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Abstract:

Twelve wet sedimentation ponds, constructed for receiving road runoff, were sampled over a two year period from April 2013 to October 2014. Samples of benthic invertebrates, zooplankton and amphibian were taken in April, June, August and October in both years. Samples for chemical analysis were taken on these occasions. Macrophytes were assessed in August/September 2013 and additional zooplankton samples were taken in August 2016.
In general, despite high pollution levels, taxa richness in all groups was high. However, there was considerable variation in taxa richness among the twelve ponds, both within the various groups and between ponds. Overall taxa richness ranged from 67 in Hovinmoen to 128 in Nordby. Tenor and Skullerud also had high overall taxa richness. There was a non-significant trend for increasing taxa richness with the age of the ponds and Average Annual Daily Traffic (AADT).

There is a significant positive relationship between macrophyte richness and zooplankton richness. There is also a trend for increasing macroinvertebrate richness with the development of the macrophyte community, although this is not significant. However, there is a significant negative relationship between taxa richness in Odonata and in Ephemeroptera as the macrophyte community develops.

Ten species of the recorded species, two macrophytes, one cladoceran, one gastropod, two odonates, one dysticid water beetle, two dipterans and one amphibian species, are all on the Norwegian Red-List.

Despite high pollution levels, wet sedimentation ponds make a positive contribution to freshwater biodiversity in a habitat that is under threat from a wide variety of impacts.

Preface

This report forms part of the research collaboration between LFI, Natural History Museum, University of Oslo and the Norwegian Public Roads Administration and their project NORWAT (Nordic Road Water). We wish to thank the Norwegian Public Roads Administration for financial funding and Sondre Meland for constructive comments and advice throughout the project. Thanks also go to Ole Wiggo Røstad, Norwegian University of Life Sciences, for identifying Dytiscidae (Coleoptera).

Oslo, March 2017

Svein Jakob Saltveit

Content

1. Introduction

In northern Europe there has been a major decline in natural and semi-natural ponds over several decades, as a result of industrial and agricultural development (Boothby 2003; Hull 1997; Zacharias & Zamparas 2010). In comparison to terrestrial habitats, freshwater habitats suffer greater biodiversity decline due to various stressors, such as habitat loss, habitat degradation and pollution (Burroni et al., 2011; Hassall, 2014). Pollution from road traffic and road maintenance has been an increasing concern over the last 10-20 years. In an attempt to mitigate the effects of such road pollution and meet the demands in the European Water Framework Directive, wet sedimentation ponds or retention ponds have been constructed alongside heavily trafficated highways to treat road runoff and prevent pollutants reaching natural rivers and lakes.

Road runoff contains a wide range of pollutants from traffic, from the road itself and from road maintenance (Lindgren 1996; Sternbeck et al. 2002; Brown & Peake 2006; Amundsen 2010). Variation in runoff from roads is mostly dependent on the size of the runoff area, variation in weather, annual average daily traffic (AADT), driving speed, proportion of heavy vehicles and numbers of vehicles with studded tyres during the winter season. Road pollution from impervious surfaces is washed into the adjoining terrain by rain or snowmelt episodes (Hvitved-Jacobsen et al. 2010). Pollutants include degraded products from tyres and brake pad wear, corrosion products from vehicle bodies and combustion products from vehicle engines. Contaminants from asphalt wear, as well as road salt used as a de-icing agent, also contribute to pollution of adjoining areas (Hvitved-Jacobsen et al. 2010). In addition, tunnel wash runoff can give rise to critical, short-term pollution and usually has higher concentrations of pollutants as accumulation occurs between each wash.

Elevated levels of metals, particularly lead, copper and zinc affect and accumulate in benthic macroinvertebrates (Timmerman 1991; Karouna-Renier & Sparling 2001; Beasley & Kneale 2002; Du et al. 2012). Pollutant accumulation can occur through the food chain, and can have lethal effects on organisms receiving concentrations of pollutants at high doses (Karouna-Renier & Sparling 2001). Beasley and Kneale (2002) found that numbers and diversity of benthic macroinvertebrates declined when the catchment area was exposed to more traffic, while Gallagher et al (2011) found that the top sediment layer of sedimentation ponds usually gave rise to toxic effects on the benthic fauna that utilize this layer. Chemical pollutants also have lethal and sublethal effects on aquatic organisms via the physiological and behavioural processes (Foltz and Dodson 2009). Accumulation of metals and organic pollutants in the sediments may have long-term adverse effects on aquatic organisms (Grung et al., 2016) and it has been shown that metals and PAHs are easily accumulated in aquatic organisms (Meland et al. 2010; Grung et al. 2016).

In most countries, blue-green solutions such as engineered sedimentation ponds and wetlands are the preferred mitigation measure for protecting receiving waters both from peak runoff volumes and elevated pollution loadings and concentrations (Meland 2010; 2016). In addition to pollution, roads and the construction of them may disturb or even destroy aquatic habitats physically. Disruption of connectivity by roads may also negatively affect the dispersal of plants and animals (Forman et al. 2003).

The question has been raised, if such ponds have the potential to provide suitable habitat for birds, amphibians, aquatic invertebrates and maybe fish, and consequently contribute to the maintenance of biodiversity, lost through road construction and the filling in of farm ponds (Le Viol et al. 2009). Due to a range of functions provided by sedimentation ponds, aquatic biodiversity in ponds can be determined by various factors. Some studies found that pond density, potentially due to higher connectivity between ponds, is a major variable that determines aquatic macroinvertebrate richness (Gledhill et al. 2008; Staddon et al. 2010; Hassall 2014). Plant cover is another factor that influences the distribution of aquatic invertebrates by, for instance, affecting predation and food availability (De Szalay and Resh 2000). The richness and density of aquatic macroinvertebrates in ponds with vegetated areas has been shown to be significantly greater than in ponds lacking vegetation (Hsu et al., 2011). Pond size may also affect aquatic biodiversity, larger ponds tending to contain more species, notably among the Odonata (Oertli et al. 2002).

McCarthy & Lathrop (2011) advocated that road engineers should consider sedimentation ponds not only for their function of retaining pollutants, but also for their potential role in increasing biodiversity in human-dominated landscapes. However, there is limited knowledge concerning the biodiversity of a range of floral and faunal groups in wet sedimentation ponds and whether they indeed promote biodiversity (Scher & Thiery 2005; Le Viol et al. 2009). Thus, the aim of the present study has been to document biodiversity in aquatic macrophytes, zooplankton, benthic macroinvertebrates and amphibians in wet sedimentation ponds and elucidate the factors determining biodiversity. We hypothesise that water quality, traffic density, the age and vegetation development of the ponds, their size and proximity to other pond/water bodies are among the factors determining biodiversity.

This report is concerned primarily with documentation of the variation in biological diversity among the wet sedimentation ponds and the relationship between the different groups of study organisms, macrophytes, zooplankton, benthic macroinvertebrates and amphibians. The relationship between biodiversity and water chemistry, both natural variation and pollutant inputs has been the subject of earlier studies (Thygesen 2013; Sun et al. submitted), as well as in subsequent analyses.

2. Materials and Methods

2.1 Wet sedimentation ponds

Several methods have been developed to reduce the contamination of rivers and lakes by road runoff), including constructed wetlands, infiltration basins, sand filters, vegetated channels and wet sedimentation ponds (Hvitved-Jacobsen et al. 2010). Wet sedimentation ponds (WSPs) are designed with a permanent volume of water and room for additional volume for temporary storage. They temporarily store road runoff from rainfall events or snowmelt to avoid direct runoff into the groundwater or downstream lakes and rivers. They also prevent spillage from accidents coming into adjacent watercourses (Scher & Thiery 2005). A few years after construction the wet sedimentation ponds will have the appearance of a natural pond, although this depends on the substrate, the degree of filling and the extent of seeding with aquatic plants. The retention time should be sufficient to allow for sedimentation of particle bound pollutants. In addition, some of the soluble pollutants are assimilated in production processes including the growth of macrophytes (Hvitved-Jacobsen et al. 2010).

Wet sedimentation ponds are mostly built with two separate basins, either entirely or partially separated. The first basin is a slam basin, where the larger particles settle. This first or inlet basin should be emptied more often than the main basin, because of the size of the particles that settle here and the small size of basin (Åstebøl et al. 2010). Smaller particles will settle in the main basin (Fig. 1).

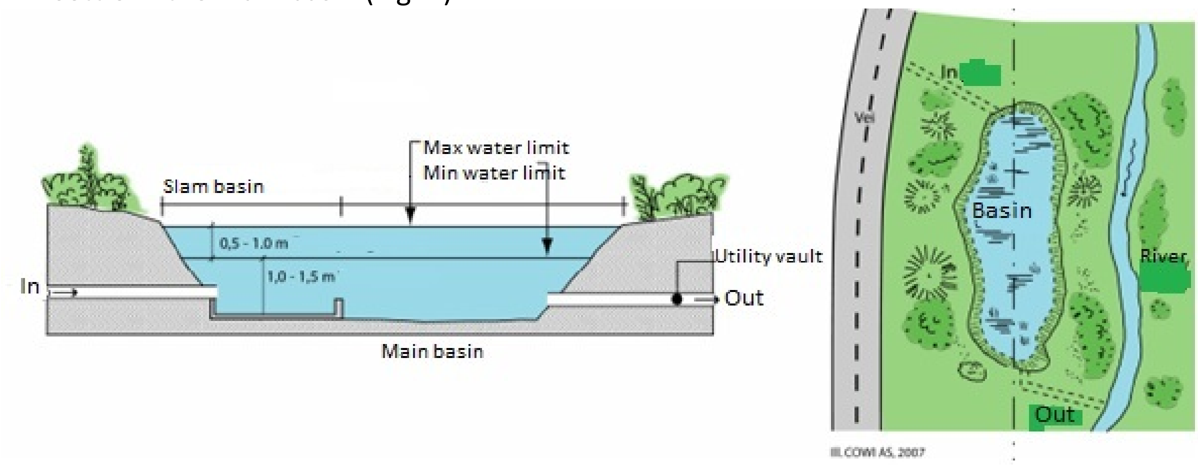


Fig. 1. Conceptual illustration of a wet sedimentation pond, both in cross-section and from above. Modified from Sundby (1995) and Åstebøl et al. (2010).

2.2 Site descriptions

Twelve wet sedimentation ponds were investigated in the present study (Table 1), 8 previously studied by Thygesen (2013). Four new ponds were studied in order to increase the geographical range of ponds and to include an urban pond, Fornebu. The new ponds also increased the range of pond age by including two ponds constructed in 2007-2008.

Apart from the single urban pond, the WSPs investigated are located along the major highways, E6 and E18, in the counties of Oslo, Akershus and Østfold (Fig. 2).

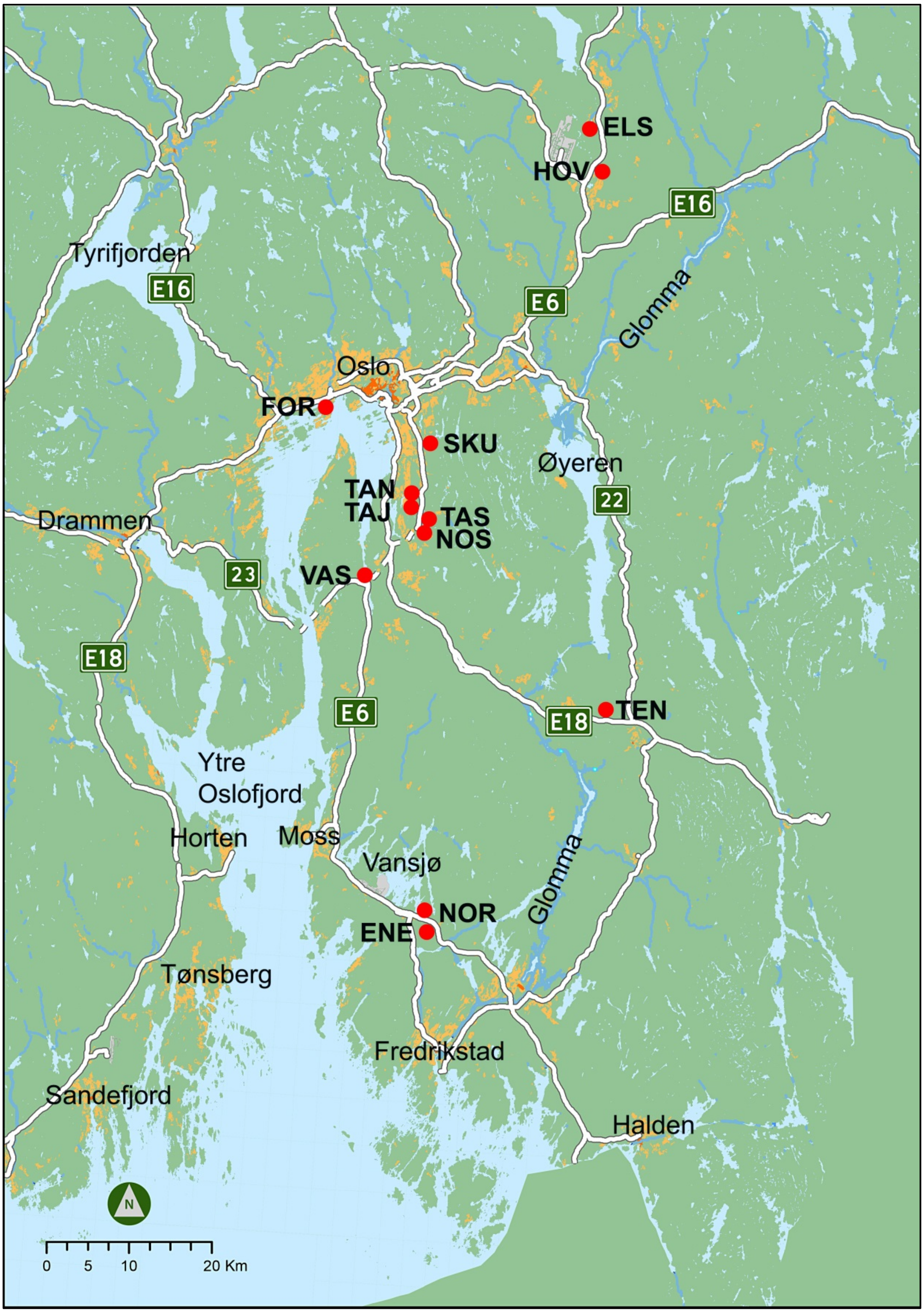


Fig. 2. Overview of the location of all the wet sedimentation ponds in this study (Source: Norwegian Public Roads Administration).

Table 1. Basic data on the wet sedimentation ponds (Kartverket ; NPRA 2011; Winter-Larsen 2010). AADT – annual average daily traffic.

Wet sedimentation pond	Construction year	Area (m^2)	AADT	Ponds within 1km	Coordinates UTM 32
Skullerud (SKU)	1998-1999	slam pool 68; main pool 68	66 500	980m to pond on E. side of E6	E:602567 N:6637508
Taraldrud North (TAN)	2004	780	42 900	450m to Snipetjern, 780m to pond, 960m to Elgrudstjern	E:603188 N:6631641
Taraldrud Junction (TAJ)	2004	1400	42 200	120m, 450m and 560m to ponds, 590m to Snipetjern, 475m to Assuren	E:603290 N:663194
Taraldrud South (TAS)	2004	474	42 200	270m to Assuren, 765m to pond, 650m to Grytetjernet	E:603294 N:6628791
Nøstvedt (NOS)	2009	slam pool 40; main pool 340	35 500	720m to Snipetejrn, 993m to pond	E:602920 N:6627376
Vassum (VAS)	2000	Slam pool 68; main pool 363	41 000	875m to Årungen, 670m, 750m and 890m to ponds	E:603188 N:6631641
Nordby (NOR)	2004-2005	Road slam pool 89; agricultural slam pool 143; main pool 389	22 735	5 ponds 600-890m. 880m to Vannsjø. 960m to WSP	E:607947 N:6580874
Enebekk (ENE)	2004-2005	Slam pool 132	23 837	4 ponds 587-1 km distant	E:609719 N:6579378
Tenor (TEN)	2007	Slam pool 175; main pool 480	12 000	56m and 340m to ponds	E:627762 N:6606543
Fornebu (FOR)	2002	Slam pool 145; main pool 480	25 000	203m, 230m and 452m to ponds	E:590955 N:6641521
Hovinmoen (HOV)	2007-2008	Slam pool 411; main pool 422	19 000	300-470m to 4 ponds; 257m to Bonntjern; 490m to Svenskersutjern	E:620290 N:6672959
Elstadmoen (ELS)	2007-2008	Slam pool 717; main pool 741	19 000	435 m to pond; 930m to Sandtjern	E:621103 N:6676671

2.2.1 *Skullerud*

Skullerud WSP was built simultaneously with rebuilding E6 into a four lane highway, and is situated directly underneath the E6, in Oslo (Figs 2, 5). The WSP was built to protect biological diversity and recreational values of the river Ljanselva from polluted runoff from the E6. The pond is divided into a closed pre-slam basin, and an open main basin (Fig. 3) (Åstebøl et al. 2010). The functioning of the Skullerud WSP is in line with the best international experiences with the cleaning effects of wet sedimentation ponds (Åstebøl et al. 2004). Skullerud is the only sedimentation pond with a fish population due to stream inflows during flooding from the adjacent river, Ljansleva.

Fig. 3. Skullerud WSP in February and June 2014. Photos: Henning Pavels.

2.2.2 *Taraldrud North*

This WSP is located on the west side of the four lane highway, E6, near the border of Oslo and Akershus (Fig. 5). It was built when the E6 was extended from Assurtjern, to the Oslo city border (Winter-Larsen 2010). It consists of a small slam basin and a larger main basin without complete separation (Fig. 4). This WSP was built to protect the stream, Snipetjern-bekken, which drains into the lake, Gjersjøen (Winter-Larsen 2010).

Fig. 4. Taraldrud North WSP pond in February and June 2013. Photos: Henning Pavels.

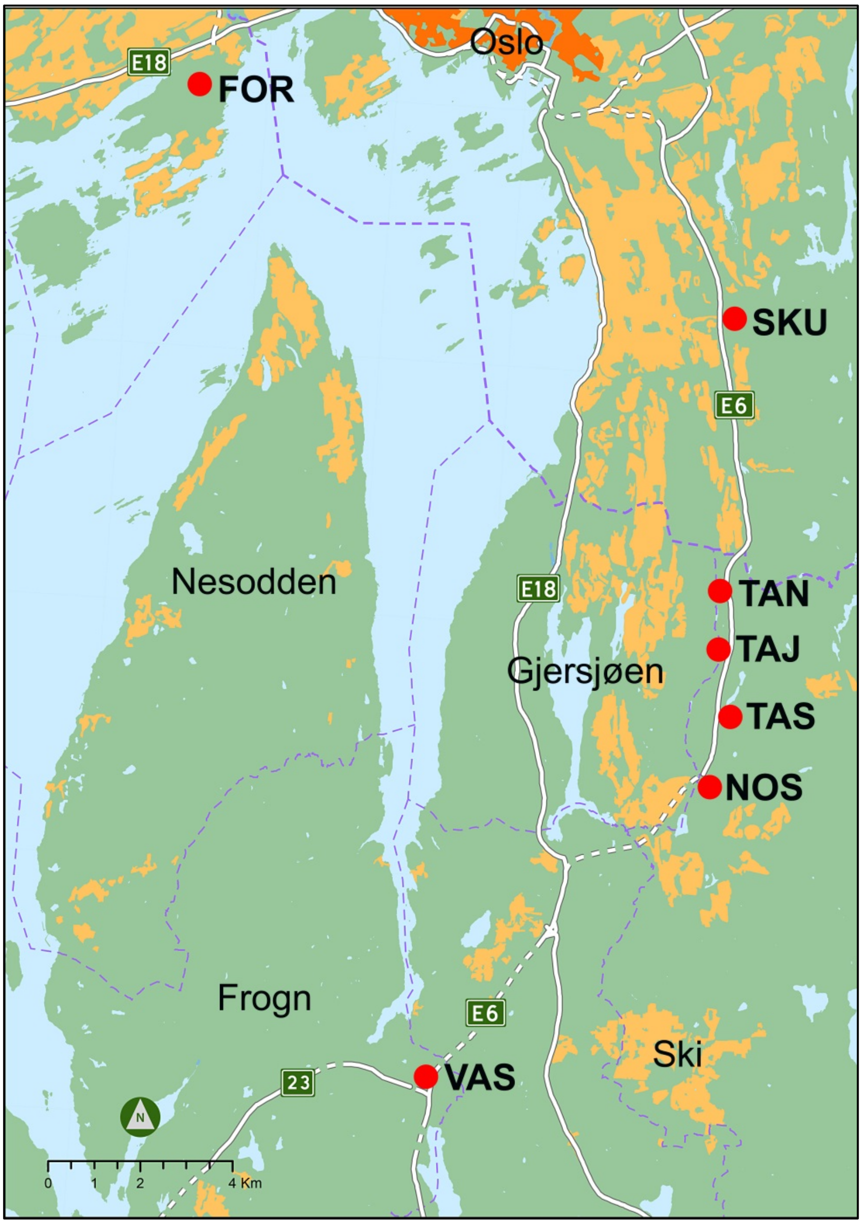


Fig. 5. Location of wet sedimentation ponds along the E6 and E18 in Oslo and Akershus and in the new urban development at Fornebu (Source: Norwegian Public Roads Administration).

2.2.3 *Taraldrud Junction*

This WSP was built at the same time and has the same construction as Taraldrud North, with coherent slam basin and a larger main basin with a shared water surface (Fig. 6). Outflow from the WSP are led into a small stream, Snipetjernbekken, which eventually discharges into the lake, Gjersjøen (Fig. 5).

Fig. 6. Taraldrud Junction WSP pond in February 2013 and August 2014. Photo: Henning Pavels.

2.2.4 *Taraldrud South*

Taraldrud South has a small slam basin which is not fully casted, although the main basin is casted (Fig. 7). It discharges into a small stream, Assurbekken, which flows into the lake, Gjersjøen (Fig. 5). The substrate of the small slam basin consists of small stones.

Fig. 7. Taraldrud South WSP in April 2013 and August 2014. Photo: Henning Pavels.

2.2.5 *Nøstvedt*

Driving in a southern direction, this WSP is located on the left side of the E6 just before the Nøstvedt tunnel (Fig. 5). The slam basin is fully casted and is connected with the main basin through pipes. Water runs from the slam basin into the main basin when the water level exceeds a certain level. In the main basin there are several thresholds that divide the basin into smaller areas where the pollutants have more time to sediment (Fig. 8) (Winter- Larsen 2010). In the main basin the substrate consists of small stones. During our study water levels were often low in the main basin, and during winter the pond froze to the bottom.

Fig. 8. Nøstvedt WSP April 2012 February 2013 and October 2014. Photo: Henning Pavels.

2.2.6 *Vassum*

Vassum WSP is located between the three tunnels, Vassum, Nordby and Smihagan (Fig. 5). It receives tunnel wash water from these three tunnels, in addition to road runoff from the E6 (Meland et al. 2010). It is constructed in two parts a concrete slam basin and a main basin of variable depth (Fig. 9). When the water level is high, the two basins have a shared water surface. It discharges into the river, Årungselva (Winter-Larsen 2010).

Fig. 9. Vassum WSP in February 2013 and October 2014. Photos: John Brittain/Henning Pavels.

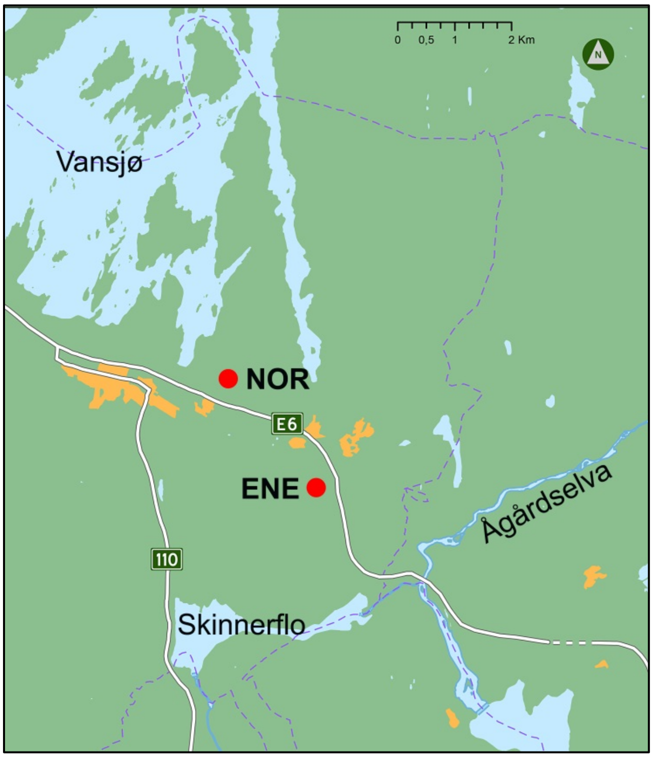


Fig. 10. Location of the wet sedimentation ponds along the E6 in Østfold County (Source: Norwegian Public Roads Administration).

2.2.7 *Nordby*

Nordby has two slam basins, one that is fully casted and receives road runoff and one which receives runoff from agriculture. These two basins drain into the same wetland filter. It is located in the middle of agricultural fields (Figs 10, 11) (Winter-Larsen 2010).

Fig. 11. Nordby WSP in February, March, August and October. Photos: Henning Pavels.

2.2.8 Enebekk

Enebekks WSP consists of a small slam basin, with drainage to a wetland filter. There is also a small stream running alongside the WSP which discharges into the wetland (Winter-Larsen 2010). The slam basin is casted in concrete (Fig. 12). It is located in an agricultural area, but surrounded by small deciduous woodland that gives considerable shade (Figs 10, 12).

Fig. 12. Enebekk WSP in April and August 2013. Photos: Henning Pavels.

2.2.9 *Tenor (Slitu)*

Tenor WSP, located along the E18 in Østfold, consists of a large divided basin and a smaller one (Figs 13, 14). The pond is adjacent to woodland on the one side and close to the motorway on the other. Trees have been planted around the pond.

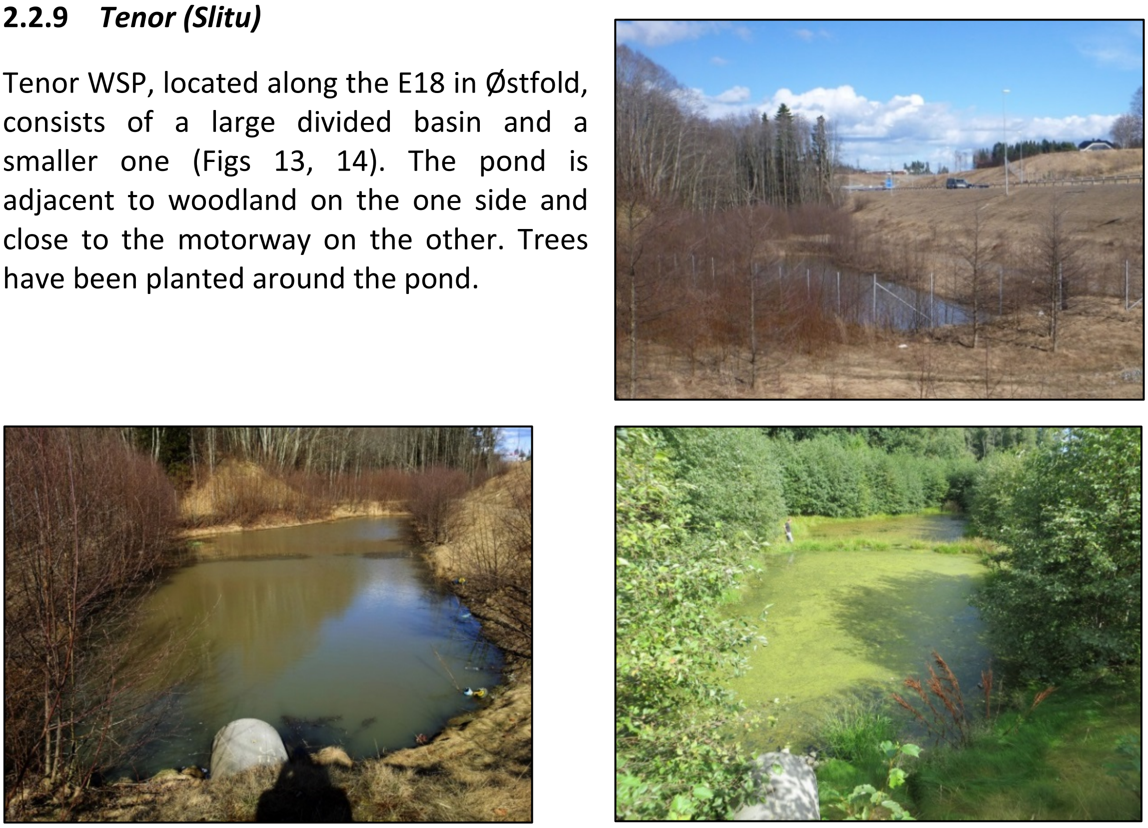


Fig. 13. Tenor WSP in April, June and October 2013. Photos: Henning Pavels.

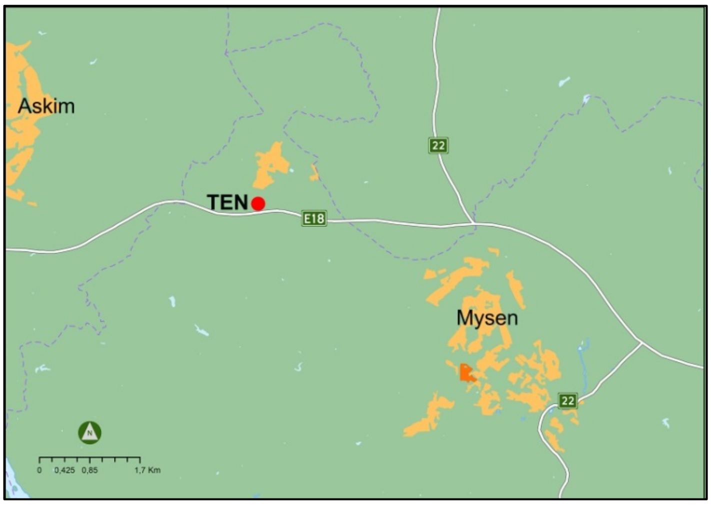


Fig. 14. Location of Tenor WSP on the E18 (Source: Norwegian Public Roads Administration).

2.2.10 *Fornebu*

Fornebu WSP is located immediately west of Oslo in an area recently developed after the closure of previous Oslo airport (Fig. 5). It is the only urban site, located at the intersection of several roads and surrounded by offices and hotels, although there are open, parkland areas between the buildings (Fig. 15).

Fig. 15. Fornebu WSP in May and October 2013. Photos: Henning Pavels.

2.2.11 *Hovinmoen*

Hovinmoen WSP is located along the E6 (north) near Gardermoen airport (Fig. 16). Hovinmoen and Elstadmoen are deeper than most of the other ponds and were constructed in 2007/2008, such that emergent macrophytes are poorly developed in both ponds (Figs 17, 18). Most of the margins and the bottom in the inlet of Hovinmoen are concrete. Hovinmoen is close to several ponds and Svenskerstutjernet Nature Reserve.

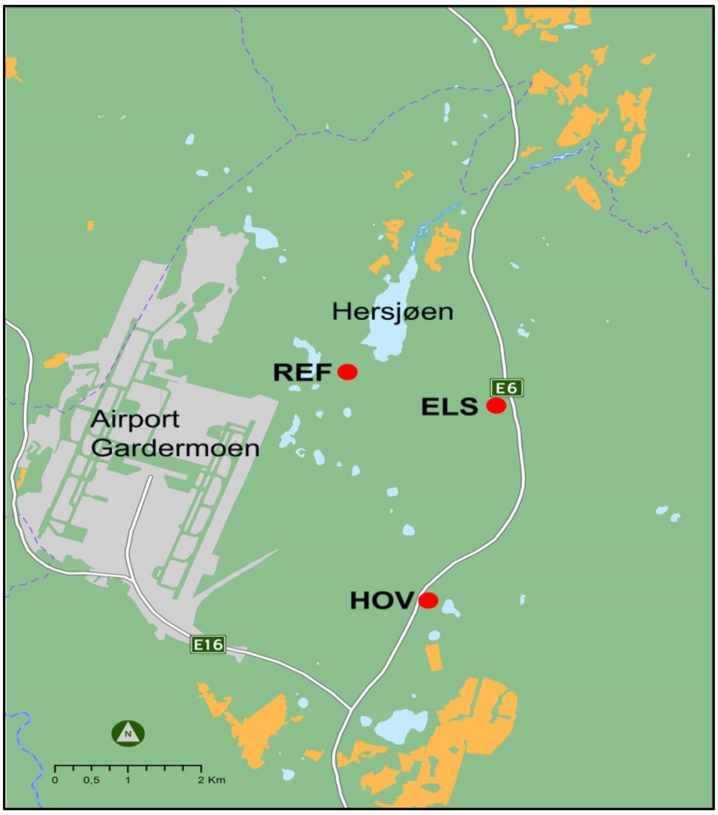


Fig. 16. Location of Elstadmoen and Hovinmoen wet sedimentation ponds on the E6 (north), and the reference pond (REF) (Source: Norwegian Public Roads Administration).

Fig. 17. Hovinmoen WSP in May and October 2013. Photos: Henning Pavels.

2.2.12 *Elstadmoen*

Elstadmoen is a large WSP, also located along the E6 (north) near Gardermoen airport (Fig. 16). It is also fairly close to Sandtjern Nature Reserve. The pond is surrounded by gravel and sand moraine material. Vegetation in the pond is still poorly developed (Fig. 18).

Fig. 18. Elstadmoen WSP in May 2013 and October 2014. Photos: Henning Pavels.

2.2.13 *Reference pond*

Two reference ponds were sampled in 2015. However, one of these ponds was found unsuitable and is not included in this report. The retained reference pond is referred to as the “old sedimentation pond” (Figs 16, 19) as it appeared to have been a sedimentation pond in the past, but not for road runoff. This pond was also not an ideal reference, but is included as it has many of the characteristics of the road wet sedimentation ponds. The pond has extensive macrophyte cover and shallow water depth.

Fig.19. The reference pond (“gamle fangdam”) in June 2016. Photo: Henning Pavels.

2.3 Sampling

The ponds were sampled in April/May, June, August and October 2013 and March/April, June, August and October 2014. The reference pond was sampled in April and October 2015. Limited physical and chemical measurements (water temperature, pH, total dissolved solids, conductivity, turbidity and dissolved oxygen) were made *in situ* using a hand-held multi-parameter water quality-probe YSI 6600 V2-4, while water and invertebrate samples were taken for subsequent analysis. Macrophytes were surveyed on 28 August and 3 September 2013, while additional zooplankton samples were taken in June 2016.

2.3.1 *Water quality*

Water samples were taken close to the inlet in all WSPs. Five bottles were used; one 125 ml acid washed polyethylene bottle for analysis of heavy metals Al, Sb, As, Ba, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, P, K, Si, Ag, Na, Sr and Zn. Two 125 ml PE- bottles were used, one for anions, chloride, nitrate and sulphate, and one for total organic carbon. Two 1L glass bottles were used one for oil analysis (hydrocarbons) and one for polycyclic aromatic hydrocarbons (PAH). The analyses were undertaken by Rambøll Analytics, Finland. The water quality data are presented and analysed in a report in Norwegian written by Stephanie Hernandez Santos, "Kjemiske karakterisering av vann og sediment fra rensebassengene i Oslo, Akershus og Østfold i forhold til prosjektet med Naturhistoriske Museum i Oslo "Biologiske mangfold i rensebassenger".

2.3.2 *Biological sampling and identification*

Most of the macrophyte species could be observed by wading. Species lists were compiled and abundance/dominance estimated on a scale 1-3: 1 < 5% cover; 2 5-50% cover and 3 > 50% cover (rare, common and abundant/dominant). Spring flowering species such as *Caltha palustris* (marsh marigold) may have been overlooked in several of the ponds.

Benthic organisms were sampled using traps and a kick net with 30x30 cm opening and mesh size of 0.45 mm. Where there were small stones on the bottom, kick sampling with five sweeps was used. When the bottom material was not covered in stones, 5 sweeps were taken through the water at approximately 50 cm depth. The samples were preserved in 70% ethanol. Sampling of organisms were carried out at three sites within each pond, close to the inlet and twice, on either side of the main basin.

Two simple traps (Thygesen, 2013) were put into the main basin at approximately the same place as the samples were taken and left in for 1-4 days, depending on the time of year. The traps were made of empty plastic bottles 1.5 L, cut in two where the bottleneck starts to form the spout. The bottleneck was turned around placing the spout inside the bottle. Transparent tape was used to attach the two parts. A string was attached to the bottle to make it easier to recover.

Zooplankton was sampled both in the kick and sweep net samples, as well as separate plankton net hauls (mesh 90 µm).

Organisms were sorted in the laboratory and identified to species level where possible. From the benthic samples microcrustaceans were picked out singly. Larger sized species (cyclopoid copepods, cladocerans > 0.8-1 mm) are included, whereas less conspicuous, smaller-sized species (e.g. small Chydoridae and Harpacticoida < 0.7-0.8 mm) are underrepresented.

A wide variety of identification literature was used to identify benthic macroinvertebrates, including Nilsson (1996, 1997). Important identification manuals included, for Cladocera Flössner (1972, 2000) and Lieder (1996), for Copepoda Sars (1913-18) and Einsle (1996), for Ostracoda Henderson (1990) and Lindholm (2014a, b, c), for Rotifers Pontin (1978) and for Chaoboridae (Nilssen 1974). Identification of adult Dytiscidae was undertaken by Ole Wiggo Røstad, NMBU, zooplankton and benthic microinvertebrates by Jens Petter Nilssen and macrophytes by Bjørn Petter Løfall, Natural History Museum, University of Oslo.

3. Results

3.1 Water quality

The results of the chemical analyses are summarized in Hernandos Santos (2014) (Appendix 1). In the water samples, copper and zinc had the highest concentrations among the metals, placing them between “moderate” and “very poor”in terms of national criteria (Klif, 2012). However metal concentrations in the sediments were classified as “background” or “good” with respect to Cd, Cr, As, Hg and Pb. The results show that the sediments have significantly higher concentrations of metals than the water, but that the pollution status of water is poorer than sediments. Concentrations of polycyclical aromatic hydrocarbons (PAH) were higher in sediment than in water. The status of PAH in water places most ponds in the “good” category, but in spring 2013 two ponds, Vassum and Nøstvedt, were classified as “very poor”.

3.2 Biodiversity

3.2.1 *Aquatic Macrophytes*

Skullerud

This is a well-established pond with rich marginal vegetation and relatively rich elodeids and nymphaeids. There are major differences between the western parts that lie underneath the motorway bridge. In these parts the vegetation is considerably poorer that the open areas. In the eastern part woodland borders the pond. A total of 24 species were recorded. Among these, *Carex pseudocyperus* is Red-Listed (NT) while the alien species, *Elodea canadensis*, is on the Black List (http://www.biodiversity.no/).

Taraldrud North

The pond has a moderately developed aquatic macrophyte community, but with rich marginal vegetation. In the pond itself *Potamogeton natans* is dominant, together with good populations of *Potamogeton berchtoldii* and *Typha latifolia*. A total of 16 species were recorded. The most interesting record, the Red-Listed species, *Carex pseudocyperus* was restricted to the inlet basin.

Taraldrud Junction

This pond has rich nymphaeid vegetation in both basins. *Potamogeton natans* was dominant, although in the main basin there are good populations of *Potamogeton berchtoldii*. Along the margins the vegetation is rich and *Carex acuta* and *Scirpus sylvaticus* dominated. In total 15 species were recorded.

Taraldrud South

The pond is developing a rich aquatic macrophyte community where *Potamogeton natans* is the dominant species, although there are also good populations of *Lemna minor*, *Potamogeton alpinus* and *Utricularia vulgaris* (in flower). In the main basin a small population of *Nuphar lutea* occurrs, strangely the only locality where this species was recorded. In total 12 species were recorded from Taraldrud South.

Nøstvedt

This pond has rich aquatic vegetation. A total of 17 species were recorded, although *Typhus latifolia* dominated both along the edge of the pond and in the basins. There were also good populations of *Lythrum salicaria* and *Alisma plantago-aquatica.*

Vassum

This pond is well covered by luxuriant and nutrient demanding aquatic and emergent vegetation. *Carex acuta* and *Phragmites australis* are the dominant species and in total 16 species were recorded.

Nordby

This pond lies in an agricultural landscape with rich aquatic and riparian vegetation. It was surprising to find *Butomus umbellatus*, a species not recorded from Østfold, an old record from Aurskog-Høland being the closest. According to Elven et al. (2013), *B. umbellatus* has poor dispersal characteristics, but it has been introduced into a few localities in southern-eastern Norway. According to plan drawing of 12.07.2014 from the Norwegian Roads Authority the following species, in addition to *Butomus umbellatus,* were planted out in the Nordby pond: *Alisma plantag- aquatica*, *, Carex rostrata, Carex vesicaria, Geum rivale, Glyceria fluitans, Iris pseudacorus, Juncus articulates, Lythrum salicaria, Trollius europaeus, Eleocharis palustris, Scirpus sylvaticus, Angelica sylvestris, Calla palustris* and *Phragmites australis.*

Nordby is the most species rich pond, with a total of 28 aquatic macrophyte species. Most of the species occur in the area, apart from *Butomus umbellatus* and *Trollius europaeus,* which are relatively rare in outer Østfold. The following planted species were not recorded in our survey: *Carex rostrata, Carex vesicaria, Geum rivale, Juncus articulates, Trollius europaeus, Eleocharis palustris and Calla palustris,* but they may still occur. The planted species that remain could in most cases have colonized naturally by making the pond attractive for water birds. Nevertheless, there are a significant proportion of natural colonisers. *Typha latifolia* and *Potamogeton berchtoldii* are not among those planted, but dominate in the pond basins. None of the species are on the Norwegian Black List (alien species) http://www.biodiversity.no/, although *Butomus umbellatus* does not occur naturally in the area.

In our analysis of the WSPs for road runoff, we have excluded the Nordby basin receiving agricultural runoff, although there was additional macrophyte diversity, bringing the total species recorded to in this pond complex to 33.

Enebekk

Despite being shaded by surrounding woodland and having a concrete bottom, this pond has a relatively well developed flora. *Typha latifolia* dominated, together with *Potamogeton natans*, *Lemna minor* and *Sparganium erectum*. *Ranunculus sceleratus* was also recorded; the sole locality for this species among the investigated ponds. A total of 14 species were recorded (Table 2).

Tenor

The pond is characterized by a moderate to rich elodeid community in which *Potamogeton natans* dominates. There are also good populations of *Potamogeton berchtoldii*, *Potamogeton alpinus* and *Lemna minor*. The margins are dominated by *Glyceria fluitans*. In Tenor, 21 species were recorded.

Fornebu

This is a well-established pond with rich vegetation along the margins and relatively rich development of elodeids and nymphaeids. 20 species were recorded in and around the pond (Table 2), with good populations of *Potamogeton natans and Potamogeton berchtoldii* in the pond itself and *Typha latifolia* along the margins.

Hovinmoen

Weeds dominate the vicinity of the pond, together with low, small bushes of *Betula pubescens*. This is most species poor pond with regard to macrophytes, with only 3 recorded species.

Elstadmoen

The aquatic and riparian vegetation are both poorly developed and the ponds edges are characterized by weeds and pioneer vegetation. *Typha latifolia* is newly established in both basins. Along the water’s edge *Juncus bufonius* was the most common species. A total of 20 species were recorded in and adjacent to the pond.

Overall macrophyte flora

Twenty-one taxa were recorded in the open water of the ponds (Table 2). The most common species were *Potamogeton natans*, *Lemna minor*, *Typha latifolia*, *Potamogeton berchtoldii* and *Alisma plantago-aquatica*. Along the edge of the ponds 57 taxa were recorded, the most common being *Carex acuta*, *Lythrum salicaria*, *Typha latifolia*, *Agrostis stolonifera*, *Epilobium ciliatum* ssp. *ciliatum* and *Glyceria fluitans*. A total of 78 taxa (including 3 taxa identified only to genus/family) were recorded in the 12 ponds. The number of species per pond varied between 3 and 28 (Fig. 20). Twelve species were only recorded from a single pond.

Table 2. Occurrence and abundance of macrophyte taxa in the WSPs (completely aquatic species) and the number of ponds they occurred (No. ponds). x rare; xx uncommon; xxx abundant; xxxx dominant.

In pond	**NOS**		**ELS**		**HOV**		**TEN**		**NOR**		**ENE**	**TAN**		**TAJ**		**TAS**		**FOR**	**VAS**		**SKU**	**No. Ponds**
	Inlet	Main	Inlet	Main	Inlet	Main	Inlet	Main	Inlet	Main		Inlet	Main	Inlet	Main	Inlet	Main	Main	Inlet	Main	Main	
Potamogeton natans							x	xxx			xx	x	xxx	xxx	xxx		xxx	xxx		xx	x	8
Lemna minor		x					xx	xx			xx					xx	x	x	x	x	x	7
Typha latifolia	xx	xxx	x	x						xx	xxx	xx			xx			xx				7
Potamogeton berchtoldii								xx		xxx		xx	xx					xx		x	xx	5
Alisma plantago aquatica		xx								xx		xx	x	xx	x							4
Potamogeton alpinus				x				xx							x	xx	xx					4
Utricularia vulgaris													x			xx	xx	xx				3
Glyceria fluitans										x											x	2
Phragmites australis		x								xx												2
Utricularia vulgaris													x					x			x	3
Juncus bulbosus												x								x		2
Schoenoplectus lacustris										xx							xx					2
Sparganium angustifolium	x																x					2
Butomus umbellatus										xx												1
Callitriche sp.																					x	1
Comarum palustre																					xxx	1
Elodea canadensis																					xx	1
Nuphar lutea																	x					1
Persicaria amphibia										x												1
Poaceae	x																					1
Sparganium erectum											xx											1
Sum taxa in pond	**3**	**4**	**1**	**2**	**0**	**0**	**2**	**4**	**0**	**8**	**4**	**5**	**5**	**2**	**4**	**3**	**7**	**6**	**1**	**4**	**8**	

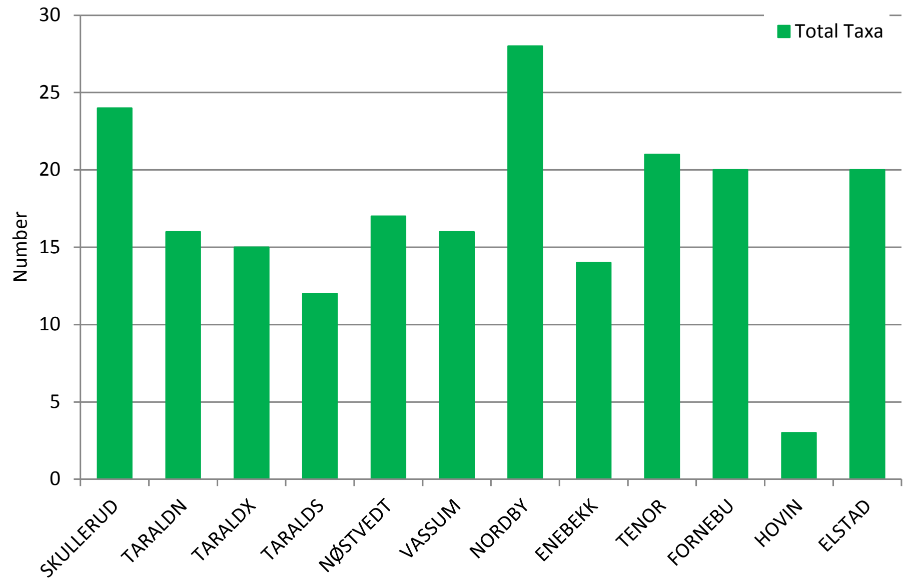


Fig. 20. Total number of macrophyte species in the WSPs (both aquatic and marginal species).

In general, there were twice as many species along the margins of the ponds compared to the truly aquatic species (Table 3; Figs 21, 22). In most ponds, there were also more species in the main basin compared to the inlet basin.

Table 3. Occurrence and abundance of macrophyte taxa in the WSPs (marginal species. x rare; xx uncommon; xxx abundant; xxxx dominant.

Marginal vegetation	**NOS**		**ELS**		**HOV**		**TEN**		**NOR**			**ENE**	**TAN**		**TAJ**		**TAS**		**FOR**	**VAS**		**SKU**	No. Ponds
	Inlet	Main	Inlet	Main	Inlet	Main	Inlet	Main	Inl.-road	Inl.-agr	Main		Inlet	Main	Inlet	Main	Inlet	Main	Main	Inlet	Main	Main	
Carex acuta		xx							x	x	x			xxx	xxx	xx	xx	xx	xx	xx	xxx	xx	8
Lythrum salicaria		xx	x				x		x		xx		x	x			xx	xx	xx		xx	xx	9
Typha latifolia		xxx								xx	xxx	xx	xxx		xx		xxx	xxx	xxx				7
Agrostis stolonifera		x		xx		x	x					xx		x	x	xx							7
Epilobium ciliatum ssp. ciliatum			x	x		x	x			x					x					x			6
Glyceria fluitans		x		xx			xxx	xxx		xx		xx							x				6
Scirpus sylvaticus							x	xx		xx	xx					xxx			xx			xx	5
Lysimachia vulgaris								x		x		x							x		x	xx	6
Phragmites australis								x	xx	xxx						x					xxx	xx	5
Carex vesicaria													xxx	xxx	xx	xx			x				3
Deschampsia cespitosa ssp. cespitosa				xx		x		x		x										x			5
Iris pseudacorus										x								xx	x		x	xx	5
Calamagrostis canescens										xx	xx								x			xx	3
Juncus effusus		x		x				x			xx												4
Scutellaria galericulata														x		x	x					x	4
Alisma plantago-aquatica											xx								xx		xx		3
Callitriche									x	x	x												1
Carex nigra ssp. nigra														x		x						x	3
Carex rostrata				xx				x											xx				3
Juncus bufonius			xxx	x					x														2
Juncus articulatus		x	x					x															3
Lycopus europaeus		x									xx											x	3
Ranunculus repens				x			x					x											3
Solanum dulcamara									x	x		x											2
Alnus glutinosa										xx	xx												1
Alopecurus geniculatus			xx	xx																			1
Caltha palustris																x						x	2
Carex sp.			x							xx													2
Carex canescens				xx							x												2
Carex pseudocyperus													xx									xx	2
Eleocharis mamillata							x	xx															1
Epilobium palustre															x	x							1
Filipendula ulmaria										x	x											x	1
Galium palustre												x										x	2
Glyceria maxima									xx	xx													1
Juncus bulbosus				x			x																2
Juncus filiformis				x				x															2
Myosotis scorpioides											xx											xx	2
Persicaria lapathifolia			x	x																			1
Phalaroides arundinacea									xx											xx			2
Rorippa palustris			x	x																			1
Rumex crispus							x		x														2
Salix pentandra									x					xx									2
Sparganium erectum												xx								x			2
Valeriana sambucifolia												x										x	2
Bidens tripartita							x																1
Comarum palustre																			xx				1
Equisetum arvense				xx																			1
Juncus conglomeratus		x																					1
Lysimachia nummularia		x																					1
Persicaria amphibia																			x				1
Persicaria hydropiper		xx																					1
Poa palustris																				x			1
Ranunculus sceleratus												x											1
Schoenoplectus lacustris																				xx			1
Sparganium											xx												1
Stachys palustris																			x				1
Total taxa - margins	**0**	**11**	**8**	**15**	**0**	**3**	**10**	**10**	**10**	**16**	**14**	**10**	**4**	**7**	**6**	**9**	**4**	**4**	**14**	**7**	**6**	**16**	

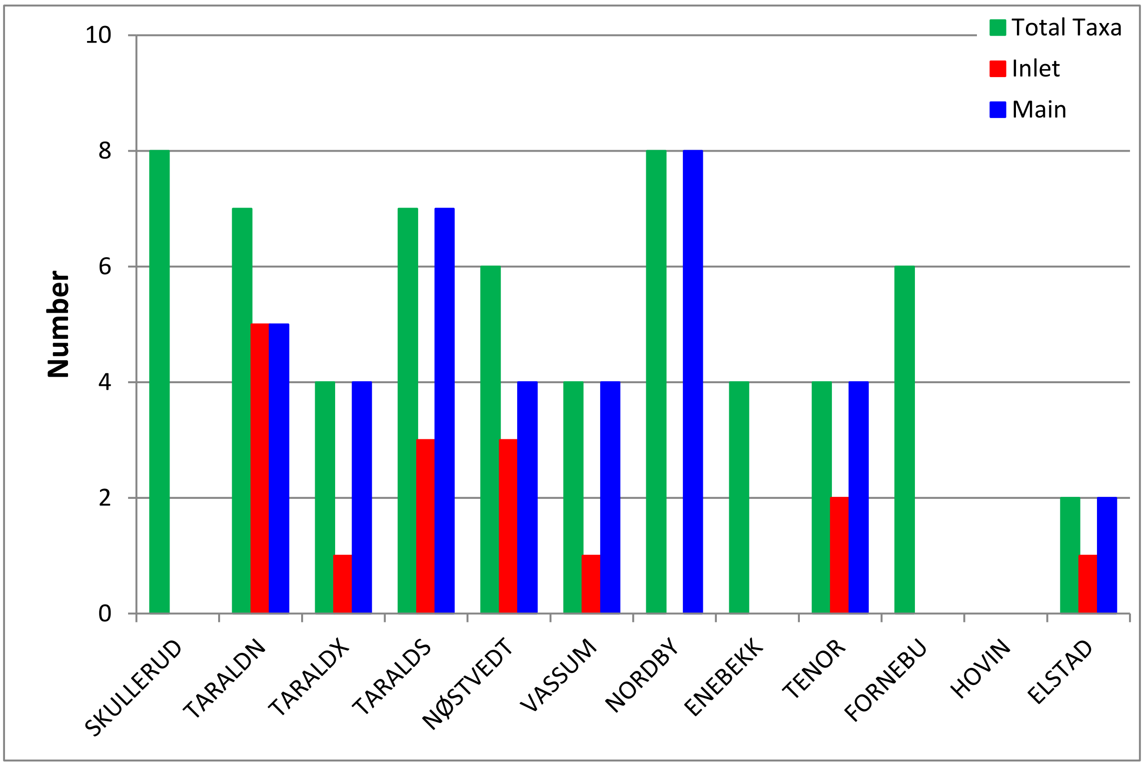


Fig. 21. Number of aquatic macrophytes in the inlet and main basins of the WSPs

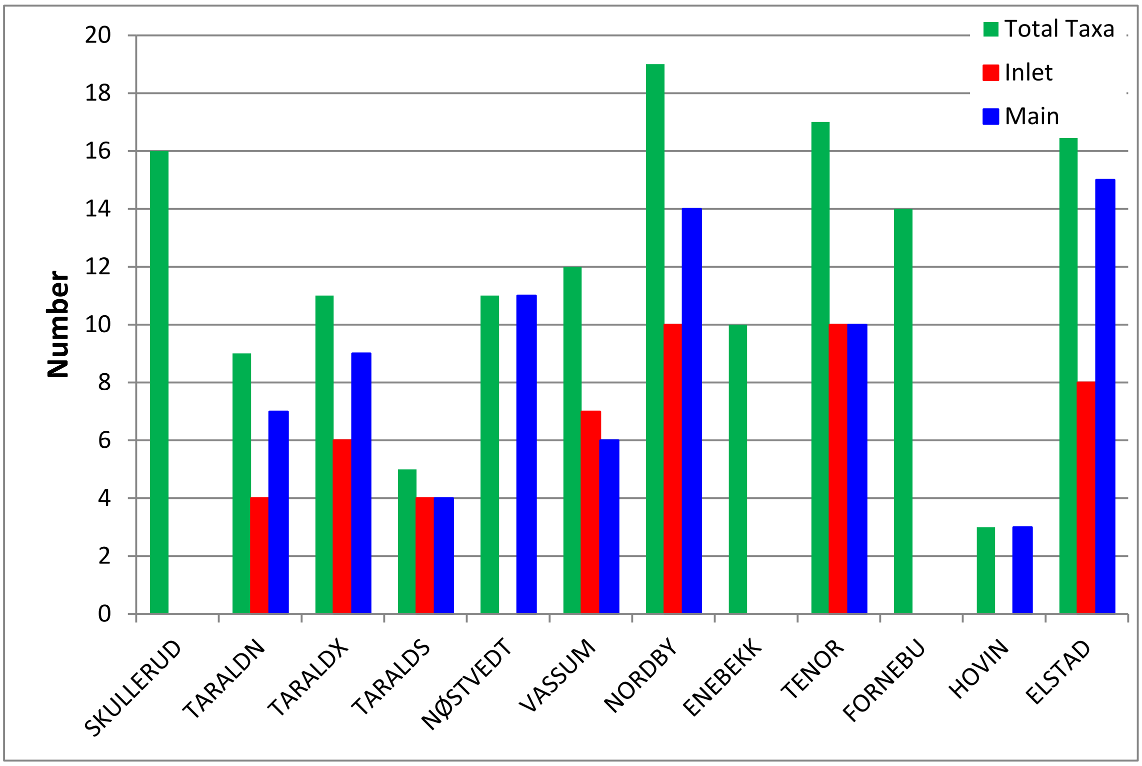


Fig. 22. Emergent macrophytes in the inlet and main basins of the WSPs.

The Red-Listed species, *Carex pseudocyperus,* (Solstad et al. 2010) was recorded in two ponds, Skullerud and Taraldrud North. This species is considered as Near Threatened (NT) on account of its decline due to draining and channelling of wetland habitats. However, the most surprising record was *Butomus umbellatus* in Nordby. This species is Red-Listed as CR (Critically Endangered) in Norway, but information from the Norwegian Roads Authority showed that the species was implanted together with other more common species.

Among the alien species (Elven et al. 2013) *Elodea canadensis* and *Epilobium ciliatum* ssp. *ciliatum*, both in the severe impact category, were recorded. *Elodea canadensis* was found at a single locality, Skullerud, while *Epilobium ciliatum* ssp. c*iliatum* occurred in small populations in six ponds.

3.2.2 *Zooplankton and benthic microinvertebrates*

Cladocera

The common species of Cladocera included *Daphnia pulex*, *D. longispina* s. str., *Simocephalus vetulus*, *S. expinosus* and *Chydorus sphaericus* (Table 4). The most important genera were *Daphnia*, *Bosmina* and *Ceriodaphnia*, whereas *Simocephalus* and chydorids become more common with increasing growth of macrophytes. Both D*. longispina* s.str. and *D. pulex* are characteristic taxa in such ecosystems. *Bosmina longirostris* is probably dominant in Skullerud because of intensive fish predation. With less predation *Daphnia* spp. would also be dominant.

Simocephalus expinosus is usually not a dominant taxon, but in these ponds it was predominant within the genus. *Moina macrocopa*, only recorded in Nøstvedt sedimentation pond, was an unexpected species and had not been collected since G.O. Sars' time (prior to 1900) before it was found in 2007 in three ponds in Lier (Børre Dervo & Bjørn Walseng unpubl. data). These ponds are characterized by extremely high sodium, sulphate and magnesium concentrations as well as high pH. This is clearly an opportunistic species, although a weak competitor.

Most cladocerans are summer species, such as *Polyphemus pediculus, Moina macrocopa*, *Daphnia, Bosmina* and *Ceriodaphnia*, whereas some species among the Chydoridae, such as *Chydorus sphaericus*, are also present during winter.

Copepoda

The calanoid copepod, *Acanthodiaptomus denticornis*, is common in forest and urban ponds in southeastern Norway, but in our study was only found in the open pond, Elstadmoen. Following a decrease in open water and encroaching macrophytes, it disappears altogether. However, invertebrate and fish predation may also contribute to its decline. The species has winter diapause in the egg stage and is summer active.

Many cyclopoid copepods are common in such pond ecosystems and are among the most characteristic species. These include *Eucyclops lilljeborgi, Cyclops strenuus, Macrocyclops albidus, Macrocyclops fuscus, Megacyclops viridis, Acanthocyclops vernalis/robustus* and *Diacyclops bicuspidatus. Eucyclops lilljeborgi* (see Alekseev et al. 2006) is not generally considered a common species, but in the wet sediment ponds it was common. *Cyclops strenuus* is active in winter and spring, and has a summer diapause in copepodid IV/V stages (Elgmork 1959, 1964). The large sized cyclopoid copepods *Macrocyclops albidus, Macrocyclops fuscus* and *Megacyclops viridis,* which were very common in our study, are typical pond species.

Acanthocyclops vernalis/robustus and *Diacyclops bicuspidatus* are both very flexible taxa, and are commonly collected from both temporal and permanent ponds. *Acanthocyclops vernalis* is difficult to distinguish from *A. robustus* and *A. americanus*; all three are recorded from northern Europe (Miracle et al. 2013). *Acanthocyclops vernalis* is a species of temporary (Nilssen unpubl.) and permanent ponds (Hov & Walseng 2003), but has also been collected in acidified lakes (Nilssen & Wærvågen 2003). *A. robustus* seems to prefer the littoral and profundal zones of lakes (Sars, 1913-1918).

Harpacticoid copepods were rarely collected, but since many of them are small (< 0.6 mm body length), and strongly associated with sediment and sediment surfaces, they may have been overlooked. The only species recorded was the larger sized species, *Canthocamptus staphylinus*.

Ostracoda

The communities of Ostracoda were surprisingly rich, with many species. Most taxa recorded are summer species, such as *Candona candida*, *Notodromas monacha*, *Cypria ophthalmica* and *Cypridopsis vidua*. These species are commonly collected in Norwegian sites (Lindholm 2014a,b,c, Nilssen unpubl.data), and several display winter diapause.

Rotifera

The rotifers were only sampled once, in June 2016. *Kellicottia longispina* is not at all common in such ponds (Nilssen unpubl.data), but was probably colonised via adjacent streams and rivers. The other species, such as *Keratella cochlearis, K. quadrata, K. valga*, *Polyarthra* spp., *Synchaeta* spp. are all commonly recorded in ponds (Elgmork 1964, Nilssen unpubl. data). All species (except *K. longispina*) are summer forms, and display winter diapause (Wærvågen & Nilssen 2003). The relative scarcity of rotifers may be due to intense competition from cladocerans such as *Daphnia* sp. (Wærvågen & Nilssen 2003). When the ponds develop dense macrophytes, rotifer densities and species decrease considerably.

Overall zooplankton fauna

A total of 52 taxa of zooplankton were identified (Table 4). The number of zooplankton taxa recorded in the ponds varied between 12 in Enebekk (unexpectedly low) to 30 in Skullerud, although most ponds had around 20 taxa. After a relatively short period of time these different fish-free ponds (except for Skullerud) develop considerably diverse zooplankton and benthic microinvertebrate communities with many taxa commonly recorded from naturally occurring ponds elsewhere. The most anomalous ecosystem in this study was Skullerud, with its fish population and frequent import of taxa, both from the river and also probably from above-lying lakes. In this study, ponds with an extensive pelagic region are dominated by cladocerans, such as *Daphnia* spp. The Nøstvedt sedimentation pond, with its Red-Listed population of *Moina macrocopa*, is unique among the study ponds.

Table 4. Zooplankton taxa recorded in the 12 WSPs. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
CLADOCERA												
Sida crystallina												xx
Daphnia pulex	xx	x	x	xxx	xx		xx	xxx	xx			x
Daphnia longispina s.str.		xxx	xx				xxx	xxx	x	xx		
Ceriodaphnia reticulata				x						x		
Ceriodaphnia quadrata m. *hamata*											x	
Ceriodaphnia spp.									x	x		
Simocephalus spp.		x					x		x			x
Simocephalus vetulus	xx		xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Simocephalus expinosus	xx			xx	xx	xx	xx	xx	xx	xx	xx	xx
Scapholeberis mucronata					x		x			x		
Moina macrocopa	x											
Lathonura rectirostris												x
Iliocryptus sordidus												x
Bosmina longirostris												xx
Acroperus harpae												x
Alona guttata							x		x			x
Alonopsis elongata												x
Peracantha truncata					x							
Leydigia acanthocercoides												x
Chydorus sphaericus	x	x	x	xx	xx		xx	x	x	x	x	xx
Polyphemus pediculus								x	x			
COPEPODA												
Acanthodiaptomus denticornis		xxx										
Eucyclops serrulatus	x			x	x					x	x	
Eucyclops lilljeborgi	xx	x	xx	x	xx	xx	xx	xx	x	x	xx	x
Eucyclops mucrurus												
Eucyclops macruroides		x	x							x	x	xx
Eucyclops speratus	x											
Cyclops strenuus				x	x		x	x	xx			xx
Macrocyclops albidus	x	x		x	xx	x		x	x			xx
Macrocyclops fuscus	xxx	x	xxx	x	xx	xx	xx	xx	x		x	x
Megacyclops viridis	x	xxx	xxx	xx	xx	x	xx	xxx	x	x	xx	xxx
Megacyclops gigas	x	x	xx		x			x			x	x
Acanthocyclops vernalis/robustus	x		x	x	x		x	x	x	x	x	xx
Mesocyclops leuckarti	x	x		x		x			x	x		
Diacyclops nanus					x	x					x	
Diacyclops bicuspidatus	x		x	x	xx	x	x	x	x	xx	xx	xx
HARP. COPEPODA												
Canthocamptus staphylinus					x			xx				
OSTRACODA												
Ostracoda spp.	x	x	x	x	x	x	x				x	
Candona candida	x		x	x	xx	xx	xx	x	x		x	x
Pseudocandona albicans				x								
Notodromas monacha	xx			x	x	x	x	x	xx	x	x	x
Cypria ophthalmica				x	x					xx	x	xx
Heteropcypris incongruens					x						x	
Herpetocypris reptans	x				xx			x				
Cyclocypris ovum					x							
Cypridopsis vidua	x	x		x	x		xx	x		x	x	
ROTATORIA												
Kellicottia longispina												x
Keratella cochlearis							x					xxx
Keratella quadrata		xxx	xxx				x			xx		xxx
Keratella valga								x				
Polyarthra spp.		x					x					x
Synchaeta spp.		xx	xx									x
Total number of taxa	20	17	15	20	25	12	21	20	19	18	19	30

3.2.3 *Benthic Macroinvertebrates*

The total number of benthic macroinvertebrate and amphibian taxa recorded in the ponds varied between 44 in Enebekk and 73 in Tenor (Fig. 23). Tenor, Nordby, Nøstvedt, Taraldrud North and Taraldrud Junction all exceeded 60 taxa. Taxa richness was lowest in Enebekk, Hovinmoen and Elstadmoen. These two latter ponds were established recently and have poorly developed aquatic vegetation.

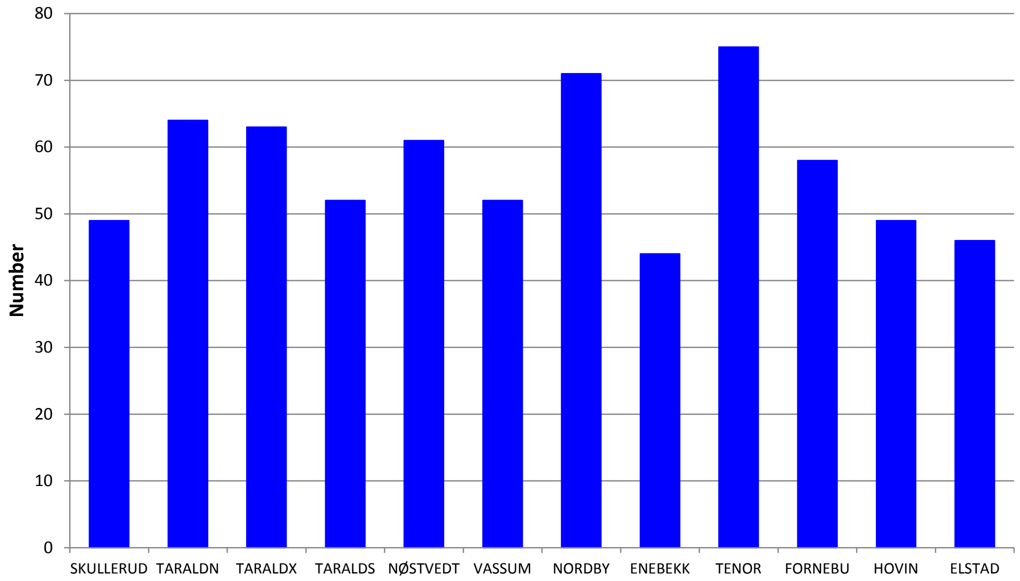


Fig. 23. Total number of benthic macroinvertebrate and amphibian taxa recorded in the 12 WSPs.

In some cases taxa richness also varied within the ponds and there were often more species in the main basin than in the inlet basin (Fig. 24). However, in Elstadmoen, Tenor, Taraldrud North and Taraldrud South there was little difference.

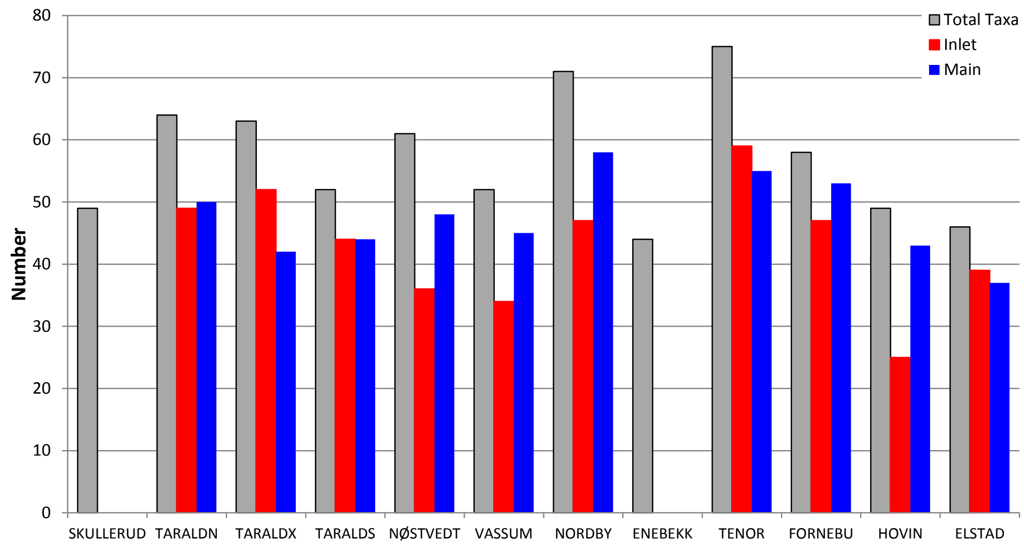


Fig. 24. Number of benthic macroinvertebrate and amphibian taxa recorded in the inlet and main basins of the WSPs.

Skullerud

In the single open basin at Skullerud, 49 macroinvertebrate taxa were recorded. Chironomids dominated throughout the year, although gastropods, notably *Gyraulus albus*, occurred in high numbers in August 2013 and from April to August in 2014. Tadpoles (*Rana temporaria*) were also abundant in June 2013 (Figs 25, 26). Skullerud has a diverse trichopteran fauna, including several limnephilids.

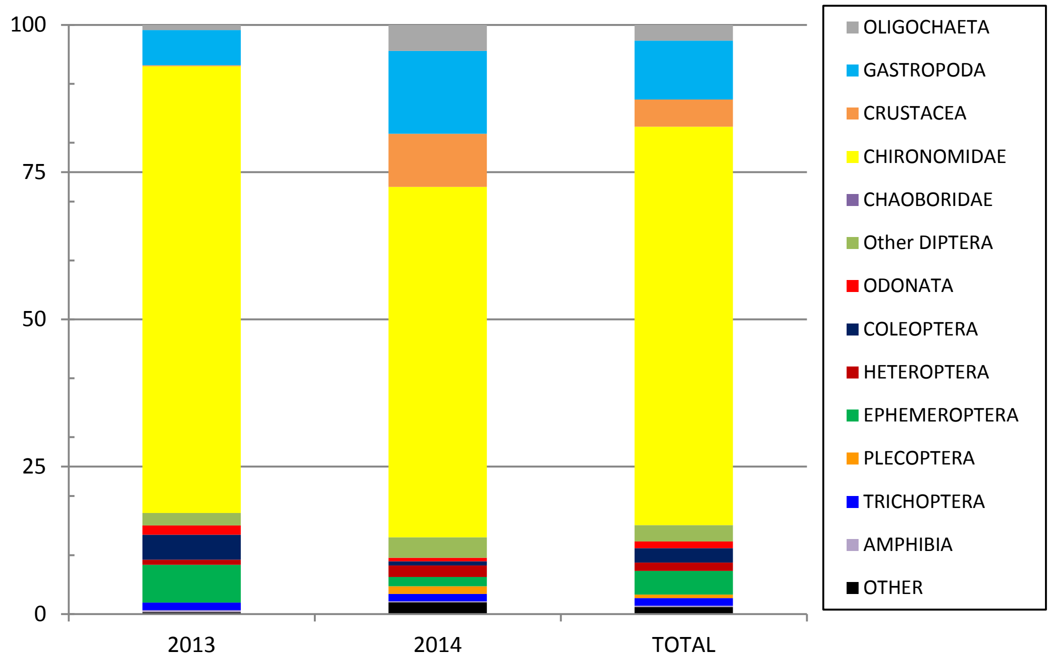


Fig. 25. Percentage of the main taxa of benthic macroinvertebrates in Skullerud in 2013 and 2014.

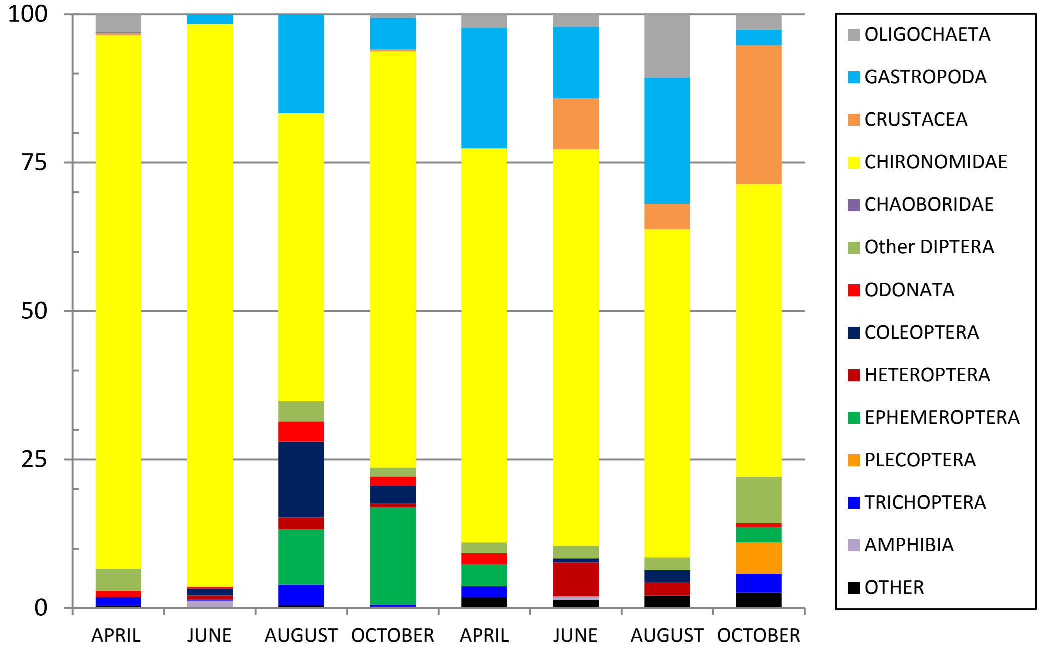


Fig. 26. Percentage of the main taxa of benthic macroinvertebrates, according to sampling month, in Skullerud.

Taraldrud North

There were only small differences between the two basins of Taraldrud North and chironomids dominate in both (Fig. 27). This was true through the seasons, although in the latter part of 2016, Ephemeroptera were equally dominant (Fig. 28). In fact during August and October 2014 the benthic macroinvertebrate fauna was more diverse. There were many species of Odonata and Trichoptera, in addition to several dipteran species.

A total of 63 macroinvertebrate taxa were recorded in Taraldrud North compared to 49 in each of the basins.

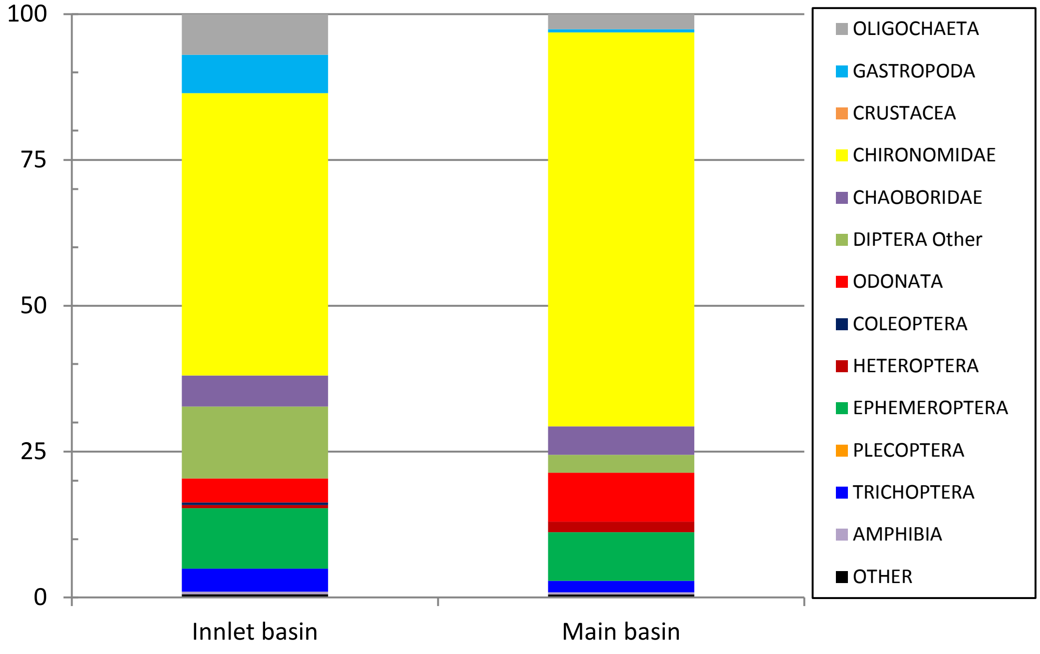


Fig. 27. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Taraldrud North.

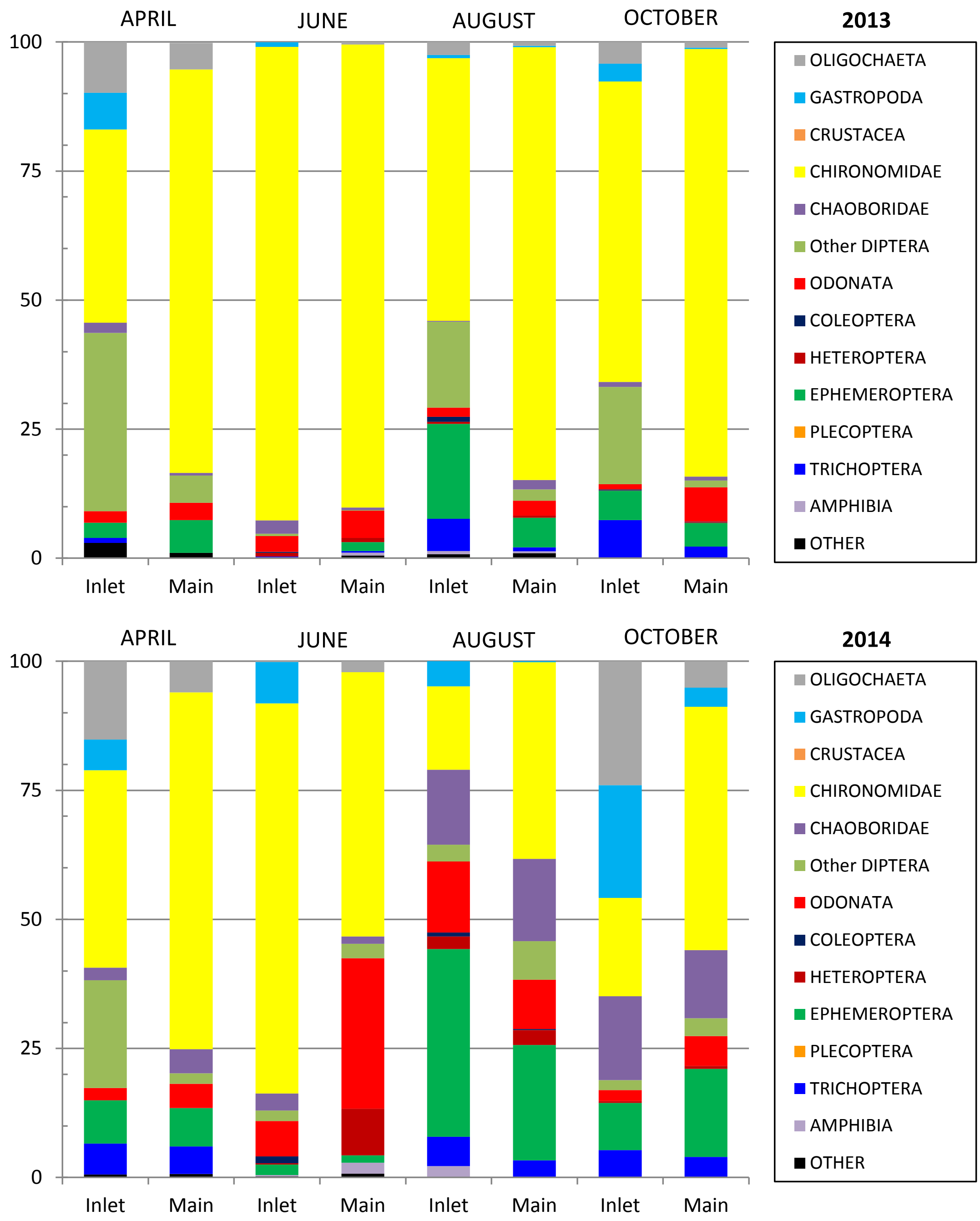


Fig. 28. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Taraldrud North.

Taraldrud Junction

The two basins in Taraldrud Junction are similar in terms of benthic macroinvertebrates (Fig. 29), with chironomids and mayflies dominating. However, gastropods were also abundant, especially in June (Fig. 30). The number of macroinvertebrate taxa was the same (63) as Taraldrud North, although there were more taxa in inlet basin. The fauna is diverse and contains several species of Odonata, Heteroptera, Trichoptera and other Diptera.

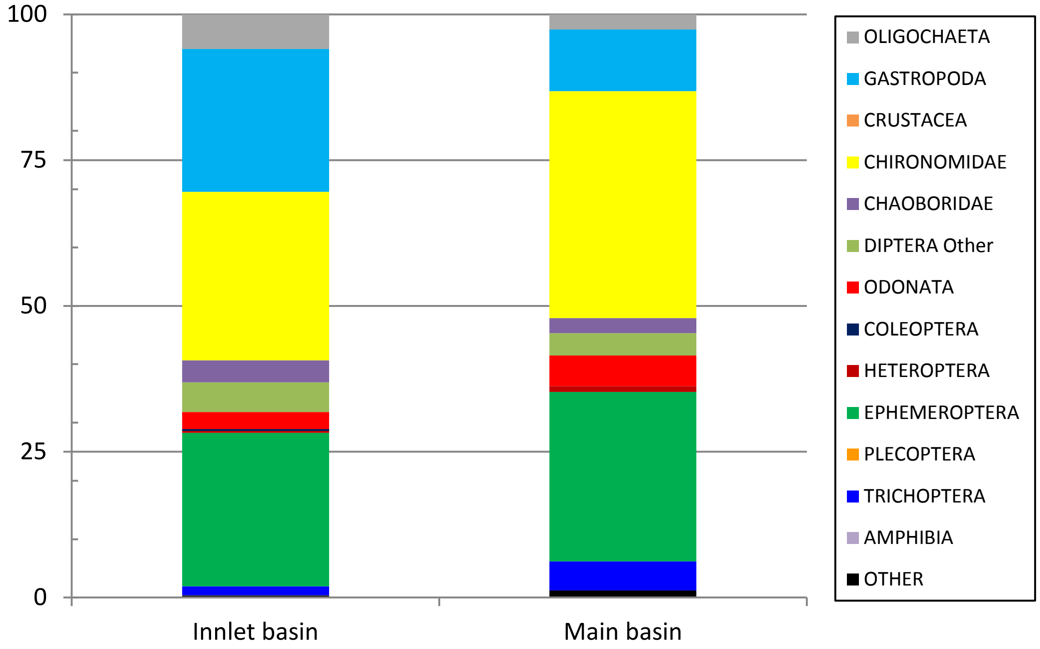


Fig. 29. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Taraldrud Junction.

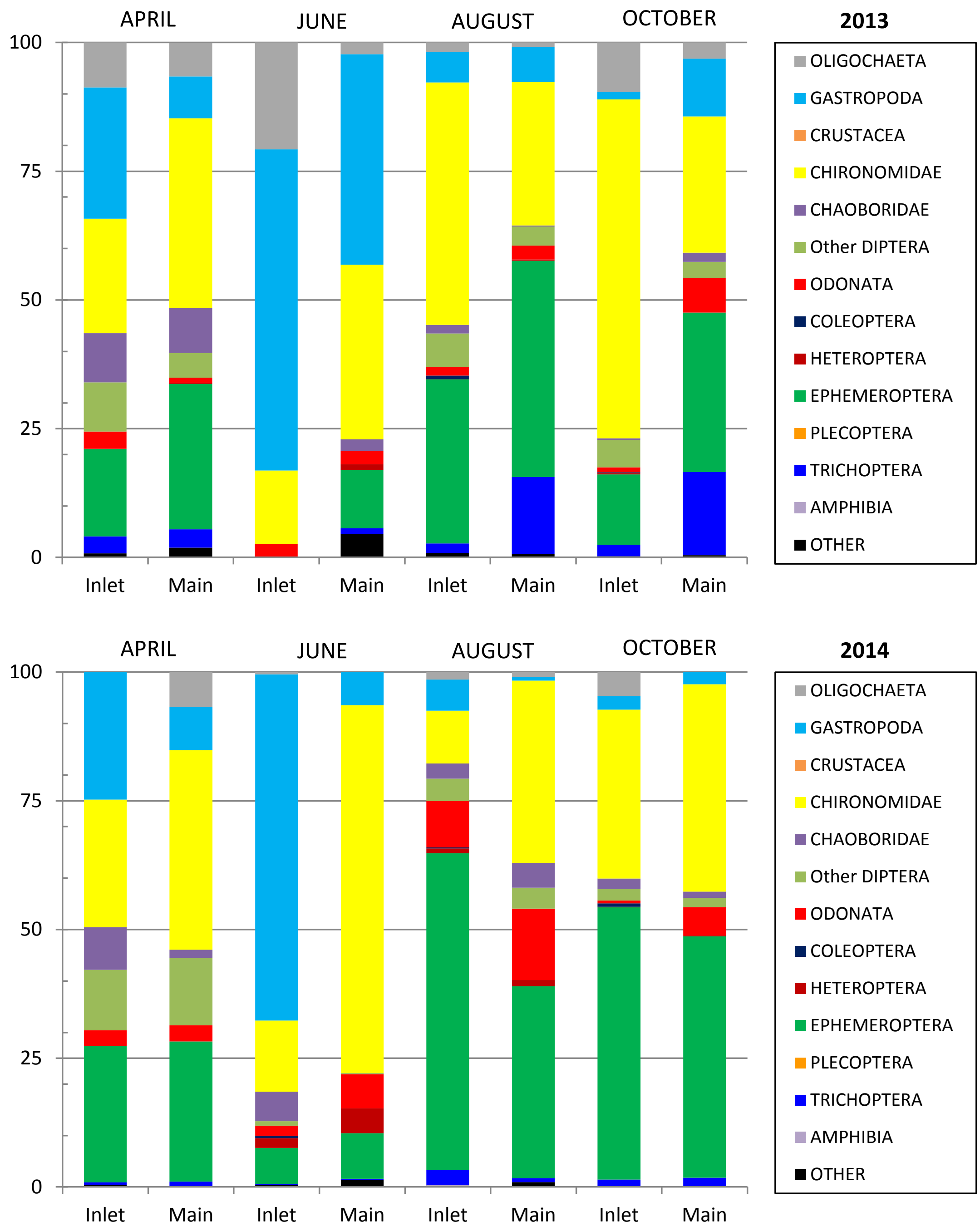


Fig. 30. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Taraldrud Junction.

Taraldrud South

This pond contained fewer taxa (52) than both Taraldrud North and Taraldrud Junction. The number of taxa was the same (44) in both basins and there was little difference in percentage composition. Chironomids and mayflies were the dominant groups although Odonata were also common (Figs 31, 32). Despite the lower total number of taxa, several species of Odonata and Trichoptera were recorded.

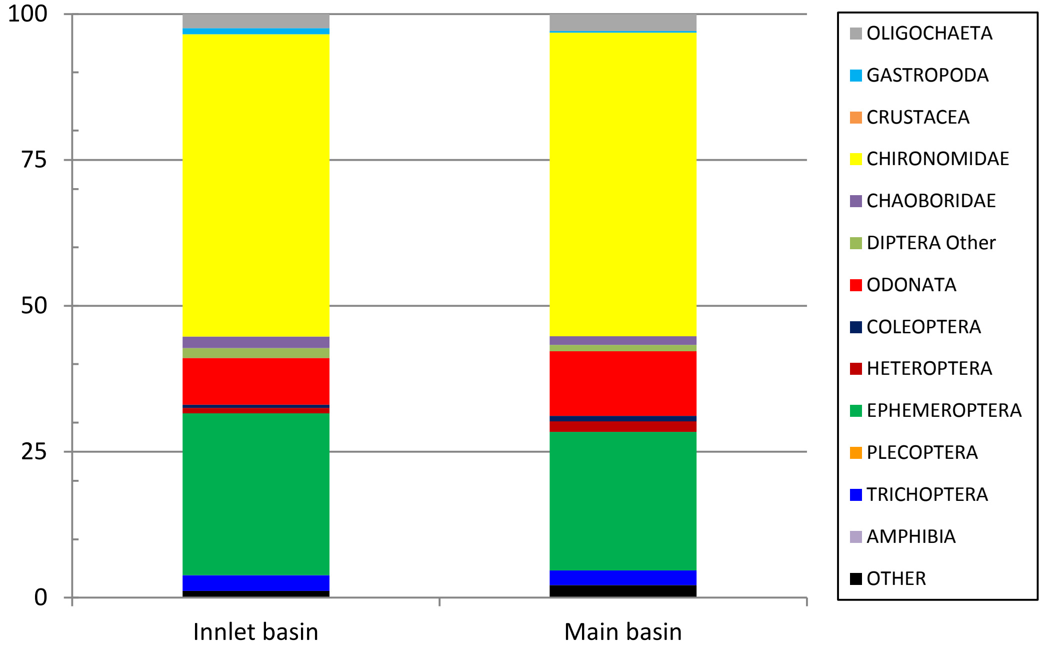


Fig. 31. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Taraldrud South.

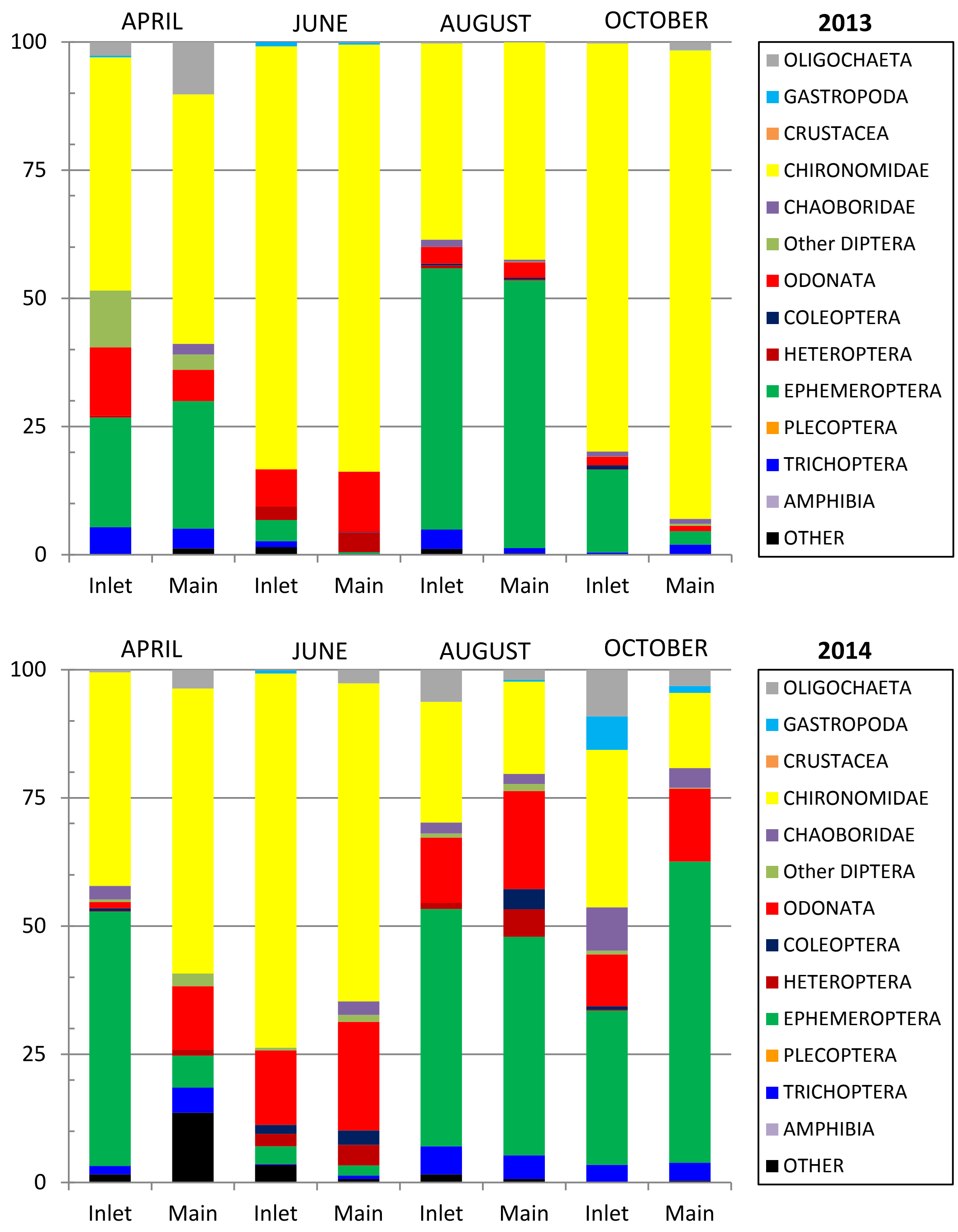


Fig. 32. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Taraldrud South.

Nøstvedt

A total of 61 taxa were recorded from Nøstvedt, most in the main basin. However, community composition was very similar in the two basins, with dominance of Chironomidae, although Gastropoda, Chaoboridae and Ephemeroptera were abundant (Fig. 33). Gastropoda, Trichoptera and Odonata were relatively species rich. In 2013 Chaoboridae were more abundant in spring and autumn, while in 2014 they were most abundant in summer (Fig. 34).

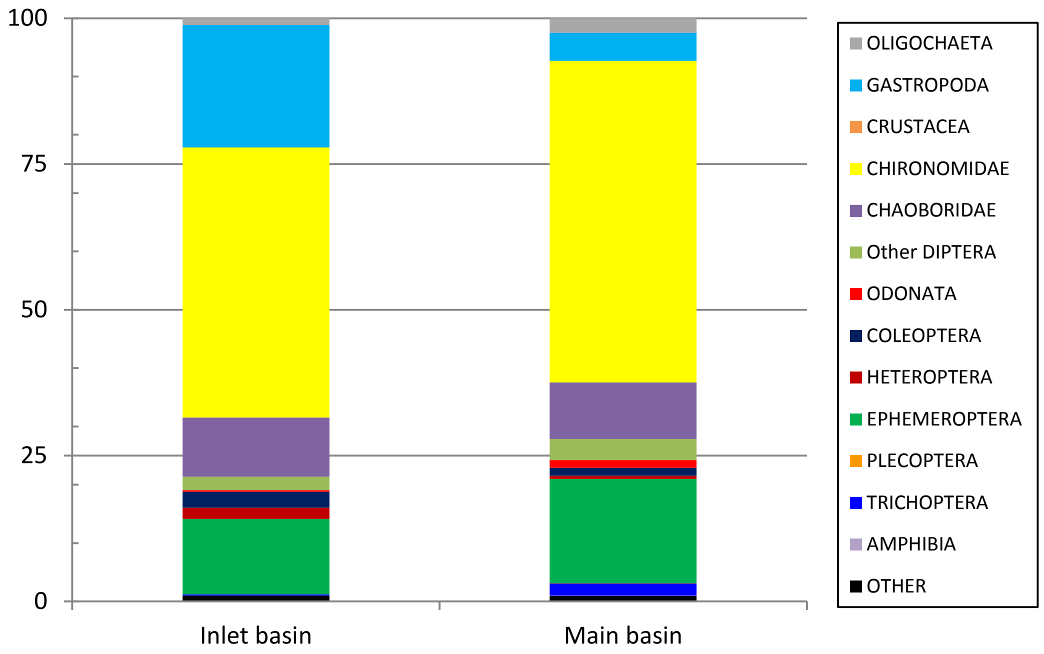


Fig. 33. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Nøstvedt.

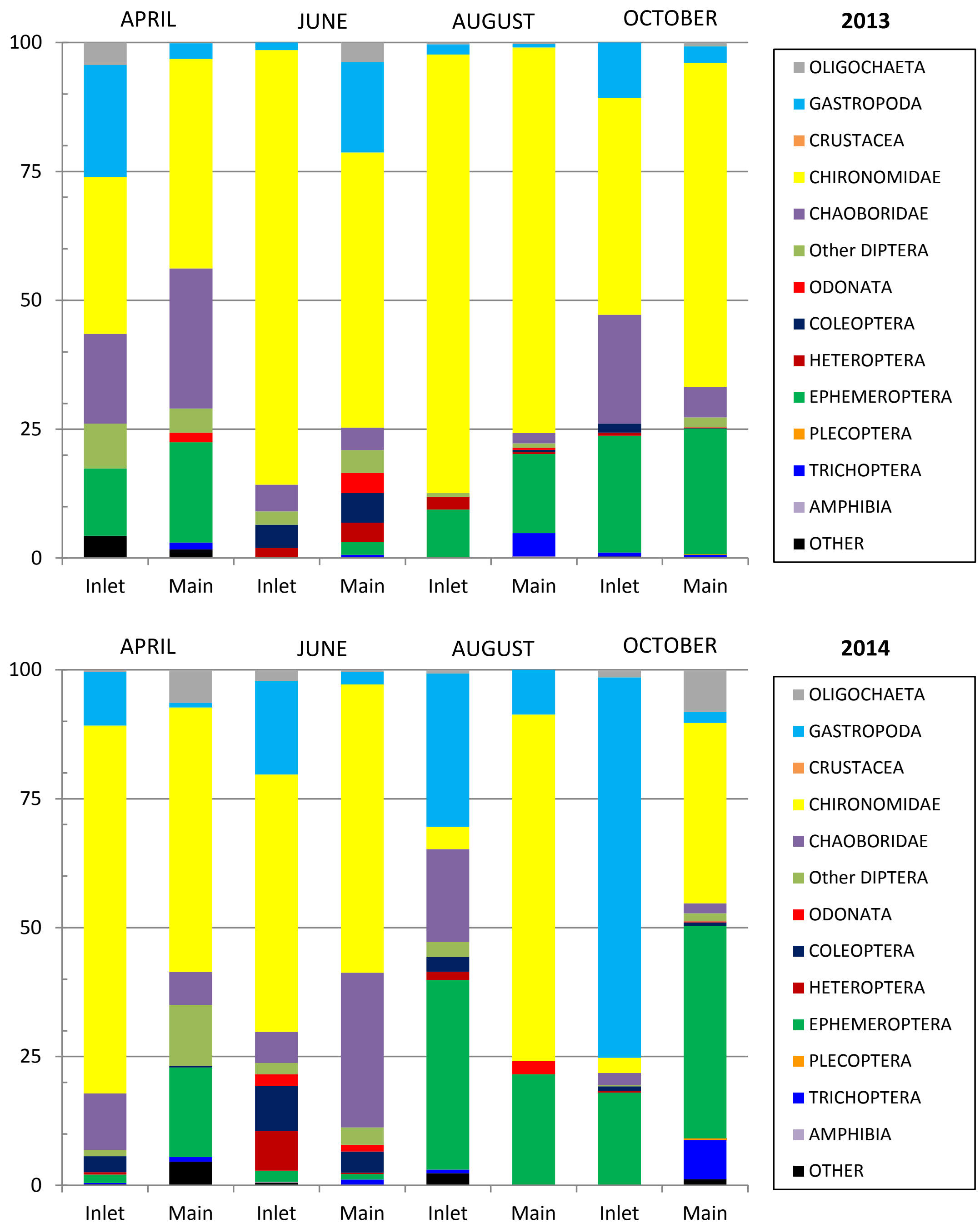


Fig. 34. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Nøstvedt.

Vassum

All together 52 benthic macroinvertebrate taxa were recorded from Vassum. As in most of the ponds, more species were recorded in the main basin compared to the inlet basin. Chironomids and other Diptera dominated the inlet basin, while in the main basin chironomids and mayflies were co-dominant (Figs 35, 36). The odonate fauna was relatively species rich, while most other taxa were only represented by a few species. In a long-term study Røstad (pers comm.) found Vassum to be extremely species rich for Dytiscidae (Coleoptera).

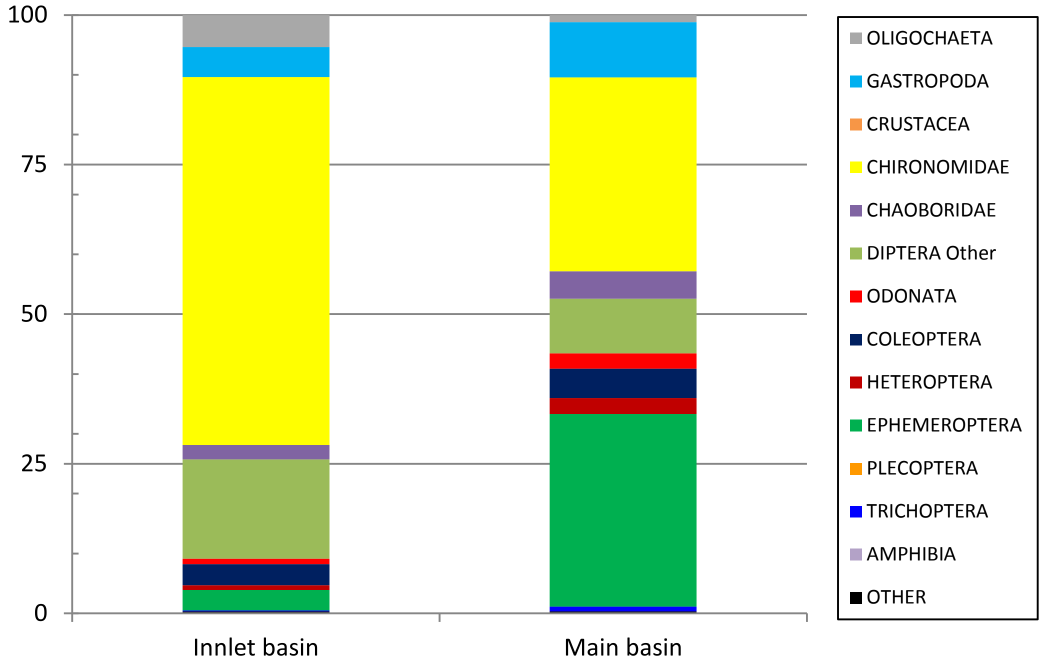


Fig. 35. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Vassum.

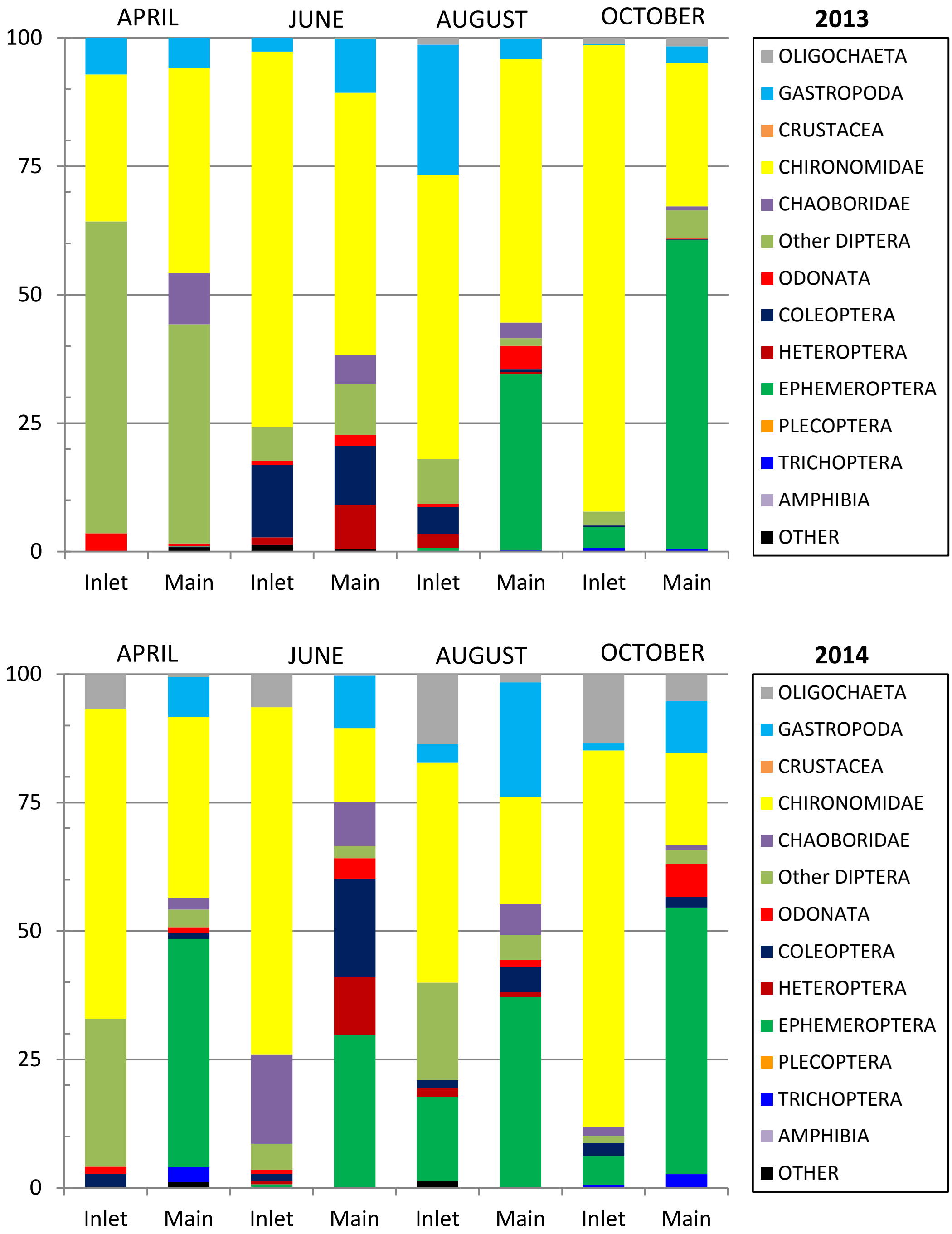


Fig. 36. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Vassum.

Nordby

Nordby had the second highest number of total recorded taxa (71), again more in the main basin than in the inlet basin. The community composition of the two basins was fairly similar, but Ephemeroptera were more dominant in the inlet basin (Figs 37, 38). Although low in numbers, the limnephilid (Trichoptera) fauna was relatively species rich. There were also several species of Dytiscidae (Coleoptera) and Gastropoda.

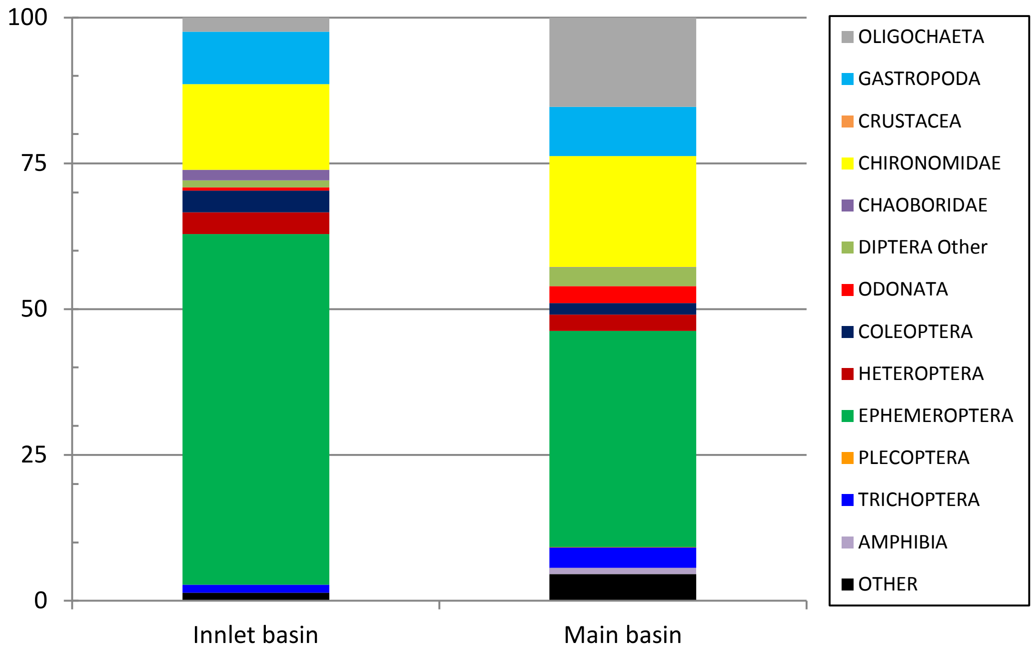


Fig. 37. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Nordby.

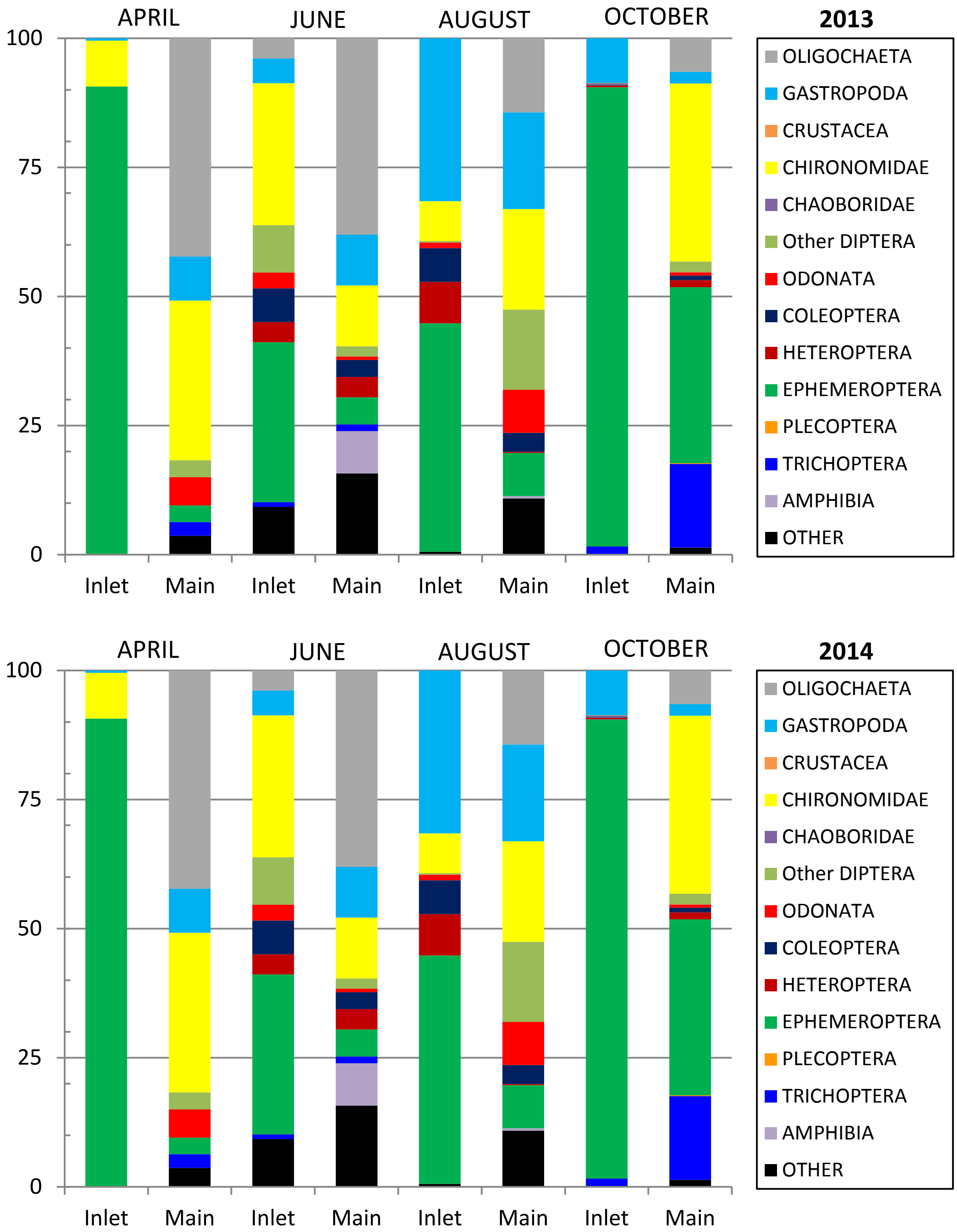


Fig. 38. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Nordby.

Enebekk

In the single basin at Enebekk 44 taxa were recorded. The community was dominated by Ephemeroptera and Chironomidae, although Gastropoda were common (Figs 39, 40). Apart from June, when Chironomidae dominated, Ephemeroptera, represented by only two species, were the most numerous major taxa. The one species, *Cloeon inscriptum,* far outnumbered the other ephemeropteran species, *Leptophlebia marginata*.

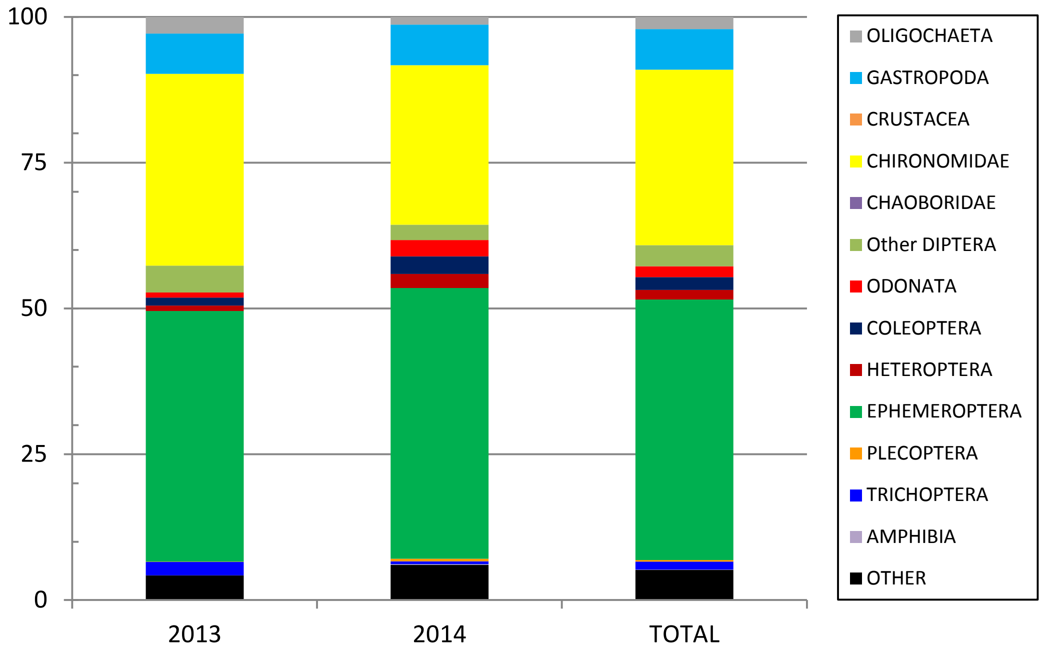


Fig. 39. Percentage of the main taxa of benthic macroinvertebrates in Enebekk.

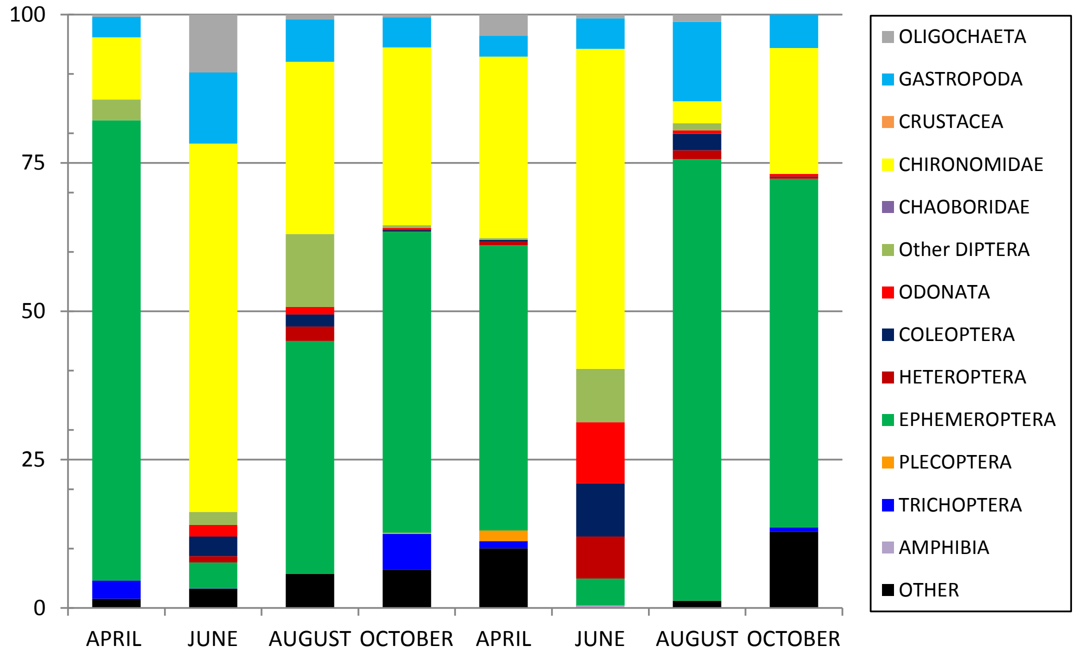


Fig. 40. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in Enebekk.

Tenor

Tenor had the highest number of recorded benthic macroinvertebrate taxa, 73, with similar numbers in the two basins. The communities of the two basins were also fairly similar, with Oligochaeta, Chironomidae and Ephemeroptera dominating (Fig. 41). Seasonally Chironomidae were dominant in April and June, while in August and October Ephemeroptera were most abundant (Fig. 42). Several higher taxa were species rich, especially Odonata, Heteroptera and Dystiscidae.

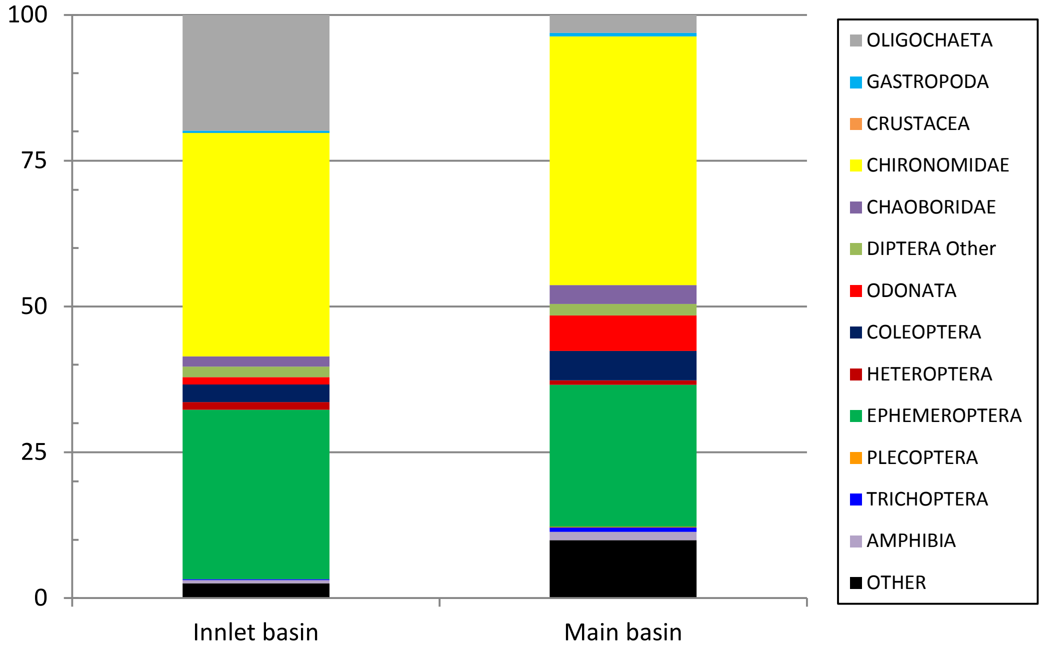
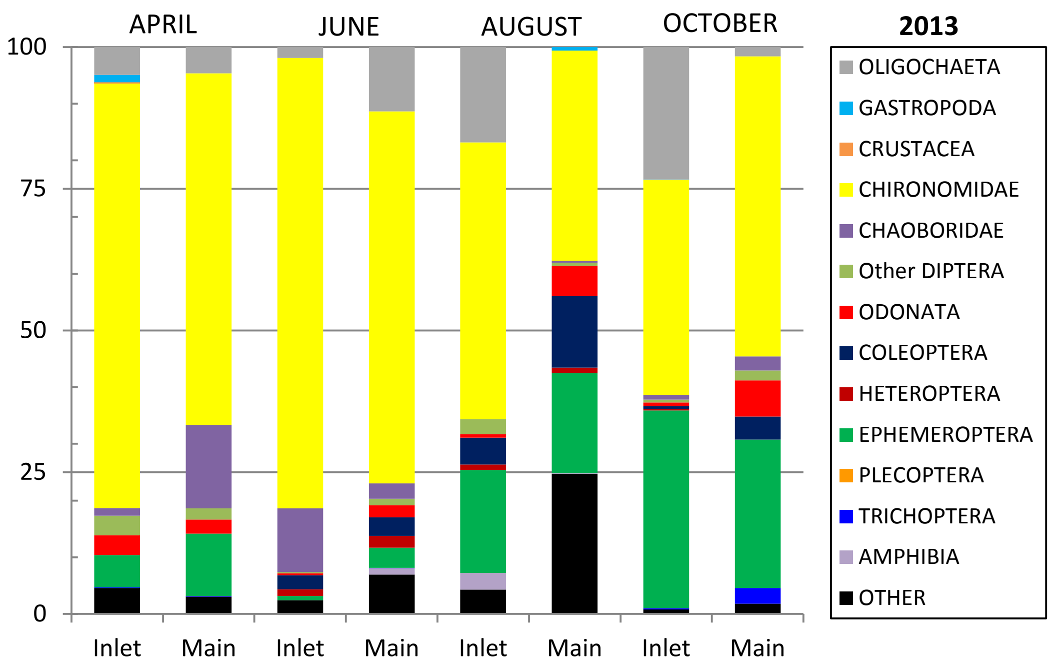


Fig. 41. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Tenor.



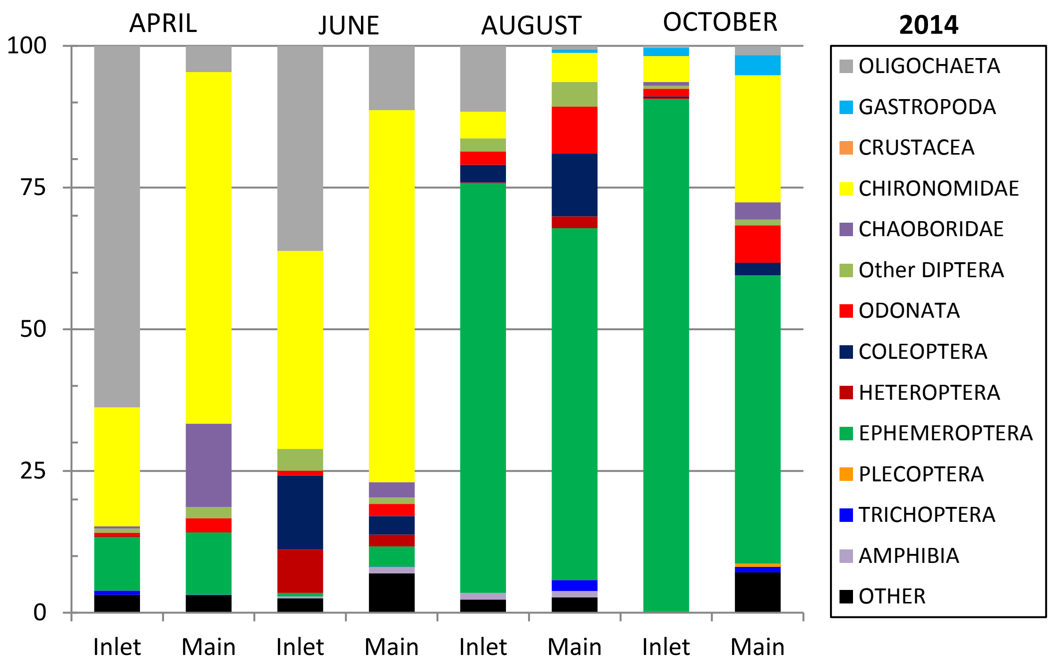


Fig. 42. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Tenor.

Fornebu

The benthic macroinvertebrate communities of the two basins were very similar and dominated by Oligochaeta, Chironomidae and Ephemeroptera, although Gastropoda were also present in high numbers. In total, 57 taxa were recorded from Fornebu, with slightly more taxa in the main basin (Fig. 43). The benthic macroinvertebrate community was more diverse in 2014 compared to 2013. In 2013 Oligochaeta and Chironomidae dominated, while in 2014, although Chironomidae and Ephemeroptera occurred in high numbers in spring and autumn, respectively, many other groups were common (Fig. 44). These included several species of Odonata, Heteroptera and Other Diptera.

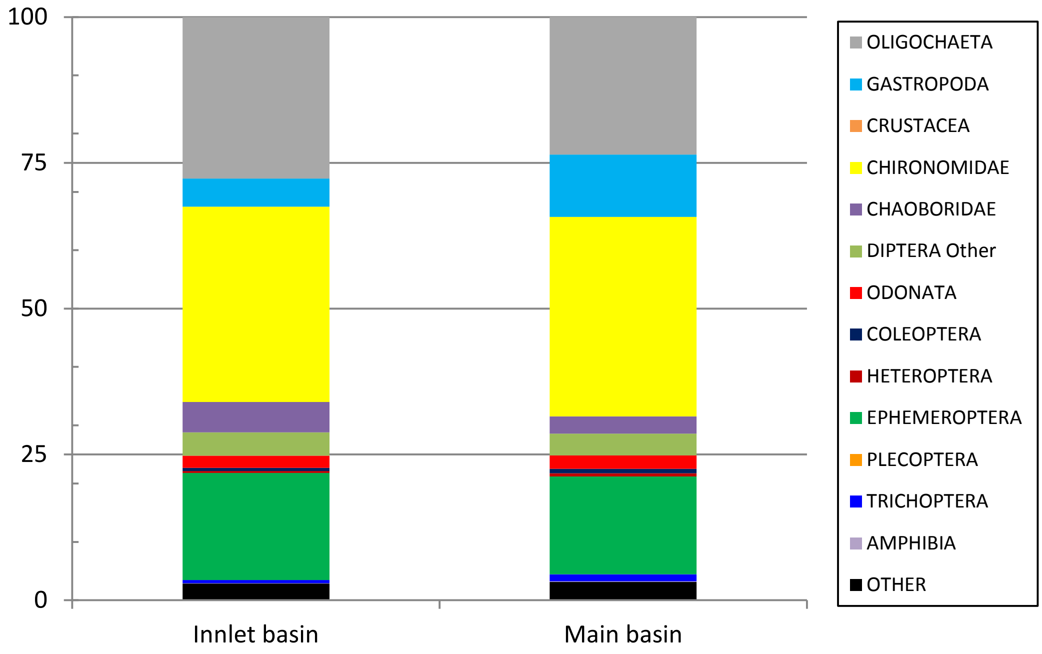


Fig. 43. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Fornebu.

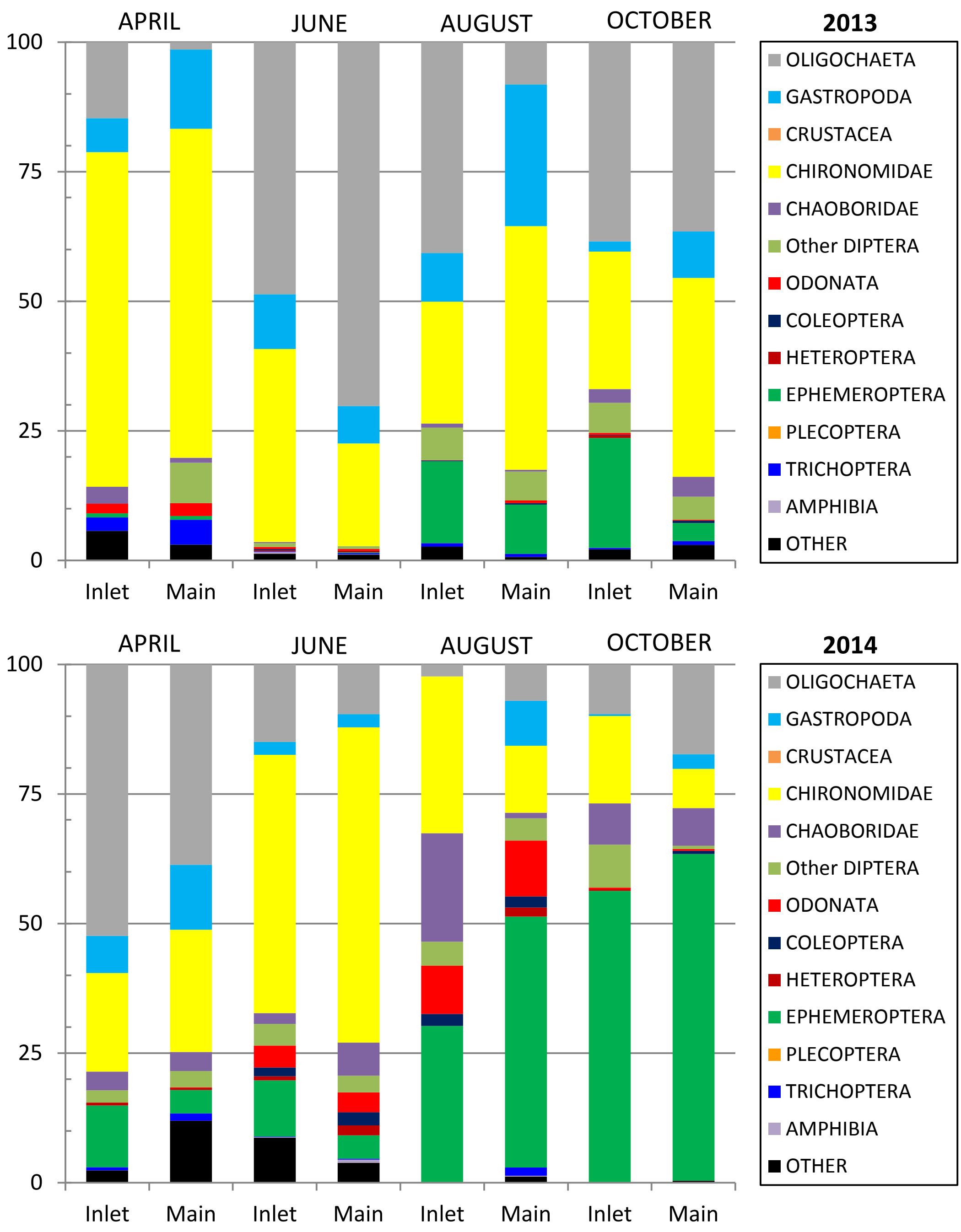


Fig. 44. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Fornebu.

Hovinmoen

A total of 49 benthic macroinvertebrate taxa were recorded from Hovinmoen. In the main basin 43 taxa were recorded, while in the inlet basin only 25 taxa were found, the lowest number among all the inlet basins. Nevertheless the community composition was similar in both basins and dominated by Ephemeroptera, Chironomidae and Coleoptera (Fig. 45). In 2013 there was a clear succession from a chironomid dominated community in the spring to a mayfly dominated community in the autumn, while in 2014 mayflies were totally dominant apart from the main basin in April and June (Figs. 46). In both years the community was most diverse during June.

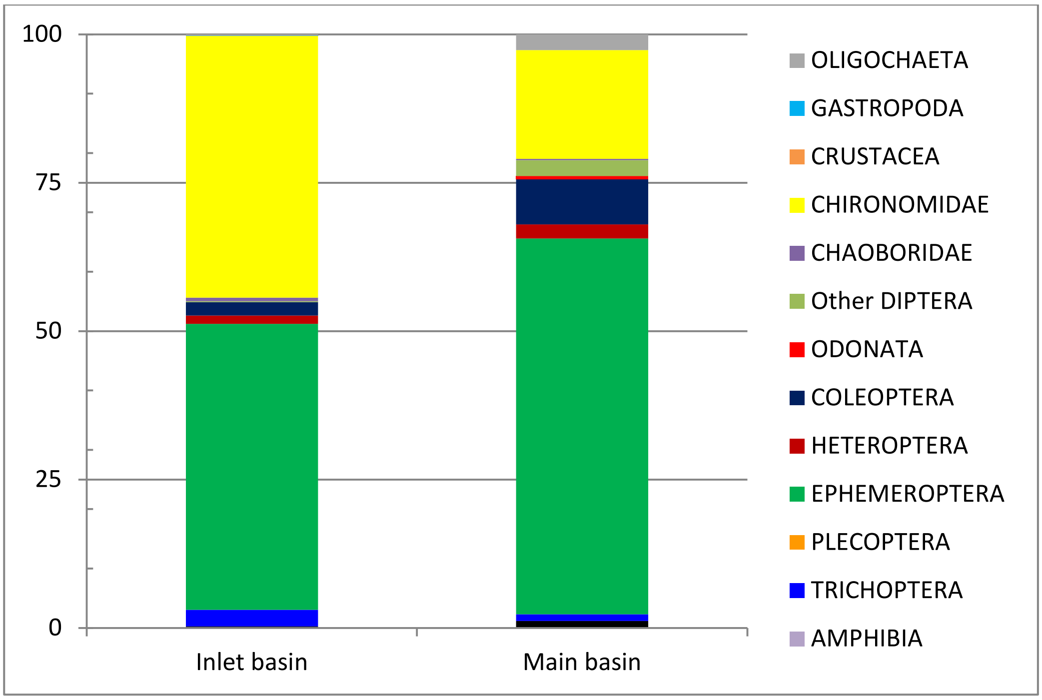


Fig. 45. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Hovinmoen.

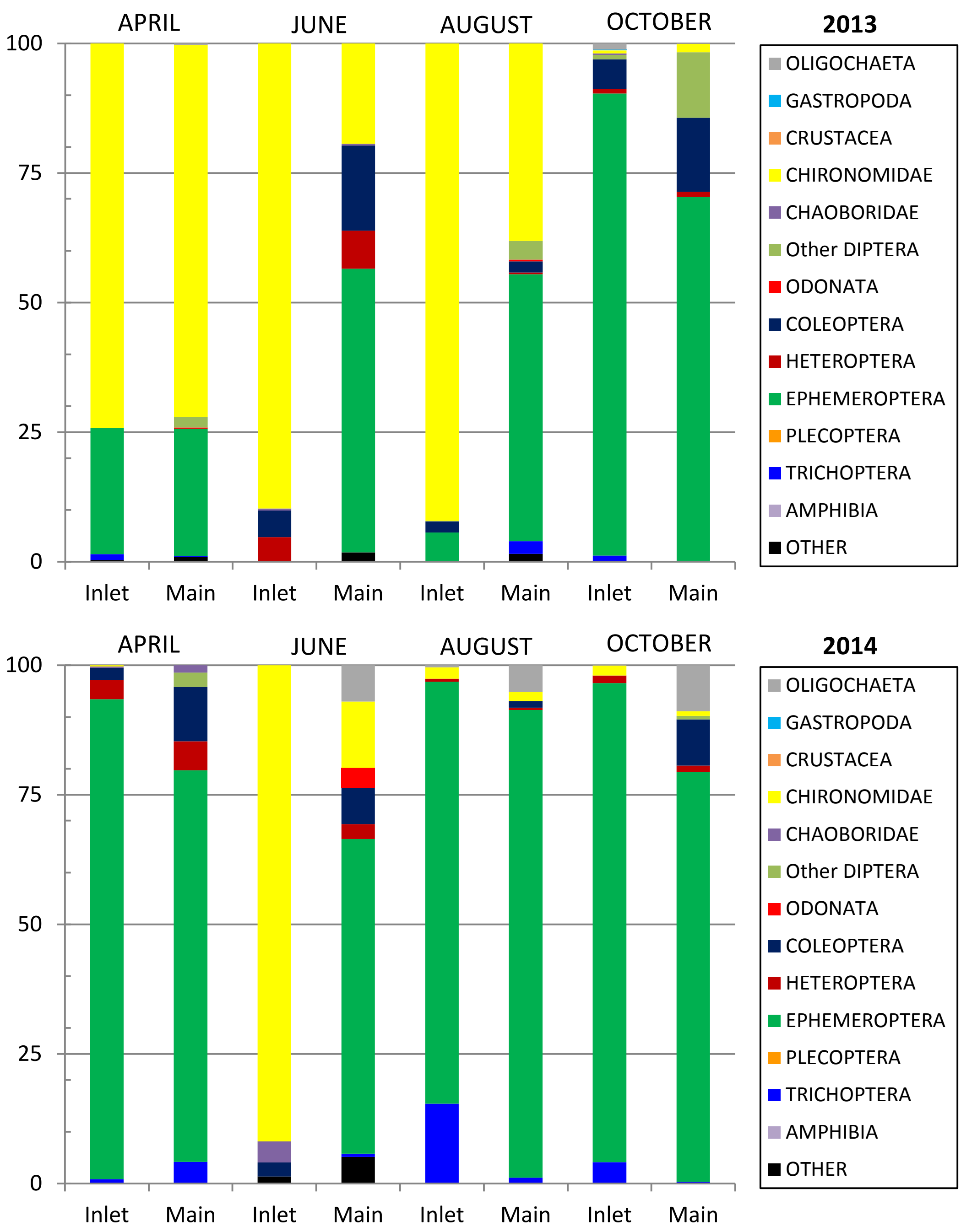


Fig. 46.Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Hovinmoen.

Elstadmoen

Elstadmoen had only 46 taxa of benthic macroinvertebrates, although the number of taxa was similar in the two basins. As in Hovinmoen, the macroinvertebrate communities were similar in the inlet basin and main basin, and dominated by Chironomidae, Ephemeroptera and Coleoptera (Fig. 47). In common with Hovinmoen, there was also a clear succession in 2013 from a chironomid dominated community in the spring to a mayfly dominated community in the autumn, while in 2014 mayflies were totally dominant apart from the main basin in April and June. In both years the community was also most diverse during June (Figs 48).

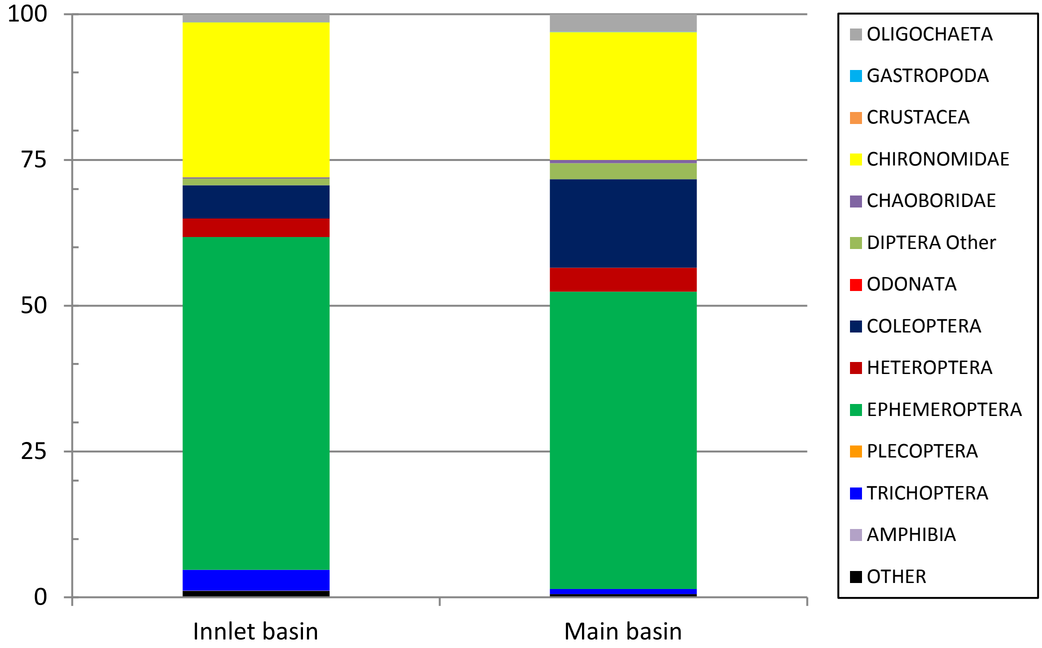
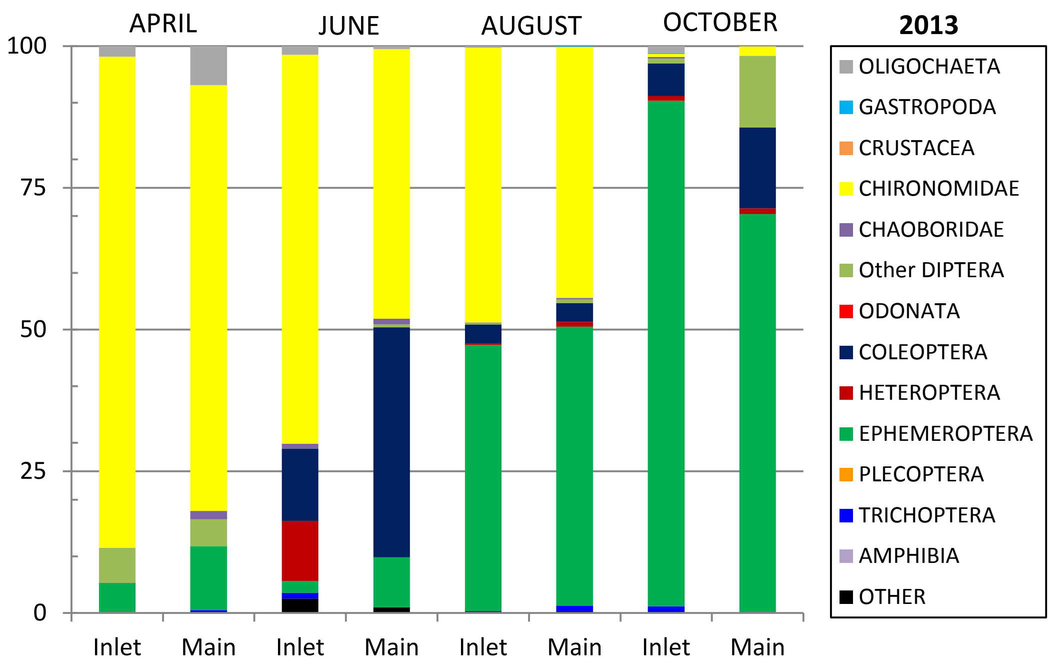


Fig. 47. Percentage of the main taxa of benthic macroinvertebrates in the two basins of Elstadmoen.



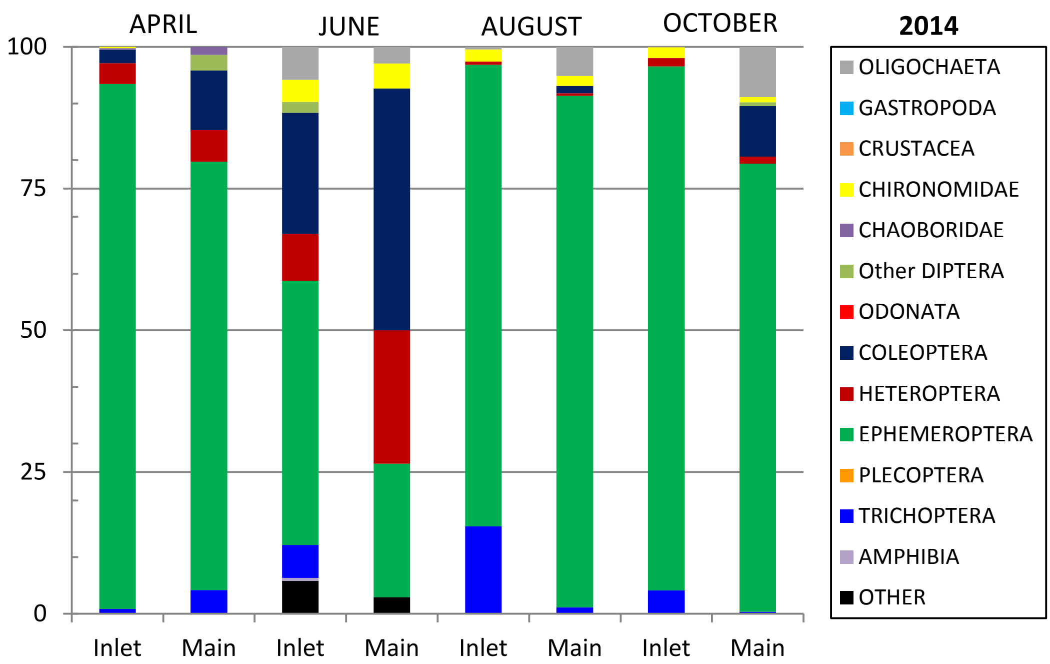


Fig. 48. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2013 and 2014 in the two basins of Elstadmoen.

3.2.4 *The abundance of the different macroinvertebrate groups*

Oligochaeta

Oligochaetes were abundant in most of the ponds. Tenor harboured most taxa, with at least 8 recorded taxa. The least diverse ponds were Elstadmoen, Hovinmoen and Vassum with only two identified taxa (Table 5). Most taxa are common in Norway, apart from *Ophidonais serpentina*, recorded only from south-eastern Norway.

Hirudinea

Three species were recorded from Tenor, again the highest number among the ponds (Table 5). Leeches were not recorded from Taraldrud North, Taraldrud Junction and Taraldrud South.

Table 5. Taxa of benthic macroinvertebrates (Nematoda, Oligochaeta, Hirudinea, Gastropoda, Bivalvia, Crustacea, Acari and Aranea) recorded from the 12 ponds. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
NEMATODA				xx	xx		xx	x		xx		x
OLIGOCHAETA												
Chaetogaster sp.				x						x		
Enchytraeidae indet		xx	x	xx								x
Eiseniella tetraedra									x			x
Lumbriculus variegatus	xx			xx	xx	xx	xxx	xxx	x	xxx	xx	x
Limnodrilus hoffmeisteri				x			x	xx				
Nais sp.	x			x			xx	xx	xx	xxxx		x
Ophidonais serpentina				xxxx								
Spirosperma ferox						x						
Tubifex tubifex								x				
Tubificidae indet				xxx	xxx	xx		xx		xxx	xxx	
Stylodrilus heringianus				xx								x
Slavina appendiculata	xx		x		xx		xx	x		xxxx		xx
Indet (small)	xx	xxx	xxx	xxxx	xxx	xxx	xxx	xxx	xxx	xxxx	xxx	xx
HIRUDINEA												
Erpobdella octoculata	x	x		xxx	xx							xx
Haemopsis sanuisuga												x
Helobdella stagnalis				xx						xx		
Glossophonia complanata	x				xx							
Theromyzon tessulatum				x		x						
GASTROPODA												
Bathyomphalus contortus	x											
Gyraulus acronicus	xxxx				xxx		xxx	xx				
Gyraulus albus												xxx
Armiger crista				xx						xxxx	xxx	
Lymnaea glabra	x			x	x							
Lymnaea palustris	x	x		x	xxx	xxx		xxx	xx	xxx	xx	
Lymnaea truncatula	xx			xx				x		x		
Hippeutis complanatus			x									
Planorbis planorbis					xx		xxx	xxx	xx			
Radix balthica	xx				xxx	xx		xxx	x	xxx	xxx	x
Zonitoides sp.	x				xx	xx						
Succinea sp.	xx			x	xx	xxx	xx		x	xx	xx	
Indet	x											
BIVALVIA												
Pisidium spp.	x		x			xxx						
Sphaerium sp.				xxx		xxx	x			xxx		
Sphaeridae indet				xxx	xx	xxx		x				
CRUSTACEA												
Asellus aquaticus				x								xxx
ACARI	xx	xx	xx	xx	xx	xx	xx	xx	xxx	xxx	xx	xx
ARANEAE										x		
Tetragnatha extensa		x					xx					

Mollusca
Mollusca were especially species rich in Nøstvedt, with at least 9 taxa recorded (Table 5). Nordby was also rich in species. This contrasts with Hovinmoen, Elstadmoen and Skullerud with only 1-2 taxa. Several of the gastropods have a restricted distribution in Norway. *Planorbis planorbis* has been previously recorded from a three localities in Oslo, Akershus and Østfold. However, in 2013 the species was found in two further localities in Oslo and in the pond at Taraldrud Junction. It is entered in the Norwegian Red-List as DD (Data Deficient). In our survey it was recorded in 4 ponds in Akershus and Østfold.

Asellus aquaticus
Asellus only occurred in two ponds, Tenor and Skullerud (Table 5), in addition to the reference pond. This species is typical of localities rich in organic matter and is a widely used indicator of organic enrichment.

Odonata
Odonata are a typical element of lowland ponds and study ponds were no exception, although the number of taxa varied considerably from Elstadmoen where no Odonata were recorded to Tenor, Taraldrud N, Taraldrud Junction and Taraldrud S with at least 9-10 species (Table 6). Odonata were recorded from Enebekk and Hovinmoen, but there were few species. Most of the recorded species of Odonata are common in ponds in Oslo, Akershus and Østfold. However, two species, *Coenagrion lunulatum* and *Orthetrum cancellatum* are listed as vulnerable in the Norwegian Red-List. *C. lunulatum*, collected from Skullerud has not previously been recorded in Oslo/Akershus, while *O. cancellatum*, collected in Tenor, has previously been recorded from Østfold.

Ephemeroptera
Ten species of Ephemeroptera were recorded in the wet sedimention ponds (Table 6). All the species, except *Baetis rhodani*, are typical of lentic habitats. *B.rhodani* was only found in Skullerud, a pond that is connected to the adjacent stream during high flows. The two ponds Elstadmoen and Hovinmoen harboured most species, seven and six species, respectively. The other ponds had only 2-4 species. *Cloeon inscriptum* was the most common species, occurring in all ponds and often in high densities. The two *Ephemera* species, *E. vulgata* and *E. danica*, were restricted to Elstadmoen.

Plecoptera
Ponds are not a typical plecopteran habitat and only two species, *Nemoura cinerea* and *Nemurella pictetii*, were recorded (Table 6). *N. cinerea* occurred in several ponds, while *N. pictetii* was only found in Enebekk.

Heteroptera
Heteroptera were common and species rich in most ponds (Table 6). None of the identified species are Red-Listed. Elstadmoen was the most species rich with at least 10 species. The other ponds had between 5 and 9 species of Heteroptera.

Table 6. Taxa of benthic macroinvertebrates (Odonata, Ephemeroptera, Plecoptera and Heteroptera) recorded from the 12 ponds. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
ODONATA												
ZYGOPTERA												
Coenagrion hastulatum	x		x	xxx	x		xxx	xxx	xxx	xxx	xxx	xx
Coenagrion lunulatum												x
Coenagrion pulchellum/puella				xx	x		xx					
Coenagrion sp.	x			xxx			xxx	xx	xxx		x	xx
Coenagrionidae indet	x			xxx	xx		xxx	xx	xx	x	xx	
Pyrrhosoma nymphula					xx							
Enallagma cyathigerum				xx			xx	x	x	x		xx
Lestes sponsa	xx			xx			xx	xx	xxx	xx	xx	
Lestes sp.	xx				x			x			x	
Erythromma najas									xx			
Ischnura elegans ?				xx	x							
Zygoptera indet			x	x			xx			xx		xx
AESHNIDAE												
Aeshna cyanea	xx		xx	x	x	xxx	xx	x		x	xx	x
Aeshna juncea	x			xx			xx	xx	xx	xx		x
Aeshna grandis	x				x		xx	x	xx	x	x	xx
Aeshna sp.							xx					
Aesnidae indet	xx			xx		xx	x		x	xx	xx	
CORDULIIDAE												
Cordulia aenea							x	x	x			
LIBELLULIDAE												
Libellula quadrimaculata	x		x	x			x		x	x		
Libellula sp.							x					
Leucorrhinia dubia									xx			
Leucorrhinia rubicunda							x					
Leucorrhidia sp.									xx			
Orthetrum cancellatum				x								
Sympetrum sp.	x					x	xx	x	xx		xx	
Libellulidae indet				x			xx	xx	xxx		x	
EPHEMEROPTERA												
Baëtis rhodani												x
Caenis horaria		xxx	xxx	xxx			xx	x		xx	x	
Centroptilum luteolum	x		x		xx							
Cloeon inscriptum	xxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Cloeon simile		xx	xx	xx								
Cloeon sp. (*C. inscriptum?*)	xxx	xxxx	xxx	xxx	xxx	xxx	xxx	xxx	xxxx	xxxx	xxx	xxx
Procloeon bifidum									x			
Leptophlebia marginata		xxx	xx			x						
Leptophlebia vespertina	xx	xxxx	xxx	x	xx		xxx	xx	xxx			
Leptophlebia sp.								xx				
Ephemera vulgata		xx										
Ephemera danica		x										
Baëtidae indet	xx	xx	x		xx	xx	xx	xxx	x	xx	xxx	xxx
PLECOPTERA												
Nemurella pictetii						xx						
Nemoura cinerea	x		x	x	x	xx						x
HETEROPTERA												
Callicorixa praeusta		x		x								
Callicorixa wollastoni		xx								x		x
Callicorixa sp.		xx	x									
Corixa dentipes		x	xx	x				x			x	
Corixidae, larvae	xx	xx	xx	xx	xx		x	xx	xx	xx	xx	x
Hydrometra gracilenta							x			x		
Sigara sp.	xx	xx	xx	x	xx	x		x	x		x	
Hesperocorixa limnaei							x		x	x		
Hesperocorixa sahlbergi		x	x	xx	xx	x	x	x	x	x	x	x
Notonecta glauca	x	xx	xx	xx	xx	xx	x	x			xx	x
Notonecta lutea							xx		xx	x		
Notonecta maculata		xx			xx			x	x			
Notonecta reuteri ?										x		
Notonectidae, larvae	xx	x	x	xx	xx	x	xx	xx	xx	x	xxx	
Gerris odontogaster								x	x			
Gerris sp.		x	x	xx	xx	x	x	x	x	x	x	xx
Gerridae, larvae	x	xx		xx	xx	xx	xx	x	xx	xx	xx	xx
Gerridae, adults			x				xx				xx	
Velia sp., larvae		x	x								x	
Microvelia sp.		x		x			xx		xx			
Veliidae indet						x	xx			x		xx
Heteroptera larvae indet	x	xx									x	

Table 7. Taxa of benthic macroinvertebrates (Trichoptera, Lepidoptera, Megaloptera and Coleoptera) recorded from the 12 ponds. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
TRICHOPTERA												
Agraylea multipunctata												x
Agraylea sexmaculata								x				
Agrypnia varia							xx		x			
Agrypnia obsoleta				x	x		xx					x
Agrypnia picta			x									
Cyrnus insolutus							x		x			
Holocentropus dubius	xx	xxx	xx	xx			xxx	xxx	xxx	xxx	x	xx
Holocentropus picicornis		x										x
Halesus sp.				xx					xx			
Grammotaulius nigropunctatus	x											
Glyphotaelius pellucidus					x							
Phryganea bipunctata	x	x										
Athripsodes sp.		xx										
Nemataulius punctatolineatus		x					x					x
Plectrocnemia conspersa			x							xx		xx
Oxyethira sp.										xx		
Limnephilus affinis					xxx							
Limnephilus auricula								x				
Limnephilus binotatus	x	x			x	x						
Limnephilus borealis					x							
Limnephilus extricatus		x			xx							
Limnephilus flavicornus					x			x				x
Limnephilus fuscicornis	x	x			x							x
Limnephilus griseus					xx							
Limnephilus lunatus					x							
Limnephilus marmoratus									x			
Limnephilus politus			xx									
Limnephilus rhombicus	x	xx		xx	xxx	xxx	xx	x			xx	x
Limnephilus stigma							x					
Limnephilus sp.	xx		x		xx	xx	xx	xx	xx		xx	x
Limnephilidae indet	x	xx	x	x	xx		xx		xx		x	xx
Leptoceridae indet			x							xx		
Polycentropodidae indet	xx						xx	xxx	xx	x	x	
Phryganidae indet							x	x	xx			
Ttrichoptera indet					x							x
LEPIDOPTERA												
Cataclysta lemata				xx	x	x		x			x	
Elophila nymphaeata				x				xx	x			
Nymphula stagnata				xx			x				x	
Pyralidae indet	x			x	x	x	x				x	
MEGALOPTERA												
Sialis fuliginosa	x											
COLEOPTERA												
Elmis aeana											x	
Gyrinus sp., larvae	x	x	x		x							
Gyrinidae, larvae					x							
Gyrinidae, imago	x	xx			x							
Haliplidae, larvae	x		x	xxx	x		xx	xx	xx	xx	xx	xxx
Haliplidae, imago	x			xxx	x		x	x	xx		x	xx
Helophorus sp., imago				xx	xx	xx			x			
Hydraena sp., imago	x			x	xx	x						xx
Donaciinae, larvae				xx							x	
Holophorus sp imago											xx	
Hydrophilidae, larvae	xx	xx	x	xx	x	xx	x			x	xx	
Hydrophilidae, imago		xx		x	x		x	x		x	x	
Elodes sp. (larvae)						x						
Dytiscidae, imago	xx	xxx	xx	xx	x	x	x		x	xx	xx	x
Dytiscidae, larvae	xx	xxx	xx	xxx	xxx	xx	x	x	xx	xx	xxx	xx
Acillius canaliculatus					x							
Acillius sulcatus				x								
Agabus bipustulatus		x	x									
Agabus nebulosus				x								
Agabus sturmii	x	x	x	x	x						x	
Donacia sp.											x	
Dytiscus marginalis					x	x					x	
Graptodytes pictus				x								
Graphoderus zonatus									x			
Hydroporus incognitus	x		x									
Hydroporus palustris	xx	xxx	xx		x							
Hydroporus planus											x	
Hydroporus striola			x								x	
Hygrotus inaequalis											x	
Hyphydrus ovatus											x	
Ilybius ater				x	x			x	x			
Ilybius fuliginosus		x	x	x		x					x	
Nebrioporus depressus		xx	xx									
Rhantus fontinalis					x							
Scarodytes halensis		x	x									
Stictotarsus griseostriatus			x									

Trichoptera
Trichoptera, especially within the genus *Limnephilus* (13 species), were rich in species in most ponds (Table 7). Elstadmoen had most species (10), while in Vassum only 2 species were recorded. However, there could be more species in Vassum as many species were in early instars and thus difficult to identify to species. None of the recorded trichopteran species are Red-Listed.

Lepidoptera
Three species of aquatic Lepidoptera were recorded from the ponds (Table 7). Tenor harboured all three species, while none were recorded in Elstadmoen, Hovinmoen, Fornebu and Skullerud. None of the recorded species are Red-Listed and all are fairly common in southern Norway, although there are fewer records for *Cataclysta lemnata*.

Megaloptera
The megalopteran, *Sialis fuliginosa*, was only recorded in Nøstvedt (Table 7), although typical of habitats rich in organic matter, both in still and running waters.

Coleoptera
Coleoptera, especially Dytiscidae, were relatively species rich (Table 6). Hovinmoen was the most species rich locality with 12 taxa of aquatic Coleoptera, although Tenor, Nordby, Elstadmoen and Vassum all have in excess of 8 taxa. *Agabus nebulosus*, Red-Listed as vulnerable (http://www.biodiversity.no/), is associated with newly established ponds lacking vegetation and there are recent records from Østfold. Its presence in Tenor is therefore surprising in view of the rich vegetation in and around the pond. None of the other aquatic Coleoptera are Red-Listed.

Diptera
Chironomidae are the dominant macroinvertebrate taxa in most of the ponds (Table 8). Other dipteran taxa, notably Chaoboridae were also frequently abundant. Four species of Chaoboridae were recorded. *Chaoborus crystalinus*, *C. flavicans* and *C. obscuripes* occurred in several ponds, but *C. pallidus* was only recorded from Fornebu. This latter species is Red-Listed as Near Threatened (NT)(http://www.biodiversity.no/). Chaoboridae are susceptible to predation by fish and larger predatory invertebrates such as Dystiscidae. This explains their absence from Skullerud and Enebekk.

There are few records of *Odontomyia* species (Stratiomyidae) and they may be rare, although there is little information on this group and they are not included in the Red List evaluation. *Tonnoiriella nigricauda* is the only species in the genus recorded from Norway and is previously known from a single locality in Hedmark (Ringsaker). The larvae live in eutrophic waters rich in organic material. The species is Red-Listed as vulnerable (VU) and was recorded from four ponds, Nøstvedt, Tenor, Taruldrud N and Taraldrud Junction.

Table 8. Taxa of Diptera recorded from the 12 ponds. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
DIPTERA												
CHIRONOMIDAE												
Chironomus sp.	xxx		x	x	xx	xx	xxx	x		xx	xxx	xx
Prodiamesa olivacea					x						x	
Tanypodinae indet	xxxx	xxx	xxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxx
Indet, larvae	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Indet, pupae	xx	xx	xx	xxx	xx	xx	xx	xx	xx	xxx	xx	xx
SIMULIIDAE	xx				x							
CERATOPOGONIDAE	xxx	xxx	xx	xxx	xx	xx	xxxx	xxx	xx	xxxx	xxx	xx
CULICIDAE	xx	x	x	xx		xx				xx	xxx	
CHAOBORIDAE												
Chaoborus crystallinus	xxx		xxx	xxx	xx		xx	xxx	xxx	xxx	xxx	
Chaoborus flavicans			x	x				x	x	xxx		
Chaoborus obscuripes, larvae	xx	xx		xxx			xxx	xxx	xx	xx	xx	
Chaoborus obscuripes, pupae	xx	x	xx						x			
Chaoborus pallidus										xx		
Chaoborus sp., pupae				xx						xx		
Chaoborus sp., larvae	xx						xx			xx	xx	
DIXIDAE												
Dixella sp.	xx	x		xx	xx	xxx	xx	xx	x	xx	x	xx
PSYCHODIDAE	x											
Tonnoiriella sp. (nigricauda?)	x			x			x	x				
Pericoma blandula												xx
EMPIDIDAE	x			xx	x			x	x			xx
LIMONIDAE		x										
Helius sp.	x				x		x	xx	xx	x	xx	
Dicranomyia sp.							x	xx		x	x	
Pilaria sp.					x	x		x				
DOLICHOPODIDAE	x											
EPHYDRIDAE	xx				xx	xx		x	xx	xx	xx	x
TIPULIDAE												
Tipula sp.	x	x		x				x			x	
SCIOMYZIDAE					xx	x	x	x				x
SYRPHIDAE					x				x		x	
STRATIOMYIDAE												
Odontomyia sp.										xx		
TABANIDAE											x	
Indet Diptera												
Pupae				x		xx						
Larvae				xx	xx							

3.2.5 *Amphibia*

Four amphibian species were recorded from the ponds (Table 9). The two frog species, *Rana alvaris* (Norw. spissnutefrosk)and *R. temporaria* (Norw. vanlig frosk), are common in southern Norway. *R. alveris* was only recorded from Taraldrud North, while *R. temporaria* was found in 6 of the 12 ponds. *Lissotriton (Triturus) vulgaris* (Norw. liten salamander) is not Red-Listed, but the crested newt, *Triturus cristatus* (Norw. stor salamander), is listed as Near Threated (NT). *L. (T.) vulgaris* occurred in 6 ponds, while *T. cristatus* only occurred in Tenor, Taraldrud North and Fornebu.

Table 9. Taxa of Amphibia recorded from the 12 ponds. x rare; xx uncommon; xxx abundant; xxxx dominant.

	NOS	ELS	HOV	TEN	NOR	ENE	TAN	TAJ	TAS	FOR	VAS	SKU
AMPHIBIA												
Rana alvaris, larvae							x				x	
Rana temporaria **,** larvae		x		x	xx	x	x					xx
Triturus cristatus , larvae				xx			x					
Triturus cristatus , adults							x			x		
Lissotriton vulgaris , larvae	x			xx	x		x	x		xx		
Triturus sp., larvae				xx								

3.2.6 *The Norwegian Red List*

Ten species recorded in the wet sedimentation ponds are Red-Listed, most in the Near Threatened (NT) and Vulnerable (VU) categories (http://www.biodiversity.no/) (Table 10). *Butomus umbellatus*, recorded from Nordby, is listed as critically endangered (CT), but has probably been introduced by planting in connection with the creation of the sedimentation pond in 2005. This may also be the case for the cladoceran, *Moina macrocopa*. Dormant eggs may have been introduced with soil and sediments associated with introduced macrophytes. Several of the Red-Listed species occur in more than one pond, suggesting that these species may have been under recorded in the past. Two Red-Listed species, the snail, *Planorbis planorbis,* and the dipteran species, *Tonnouriella nigricauda,* were abundant in the reference pond (see below).

Table 10. Species on the Norwegian Red List recorded in the ponds.

Species	Higher Taxon	Red List category	Ponds
Carex pseudocyperus	Cyperaceae	NT	Skullerud, Taraldrud N
*Butomus umbellatus**	Butomaceae	CR	Nordby
Moina macrocopa	Cladocera	NT	Nøstvedt
Planorbis planorbis	Gastropoda	DD	Nordby, Taraldrud N, Taraldrud Junction and Taraldrud S
Coenagrion lunulatum	Odonata	VU	Skullerud
Orthetrum cancellatum	Odonata	VU	Tenor
Agabus nebulosus	Coleoptera	VU	Tenor
Chaoborus pallidus	Chaoboridae	NT	Fornebu
Tonnouiriella nigricauda	Stratiomyidae	VU	Nøstvedt, Tenor, Taraldrud N, Taraldrud Junction
Triturus cristatus	Amphibia	NT	Tenor, Taraldrud N and Fornebu

*probably introduced

3.2.7 *Overall taxa richness among the ponds*

There was a considerable range in taxa richness from 67 in Hovinmoen to 128 in Nordby (Fig. 50). In Nordby, macrophytes diversity was the highest recorded, while zooplankton and benthic invertebrates were the second highest after Skullerud and Tenor, respectively. Tenor and Skullerud had also high overall richness, notably for benthic macroinvertebrates in Tenor and zooplankton in Skullerud. Enebekk and Hovinmoen had the lowest taxon richness, although the number of benthic invertebrate taxa was the same as Skullerud. The low macrophyte richness contributed to low overall richness in Hovinmoen, while in Enebekk zooplankton and benthic macroinvertebrate richness was the lowest recorded.

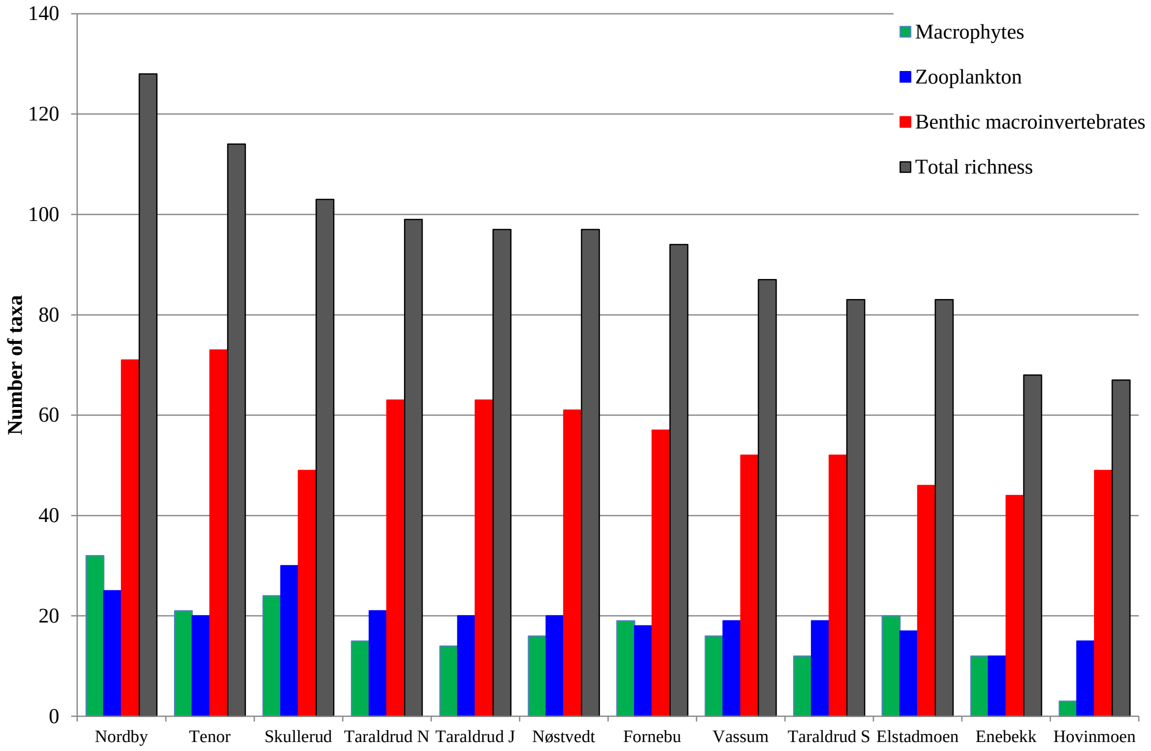


Fig. 50. Overall taxa richness in the 12 wet sedimentation ponds.

3.2.8 *Reference pond*

The macroinvertebrate fauna of the reference pond was dominated by oligochaetes, gastropods, *Asellus* (Crustacea in Fig. 51) and chironomids, there being little difference between the spring and autumn samples (Fig. 54). The number of macroinvertebrate taxa (c. 47) was similar to the less taxa rich sedimentation ponds, such as Skullerud and Hovinmoen. The faunal compostion was similar to Skullerud, with a large population of *Asellus*. This suggests organic enrichment. Odonata and Ephemeroptera were less abundant and less species rich than many of the other ponds, although there were two species of Plecoptera. Two Red-Listed species, the snail *Planorbis planorbis,* and the dipteran species, *Tonnouriella nigricauda,* were abundant (Table 11).

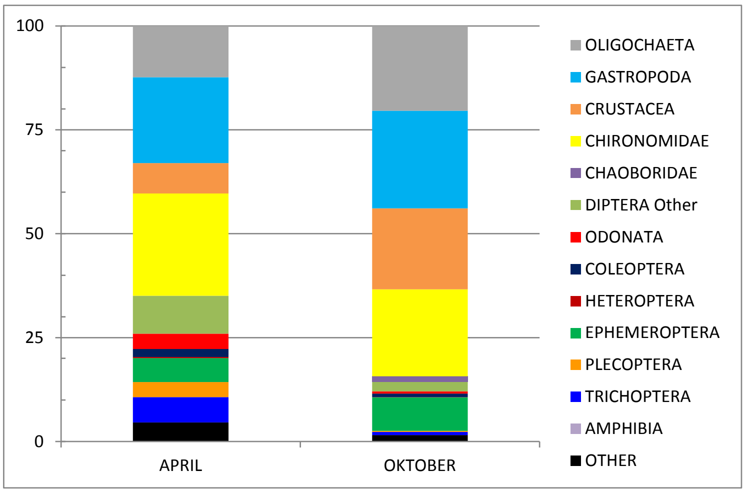


Fig. 51. Seasonal changes in the percentage of the main taxa of benthic macroinvertebrates in 2015 in the reference pond.

Table 11. Taxa and abundance of benthic macroinvertebrates recorded from the reference pond in 2015. x rare; xx uncommon; xxx abundant; xxxx dominant.

		HETEROPTERA	
HYDRA	x	Gerridae indet.	xx
TURBELLARIA	xxx	*Hesperocorixa sahlbergi*	xx
OLIGOCHAETA		*Notonecta glauca*	x
Lumbriculus variegatus	xxxx	**TRICHOPTERA**	
Indet. Naididae, Enchytraeidae	xxxx	Limnephilidae indet.	xxx
Indet. Tubificidae	xxx	*Limnephilus* sp.	xxx
HIRUDINEA		*Limnephilus binotatus* (?)	x
Erpobdella octoculata	xxx	*Limnephilus flavicornis*	xxx
Glossophonia complanata	x	*Limnephilus rhombicus*	xxx
GASTROPODA		*Nemataulius punctatolineatus*	xx
Armiger crista	xxxx	**LEPIDOPTERA**	
Bathyomphalus contortus	xxxx	*Cataclysta lemata*	xxx
Hippeutis complanatus	xxx	**COLEOPTERA**	
Planorbis planorbis	xxxx	Dytiscidae indet. (larvae)	x
Planorbidae indet.	xxxx	*Scirtes* sp., larvae	xxx
Succinea sp.	xx	*Haliplus* sp. (larvae)	x
BIVALVIA		*Haliplus* sp. (imago)	xxx
Sphaeridae indet	xxx	**DIPTERA**	
CRUSTACEA		CHIRONOMIDAE	
Asellus aquaticus	xxxx	*Chironomus* sp.	xx
ACARI	xx	Tanypodinae indet.	xxxx
COLLEMBOLA	xxx	Indet	xxxx
ODONATA		CERATOPOGONIDAE	xxx
ZYGOPTERA		CULICIDAE	xxx
Coenagrion hastulatum	xxx	CHAOBORIDAE	
Coenagrionidae indet.	xx	*Chaoborus crystallinus*	xxx
AESHNIDAE		DIXIDAE	
Aeshna cyanea	x	*Dixa* sp.	xx
Aeshna grandis	xx	CYLINDROTOMIDAE	
Aeshna juncea	xx	*Phalacrocera replicata*	x
LIBELLULIDAE		LIMONIIDAE	
Leucorrhinia rubicunda	x	*Helius* sp.	xx
EPHEMEROPTERA		PSYCHODIDAE	
Cloeon inscriptum	xxxx	*Tonnoiriella* sp.	xxx
PLECOPTERA		SCIOMYZIDAE	xx
Nemoura cinerea	xxx	STRATIOMYIDAE	
Nemurella pictetii	xx	*Odontomyia* sp.	xxxx
Nemoura sp.	xxx	Indet. Pupae	x

3.2.9 *Environmental variables and biodiversity*

There was no clear single correlation between total taxa richness and age, size, average daily traffic (AADT) and distance to the nearest water body for the studied wet sedimentation ponds. However, there was a trend for increasing richness with age and AADT, although none of these trends were significant. However, both zooplankton and macroinvertebrate richness is clearly dependent on the development of macrophytes. This is obvious in Hovinmoen where there are few macrophyte species and the vegetation is as yet poorly developed.

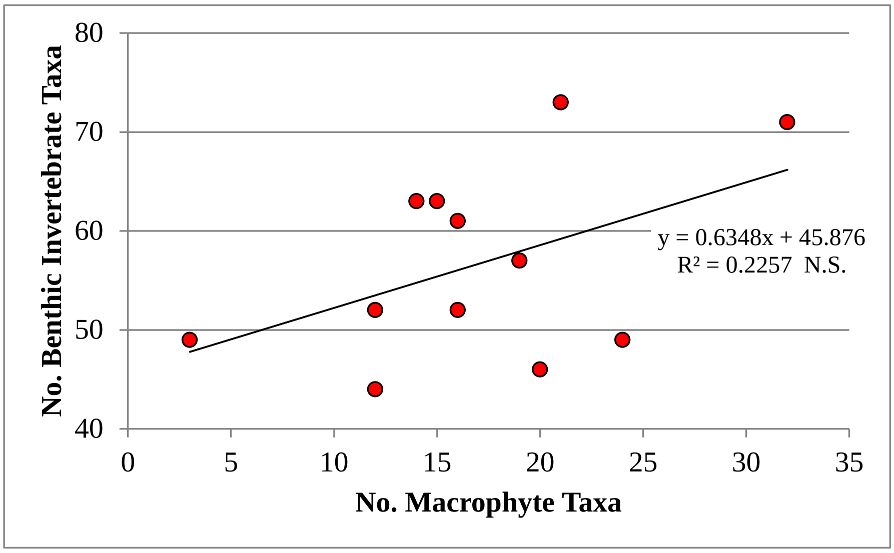


Fig. 52. Relationship between the number of macrophyte taxa and the number of benthic microinvertebrate taxa. The outlier Skullerud is omitted as the zooplankton community is enriched from above-lying lakes.

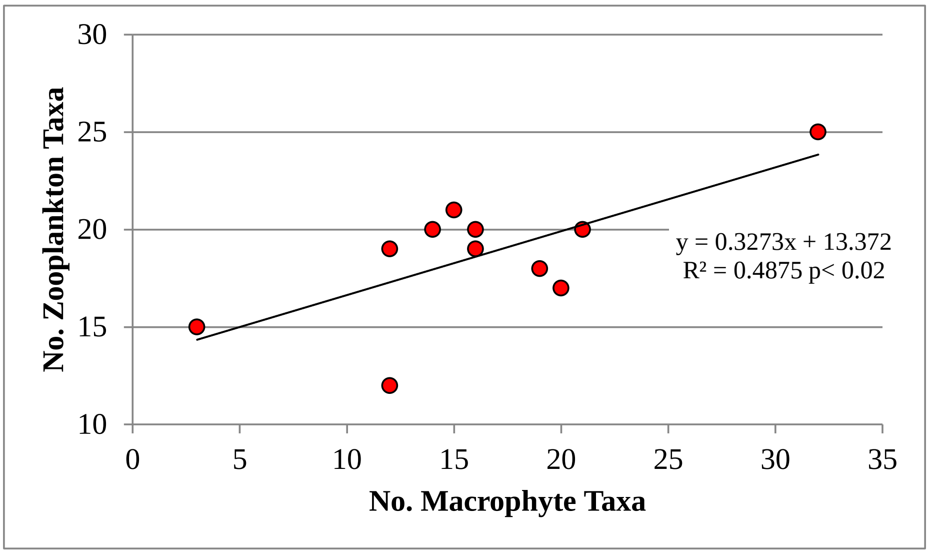


Fig. 53. Relationship between the number of macrophyte taxa and the number of benthic invertebrate taxa.

There is a significant relationship between the number of macrophyte taxa and the number of zooplankton and benthic microinvertebrate taxa (Fig. 52). The relationship between macrophyte taxa and benthic macroinvertebrate taxa was, however, not significant, although the trend was obvious (Fig. 53). At the same time as the aquatic and emergent vegetation develops, the composition of the macroinvertebrate community changes, from an Ephemeroptera rich community to one rich in Odonata. This can be clearly seen in the contrast between Hovinmoen and Elstadmoen, with 6-7 ephemeropteran species and none or few Odonata, and the Taraldrud ponds that together with Tenor had only 3-4 ephemeropteran species and at least 9-10 species of Odonata. This inverse relationship between the number of odonate taxa and the number of ephemeropteran taxa is statistically significant (Fig. 54).

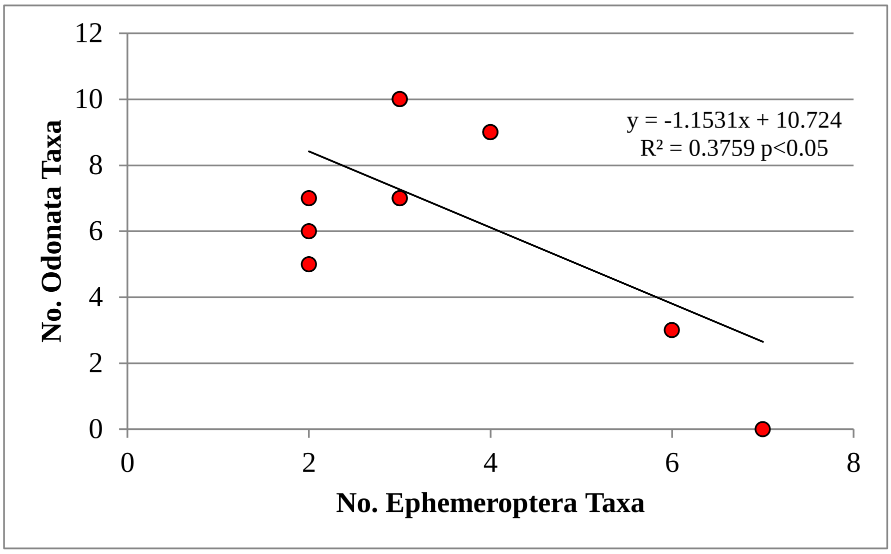


Fig. 54. Relationship between the number of odonate taxa and the number of ephemeropteran taxa. The outlier Enebekk is omitted as this pond is unusual in several respects and has few species of both orders.

4. Discussion

The biodiversity of natural ponds has been the subject of many studies over the last decade (e.g. Jeffries 2011, 2012; Boix et al. 2012; Bosiacka & Pienkowski 2012; Céréghino et al. 2012). However, there have been few studies of biodiversity in wet sedimentation ponds constructed for road runoff and most have focused on a single group of organisms, such as Odonata and Amphibia (Scher & Thièry 2005) or aquatic macroinvertebrates (Le Viol et al. 2009 ; Stephansen et al. 2016). In the present study we have documented biodiversity in macrophytes, zooplankton, benthic micro- and macroinvertebrates and amphibians in twelve Norwegian wet sedimentation ponds in Oslo and the adjoining counties of Akershus and Østfold. The ponds differed in several characteristics, such as age, size, ecosystem development and concentration of pollutants. All twelve ponds, especially the sediments, were heavily polluted with both heavy metals, PAH and other organic compounds (Hermandos Santos 2014). Despite this extensive pollution from road runoff, there was considerable biodiversity in all ponds, although there were clear differences between ponds and between organism groups.

There was no clear single correlation between total taxa richness and age, size, average daily traffic (AADT) and distance to the nearest water body for the studied wet sedimentation ponds. However, there was a trend for increasing richness with age and AADT, although neither of these trends are significant. In an ordination of earlier data from twelve wet sedimentation ponds, eight of which were the same as in the present study, Sun et al. (submitted) showed that more species and taxa were present in the older ponds. This is in agreement with Hart & Horwitz (1991) who suggested that older ponds have greater species richness. Moreover, Williams et al. (2008) also found that compared with younger ponds, 6-12 year old ponds were able to support significantly more species and more uncommon species, although Gee et al. (1997) found that the number of taxa of macroinvertebrates was not significantly related to pond age. In our study, there may be uncertainties related to pond age as maintenance including removal of sediment and vegetation may have an impact on faunal composition.

Hsu et al. (2011) found that taxon richness and macroinvertebrate density increased with the cover of aquatic macrophytes that served as refuges for many aquatic organisms and provided additional food resources to the macroinvertebrates in ponds (Dodson 2008; Hsu et al. 2011). However, not all macroinvertebrates prefer ponds with a high percentage of vegetation cover. Certain taxa living at or near the surface of water, which exposes them to visual predators and surface turbulence (De Szalay and Resh 2000), tend to prefer environments with dense vegetation. In contrast, other taxa, such as Hemiptera and Dytiscidae, have been found to be negatively correlated with plant cover (De Szalay and Resh 2000).

Surprisingly, there was a trend for increasing biodiversity with increasing traffic (AADT). This was also found by Thygesen (2013) and Sun et al. (submitted). This may be due traffic density being highest where the ponds are largest. Large ponds may be important in reducing contaminant concentrations. Kayhanian et al. (2003) found that although AADT has an influence on most highway runoff constituent concentrations, there was no direct linear correlation between pollutant concentration in highway runoff and AADT.

Among the macrophytes, the number of taxa ranged from 28 in Nordby to only three in Hovinmoen. Nordby is four years older than Hovinmoen and aquatic macrophytes were planted in Nordby. Hovinmoen is also located in a forest area on moraine deposits of sand and gravel, while Nordby is in the midst of productive agricultural land. The extent of aquatic vegetation also varied between ponds, with extensive cover of *Potamogeton* species in Taraldrud North, Taraldrud Junction, Taraldrud South, Fornebu, Tenor and Nordby and *Typha latifolia* in Nøstvedt and Nordby. In our study macrophytes taxa richness influences taxa richness in both zooplankton and benthic invertebrates, with increasing zooplankton and benthic invertebrate richness with increasing macrophytes richness, although the relationship was not significant for benthic invertebrates. Aquatic macrophytes clearly provide habitat structure and diversity for the pond fauna. The importance of aquatic macrophytes for macroinvertebrate community composition has been earlier demonstrated in wetlands constructed for wastewater treatment (Hsu et al. 2011), in stormwater ponds (Dodson, 2008) and in wet sedimentation ponds by Sun et al. (submitted). In a polish study of plant distribution in natural ponds (Bosiacka & Pienkowski 2012), the advantage of proximity for colonization and the disadvantage of isolation were highlighted, but there was no obvious relationship for the studied wet sedimentation ponds.

In general the zooplankton and benthic microinvertebrate fauna of the ponds was typical of natural ponds, most ponds having about 20 taxa. Zooplankton and benthic microinvertebrate richness was clearly dependent on the development of the macrophyte community. The most important pelagic genera were the cladocerans, *Daphnia*, *Bosmina* and *Ceriodaphnia* together with the copepod*, Acanthodiaptomus denticornis*, while benthic taxa, *Eucyclops*, *Simocephalus,* Ostracoda and Chydoridae became more common with increasing growth of macrophytes.

In temporary ponds, suffering intermittent drying, there is a change in the macroinvertebrate community (Jeffries 2011). However, all the wet sedimentation ponds were permanent and none of them dried out, although water levels in some of the ponds varied over time in relation to temporal variation in road runoff.

The abundance and diversity of zooplankton and amphibian communities in ponds is strongly influenced by the presence of fish (Koch 2003; Jeliazkov et al. 2014). Skullerud was the only study pond with a permanent fish population. In Skullerud taxa richness was high due to colonization from above-lying lakes during high flows, although *Bosmina longirostris* was dominant because of fish predation. *Daphnia* species would be expected to dominate the cladoceran fauna in the absence of fish. As to be expected, amphibian richness in Skullerud was low with only one species recorded.

In the same way as wet sedimentation ponds have been constructed to receive road runoff, ponds and wetlands have also been constructed to receive agricultural runoff. In fact, one of the ponds in the present study, Nordby, has two inlet basins, one for receiving road runoff and one receiving agricultural runoff. As is the case with wet sedimentation ponds, freshwater invertebrate biodiversity, including several Red-Listed species, can be high in ponds in the same region constructed for agricultural runoff (Stokker et al. 1999; Ekeberg & Walseng 2000; Hov & Walseng 2003).

The diversity of benthic macroinvertebrates was high in most of the ponds and in Tenor, Nordby, Nøstvedt, Taraldrud North and Taraldrud Junction, the number of taxa exceeded 60. However, there was a clear difference in the development of the macroinvertebrate community across the ponds. As the aquatic vegetation develops, there is a significant change from an ephemeropteran rich community to one rich in Odonata. Whereas many species of herbivorous Ephemeroptera thrive well in open water habitats with extensive periphyton growth, the predatory Odonata rely on macrophytes for camouflage when stalking their prey.

Amphibians are threatened by habitat loss and several species are on the European Red-Lists. Wet sedimentation ponds have the potential to provide suitable refugia for such Red-

Listed species. Amphibians were recorded from all the ponds, although the individual species were only recorded in between one and six ponds.

Several of the species recorded in the ponds, ten in total, are on the Norwegian Red-List (http://www.biodiversity.no/). They include species in all the major floral and faunal groups studied in this investigation, macrophytes, zooplankton, benthic macroinvertebrates and amphibians. Four species are listed as Near Threatened (NT), four as Vulnerable (VU), one as Critically Endangered (CR) and one as Data Deficient (DD). Although some of these species may be under recorded, it is clear that the wet sedimentation ponds provide habitat for endangered species.

In an earlier study (Thygesen 2013; Sun et al. submitted) of twelve wet sedimentation ponds, eight of which were the same as in the present study, the analyses showed that metals, chloride, phosphorous, and pond size were the most important variables governing the variation in macroinvertebrates. Nearby ponds were also important for macroinvertebrate diversity. Small ponds with high pollutant loadings were with low diversity and dominated by a limited number of pollutant tolerant taxa.

In a recent study in Denmark, Stephansen et al. (2016) invertebrate diversity in nine wet sedimentation ponds was compared with that in eleven small shallow lakes. Their analysis showed that the invertebrate populations of the ponds and small lakes could not be distinguished despite the pollution loads to the ponds. In an earlier study, Le Viol et al. (2009) also showed that the macroinvertebrate fauna in wet sedimentation ponds was at least as rich and diverse as surrounding ponds. In a study focused on Odonata and amphibians in wet sedimentation ponds, Scher & Thiéry (2005) found high Odonata richness with some regionally less common taxa, while amphibians were characterized by widespread and /or pioneer taxa.

In a study of stormwater ponds in an urban area Hassal and Anderson (2015) found similar macroinvertebrate community structure compared to natural wetlands. Our reference pond, although clearly not a natural pond, had most of the faunal elements present in the wet sedimentation ponds. In a study of natural farm ponds in the same region as the wet sedimentation ponds (Koch 2003) macroinvertebrate community structure was similar, although there were differences in the species richness, largely due to different levels of identification in the various orders.

5. Conclusions

There was considerable biodiversity in the twelve studied wet sedimentation ponds. Although taxa richness varied across the range of ponds, overall taxa richness was high within aquatic macrophytes, zooplankton, benthic macroinvertebrates and amphibian and similar to natural ponds. Species on the Norwegian Red-List were recorded in all these major groups. The development of the macrophyte community determined the richness of zooplankton and benthic micro- and macroinvertebrate communities. Wet sedimentation ponds make a positive contribution to biodiversity across a wide range of taxa that includes several Red-Listed species. In this way they contribute to offset both some of the negative effects of road traffic and the reduction in the number of natural ponds through urbanization and changes in agricultural practice.

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