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Constructed wetlands: high-quality habitats for Odonata in cultivated landscapes

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Abstract

In Norway and throughout the rest of Europe, a continuous decline in the number of small lakes and ponds has taken place. As a consequence, many pond-dwelling organisms have become rare or extinct. Constructed wetlands (CWs) have since the 1990s been used as a remedial action against agricultural runoff. This study has investigated the potential these wetlands have as habitat for freshwater organisms, exemplified by Odonata. Four different CWs in southern Norway were investigated, and larval Odonata species composition was related to a wide range of environmental variables. The material was ordinated using Detrended Correspondence analysis (DCA) and Canonical Correspondence analysis (CCA). All the CWs had high nutrient values and high diversities of aquatic plants. Of the 11 Odonata species found, the richest CW contained 10 species. During the study, one of the CWs was exposed to diazinon (an insecticide). Sun exposure and nutrient content were the most important variables determining species composition. The species that dominated the wetlands were typically euryoecious species, indicating harsh living conditions. Despite the high nutrient content, the results clearly indicate that CWs have an obvious role in pond habitat creation, especially in areas managed according to pesticide-free management.

Introduction

The single most important cause of insect extinctions is the destruction of natural biotopes (Pyle et al. 1981). During the last fifty years there has been a continuous decline in the number of farm ponds and small lakes in the cultivated landscapes of Southern Norway (Olsvik et al. 1990; Olsvik & Dolmen 1992). As an example, the municipality Aurskog-Høland has experienced a pond habitat loss of 48% since 1958 (Reierstad 1999). This number seems to parallel that of pond losses throughout Scandinavia and the rest of Europe (Hull 1997). In Norway, this decline is mainly due to the Norwegian law of 1957, demanding pond owners to fence ponds or close them up (Dolmen 1995a). Furthermore, wetlands have vanished because of conversion of natural habitats for agricultural purposes. As a consequence, many common pond-dwelling organisms have become rare and even extinct, including some odonates (Olsvik et al. 1990; Dolmen 1995a). There have been several studies on benthic, littoral and pond dwelling organisms in Norway (e.g. Halvorsen et al. 1994; Sloreid et al. 1995; Arnekleiv & Haug 1995; Bækken et al. 1999), but only a few of them have focused on declining species diversity in ponds (Olsvik et al. 1990; Dolmen 1995b). On an international basis, published research about wetland insects has proliferated since the middle of the 1980s (Batzer & Wissinger 1996).

When natural biotopes have been lost through landscape disturbance, it should be possible to recreate them (Steytler & Samways 1995). One of the major providing actions against pond declining is to build and restore ponds, and to keep them in different succession stages (Biggs et al. 1994; Collinson et al. 1995). This work is expensive, and a great financial support is needed. No specific pond conservation strategies are financed in Norway to this date. However, the Ministry of Agriculture has since 1993 funded projects that will establish and restore natural animal and plant life elements of cultivated landscapes (Ministry of Agriculture 1993).

Since the beginning of the 1990s constructed wetlands (CWs) have been used as a remedial action against agricultural runoff in Norway. CWs are artificial wetlands constructed as expansions of natural streams running through cultivated land. Such ponds hinder runoff from entering waterways by withholding particles, nitrogen and phosphorus (Braskerud 1997). Almost similar wetlands, called Water Pollution Control Ponds (WPCP), with the same purpose have been constructed during the 1990s in Australia (Bayliss 1999). Stokker et al. (1999) found a high species diversity of freshwater organisms in their study of two Norwegian CWs. Thus, it seems clear that CWs play a role in providing alternative habitats for wetland fauna and flora. Farmers in Norway are generally willing to create CWs to reduce runoff, but need financial support. If, in addition, building of CWs increases wetland diversity, it will be easier to obtain money from subsidizing authorities.

As top predators, both anisopterans and zygopterans are important and widespread components of freshwater ecosystems (Corbet 1980). Biotope preferences of Scandinavian dragonflies have recently been well documented by Sahlén (1996) and Nielsen (1998). Because of the complex habitat requirements of individual species, the presence of a vigorous and diverse odonate fauna will always be a reliable indicator of the stability, health and integrity of a wetland ecosystem (Corbet 1999). A study of odonate communities in different types of CWs will give valuable information of how CWs can serve as habitat for freshwater organisms in general. The aim of this study is to assess the properties of CWs as freshwater habitat exemplified by odonates. The investigation is a part of a larger project financed by the Ministry of Agriculture, where the silt-filtering ability of CWs is a major focus.

Materials and methods

Study area and environment

Four CWs in the drainage basin of the Halden catchment area in southern Norway, south-east of Oslo, were investigated during the summer seasons of 1997 and 1998 (Fig. 1).

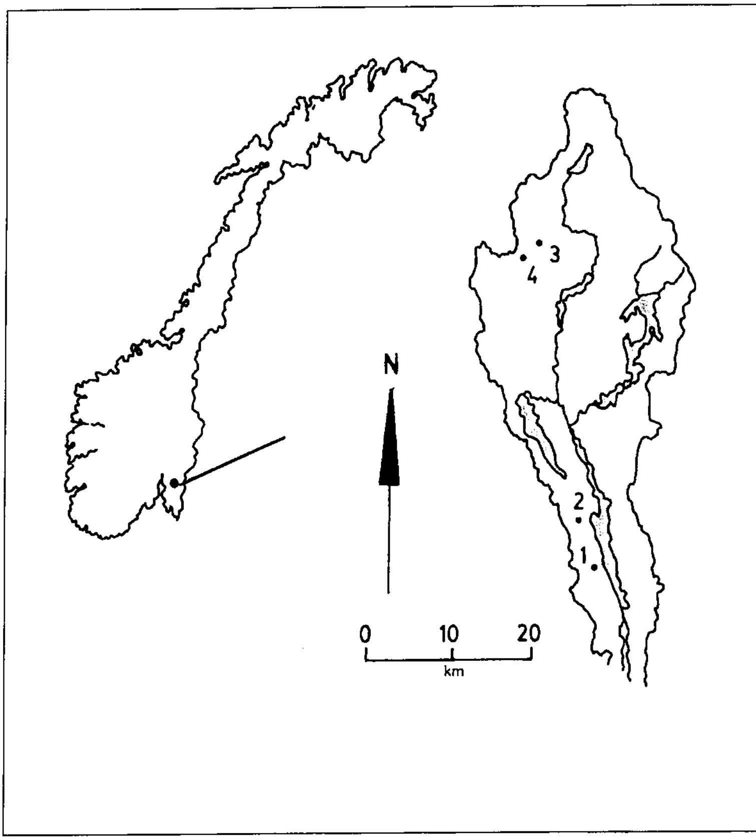

Figure 1. Map of Norway and an enlarged section of the upper Halden catchment area in southern Norway. The line and the numbers designate the studied constructed wetlands (CWs) (1: 59°30'00''N, 11°35'00''E; 2: 59°36'50''N, 11°33'38''E; 3: 59°55'50''N, 11°24'38''E; 4: 59°55'28''N, 11°24'13''E).

Two CWs were located in Aurskog-Høland, Akershus, and the two others in Marker, Østfold. A CW consisted of a sedimentation chamber near the inlet, usually 1-2 m deep and up to 10 m long. The following wetland filter was a 40-90 m shallow stream planted with aquatic plant species. The CWs were constructed between two fields and thus highly exposed to runoff from agriculture. Sediments were held back in the sedimentation chamber and nutrients were assimilated in the wetland vegetation (Braskerud 1997). The CWs in this study were all built in 1990. None contained fish. The size of the wetlands varied from 260 to 900 m^2; they were all relatively sun exposed, and had a wide range of aquatic plant species. The CWs are listed with characteristics and environmental variables in Table 1. Agriculture was the prominent trade in the district, and cultivated landscapes dominated the study area (forestry, corn and livestock).

Sampling of species

Odonate larvae were sampled once per month during May to September in 1997 and from April to September in 1998. Each CW was divided into sections of 3-4 m^2 from inlet to outlet to get comparable samples. Samples were obtained by one "Z-stroke" per section with a frame net. The frame net was submerged into the water and pulled 1.5 m lengthwise 2-3 cm over the waterbed - to the left, then right, and back to the left (for details see Dolmen 1992). The frame net had a 25 x 25 cm frame with mesh-width 0.5 mm. This method gives a semi-quantitative estimate of larval density in each section, and a measure of relative density between the sections. Adults close to the wetland were identified by sight observation, or by collecting individuals. The species were identified according to Ander (1926), Franke (1979), Askew (1988) and Hammond et al. (1997).

Environmental variables

During the seasons of 1997 and 1998, 13 categories of environmental variables were recorded for each CW (Table 1). Area, length, sun exposure and vegetation were considered constant through the season and year. Sun exposure was estimated by a method developed by Refsaas (1986), based on sun exposure in the morning, midday and evening. The intensity of sun radiation ranges from 0 to 2 (0 = shade, 1 = moderately shade, 2 = sunny), and the highest value is thus six if the CW is fully exposed to sun radiation in the morning, midday and evening. The vegetation index is a qualitative description of vegetation in the wetland and waterside. It describes the relative species richness of plants in a given locality compared to the species richness of plants registered in all the studied localities, based on Romme (1982). All the water quality variables were measured near the outlet. Phosphorus and nitrogen were measured with a composite sampler (for further description see Braskerud 1997). Flow rates were continually measured by a data-logger and converted into flow rate per month. The remaining water quality variables were derived from spot checks and measured approximately once per month. Number of measures/spot checks during the season and year is given for each CW in Table 1. In addition, in relation to their project, Jordforsk checked for pesticides in nos 1 and 2 (Braskerud 1997).

Ordination of data

The species material was ordinated using CANOCO version 4 (ter Braak & Smilauer 1998). Both detrended correspondence analysis (DCA) (Hill 1979; Hill & Gauch 1980) and canonical correspondence analysis (CCA) (ter Braak 1986, 1987) options were used. The CWs were ordinated with species data from each sampling month. In CCA, some of the environmental variables were $\log_{10}x$-transformed to obtain normality. The ordination axes were interpreted using Spearman Rank Correlation between plot coordinates and environmental variables (Conover 1980), using SigmaStat 1.0 (Jandel Scientific 1994). Because of few species and few sites, only the explanatory power of the two first ordination axes was considered.

Table 1. The four constructed wetlands (CWs) and the measured environmental variables. The values are averages of samples through the seasons and year with standard errors. The superscripted numbers show the number of samples taken.

Environmental variables	Abbreviation	CW no. 1 Kinn	CW no. 2 Storløs	CW no. 3 Berg	CW no. 4 Finsrud
Area (m^2)	AREA	345	265	900	630
Sun exposure	SUN	4	6	6	6
Length (m)	LEN	70	80	105	80
Vegetation index	VEG	31.8	34.1	34.1	36.4
Conductivity (mSm^{-1})	K25	11.6 ± 1.9^{10}	9.7 ± 1.0^{9}	5.3 ± 0.4^{10}	3.6 ± 0.3^{10}
Phosphorus (mgl^{-1})	PHOS	0.25 ± 0.03^{12}	0.23 ± 0.04^{7}	0.09 ± 0.01^{10}	0.12 ± 0.04^{4}
Nitrogen (mgl^{-1})	NITR	4.28 ± 0.81^{12}	4.94 ± 1.38^{7}	2.97 ± 0.57^{11}	1.39 ± 0.48^{4}
Acidity (pH)	PH	6.3 ± 0.1^{10}	6.4 ± 0.1^{9}	6.3 ± 0.1^{10}	6.1 ± 0.2^{10}
Water colour (Pt)	PT	133 ± 25^{9}	97 ± 21^{8}	112 ± 10^{9}	129 ± 11^{9}
Hardness ($CaCO_3$)	HARD	58 ± 12^{9}	51 ± 5^{9}	36 ± 4^{10}	24 ± 2^{10}
Water temperature (°C)	WTEMP	12.3 ± 1.5^{10}	12.3 ± 1.3^{9}	13.1 ± 1.7^{10}	13.3 ± 1.7^{10}
Flow rate (ls^{-1})	FLOW	6.5 ± 1.7^{11}	7.6 ± 2.5^{11}	10.7 ± 3.0^{11}	3.5 ± 2.5^{5}
Diazinon (μgl^{-1})	DIAZ	0	0.29^{1}	0	0

Results

Species richness in the CWs

Of the 932 larvae collected, 753 were identified to species and included in the analyses. The analysed species material consisted of 11 species (Table 2).

The odonate community in CW no. 1 was dominated by *Aeshna cyanea* (80.3% of identified larvae in the CW). No. 1 had a total of six identified species, including *Pyrrhosoma nymphula* that was only found here (Table 2). This CW had a high nitrogen and phosphorus content and the lowest sun exposure value (Table 1).

The water in CW no. 2 had a high nutrient content (Table 1). Two odonate species were registered early in the season of 1997. After this, no odonate larvae were found. A considerable decline in the amount of other invertebrates was also observed in this CW that year (Bang 1999). A single spot check of water analysed for pesticides, in September 1997, revealed remains of diazinon (Braskerud 1997). Diazinon is an insecticide that has lethal or sublethal effects on aquatic insects, even in low concentrations (Environmental Protection Branch 2000).

In the largest CW, no. 3, seven species were registered. Two species dominated, the zygopteran *Coenagrion hastulatum* (18.5%) and the anisopteran *Aeshna juncea* (57.3%). The water was nutrient rich, but levels were not as high as in no. 1 and 2.

The fourth CW had good-sized populations of *C. hastulatum* and *A. juncea* as well. Here *C. hastulatum* dominated (53.7%), whereas 35.3% of the larvae belonged to *A. juncea*. This CW had the highest number of species (10) and the highest vegetation index value (Tables 2 and 1, respectively). It had the lowest nutrient content, but was still nearly hypereutrophic, as defined by Forsberg & Ryding (1980).

In no. 1 larvae were found near the outlet only, whereas no differences in species composition and abundance between the sections were found in nos 2, 3 and 4. These differences appeared to be related to the full sedimentation chamber in no. 1, resulting in a shallow narrow stream path near the inlet.

Generally, most of the species detected as larvae were also observed as adults nearby. In 1998 many species were found as larvae only, perhaps due to the bad weather that year. Climatic data for Akershus, April-September, showed a marked increase in precipitation in 1998 (582 mm) compared to 1997 (298 mm). Mean water temperatures were 9.1°C in 1997 and 10.3°C in 1998 (CW no. 3).

Table 2. The species and number of Odonata larvae collected May-September 1997 and April-September 1998 in the four constructed wetlands (CWs).

		CW no.				Total number
	Abbreviation	1	2	3	4	of specimen
Lestes sponsa (Hansemann)	LE SP	5	0	37	7	49
Coenagrion armatum (Charpentier)	CO AR	0	0	0	2	2
C. hastulatum (Charpentier)	CO HA	7	4	53	204	268
Pyrrhosoma nymphula (Sulzer)	PY NY	1	0	0	0	1
Aeshna cyanea (Müller)	AE CY	61	6	10	10	87
A. grandis (Linnaeus)	AE GR	1	0	16	6	23
A. juncea (Linnaeus)	AE JU	1	0	164	134	299
Cordulia aenea (Linnaeus)	CO AE	0	0	0	1	1
Somatochlora metallica (Vander Linden)	SO ME	0	0	4	8	12
Sympetrum danae (Sulzer)	SY DA	0	0	2	5	7
Leucorrhinia rubicunda (Linnaeus)	LE RU	0	0	0	4	4
Unidentified species		1	0	38	140	179
Total larvae found in the CW		77	10	324	521	932

Ordination

The two first DCA ordination axes could explain 48.6% of the species variance (Table 3). As many as nine environmental variables were significantly correlated with the first ordination axis, and eight were correlated with the second axis (Spearman Rank, Table 3). Conductivity, hardness, acidity and vegetation appeared to be the most important significant variables.

Table 3. DCA of the samples from the four constructed wetlands[1].

	1. axis	2. axis
Eigenvalue	0.682	0.215
Lengths of gradient (SD)	2.196	2.189
Cumulative explanatory power (%)	36.9	48.6
K25	r = - 0.70***	r = - 0.72***
HARD	r = - 0.60***	r = - 0.58**
PH	r = - 0.63***	r = - 0.43*
VEG	r = 0.57***	r = 0.76***
SUN	r = 0.48**	r = 0.70***
AREA	r = 0.41*	r = 0.60**
FLOW	r = 0.51**	-
WTEMP	r = - 0.36*	-
LEN	r = 0.35*	r = 0.55***
PHOS	-	r = - 0.65***

[1] r shows the correlation between the environmental variable and the two first ordination axes (Spearman Rank). Only significant variables are listed, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

In the DCA species plot the species were scattered into a cluster to the upper right of origin (Fig. 2a). Three species were outliers: *Cordulia aenea*, *Leucorrhinia rubicunda* and *P. nymphula*. The month-test plot showed a differentiation along the second axis between CW 1-2 and CW 3-4, with only a small overlap (Fig. 2b). This underlines the differences in species composition between the CWs. There was no correlation between time of year and these clusters. CW no. 1 had only small variations in the location of spots in the plot, five spots being on the same coordinate on the second axis (Fig. 2b). Compared to the species plot (Fig. 2a) this point coincides with *A. cyanea*. CW no. 3 had the most densely packed cluster, moderately differentiated along the first axis.

To interpret the plots from DCA, a CCA-ordination was run on the results from DCA. Variables that influenced other variables were omitted. The two first axes could explain 81.3 % of the species-environment correlation (Table 4). The axes were significant (p = 0.005, Monte Carlo). The species plot revealed a cluster of species around origin (Fig. 3). Only two species differed from the others and seemed to have a preference for high phosphorus content and were negatively correlated with sun exposure: *P. nymphula* and *A. cyanea*. Compared to the DCA ordination plot (Fig. 2b), the positions for the spot check dots in the CCA ordination plot (Fig. 4) are relatively alike. The dots are separated as CW 1-2 and CW 3-4, but this time spread along the first axis. The species composition of CW nos 1 and 2 is negatively correlated with sun exposure and vegetation. The samples from CW no. 3 are positioned both over and under the first

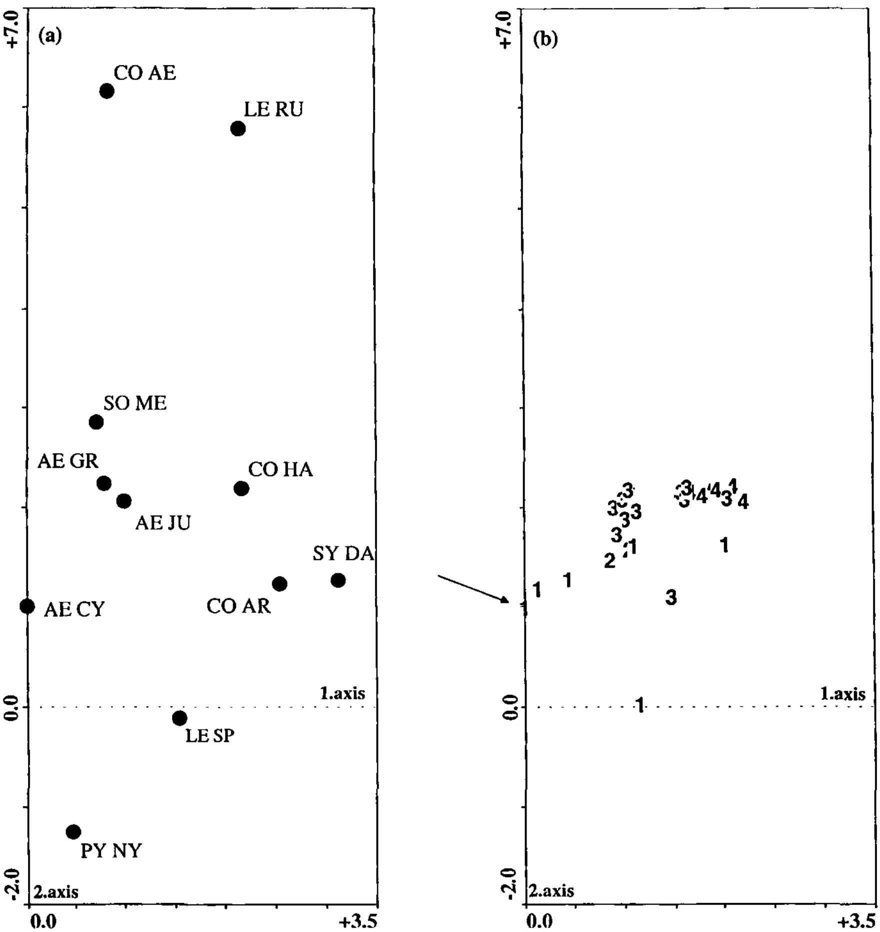

Figure 2. DCA ordination plot of (a) Odonata species and (b) samples from the four CWs, May-September 1997 and April-September 1998. In (b), every sample represents one month (abbreviations in Table 2). The arrow designates five overlapping points.

Table 4. CCA of the samples from the four constructed wetlands.

	1. axis	2. axis
Eigenvalue	0.600	0.342
Species-environment correlation	0.946	0.838
Cumulative%-variance, species data	32.5	51.0
Cumulative %-variance, species-environment correlation	51.8	81.3

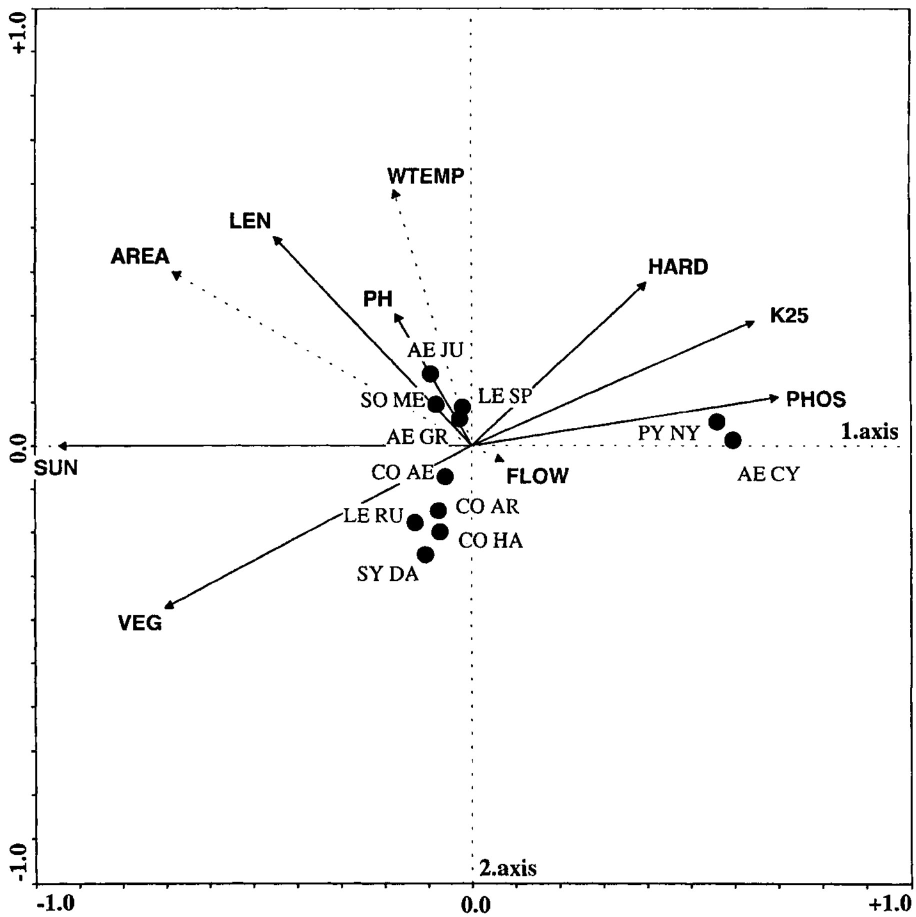

Figure 3. CCA ordination plot of Odonata species and environmental variables from the four CWs, May-September 1997 and April-September 1998. Only significant variables are included. Dotted lines $p < 0.05$, solid lines $p < 0.001$ (abbreviations in Table 1 and 2).

axis, close to the left of the second axis. The species composition seems to be positive correlated with both acidity and vegetation. The samples from CW no. 4 are located generally below the first axis and are correlated with vegetation.

Discussion

As pointed out by Bayliss (1999), CWs have an obvious role in habitat creation, restoration and protection. This study demonstrates that they have great potential as

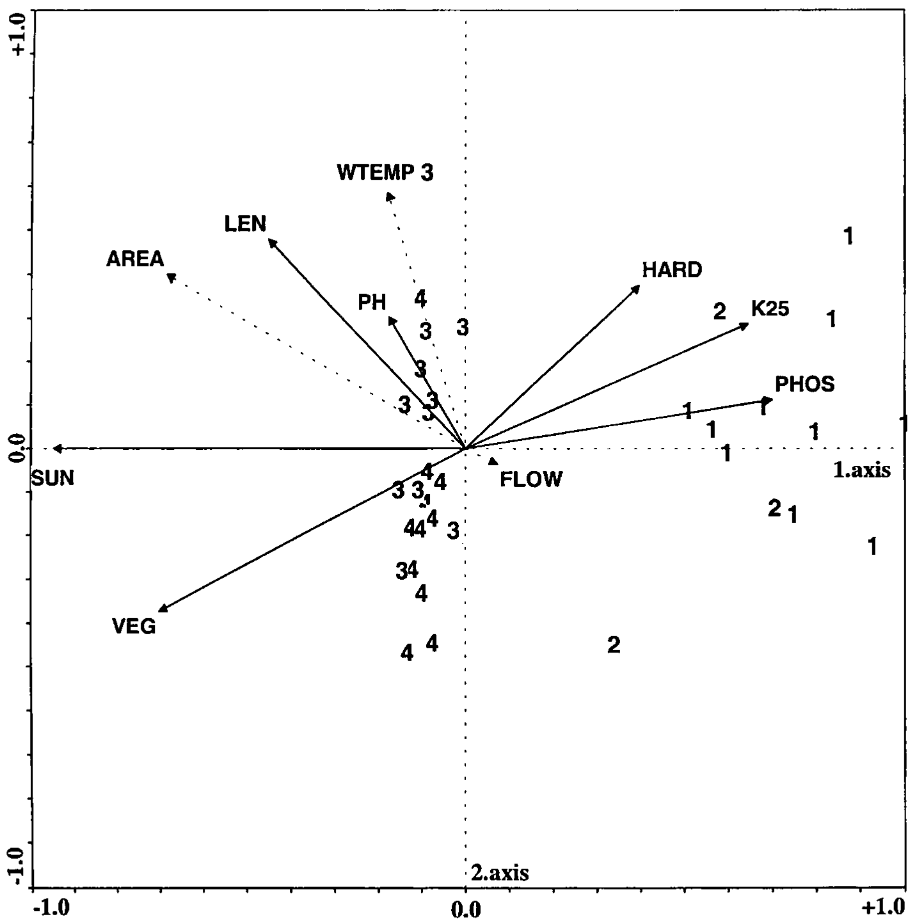

Figure 4. CCA ordination plot of month samples and environmental variables from the four CWs, May-September 1997 and April-September 1998. Only significant variables are included. Dotted lines $p < 0.05$, solid lines $p < 0.001$ (abbreviations in Table 1).

habitat for odonates and probably other freshwater organisms as well. The investigated CWs captured over half the Odonata species registered in the surrounding area, and two of them, nos 3 and 4, could be characterised as high-quality freshwater habitats. No. 4 is a species-rich wetland, compared to farm ponds and small lakes investigated in a similar way in southern Norway (Dolmen 1992; Kjærstad 1998). An investigation of 11 natural ponds of the same local area as the CWs revealed ten species in the richest pond (Bang 1999).

From the fact that the clusters in both of the ordinations are relatively similar (only spread along different axes), one can assume that the same environmental variables explain the variation in both DCA and CCA (Kremen 1992). Hardness, conductivity and phosphorus can play a role in determining the species composition in CW no. 1, and maybe even in CW no. 2 (Fig. 4). Thus, according to the field samples and ordination results, water quality seems to be important determining species composition in all the CWs.

According to the high values of conductivity, nitrogen and phosphorus, the CWs were highly polluted. Periodically high amounts of pesticides and allochtonous material also pose special challenges to the organisms. The most common aeshnid in Norway (Olsvik et al. 1990), *Aeshna juncea*, dominated in nos 3 and 4. It can be found in many different sorts of habitats such as forest lakes, marshes and cultivated landscapes (Sahlén 1996), and has also been found to be abundant in oligotrophic ponds that are partly dried out during the summer (Nielsen 1998). Another species that dominated was *Coenagrion hastulatum*. It is often the dominant zygopteran species in a pond (Norling 1984; Hargeby et al. 1994), and is described as the most frequent zygopteran in Norway (Aagaard & Dolmen 1977; Dolmen 1992). It exploits a wide range of habitats. The larvae can survive dry summers with very little water (Corbet 1999). Another zygopteran, the rare *C. armatum*, was found in no. 4, but not in the other CWs. In Great Britain this species is extinct because of pollution and heavy eutrophication (Askew 1988; Hammond et al. 1997). No. 4 was the least polluted CW, and this can explain why *C. armatum* survived there. This supports the theory of Olsvik & Dolmen (1992), that *C. armatum* can live in eutrophicated environments, but not in those highly eutrophicated. Thus, it seems that euryoecious species like *A. juncea* and *C. hastulatum* have a greater potential to colonize CWs than stenoecious species.

The negative effects of insecticide contamination on freshwater fauna are clearly shown in no. 2. Among pollutants, insecticides constitute the gravest threat to wetland insects (Batzer & Wissinger 1996). The insecticide detected in no. 2, diazinon, belongs to the organophosphates. This is the second most toxic group of insecticides to odonate larvae, after organochlorines (Corbet 1999). It has been shown that zygopterans are more susceptible to diazinon than other coexisting aquatic invertebrates (Arthur et al. 1983). Mathias & Moyle (1992) claim that waterways with heavy agricultural pollution have low biological diversity and tend to be dominated by a few tolerant organisms. CWs designed to retain runoff are always more or less exposed to pesticides (B.C. Braskerud pers. comm.), and even if there is no insecticide contamination, herbicides can be a serious problem (Stephenson & Mackie 1986). It thus seems clear that a CW with high biodiversity is not compatible with heavy pesticide use.

The ordination also revealed that sun exposure is important for some of the species. *A. cyanea* was the most abundant species in no. 1. It showed negative correlations with sun exposure in the ordination diagram, suggesting affinity to shade. Sandhall (1987) claims that *A. cyanea* prefers water bodies with riparian trees and bushes. However, *A. cyanea* is known as a moderately euryoecious species, inhabiting a range of habitats (Dolmen 1992; Corbet 1999).

The great diversity of aquatic plants should make CWs attractive as habitat for many odonates, and this is to a certain extent confirmed by the ordination analysis. Both vertical and horizontal plant structures are important for oviposition among many species of odonates, and the water vegetation functions as shelter for smaller larvae and other invertebrates (Patrick 1976; Lenz 1991). The presence of *Equisetum* *fluviatile* (L.) and decomposed floating plant fragments in the CWs makes ideal conditions for oviposition for *C. hastulatum* (Nielsen 1998). It is also known that *A. juncea* usually prefers standing waters with high plant diversity (Sandhall 1987). A species found in no. 4 only, *Leucorrhinia rubicunda*, has been related to mesotrophic *Sphagnum* bogs on moorland and in forests (Askew 1988). This is because it oviposits on the floating *Sphagnum* where high temperatures accelerate embryonic development (Corbet 1999). Refsaas (1986) claims that it rather prefers water lilies (*Nuphar* sp.) and *Cladium mariscus* (L.) to *Sphagnum*. There has been no *Sphagnum* in no. 4, but it contained the Yellow water lily, *Nuphar lutea* (L.), and was near a *Sphagnum* pond. This may explain why the species was found in this CW. The present results thus give support to the hypothesis that vegetation diversity is one major factor determining species composition in CWs.

CWs can be useful alternative habitats for freshwater organisms, especially in areas managed according to ecological agricultural principles. Such pesticide-free management is becoming increasingly popular in Norway (Ministry of Agriculture 1999), and is a major focus for funding by the Ministry of Agriculture (Ministry of Agriculture 2000). Such ecological fields have shown reduced amounts of phosphorus and nitrogen runoff, relative to conventional agriculture (Gabrielsen 1989). However, there will still be runoff from such fields, and CWs should play a major role in reducing this wastewater to a minimum. By building CWs, we combine the benefits from both ecological agriculture and pond conservation. CWs with exposure to sun, plant heterogeneity and different succession stages and kept insecticide-free, can be an important source of biodiversity.

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