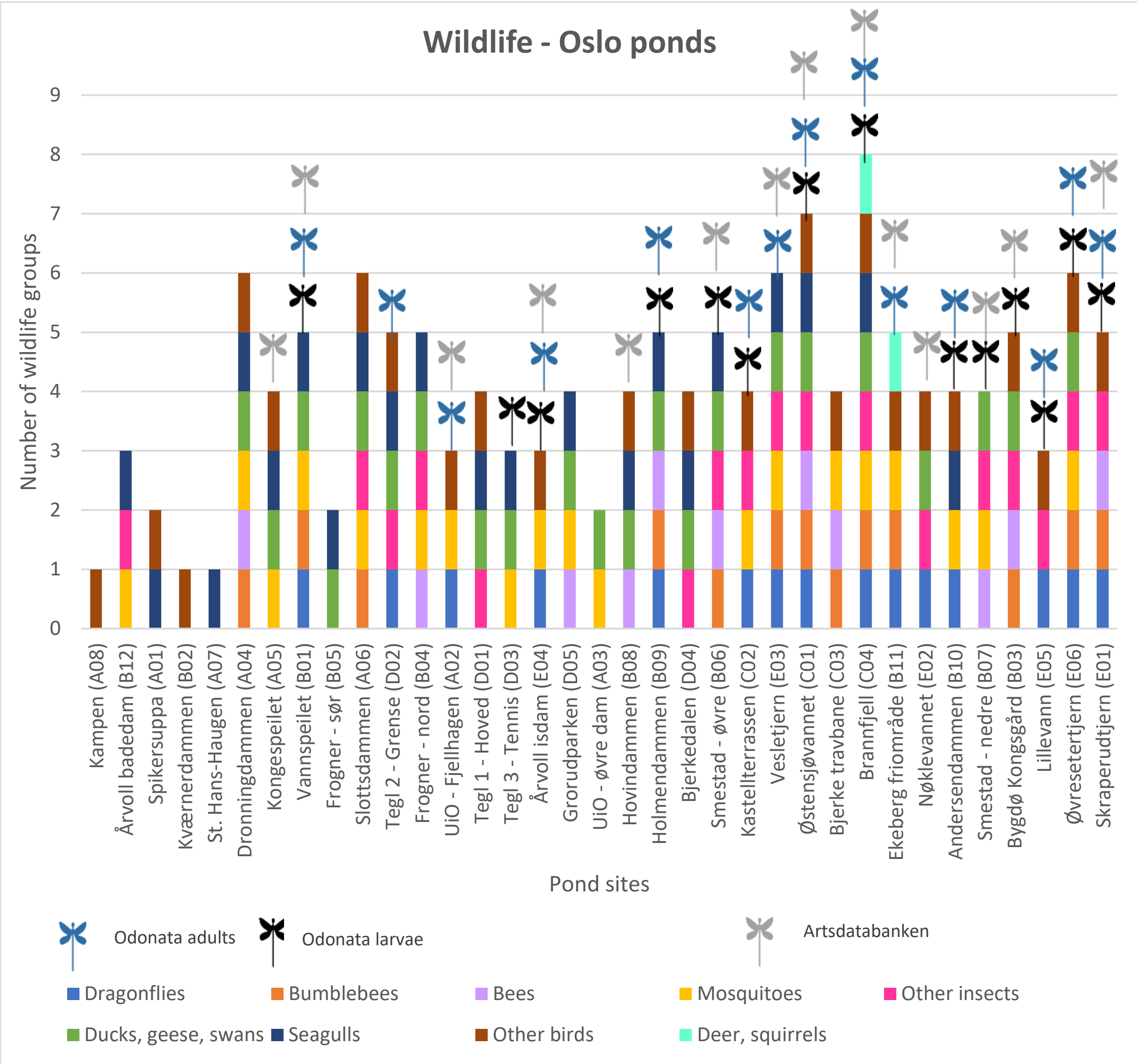


Figure 3.22 Wildlife at Oslo ponds, including observations for the presence of Odonata, made during fieldwork, and combined with registrations from Artsdatabanken. The study sites are arranged (left to right) in order of their ranking on the Odonata Habitat Ecological Index (OHEI)

3.71 Outside temperature observations and weather during the study

This information about temperature at the pond sites is provided because it can impact on the activity of wildlife, as well as human behaviour. In examining the data, after fieldwork it was found that all sites had at least one observation that was made during "sunny/fine weather".

Outside temperatue on site

The outside temperature was noted upon arrival at each site according to the AccuWeather app (https://m.accuweather.com) reading for Oslo. The current temperature is recorded as well as the high and low expected for the day.

The temperature range for site visits, during July 2017, was 13°C – 25°C. The average was 18 °C. The readings of 13°C and 25°C were both recorded on Thursday 20 July – the lowest readings (3 sites) at 8 am, and the highest reading at 12 noon (1 site).

The temperature range for site visits, during August 2017, was 14°C – 20°C. The average was 17 °C. The lowest temperature of 14°C was recorded on Thursday 24 August – an overcast day with heavy rain in the afternoon.

The temperature was recorded along with a note about the weather – sunny, overcast, pouring rain. This was done to provide some assistance when interpreting social data, and observations about other wildlife (dragonflies, bees, birds). A note was also made if it was particularly windy as dragonflies usually seek shelter in such conditions.

3.72 pH ranges of the pond sites

pH impacts on Odonata diversity, as well as the presence of plants, fish and algae. The results of the water samples collected during fieldwork, and later analysed in the laboratory, are presented in Figure 3.2

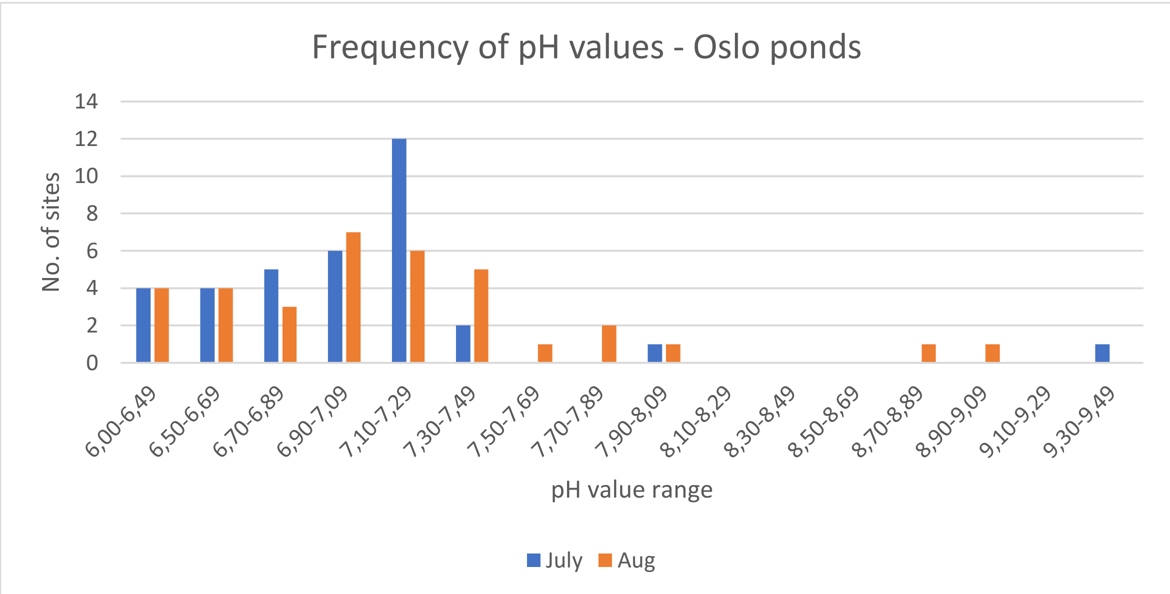


Figure 3.23 Frequency of sites with pH values in the ranges used in the Odonata Habitat Ecological Index (OHEI)

The frequency of pH site readings within the ranges used in the Odonata Habitat Ecological Index (OHEI) is presented in **Figure 3.23**. A clustering of a clustering of values in the range 6,70 – 7,30 is apparent. Apart from some outlying values, it can be seen that the water in urban ponds is close to neutral ie. either slightly acidic, or slightly alkaline.

4. DISCUSSION

4.1 General observations about the study

There are several challenges connected with attempting to identify Odonata assemblages, particularly in Norway. This includes accurate identification of larvae, and the difficulty of observing adults in inclement weather. Furthermore, exuviae (larval exoskeletons, **Figure 3.2** from which the dragonfly emerges), also tend to disintegrate quickly in the rain. This is unfortunate as they can be found in vegetation lining ponds, and are an excellent way to identify species breeding at a site, providing they are collected quickly.

As a specific aim of this study was to identify dragonfly breeding sites, and adults can disperse several hundred metres to several thousand kilometres from their juvenile environments, larval sampling was deemed necessary. Sampling 35 sites, using public transport and walking to access them, validated the decision to exclude adult sampling from the study. Comprehensive exuviae sampling would also have been impractical. There was insufficient time to conduct both transect walks, and sample for juveniles.

The use of public transport and walking is mentioned because an awareness of the contextual, qualitative information that can be gathered in this way is an important experience gained from conducting this study.

Figure 4.1 Interaction with the water is an important human response to water features. This pond at Bjerkedalen, Oslo (site D04) is also the centrepiece of a park where many recreation activities are enjoyed.

In the context of this study, and walking from Risløkka metro station to the pond at Bjerkedalen park (site D04), it exposed the need for Bjerkedalen park in that area. This is not only because it is located between so many medium-rise apartments, which lack their own gardens, but because the number of trees, and sense of greenery is perceived to decrease markedly when walking from that metro station. Interestingly, site D04 was one of the highest scoring locations in terms of the variety of recreational activities observed **(Figure 3.18).** Furthermore, even though the water is polluted, and a sign advises people not to swim, people still "interact" with the water. **Figure 3.20** and **Figure 3.21** show this information for all sites.

Another observation made in the course of conducting fieldwork, is that most park benches are placed in the sun. This reflects a Norwegian cultural desire to sit in the sun, especially in spring. However, on a hot day, especially when walking and carrying a heavy pack, the need to find shade often meant ignoring the benches in favour of an uncomfortable patch of grass. It is possible that in hot weather, Oslo residents are not sitting down to enjoy a view of the water. Looking at the water was the most frequently observed activity when recording "interaction with the water", occurring at 89 % of the pond sites (**Figure 3.21**). If dragonflies are present, and there is nowhere comfortable to observe them, urban inhabitants are missing out on a wildlife experience. As **Figure 3.22** shows, dragonflies have been observed as adults or juveniles, at 21 of 35 study sites (60 %).

An additional point is that all of the sites within a 3 km radius of the city centre would have been difficult to access if using a car. Negotiating traffic, one-way streets, and trying to find a parking place is not easy in the centre of a city. In Oslo it is made more challenging by an environmentally-driven municipal policy to reduce the number of on-street parking places, and remove cars from the city centre.

4.1.1 Larvae sampling and the hypotheses

This study began with two hypotheses: 1) Odonata larvae do not exist in ponds in the Oslo urban area (Oslo municipality); and 2) Odonata larvae do not exist in ornamental ponds in Oslo city centre (2 km radius of Spikersuppa). As Odonata larvae were found in 14 of the 35 ponds sampled **(Table 3.1)**, Hypothesis 1 was disproved. Hypothesis 2 can neither be proved nor disproved with the results of this study. Larval sampling yielded 13 species, and the addition of exuviae, expanded the Oslo municipal assemblage as described by this study, to 14 species **(Table 3.1)**.

During fieldwork in August 2017, several species of dragonflies were observed laying eggs in the water and mud banks of the newly landscaped pond in the Botanic Garden (Site A03). It is therefore possible that Odonata larvae may have been found if sampling had also been conducted in September and October 2017. Odonata eggs take between two to four weeks to hatch, depending on species, unless they enter obligate diapause, and hatch the following spring (Askew, 2004a). Even if Hypothesis 2 could not be disproved, I observed that the site is used as a breeding habitat, and recorded a video of the behavioural activity.

However, whether dragonflies larve will emerge in 2019 is another matter entirely. This is not simply because development time is species and temperature dependent: a single event could abruptly terminate their existence. In the context of that particular site, at the Botanic Garden, such an event could constitute a maintenance decision to temporarily drain the pond. Furthermore, a very hot summer, such as that which

Oslo has recently experienced (2018), could raise the water temperature to a level beyond the tolerance of any species which are present. The pond is 141 m^2, the smallest site of all those surveyed, and it will absorb and retain warmth from the surroundings.

4.1.2 Exuviae collection recommended in urban ponds

Dragonfly larvae inhabiting the managed environment of an urban pond face unpredictable threats that are quite different to those arising in surroundings less impacted by urbanisation. This is the key reason that studies designed to map the abundance and diversity of urban Odonata should include exuviae collection in design. The collection of exuviae is the only way to confirm that the Odonata egg has developed, and that the juvenile has emerged as an adult. This subject is discussed, in depth, by (Raebel et al., 2010).

Although it was not possible to collect exuviae in a standardized manner, in this study, the identification of those exuviae that were found added one species, *Sympetrum vulgatum*, to the overall species assemblage (14 species). This is shown in **Table 3.1.** Furthermore, exuviae collection added one species to the species assemblage of every site at which they were found **(Figure 3.1).**

Another important benefit of exuviae collection is that they provide data about the emergence periods of each species. Exuviae are quite fragile and will disintegrate within a few days, depending on weather conditions. In this study, eight exuviae (67 %) were *Aeshna grandis,* and seven were found in July. Only five of the larvae collected were of this species. This suggests that *A. grandis* emerged in the first week of July (in 2017), in Oslo municipality. The emergence times for this species, for Norway and Sweden, range from the last week of June until the end of September, with the main period being from the fourth week of July (Boudot & Kalkman, 2015). This further suggests that the majority of *A. grandis* may have emerged two weeks earlier than usual, for this latitude. However, exuviae collection was not standardized, and the numbers or exuviae and larvae were not sufficient to give much weight to this proposal.

4.1.3 Noteworthy locations and species

An interesting issue with hypothesis 2, is that Odonata larvae were in fact found at a pond within a 2 km radius of Spikersuppa (A01). Five larvae, from two species, were obtained from Vannspeilet (site B01). An exuvium of a third species was also found. This site is not an ornamental pond, but is an artificial pond, completed in 2000, and built at an exit point of the Alna watercourse (Oslo elveforum, 2017). The stream emerges from an underground pipe at the southern end of the pond, where the edge vegetation is plentiful and within 20 m – 50 m of where the larval samples and exuvium were collected.

This site (B01) is discussed in relation to the Odonata Habitat Ecological Index (OHEI) in **section 4.3.**

Another noteworthy location was Tegl-3 Tennis(D03). This is one of the ponds constructed along the restored stretch of Hovinbekken stream, which was "daylighted" in 2015. It is situated between a road, a car park, an overpass, and the metro line. It might appear to be a most unpromising location, due to the surrounding infrastructure, and the evidence of heavy waterfowl use (extensive excrement in the grass, feathers and a greasy, eutrophic appearance to the water). The score of 42 which it was assigned on the Odonata Habitat Ecological Index (OHEI) suggests that Odonata are not likely to be found there.

Figure 4.2 An *Aeshna cyanea* larva was discovered at the base of this plant. The pond is located next to a the Hasle S metro station in central Oslo.

Nonetheless, a large *Aeshna cyanea* (44 mm) was discovered at the base of the rushes in **Figure 4.2**. The size indicated that it was likely to emerge (become an adult), and the two – to three year development cycle of the species suggest that the egg from which it hatched was laid in late 2015.

An important feature of this pond is that the stream restoration process, and pond creation, was based on ecological principles. There was a particular focus on making Hovinbekken a more suitable environment for endemic fish.

Odonata juveniles are prey for fish, and ornamental fish are not recommended for ponds if there is an intention to encourage dragonflies. However, this pond is located on a stream, and the design included vegetation suitable for nurturing fish presence, and improving water quality. Such a design parameter is likely to benefit other species, even if they are prey for fish. This then raises questions about the low score on the OHEI. In this case, one factor is that the reed and rushes in the left of the photo (the centre area between two ponds) were probably incorrectly scored during fieldwork.

According to Boudot and Kalkman (2015), *A. cyanea* is "one of the most common dragonflies at garden ponds" in Central Europe. This suggests that the species tolerates a wide range of environments. The implication for this study is that habitats that appear to be marginal, or even have an unpromising OHEI score, can still function as breeding habitas for generalist species. Given the location of the pond next to a car park, and adjacent to the Hasle S metro station, the possibility exists for commuters to experience wildlife on their way to work.

The collection of several specimens of *Aeshna mixta* **(Figure 4.3)** is an interesting find as this is a relatively new addition to the Norwegian fauna. This is discussed in more detail in **section 4.2.6.**

The presence of *Sympetrum sanguinem* is also noteworthy as this species appeared on the Norwegian Red List in 2006 and 2010. It was removed in 2015 due to its abundance being greater than previous mapping data had indicated (Kjærstad, G & Olsvik, H, 2015). In addition to obtaining juvenile samples of *S. sanguinem*, four adults were observed at Østensjøvannet during sampling in August 2017.

4.1.5 Impact of sampling period on Odonata assemblage data

The majority of Odonata do not begin to emerge in Norway until mid-June, and this continues through to September for some species (Sandhall, 1987). As fieldwork was undertaken in July and August 2017, species which emerge in spring and early summer are therefore less likely to be included in the samples, and certainly unlikely to be obtained as final instars.

Furthermore, some species undergo delayed embryonic development, og "egg diapause". According to Corbet and Brooks (2008), this may be obligate or facultative, at least where British Odonata are conderned. Species of *Sympetrum* are particularly sensitive to the timing of oviposition, and the later eggs are laid in summer, the more likely it is that they will not hatch until spring (Corbet & Brooks, 2008). However, in the following species (of which samples were collected), egg diapause is obligate: *Aeshana cyanaea*, *A. grandis*, *A. juncea*, *A. mixta*, *Sympetrum danae*, and all species in the Lestidae (Corbet & Brooks, 2008).

The sampling periods for the study can thus explain why some particularly small Aeshnidae instars were obtained. Aeshnidae have a two year development cycle, and obligate egg diapause. The eggs from which these larvae developed are likely to have been laid in summer/autumn 2016, and hatched in early spring 2017.

4.1.6 Habitat preferences and behaviour

All of the species obtained during sampling were generalists, tolerating a range of lentic environments, from oligotrophic (nutrient poor) to somewhat eutrophic (nutrient rich), or slightly acidic to slightly alkaline. This is not an unexpected result, as urban biodiversity studies often show a predominance of generalist species, including among Odonata (Le Gall et al., 2018)

Although a stringent effort was made to standardize sampling, difficulties with accessing all areas of the pond edge, as well as the sampling technique ("z sweep") can have resulted in particular species avoiding capture.

Corbet (1999) categorizes larval Anisoptera (dragonflies only, not damselflies) into four groups, based on their behaviour, morphology and microhabitat preference. The "claspers" and "sprawlers" can be found in vegetation close to the surface, and examples include *Aeshna cyanea* (clasper) and *Sympetrum danae* (sprawler). Larval samples of both species were collected (**Table 3.1).**

Larval samples of a "hider" (*Cordulia aenea*) were also obtained, although three of these four specimens were found in thick sphagnum (Lillevann (E05), not the "fine detritus…[or] coarse leaf litter" which Corbet (1999) describes.

A deliberate effort was made to search for, and sample, gravel and sand substrates, as "burrowers" will be found in this habitat. "Burrower" species include the riparian *Cordulegaster boltonii*, and *Libellula depressa* which can be found in both lotic (river) and lentic (pond) environments (Corbet, 1999). Neither of these species were found.

The species assemblage reveals a predominance of claspers and sprawlers, but it is difficult to determine if this reflects the sampling technique, or other factors, including habitat variables.

4.2 Artsdatabanken

Analysis of the species observation records in the "Artsobservasjoner" database indicated that this database is an important source of data on Odonata diversity at the Oslo municipal scale. The species assemblage for Oslo, based on this data, contains 31 of the 50 species registered in Norway **(Figure 31)**. It also provides a useful dataset with which to compare the results of larval sampling studies, or standardized counts of adults. **Table 3.4** provides a comparison of the data with the results of my own study.

4.2.1 Limitations for decision-making at a fine-scale

Nonetheless, there are some significant issues associated with relying solely on these records to draw conclusions about Odonata diversity in Oslo, and is inadequate, on its own, for making informed decisions at a fine-scale, eg. a single neighbourhood.

Firstly, the datase has been open since 2008 for public registration. Observers must create an identity record on the database, and anyone is able to do this. This allows for "citizen science" with the accompanying positives and negatives.

In the case of the Artsdatabanken database, it has created an issue with a lack of consistency in the names used to identify Odonata observation sites. As an example, **Table 3.2** shows six name variations for Halsentjern on Bygdøy, as well as different coordinates being used when the same name variation was used. The difficulty this creates is if a user wishes to analyse Odonata biodiversity at a very small scale, for example, a biologist advising about the environmental impact of filling in a small pond in order to provide land for a new kindergarten.

I attempted to search the downloaded dataset to match observations of Odonata registrations at all my study sites by sorting the data. This proved to be impossible, both because of name inconsistencies, and variations in the precision of the geographical coordinates, for example, a registration could be within 3 km, 450 m, or 50 m of a site. Eventually, due to time constraints, I had to use the online map function (Artskart) connected to the database, and zoom in on each of the 35 study sites. This is how I created **Figure 3.22**, the only chart comparing my Odonata data with that in Artsdatabanken. It shows that Odonata have been either sampled, or observed as adults, at 18 of the 35 study sites (51.4%).

4.2.2 Pitfalls of a "citizen science" approach

Another issue is that the non-compulsory data field "Institution" contains data, even though this is not a requirement. All records for Oslo municipality have data in the "Institutional" field, and it suggests a legitimacy to the data which is not necessarily warranted. To elaborate, the two organisations which are associated with the highest number of registrations are: the Natural History Museum, with 48 records (2.5 %); and the Norwegian Entomological Association, with 1295 records (67 %). The data registrations connected with the Norwegian Entomological Association are largely made by individuals, not groups. (In some small number of cases, two or three names are registered together). As **Table 3.3** shows, five individuals have contributed 87.2 % of all observations, and one individual "Observer 1" has contributed 59.3 % of all observations.

The data showing that one individual is responsible for 59% of the species observations in Oslo is disquieting. It is not that it is problematic that Observer 1 is collecting the data (provided it is correct), it is a problem that it is all coming from one source. Having one person contribute so much data will skew the assemblage information in Oslo in a way that reflects biases in the behaviour of the observer. These biases include: a tendency to visit certain areas (perhaps close to where they live), a tendency to search for particular species, and be more aware of them (perhaps for aesthetic reasons), a tendency to be outside ("collecting data") at particular times of the day, or times of the year.

Table 3.4 shows 200 registrations for *Sympetrum danae*, suggesting it is the dominant species in the Oslo Odonata fauna. However, this species begins flying in late June, and continues through August (Boudot & Kalkman, 2015). Is it really the dominant species, or does this simply reflect the fact that the the official annual summer holiday period in Norway is in July? Amateur Odonata enthusiasts are likely to be out in the field at this time. Indeed, one of the volunteer species mapping projects undertaken by the Norwegian Entomological Association was organised to coincide with the summer holidays of the members organising the project (Knutsen, 2013).

Further analysis of the database registrations, and a comparison of the flying times (breeding periods after emergence) of the registered Odonata species, are required to identify if this is indeed a problem, or just the possibility of one. Such analysis was beyond the scope of this study.

4.2.3 Species validation and data entry issues

A further issue is that the database may contain species identifications that are incorrect. In the case of the registrations in the Artsdatabanken database, users can select for "validated finds". Unfortunately, only 96 of the 1909 registrations for Oslo are validated, and only 18 of those validated records are for a museum specimen. Clearly there is some inconsistency in the data entry, because another search will show that there are more than 450 museum specimens with registrations in the database. The key problem is that the responsible approach of making decisions based solely on "validated finds" yields too little data on the true status of documented Odonata diversity in Oslo, and species diversity will be underestimated.

Perhaps the most serious issue is that users are probably not aware that this problem exists, and rely on the legitimacy afforded by this being public database, managed by the foremost authority on biodiversity in Norway.

A positive observation about the database records is that there appear to be a large number of photos accompanying observations of unvalidated finds. It was beyond the scope of this study to analyse the number of photos, or their quality, but it suggests that there is potential to increase the validation status of some registrations. It is also encouraging that observers are responsibly attempting to document their observations.

The issue of validation has implications beyond local decision-making. This data set is available for international use, and has much to contribute in terms of global knowledge about biodiversity. It is particularly important in terms of mapping changing distributions of species, especially with regard to climate change pressures.

4.2.4 Contribution to the Norwegian Red List data

Nonetheless, the potential pitfalls of using Artsdatabanken data as the only source of species information in Norway, must be weighed against the negatives. We need species mapping in some form. It is thus positive that some few individuals are making strenuous efforts to contribute data, rather than no data being collected at all. Indeed, one of the reasons that *Sympetrum sanguinem* was removed from the 2015 Norwegian Red-List, was because increased species mapping led to the conclusion that the species was much more widespread than previously thought (Kjærstad, G & Olsvik, H, 2015).

This suggests that a greater responsibility lies with other biologists to contribute data. It would also be an interesting project to survey biologists, members of professional organisations, to ask whether they contribute data, and if not, to ascertain the barriers to their participation.

It is of note that the species assemblage for Oslo municipality does not contain any records of Gomphidae. This is a riparian group, and under threat globally. Both the Norwegian species, *Onychogomphus forcipatus* and *Gomphus vulgatissimus* have Red List status of "Near Threatened" (Kjærstad, G & Olsvik, H, 2015)

4.2.5 Mapping the continuity of species presence

An important use for the data from Artsdatabanken is that it can be used to infer the continuity of species presence in a particular area. One of the larval species obtained from the pond at Bygdø Kongsgård was *Lestes sponsa*. The pond was established in 1790-1795 (Oslo elveforum, 2017). The earliest recording of *Lestes sponsa* for Oslo municipality is a specimen that was found in 1872, at a site approximately 450 metres south-east of the pond at Bygdø Kongsgård.

This is a reasonable distance for what Corbet (1999) describes as "commuting", from breeding sites to foraging and roosting areas, or even the "maiden flight" of the newly emerged (teneral) dragonfly. It is thus reasonable to infer that the presence of *Lestes sponsa* on Bygdøy has been continuous for at least 145 years. (There are five other pond/wetland sites on Bygdøy, including another pond which was established in the 1700s, located approximately 400 metres east of the site where the specimen was obtained. Consequently, there are two possible breeding habitats for the collected specimen.)

4.2.6 Documentation of a new species – Aeshna mixta

Artsdatabanken records are also important for tracking the arrival of new species in Norway. One of the most interesting finds from the larval sampling study was the collection of six specimens of *Aeshna mixta* **(Figure 4.3)**. This species has recently been included in the Norwegian fauna after an increasing number of observations over the past decade. The first observation was made in Telemark in 2004. The first validated observation, where the identification was confirmed from photographs by an expert, was made in Mandal, in southern Norway, in 2005. There are now 239 observations, the most recent of which was in 2017. The distribution of *A. mixta* in Norway, based on these registrations, is shown in **Figure 4.4.**

Artsdatabanken holds only seven records for observations of *A. mixta* in the Oslo municipality. The first sighting was at Hovindammen (B08) in 2008. Another five registrations record its presence at Østensjøvannet in the years 2009-2011. Several of these registrations are accompanied by photographs. There was also one observation, in 2016, at Årvoll isdam (E04).

Figure 4.3 *Aeshna mixta* is a relatively new addition to the Odonata fauna in Norway. Larval specimens obtained from Årvoll isdam confirms that it breeds in Oslo municipality. Photo: Ove Bergesen, Artsdatabanken

Two of the specimens collected in the larval samping study were found at Årvoll isdam (E04). This is important because as Askew (1988) points out, *A. mixta* is "migratory and can be found far from water, even in tree-lined lanes". The observation made at Årvoll isdam (E04) in 2016 may have been a species that spent its juvenile period in another water body. The results of the larval sampling study confirm that the species breeds there.

The other specimens in the larval sampling study were found at: Smestad-nedre, B07 (2 specimens); Kastellterrassen, C02 (1 specimen); and Brannfjell, C04 (1 specimen). These breeding sites occur in four categories of pond, and the sites were assigned scores ranging from 47 to 70 on the Odonata Habitat Ecological Index (OHEI). Consequently I am unable to suggest a common feature that might explain *A. mixta* breeding in these locations. Perhaps the relevant point is that it is a migratory species, and as such has evolved characteristics that allow it to breed in a range of habitats.

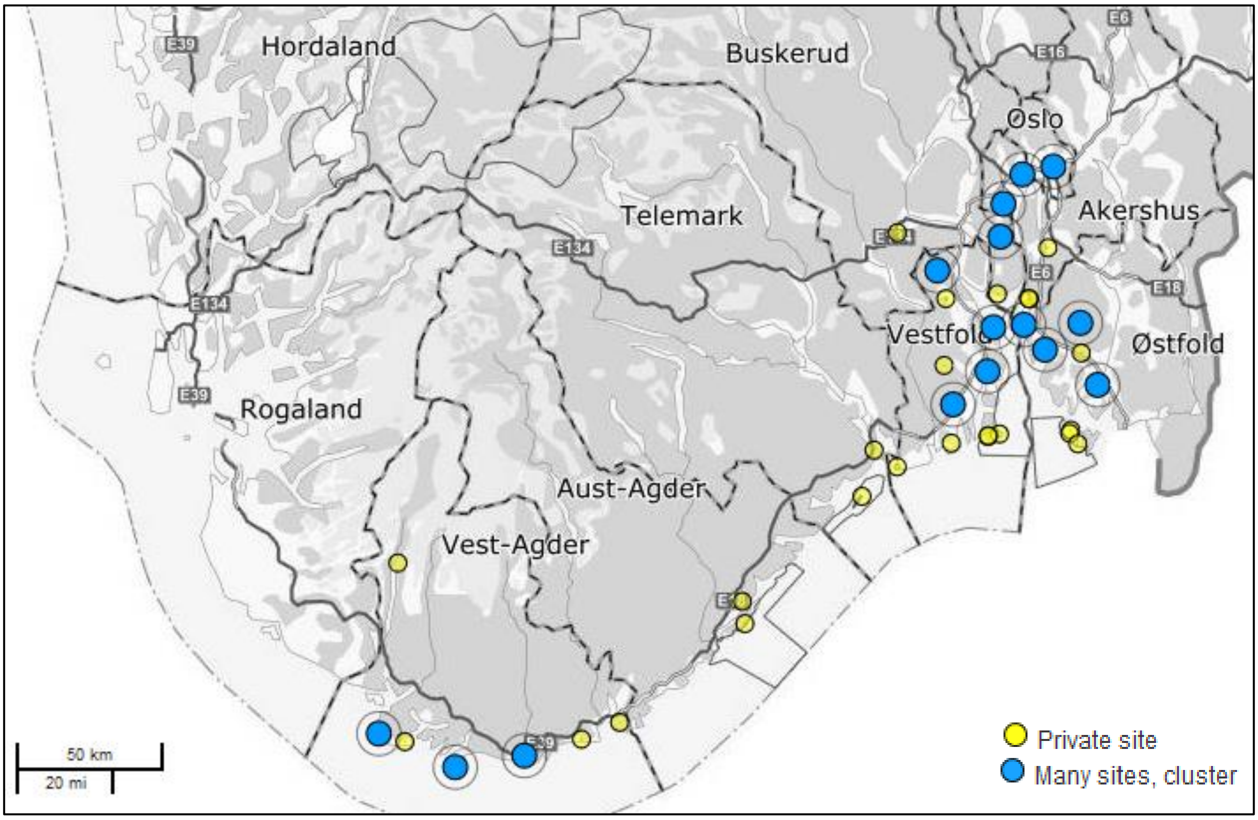


Figure 4.4 Map showing the distribution of *Aeshna mixta* in Norway. Source: Artsdatabanken

4.3 Pond assessment - Odonata Habit Ecological Index

The rankings on the Odonata Habita Ecological Index (OHEI) strongly suggest that the OHEI has accurately captured the parameters that describe a suitable habit for dragonfly larvae. An examination of **Figure 3.9** reveals that the six highest ranking water bodies were all found to contain Odonata.

It appears that all the parameters contribute to the larger scores. A high score is not possible with only a few variables. In this sense the OHEI can assist in providing for structural diversity in ponds – something which is important for Odonata.

Statistical analysis

The Pearson r correlation result of 0.5 indicates a strong relationship between the Odonata Habitat Ecological Index and the presence of larvae. This strengthens the validity of this Index as a suitable tool for assessing urban ponds as Odonata habitats, and possibly using it to assist with pond design. If the correlations between the variables had been weak, it would have suggested that it was mere chance that Odonata larvae were obtained in ponds with higher rankings. Although further testing of the OHEI is desirable, it assisted in understanding the variables present in a set of very different ponds (in this study) in terms of their suitability as Odonata habitat.

The three highest ranking ponds (score of 74 – 78) are type E (forest pools), a habitat that would be expected to be suitable for Odonata. The ponds below these, sites B07, B10, B03, are all landscaped ponds, close to human habitation. The OHEI appears to also function well in an urban environment.

The most interesting result is the score of 34 for Vannspeilet (site B01). As **Figure 3.5** indicates, five specimens of two species (*Sympetrum sanguinem* and *Aeshna juncea*) were obtained from this pond. This is the lowest score for any pond with Odonata samples.

This is a large pond (24,109 m^2), and it has a large amount of reeds and low growing vegetation at the southern end (**Figures 4.5** and **4.6**). Furthermore, the way it has been landscaped with dense vegetation, as well as the steepness of the banks, keeps the waterfowl and dogs from easily accessing the edge in this area. This also a large edge area with grass to the water's edge. This edge area allows easier access to the water for ducks and geese. A reed area at the northern end contained visible feathers and down, and the lawns in this area were covered with waterfowl excrement. It appeared that this reed area was preferred by the waterfowl.

It is possible, and seems likely, that the presence of the northern reed area, adjacent to the open banks, provides a desirable foraging area for the waterfowl, and deters them from exploring the southern reed areas. This has been cited as an important strategy for improving wetland habitat (Chovanec, 1994;

Chovanec et al., 2000). Such an effect seems most likely to occur on a larger water body, so it is not a strategy that could be employed by designers for smaller ponds.

More investigation of this particular pond would be needed, including the behavioural patterns and numbers of the waterfowl, in order to determine if my qualitative observations (about feathers and excrement) substantiate my conclusion.

In terms of the Odonata Habitat Ecological Index (OHEI) it would appear that it might need calibrating for water bodies above a particular size. This could mean inserting a question, for example:

- Is the water body >20 000 m2? If yes,
- Does it have two or more areas of "Dense reeds/rushes" (see OHEI – 3b) separated by >50 m?

If yes, allocate 8 points.

This score of 8 points is usually given when areas of dense reeds/rushes are > 50% of the pond edge. This would boost the score.

Figures 3.12 – 3.16 show the scores of each pond, depending on their pond category (Type A, B, C, D or E). More analysis is required to determine which variable, if any, is the most important. However, a prediction is that the variables for reed/rush presence are the most critical. It would be interesting to test this in the Type A dams. **Figure 3.12** indicates that only two of those sites (A02 and A03 in the Botanic Garden) have reeds.

The term"pond" is used in this study to designate the freshwater sites which were sampled for Odonata, and studied in terms of recreational activities. The surface area data clearly demonstrates that "pond" is a misnomer for water bodies at the upper end of the size range. The largest site, Nøklevannet, is a lake not simply because of its volume, surface area, and freshwater biology, but because of its geological history. This is one of the vast number of lakes formed by the retreat of glaciers in the late Pleistocene (Wetzel, 1983). Even though this definition should have been defined at the beginning of this study, it is perhaps useful that this was not the starting point. Having begun with a desire to chart Odonata diversity in Oslo, I was open to all the possibilities, rather than being limited by restricting myself to sites that matched a theoretical definition.

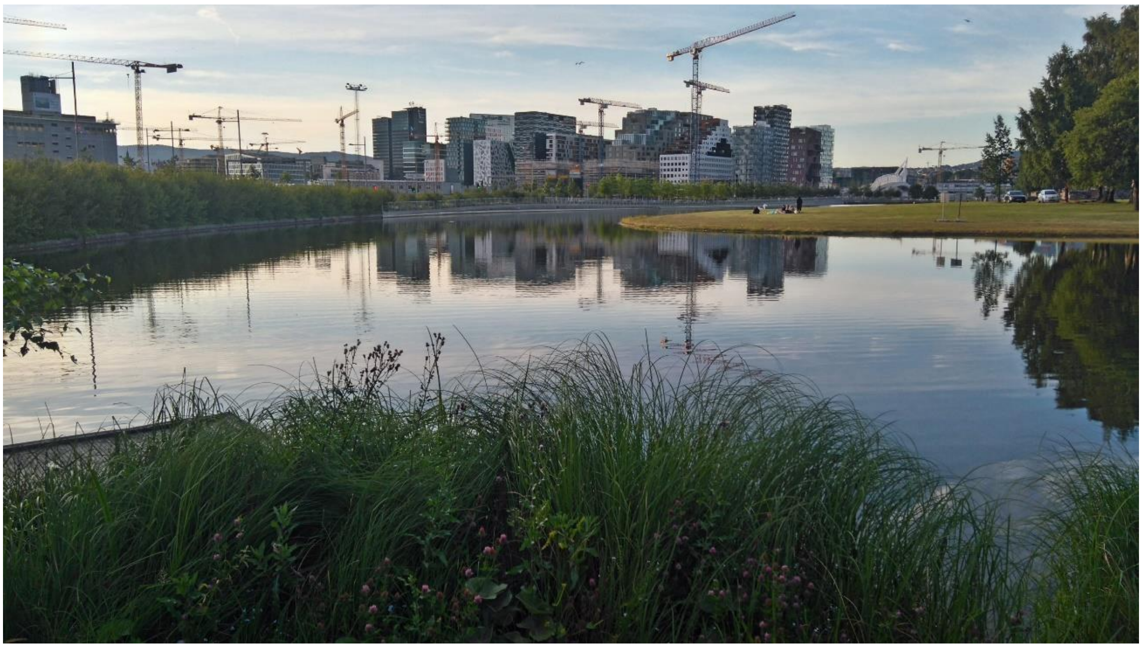


Figure 4.5 Looking north towards the Oslo city centre from Vannspeilet (B01) at Middelalderen park. This is a dragonfly breeding site despite its relatively low score on the Odonata Habitat Ecological Index.

Figure 4.6 The southern end of Vannspeilet (B01) looking southwest. The reed presence and low growing vegetation edging the water make this part of the pond an ideal dragonfly breeding habitat.

Another issue is that the presence/absence, and extent of waterfowl probably needs to be incorporated into the OHEI. The presence of waterfowl is known to be negatively correlated with Odonata (Goertzen & Suhling, 2013), and for this reason I noted their presence/absence during fieldwork.

I later considered trying to incorporate this into the OHEI, but reasoned that waterfowl are part of the human urban pond experience. Fieldwork data substantiated that ducks and geese were present at 22 sites (62.9%) (**Figure 3.22)**. Other sites, for example, St Hanshaugen (A07) and Kværnerdammen (B02), had feathers floating in the water, although these may have come from seagulls. At nine sites (26%), people were engaged in feeding ducks, and at the main pond at Tegleverket (D01), this took place next to a sign specifically requesting people not to feed the birds.

It seemed that watching, photographing, and feeding ducks is a vital part of the "nature/wildlife interaction" that city-dwellers experience. Advocating to remove this experience, even on the grounds of it reducing overall biodiversity, seems counterproductive. Including an indictor which framed waterfowl as negative, was something I wished to avoid. (I recognise this is a bias).

However, the results of the OHEI, indicate that it is probably unavoidable. Counterintuitively, these same results also suggest an appropriate way to score waterfowl presence.

Other ponds where Odonata larvae were not found to be present had a heavy presence of waterfowl. Hovindammen (B08) has an OHEI score of 51 (**Figure 3.9**). It is ranked 19 out of 35 ponds, and has a score only 1 point less than Holmendammen (B09) where Odonata samples were collected. Registrations from Artsdatabanken indicate that adults have been seen in the vicinity.

The pond seems a likely breeding habitat for Odonata, with the presence of heavy reeds at the north-eastern end (**Figure 2.9**, other angles below in **Figure 4.7** and **4.8)**. One of the difficulties with sampling this site was accessing the reed beds to take samples. Despite all attempts, I was unable to come down the steep bank, or through the bushes on the north-eastern side.

I strongly suspect Odonata are breeding there, but was unable to substantiate it. If my hypothesis that they breed there is correct, then the OHEI is probably giving a good score ie. it works. However, I was only able to test on substrates that the waterfowl were using as foraging areas. This was apparent from the amount of feathers, the trampling of vegetation, and the presence of ducks in the reeds when I sampled.

Also, as **Figure 4.8** shows, there is a heavy presence of waterfowl at Hovindammen. The grass was thick with excrement on the lawns in this area.

The OHEI needs to be calibrated for waterfowl presence primarily if it is to be used as a design tool. If waterfowl are present, they negatively impact on Odonata habitats. However, large areas of dense reeds (if pond size allows it) may mitigate this affect. I would suggest subtracting 5 points if waterfowl are present at a pond site. Designers could also be encouraged to focus on increasing reed vegetation to boost the score, and compensate for this factor.

Figure 4.7 Hovindammen (B08) looking northeast. The heavy waterfowl presence at this site appears to make it a less than ideal Odonata habitat. Adults have been sighted here according to Artsdatabanken.

Figure 4.8 Hovindammen (B08) looking south toward the pond. Heavy waterfowl presence on the grass.

Grorudparken (D05), shown in **Figure 4.9,** scores 48 points on the OHEI. No Odonata samples were obtained. There is also a heavy presence of waterfowl as evidenced by feathers and damaged vegetation.

The pond was re-opened in 2013, and has been designed to improve water quality and enhance biodiversity. If the OHEI were used as a tool in this design process, the score of 48 would indicate that it might be a suitable Odonata habitat, although at the lower end of the range. Removing 5 points from the score would still keep it within what appears to be an OHEI range, however, it would encourage playing with the variables to increase the score. In the case of the pond at Grorudparken, an increase in the width of the edge vegetation, and planting a dense reed bed area, would be good adjustments and support Odonata presence.

Figure 4.9 Grorudparken (D05) on the Alna river. The original dam wall dating from 1870 is visible at the far end. The dam was originally constructed to provide power for a textile factory. It was restored in 2013.

4.3.1 Assessing pH readings in the context of suitable Odonata habitat

Of particular interest for the study of urban dragonflies in Oslo are Odonata studies from the northern latitudes (Finland, Canada and Sweden) which indicate the lower tolerances of some species. Corbet (1999) notes that a pH of 4.2 – 4.6 is the lower limit for healthy aquatic ecosystems, citing a study by Gorham et al. (1984). Nonetheless, *Libellula quadrimaculata*, *Lestes sponsa*, *Pyrrhosoma nymphula*, and *Enallagma cyathigerum* may be able to tolerate levels of between 3 and 4 (Corbet, 1999). Upper tolerance levels of pH 8.0 have been recorded for *E. najas*, *C. boltonni*, *S metallica* in the estuarine waters of the Gulf of Bothnia, Sweden (Corbet, 1999).

Furthermore, Oslo contains small ponds lined with sphagnum (**Figure 4.10**), an indicator of an acidic ecosystem. These are potential urban breeding ponds for a species like *Somatochlora arctica* which typically inhabits such ecosytems.

Figure 4.10 Sphagnum moss lines the edge of Lillevann (site E05) in urban Oslo. This is indicative of an acidic ecosystem, and potentially a habitat for several threatened species of Odonata.

Corbet (1999) provides a detailed discussion of why pH, alone, is insufficient for measuring the ecological quality of water bodies. Quite simply, it can be affected by precipitation (becoming more acidic after rain) or season; and different dragonfly species have different tolerances.

Nonetheless, pH is a valuable descriptive indicator of water in an urban environment. This is particularly relevant as eutrophication can be an issue due to management practices regarding use of fertilizer, if the pond is situated in a park, or adjoining a golf course or other turfed area (Bachman et al., 2016; King et al., 2012). Excrement from waterfowl, birds such as ducks and geese, will also add nutrients to the water, making it more eutrophic, and increasing the pH level so that the water becomes more alkaline (Jimenez et al., 2011; Liu et al., 2014).

Alternatively, pH levels can decrease, and the water will become more acidic if the pond or lake is collecting dead leaves or needles, especially from trees such as oaks, maples, and pines (Newman, 2013). This is relevant in Oslo, where Scots pine (*Pinus sylvestris*), common oak (*Quercus robur*), sessile oak (*Quercus petraea*), and Norway maple (*Acer platanoides*) are native, and found throughout parks, gardens, and forested recreation areas in the municipality.

Indeed, the Norway maple has been recorded as the most common tree in Oslo (Fostad & Pedersen, 1997). This ranking has been overtaken by linden trees (*Tilia spp*), but the Norway maple still makes up 18.5% of the tree stock in the city centre, and oaks 3.2% (Sjöman et al., 2012). Furthermore, the non-native, and black-listed sycamore (*Acer pseudoplatanus*) occurs in Oslo, although it comprises only 3.9% of the city trees (Sjöman et al., 2012). These statistics indicate that at least a quarter of the trees produce leaves that will increase water acidity.

Geology also impacts on the pH of soils, and subsequently on the pH of natural water bodies. Norwegian soils are derived from granites and gneiss, which are acidic in nature, and one of the reasons acid precipitation has been such a serious environmental issue in Norway in recent decades (Miljødirektoratet, 2011).

These examples indicate why pH can only contribute to an overall evaluation of the ecological quality of a pond site in Oslo, and cannot be used as a stand-alone indicator.

5. CONCLUSION

This study establishes that Odonata breed successfully in ponds in the Oslo municipality. Observations made during this study also confirm that Odonata are laying eggs in the ornamental pond below in the Botanic Garden (A02). This is excellent news in terms of the biodiversity of Odonata in Oslo. It also provides an opportunity for organisations such as the Norwegian Entomological Association and the Natural History Museum (University of Oslo) to engage with the general public, and foster enthusiasm for dragonflies, and concern for their conservation.

The Odonata Habitat Ecological Index (OHEI) is a tool that could be tested with urban planners, biologists, landscape architects, and other individuals and organisations making decisions that impact on biodiversity in ponds, and Odonata in particular. It is hoped that it is a small contribution to better decision regarding the stewardship of lentic environments, especially those in the Oslo municipality.

Ultimately, it is hoped that this study will inspire others to also answer the question: how can we design for dragonflies?

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Photographs

All photos are taken by Maritza Ilich Mauseth unless otherwise indicated.

Artsdatabanken images - Odonata

All photos are taken by Ove Bergesen.

APPENDICES

Appendix 1. – Dragonfly and damselfly (Odonata) species in Norway

	Species	Norwegian name - Artsdatabanken (July 2018)	Norwegian name (Older versions*)
	Zygoptera - Damselflies		
1	*Calopteryx splendens*	Båndpraktvannymfe	Blåbandvannymfe
2	*Calopteryx virgo*	Blåpraktvannymfe	Blåvingevannymfe
3	*Lestes dryas*	Sørmetallvannymfe	Sørlig metallvannymfe
4	*Lestes sponsa*	Nord metallvannymfe	Vanlig metallvannymfe
5	*Platycnemis pennipes*	Fjærbeinvannymfe	Elvevannnymfe
6	*Coenagrion armatum*	Klypeblåvannymfe	Armert blåvannymfe
7	*Coenagrion hastulatum*	Spydblåvannymfe	Vanlig blåvannymfe
8	*Coenagrion johanssoni*	Nordblåvannymfe	Nordisk blåvannymfe
9	*Coenagrion lunulatum*	Måneblåvannymfe	Måneblåvannymfe
10	*Coenagrion puella*	Sørblåvannymfe	Sørlig blåvannymfe
11	*Coenagrion pulchellum*	Fagerblåvannymfe	Variabel blåvannymfe
12	*Erythromma najas*	Rødøyevannymfe	Rødøyevannymfe
13	*Pyrrhosoma nymphula*	Rødvannymfe	Rød vannymfe
14	*Enallagma cyathigerum*	Innsjøvannymfe	Stor blåvannymfe
15	*Ischnura elegans*	Kystvannymfe	Kystvannymfe
16	*Ischnura pumilio*	Pyttvannymfe - new species in Norway	N/A
	Nehalennia speciosa	Listed on Artsdatabanken site	
	Anisoptera - Dragonflies		
17	*Aeshna caerulea*	Fjellibelle	Fjelløyenstikker
18	*Aeshna cyanea*	Blågrønnlibelle	Blågrønn øyenstikker
19	*Aeshna grandis*	Brunlibelle	Brun øyenstikker
	Aeshna isoceles	Listed on Artsdatabanken site	
20	*Aeshna juncea*	Starrlibelle	Vanlig øyenstikker
21	*Aeshna mixta*	Septemberlibelle	Høstøyenstikker
22	*Aeshna serrata*	Takrørlibelle	Takrørøyenstikker
23	*Aeshna subarctica*	Torvmoselibelle	Torvmosaikkøyenstikker
	Aeshna viridis	Listed on Artsdatabanken site	
24	*Anax ephippiger*	Vandrekeiserlibelle	Trekkøyenstikker
50	*Anax imperator*	Storkeiserlibelle - new species in Norway	N/A
25	*Brachytron pratense*	Vårlibelle	Vårøyenstikker
26	*Gomphus vulgatissimus*	Klubbeelvelibelle	Klubbeelveøyenstikker
27	*Onychogomphus forcipatus*	Tangeelvelibelle	Tangøyenstikker
	Ophiogomphus cecilia	Listed on Artsdatabanken site	
28	*Cordulegaster boltoni*	Kongelibelle	Kongeøyenstikker
29	*Cordulia aenea*	Smaragdlibelle	Smaragdøyenstikker
30	*Epitheca bimaculata*	Toflekklibelle	Toflekketøyenstikker
31	*Somatochlora alpestris*	Fjellmetallibelle	Fjellmetalløyenstikker
32	*Somatochlora arctica*	Myrmetallibelle	Myrmetalløyenstikker
33	*Somatochlora flavomaculata*	Gulflekkmetallibelle	Gulflekketmetalløyenstikker
34	*Somatochlora metallica*	Glansmetallibelle	Vanlig metalløyenstikker
35	*Somatochlora sahlbergi*	Tundrametallibelle	Nordlig metalløyenstikker
36	*Libellula depressa*	Blåbredlibelle	Bred blålibelle
	Libellula fulva	Listed on Artsdatabanken site	
37	*Libellula quadrimaculata*	Firflekkbredlibelle	Fireflekklibelle
38	*Orthetrum cancellatum*	Storblålibelle	Stor blålibelle
39	*Sympetrum danae*	Svarthøstlibelle	Svart høstlibelle
40	*Sympetrum flaveolum*	Gulvingehøstlibelle	Gulvinget høstlibelle
41	*Sympetrum nigrescens*	Vestlig høstlibelle	Vestlig høstlibelle
42	*Sympetrum sanguinem*	Blodhøstlibelle	Blodrød høstlibelle
43	*Sympetrum striolatum*	Senhøstlibelle	Rødbrun høstlibelle
44	*Sympetrum vulgatum*	Sørhøstlibelle	Sørlig høstlibelle
45	*Leucorrhinia albifrons*	Grå torvlibelle	Grå torvlibelle
46	*Leucorrhinia caudalis*	Vannliljetorvlibelle	Vannliljetorvlibelle
47	*Leucorrhinia dubia*	Småtorvlibelle	Liten torvlibelle
48	*Leucorrhinia pectoralis*	Gulflekktorvlibelle	Stor torvlibelle
49	*Leucorrhinia rubicunda*	Østtorvlibelle	Østlig torvlibelle

According to the Norwegian Biodiversity Information Centre (Artsdatabanken) there are 50 species registered (breeding) in Norway as at July 2018. Their overview lists 55 species which includes migrant species.

https://www.biodiversity.no/Pages/236150

Appendix 2. – Sites by pond type

The list of study sites grouped into pond types, and the altitude of each site.

Type	Pond type	Description	Sites		Altitude (metres)
A	Ornamental	Ornamental ponds within parks, or residential areas, most of which have concrete edges. Some sites are drained in winter, others have a weekly drainage regime. They all have pump systems, and are disconnected from the local network of streams. Altitude range: 6 – 76 metres.	A01	Spikersuppa	6
			A02	UiO - øvre dam	16
			A03	UiO - Fjellhagen	25
			A04	Dronningdammen	27
			A05	Kongespeilet	28
			A06	Slottsdammen	31
			A07	St. Hans-Haugen	52
			A08	Kampen	76
B	Natural (landscaping)	The ponds are located on the network of city streams. They exist within a managed landscape such as a public park, residential area, or private garden. The ponds mostly have vegetation such as rushes, reeds, and floating macrophytes, or it may be a concrete basin. Altitude range: 21 – 182 metres	B01	Vannspeilet	4
			B02	Kværnerdammen	21
			B03	Bygdø Kongsgård	24
			B04	Frogner - nord	34
			B05	Frogner - sør	29
			B06	Smestad - øvre	56
			B07	Smestad - nedre	46
			B08	Hovindammen	88
			B09	Holmendammen	113
			B10	Andersendammen	121
			B11	Ekeberg friområde	129
			B12	Årvoll badedam	182
C	Natural	The ponds are on the network of streams. They may be fenced, but the landscape is not managed. Vegetation includes rushes, reeds, and floating macrophytes. Altitude range: 109 – 185 metres.	C01	Østensjøvannet	109
			C02	Kastellterrassen	143
			C03	Bjerke travbane	154
			C04	Brannfjell	185
D	Restored	The ponds are natural or artificial basins on the stream network. These sites have been developed with the intention of improving their ecological and chemical quality. Altitude range: 77 – 169 metres.	D01	Tegl 1 - Hoved	77
			D02	Tegl 2 - Grense	77
			D03	Tegl 3 - Tennis	79
			D04	Bjerkedalen	121
			D05	Grorudparken	169
E	Forest	The lake is situated within the forest fringes of Oslo. It feeds into the network of streams that connect with the primary watercourses in the Oslo watershed. Altitude range: 120 – 482 metres.	E01	Skraperudtjern	120
			E02	Nøklevannet	166
			E03	Vesletjern	233
			E04	Årvoll isdam	242
			E05	Lillevann	426
			E06	Øvresetertjern	482

Appendix 3. – Fieldwork survey form

The form used to conduct fieldwork in July and August 2018.

Masteroppgave – vann, øyenstikker og mennesker i byen

Site observations – variables

Norges miljø- og biovitenskapelige universitet

Site name: ______________________________ Site ID ________________________

Date: __________________________ Day: _________________ Week no. _____________

Temperature (outdoors): ______________ Description: ____________________

	Site 1	Site 2	Site 3
Depth			
Water temp:			
Conductivity			
pH			

Colour	Clear	Green	Brown

Water	Yes	No	Number
Waterfowl			
Ducklings			
No feeding signs			
Obvious fish?			
Other birds?			

VEGETATION / STRUCTURE	0	1	2	3
Hard edge				
Open banks				
Sand beach				
Water lillies				
Other floating macrophytes				
Rush/reed				
Dense reed				
Low growing veg				
Trees shadowing water				
0 = absent 1 = a few 2 = 50/50 3 = dominant				

INSECTS	Yes	No
Dragonflies		
Bumblebees		
Beetles (water)		
Beetles (ground)		
Other insects		

Dragonflies	Yes	No
Flying		
Perching		
Species:		

	Western	Non-western	Total
Sitting alone			
Sitting with person			
Walking - solitary			
Walking with others			
Sunbathing			
Picnic/BBQ			
Running past			
Cycling past			
Other exercise			
Walking dog			
Other activity			

Interaction with water	Western	Non-western	Total
Looking			
Feeding ducks			
Poking with stick			
Skimming stones			
Boats			
Splashing			
Other			

Is there a playground on site?	Yes / No
Other attraction?	
Benches / Seating?	Yes / No

Appendix 4. – Surface area of study sites

The area of each water body was extracted from the FKB-vann maps which are available as publicly accessible geospatial data from the Norwegian Mapping Authority (Kartverket, 2017a).

Table A – Pond sites ranged according to surface area

Study site	Area (sq metres)	OHEI score
UiO - Fjellhagen (A02)	141	40
UiO - øvre dam (A03)	169	48
Tegl 3 - Tennis (D03)	530	42
Kværnerdammen (B02)	675	21
Bjerke travbane (C03)	719	66
St. Hans-Haugen (A07)	825	25
Ekeberg friområde (B11)	856	67
Kampen (A08)	896	12
Kastellterrassen (C02)	975	59
Tegl 2 - Grense (D02)	1031	38
Spikersuppa (A01)	1177	18
Slottsdammen (A06)	1180	35
Brannfjell (C04)	1472	67
Kongespeilet (A05)	1565	31
Andersendammen (B10)	1609	70
Bjerkedalen (D04)	1635	56
Dronningdammen (A04)	2073	28
Grorudparken (D05)	2301	48
Bygdø Kongsgård (B03)	2505	71
Årvoll badedam (B12)	4671	17
Tegl 1 - Hoved (D01)	5977	42
Årvoll isdam (E04)	6152	47
Hovindammen (B08)	6834	51
Smestad - nedre (B07)	7436	70
Lillevann (E05)	8860	74
Frogner - nord (B04)	11564	40
Frogner - sør (B05)	11699	35
Smestad - øvre (B06)	12378	58
Holmendammen (B09)	21941	53
Vannspeilet (B01)	24109	34
Vesletjern (E03)	28245	59
Øvresetertjern (E06)	29595	76
Skraperudtjern (E01)	41834	78
Østensjøvannet (C01)	343304	61
Nøklevannet (E02)	762940	69

Table B – Pond sites ranged according to the OHEI

Study site	Area (sq metres)	OHEI score
Kampen (A08)	896	12
Årvoll badedam (B12)	4671	17
Spikersuppa (A01)	1177	18
Kværnerdammen (B02)	675	21
St. Hans-Haugen (A07)	825	25
Dronningdammen (A04)	2073	28
Kongespeilet (A05)	1565	31
Vannspeilet (B01)	24109	34
Slottsdammen (A06)	1180	35
Frogner - sør (B05)	11699	35
Tegl 2 - Grense (D02)	1031	38
UiO - Fjellhagen (A02)	141	40
Frogner - nord (B04)	11564	40
Tegl 3 - Tennis (D03)	530	42
Tegl 1 - Hoved (D01)	5977	42
Årvoll isdam (E04)	6152	47
UiO - øvre dam (A03)	169	48
Grorudparken (D05)	2301	48
Hovindammen (B08)	6834	51
Holmendammen (B09)	21941	53
Bjerkedalen (D04)	1635	56
Smestad - øvre (B06)	12378	58
Kastellterrassen (C02)	975	59
Vesletjern (E03)	28245	59
Østensjøvannet (C01)	343304	61
Bjerke travbane (C03)	719	66
Ekeberg friområde (B11)	856	67
Brannfjell (C04)	1472	67
Nøklevannet (E02)	762940	69
Andersendammen (B10)	1609	70
Smestad - nedre (B07)	7436	70
Bygdø Kongsgård (B03)	2505	71
Lillevann (E05)	8860	74
Øvresetertjern (E06)	29595	76
Skraperudtjern (E01)	41834	78

Appendix 5. – Shannon-Wiener index

Calculations for evaluating the Shannon-Wiener index for Odonata diversity (study sites) and Odonata diversity (Artsdatabanken registristrations).

Shannon-Wiener - Odonata larvae samples in Oslo (July and August 2017)				
Species	**Number**	pi	ln(pi)	pi*ln(pi)
Lestes sponsa	4	0,067	-2,703	-0,180
Coenagrion hastulatum	1	0,017	-4,074	-0,068
Coenagrion puella/pulchellum	2	0,033	-3,411	-0,114
Erythromma najas	1	0,017	-4,074	-0,068
Aeshna cyanea	12	0,200	-1,609	-0,322
Aeshna grandis	5	0,083	-2,488	-0,207
Aeshna juncea	13	0,217	-1,527	-0,331
Aeshna mixta	6	0,100	-2,302	-0,230
Cordulia aenea	4	0,067	-2,703	-0,180
Somatochlora metallica	3	0,050	-2,995	-0,150
Sympetrum danae	1	0,017	-4,074	-0,068
Sympetrum flaveolum	2	0,033	-3,411	-0,114
Sympetrum sanguinem	6	0,100	-2,302	-0,230
Total	**60**	**1,00**		**-2,262**

H = 2,262
Shannon Diversity Index (H) = 2,262
Evenness = 0,88

ln(N) = ln(Number of species) = ln (13) = 2,5649
Hmax = 2,565

Evenness = 2,262/2,565 = 0,8818

Shannon-Wiener diversity index

$$H = -\sum_{i=1}^{S} (p_i)(\ln p_i)$$

where H = index of species diversity
S = number of species
p_i = proportion of total sample belonging to *i* the species

Shannon-Wiener - Artsdatabanken Odonata registrations (Oslo)				
Species	**Number**	pi = sample/sum	ln(pi)	pi*ln(pi)
Aeshna caerulea	1	0,000523834	-7,554334824	-0,003957221
Coenagrion armatum	4	0,002095338	-6,168040463	-0,012924129
Sympetrum flaveolum	4	0,002095338	-6,168040463	-0,012924129
Ischnura elegans	6	0,003143007	-5,762575354	-0,018111814
*Libellula depressa***	6	0,003143007	-5,762575354	-0,018111814
Aeshna mixta	7	0,003666841	-5,608424675	-0,020565203
Somatochlora arctica	12	0,006286014	-5,069428174	-0,031866495
Leucorrhinia rubicunda	13	0,006809848	-4,989385466	-0,033976957
Aeshna subarctica	15	0,007857517	-4,846284623	-0,038079764
Coenagrion puella	1	0,000523834	-7,554334824	-0,003957221
Coenagrion pulchellum	15	0,007857517	-4,846284623	-0,038079764
*Onychogomphus forcipatus****	16	0,008381351	-4,781746101	-0,040077495
*Sympetrum sanguinem***	25	0,013095862	-4,335458999	-0,056776571
Coenagrion johanssoni	37	0,019381875	-3,943416911	-0,076430815
Erythromma najas	42	0,022001048	-3,816665205	-0,083970633
Somatochlora metallica	42	0,022001048	-3,816665205	-0,083970633
Pyrrhosoma nymphula	57	0,029858565	-3,511283556	-0,104841887
Cordulegaster boltonii	61	0,031953903	-3,44346096	-0,110032016
*Sympetrum vulgatum**	71	0,037192247	-3,291654947	-0,122424045
Calopteryx virgo	75	0,039287585	-3,23684671	-0,127167891
Leucorrhinia dubia	80	0,041906757	-3,172308189	-0,13294115
Cordulia aenea	82	0,042954426	-3,147615576	-0,135204022
Libellula quadrimaculata	88	0,046097433	-3,076998009	-0,14184171
Sympetrum striolatum	104	0,054478785	-2,909943925	-0,158530209
Enallagma cyathigerum	115	0,060240964	-2,809402695	-0,169241126
Aeshna cyanea	119	0,062336302	-2,775211331	-0,172996411
Coenagrion hastulatum	127	0,066526977	-2,710147737	-0,180297937
Lestes sponsa	128	0,067050812	-2,70230456	-0,181191715
Aeshna juncea	171	0,089575694	-2,412671267	-0,216116703
Aeshna grandis	185	0,096909377	-2,333978999	-0,22618445
Sympetrum danae	200	0,104766894	-2,256017457	-0,236355941
Total	**1909**	**1**		**-2,989147869**

H = 2,989
Shannon Diversity Index (H) = 2,989
Evenness = 0,870

ln(N) = ln(Number of species) = ln (31) = 3,433987204
Hmax = 3,434
Evenness = 2,989/3,434 = 0,870

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